AN ABSTRACT OF THE THESIS OF

ALAN ROY KING for the degree of MASTER OF SCIENCE

in OCEANOGRAPHY presented on March 1, 1977

Title: ACUTE EFFECTS OF SEDIMENTATION ON CUMELLA VULGARIS HART 1930 (CUMACEA)

Redacted for Privacy

Abstract approved: Dr. James E. McCauley

The ability of Cumella vulgaris to avoid burial under different rates of sedimentation and to recover from burial once buried was studied. Sedimentation rates higher than 0.25 cm/min are necessary to bury 50% of C. vulgaris with the deposition of 4 cm of sediment.

Cumella vulgaris can swim several times faster than the sedimentation rates at which fine sand successfully buried it. Immatures and females swam at speeds of 0.25-1.5 cm/sec; males swam at speeds up to 5 cm/sec. Sinking speeds of live C. vulgaris were proportional to size and varied from 0.2-1.6 cm/sec.

Cumella vulgaris should be able to avoid burial by dredging-caused sedimentation. Dredging's most important impact on this species would most likely be long term changes in a bay which might reduce its habitat.

Dead *C. vulgaris* were buried in their habitat in winter. Four days later one-half were successfully recovered by coring. When doing field studies of the acute effects of dredging on a habitat one needs to be aware that victims of burial may be recoverable for several days after death and may need to be distinguished from living animals.

Acute Effects of Sedimentation on
Cumella vulgaris Hart 1930 (Cumacea)

by

Alan Roy King

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Completed March 1977

Commencement June 1977

APPROVED:

Redacted for Privacy

Associate Professor of Oceanography
in charge of major

Redacted for Privacy

Dean of School of Oceanography

Redacted for Privacy

Dean of Graduate School

Date thesis is presented March 1, 1977

Typed by Lyndalu Sikes for Alan Roy King

ACKNOWLEDGEMENTS

First and foremost I would like to thank my wife Nancy for all she has done to make this thesis possible. I love her for her patience, faith, practicality, and more. Her willingness to work at jobs that have often been boring made this thesis financially possible.

Talks with Dr. James McCauley, my major professor, helped in determining what could or could not be said on the basis of my experimental results. His reading of many drafts of this thesis did much to make it more organized, coherent and readable.

Comments by members of the oceanography Peanut Butter Club on a rather green oral version of this thesis were helpful in pointing out the necessity of clarifying how the different experiments tie together as a whole. They were needed and appreciated.

Others to whom thanks are due include: Dr. Kenneth Williamson for the use of his cold room, Dr. Charles Sollitt for his barrel and mixer, Wayne Fletcher for his cement mixer, Danil Hancock for reading and commenting on drafts of the thesis, and Dr. Charles Miller for assigning the zooplankton class project through which I became aware of *Cumella vulgaris*.

Partial support was supplied by the National Science Foundation RANN grant GI 34346.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

ACUTE EFFECTS OF SEDIMENTATION ON *CUMELLA VULGARIS* HART 1930 (CUMACEA)

INTRODUCTION

The cumacean, *Cumella vulgaris* Hart, 1930, has been reported in bays from San Francisco, California (Jones, 1961) to Kodiak, Alaska (Zimmer, 1943). As a member of the epibenthic fauna in bays it may be affected by the mechanical disruption caused by dredging to maintain and enlarge shipping channels or for other purposes. Knowledge of the effects of dredging on estuarine ecology is necessary if one is to predict accurately whether the changes in bays resulting from dredging will be acceptable. This study looks at one small aspect of the possible ecological effects, namely whether or not *C. vulgaris* is likely to be a victim of dredging operations.

Cumella vulgaris (Figure 1) is not noticed by the casual stroller in the intertidal as the adults are only about 2.5 mm long with a carapace length of only 0.7 mm. Distinguishing characteristics between adult males and females include: the bases of all of the thoracic legs of the males are more swollen than those of the females, mature females have oostegites on the "third maxillipeds and the first three pairs of peraeopods" (Jones, 1963). The manca,

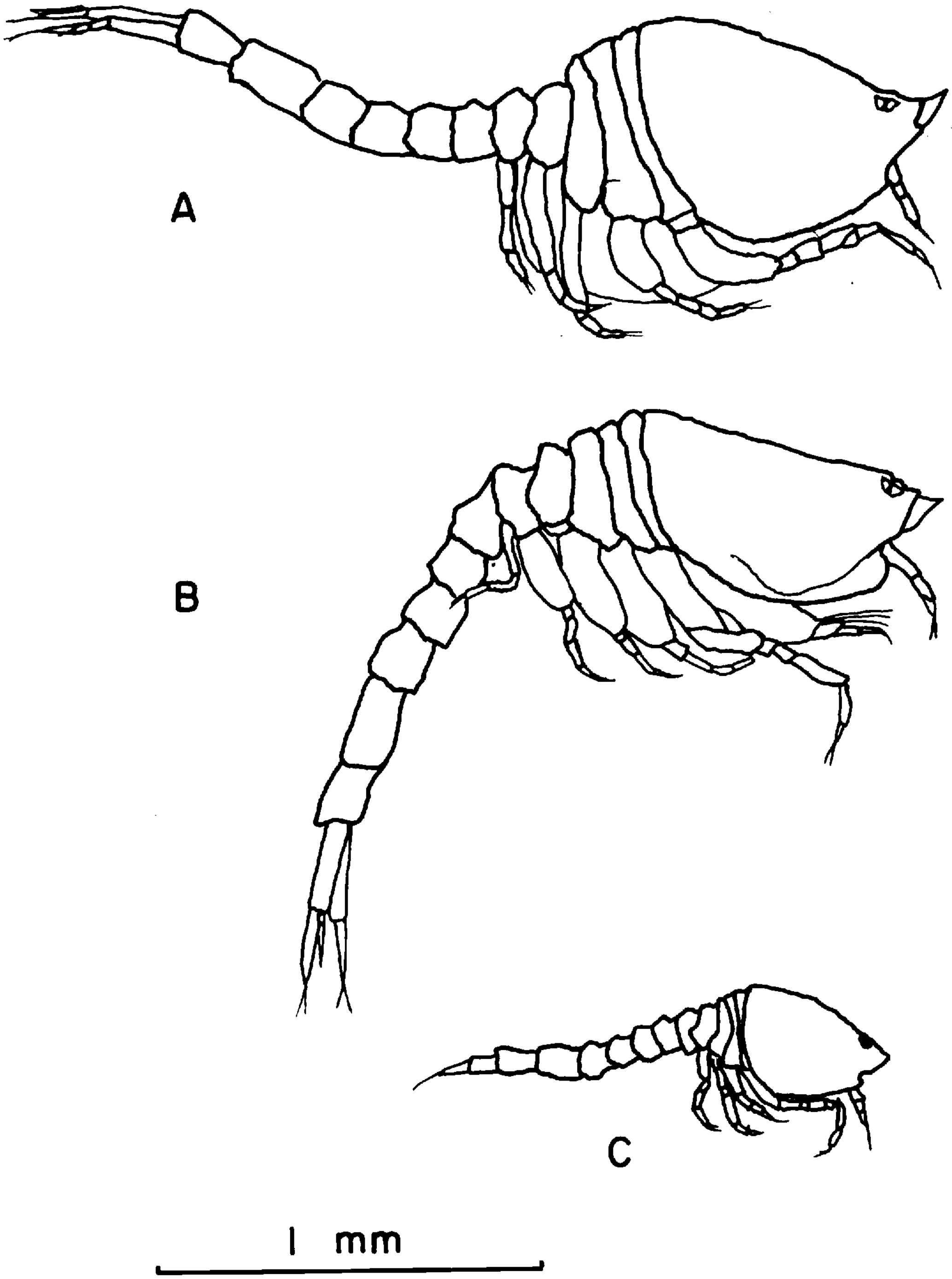

Figure 1. Cumella vulgaris, camera lucida drawings. A-mature female, B-mature male, C-manca. (Eye is singular, median, many faceted in spite of drawings appearance).

the stage at which the immature cumacean leaves the marsupium (Jones, 1963) can be distinguished from older stages by its lack of dark pigmentation, its small size (carapace length about 0.37 mm), and the presence of four pairs of thoracic legs instead of five as in all subsequent stages. On the manca, there are no legs on the fifth segment. A newly released manca is already larger than the median grain size of the coarsest sediment on which it is found (0.35 mm). Smaller stages and eggs are protected from burial as they are carried in the marsupium of the female.

Cumella vulgaris has been reported from water as deep as 10 m in San Francisco Bay (Jones, 1961) to as high as 1.7 m above MLLW (mean lower low water) on fine sand that remains moist while exposed to the air. It may be found even higher in tide pools (Wieser, 1956). In Coos Bay, Oregon, C. vulgaris is not found in areas with fast currents (McCauley et al., 1977).

Cumaceans live in the surface of the sediment, kicking the sediment out from under themselves with their peraeopods as they settle into its surface far enough to bury their bodies, but leaving their heads exposed (Dixon, 1944; Jones, 1961; Gnewuch and Croker, 1973; Wieser, 1956).

In sand finer than 0.15 mm, C. vulgaris is a deposit feeder ingesting whole sediment; in coarser sediments it is an epistrate feeder, scraping food from the surface of the sand grains (Wieser, 1956). Wieser (1959) found C. vulgaris on sediments with a median grain size smaller than 0.2 mm. McCauley et al. (1977) found C. vulgaris on sediments with a median grain size as large as 0.35 mm. In trays of C. vulgaris I have observed the sediment surface covered with small crooked grooves, possibly from the cumacean's plowing along at the surface while feeding.

The usual habitat of C. vulgaris, shallow or intertidal fine grained sediment, is found in protected areas such as bays, sounds, or inlets. In checking locations where C. vulgaris has been reported, those areas for which salinity data were available, commonly had salinities less than that of the open ocean. Male C. vulgaris have been recovered at the water's surface one mile off the mouth of the Yaquina River, Oregon. Data were not available to determine whether they had been washed from the bay or were living on the bottom below where they were recovered.

Cumella vulgaris was found by Jones (1961) near Point Richmond in San Francisco Bay at densities up to 8,000/m^2. Densities at each location were determined by averaging 30 cores taken by a glass tube 2 cm in outside diameter. By comparing the number captured in the cores with Poisson distributions of the same mean, Jones determined that C. vulgaris was probably randomly distributed in the area examined. The highest population densities found in Yaquina Bay were about $100,000/m^2$ as determined from 10.1 cm diameter cores taken 0.3 m above MLLW tide level.

There is little literature available on the responses to burial at high sedimentation rates for any species. The ability of clams to survive burial has been found to vary with species. The success of those that can survive depends on the depth buried, the sediment type, and the presence of wave action (Armstrong, 1965; Shulenberger, 1971; McKnight, 1969). Schulenberger (1971) reported that *Gemma gemma* and Armstrong (1965) reported that *Tivela stultorum* and *Siliqua patula*, all of which are normally active burrowers, are least affected by burial of all clams studied.

Since there is little useful literature to help predict the short term fate of *C. vulgaris* under dredging-induced sediment fall-out, a hypothetical model was constructed to consider various alternatives. This model is shown graphically in Figure 2. The short term factors were examined experimentally in the laboratory. Long term effects were considered primarily on the basis of information in the literature.

When examining Figure 2 and choosing between a pair of possible fates, what actually would happen would depend on many things, not all of which were, or could be, examined in detail. For example, whether or not *C. vulgaris* will be buried or avoid burial will likely depend on sedimentation rate, animal size and

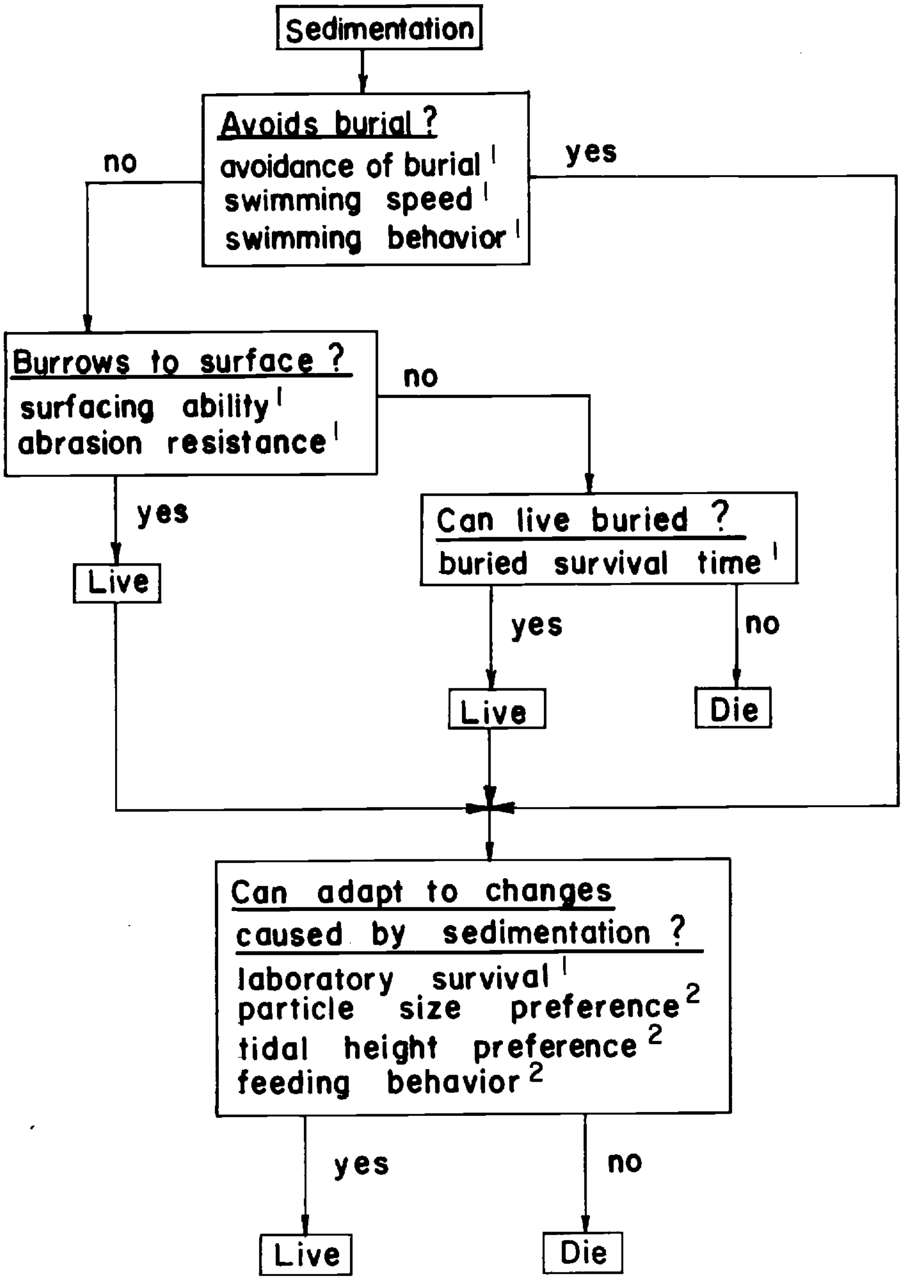

Figure 2. Conceptual model of possible effects of sedimentation on C. vulgaris. 1- examined experimentally, 2- information taken from the literature.

sex, particle size distribution, and perhaps a number of more subtle factors. The swimming speed, which could be a measure of the ability to avoid burial and the ability to avoid burial under high sedimentation rates by fine sand were both examined.

The ability to burrow to the surface was studied by burying animals and checking periodically for vertical mobility. Their ability to survive when buried (important if they cannot burrow to the surface) was studied by burying animals at various depths and for various time periods.

Other observations and experiments, useful for experimental design, but not directly related to dredging, were also made.

One of the major problems associated with any meiobenthic study is the separation of animals from sediment and debris. The swimming behavior was examined in order to develop methods of separating the animals from sediment and detritus. Knowledge of abrasion resistance helps to assess the effect of sediment stirring by boat prop wash, currents, and passage through dredging systems. Abrasion resistance experiments gave an idea of how much physical abuse the animals can tolerate.

The decomposition rate of animals buried in the field was briefly examined to demonstrate that it might be possible to evaluate what time periods could be expected to be useful for assessing mortality from burial.

MATERIALS AND METHODS

Animal Collection

Animals were collected at about the zero tide level, MLLW near the Oregon State University Marine Science Center small-boat pier at Newport, Oregon. They were collected by scraping the surface of the sediment, less than 5 mm deep, with the edge of a tray. The sediment was dumped into an ice chest containing bay water while stirring to slow the settling of the sediments and to give the animals already in the chest a better chance of avoiding burial.

Before experiments were made, animals were stored at 10-11 C for at least two weeks to allow acclimation to laboratory conditions and to give time for animals damaged in collection to die. Animals used in the avoidance-of-burial experiments were collected within twenty four hours of their use. Avoidance-of-burial experiments were run within one degree (C) of the water temperature at the time the animals were collected.

The animals were kept in trays, 43 cm x 29 cm x 5 cm, filled with approximately 2 cm of sediment and 2 cm of bay water. Animals were kept successfully in the laboratory in 24 and 31 ppt salinity water for more than four weeks. Evaporation losses from the trays were made up by adding well water to a constant level.

Cumella vulgaris in an aquarium was observed to swim more at night than during the day, therefore a fluorescent fixture with two 40 watt cool-white bulbs, turned off at sunset and on at sunrise by a timer, was suspended approximately 60 cm above the trays. The trays were not artificially aerated.

Separation of Animals from Sediments

Counting all of the animals in a tray of sand without first separating them from the sand would have required several days of work. This length of time was not acceptable as it was desired to determine the number of animals still alive after various periods of time. A long counting period would increase the errors resulting from animals dying during the counting period. Determining the number of animals alive after short periods, say 12 hours, would have been impractical as it would have taken longer than 12 hours to find and count the animals.

Others have separated animals from sand sediments by shaking water and sediments and decanting the water through a sieve (Birkett and McIntyre, 1971). In my work, when quantitative recovery of animals was required, sediment from which the animals were to be removed was placed into one of two plastic buckets. Filtered bay water was rapidly poured from one bucket onto the sediment in the other bucket to stir it. The water was then decanted through a 0.124 mm sieve. The water was decanted as fast as possible without catching much sand in the sieve. This procedure was repeated until the material collected by the sieve on successive decantings appeared to be relatively free of detritus. Animals and detritus retained by sieving were washed into jars and preserved in a solution of approximately ten percent formalin unless it was necessary to count living and dead animals. Recovery rates were high, 86% to greater than 96%, as shown in the surfacing-ability and the abrasion-resistance experiment.

Non-quantitative separation from decanted detritus of living animals for experiments was accomplished by two methods. 1) A small bottle of detritus and live animals was placed on the bottom of a bucket of filtered bay water. The animals tended to swim out of the bottle and into the clean bucket water from which they were easily removed, after a few hours, by sieving. *Cumella vulgaris* of all sizes and sexes swam out of the detritus, though not all of the animals of any size left the detritus. Even when a bottle of detritus and animals was placed in several successive buckets of clean water all *C. vulgaris* would not swim into the bucket. 2) Animals and detritus were placed in a large jar of bay water. The detritus sank to the bottom and the animals swam up and down the lighted side where they could be picked up with a large pipette (baster). Animals were further separated in a petri dish where they swam to the lighted side and were removed with an eye dropper. This second step resulted in almost no contamination from detritus and little from other species. The separation was not quantitative, but it was useful in providing lively detritus-free animals. The tendency of *Cumella vulgaris* to swim towards light was also observed by Wieser (1956). It should be noted that *C. vulgaris* does not normally swim in bright light unless somehow disturbed, in which case, it swims towards it.

Sediment Cleaning

First attempts at experiments were with unprocessed natural sediments. But due to the small sieve size necessary to retain immature *C. vulgaris,* the amount of decanted detritus also retained was large. Separating animals under a microscope from detritus was time consuming and produced counting errors due to missed animals. Speed, as well as accuracy, in counting was critical because the number of animals alive after a given time might change with long counting times. Cleaning the sediment of detritus and animals served to produce a cumacean-free sediment for use in experiments in which a known number of animals were to be added to a sediment sample . Experimental animals could be removed from cleaned sediment without contamination with detritus. Cleaned sediment was allowed to set two weeks without surface water, aeration, or cooling in an attempt to kill and decompose any cumacea which might have escaped the cleaning process.

Sediment was cleaned by decanting through a 0.124 mm sieve as described for the separation of animals from sediment. Everything caught by the sieve, detritus, animals and some sand, was thrown away. Cleaned sand and the sieved water containing clay and silt were poured into a large barrel. After the silt and clay settled out of the water in the barrel, the water was reused for washing more sediment to minimize the volume of sea water which had to be saved. The fines were thereby kept in the cleaned sediment and the change in the particle-size distribution was minimized. After the fines had settled out of the water in the barrel of cleaned sediment, most of the water was removed and the remaining sand and water were stirred to produce a uniform mixture.

Avoidance of Burial

Avoidance of burial was examined by two different methods.

1) One involved a screen-bottom box full of wet sand supported above a plywood aquarium which had a removable plexiglas end (Figure 3A). Water added to the box of moist sand caused sand and water to drip down into the aquarium. The sand dripped fast enough that the sand level in the aquarium rose 4 cm and filled the

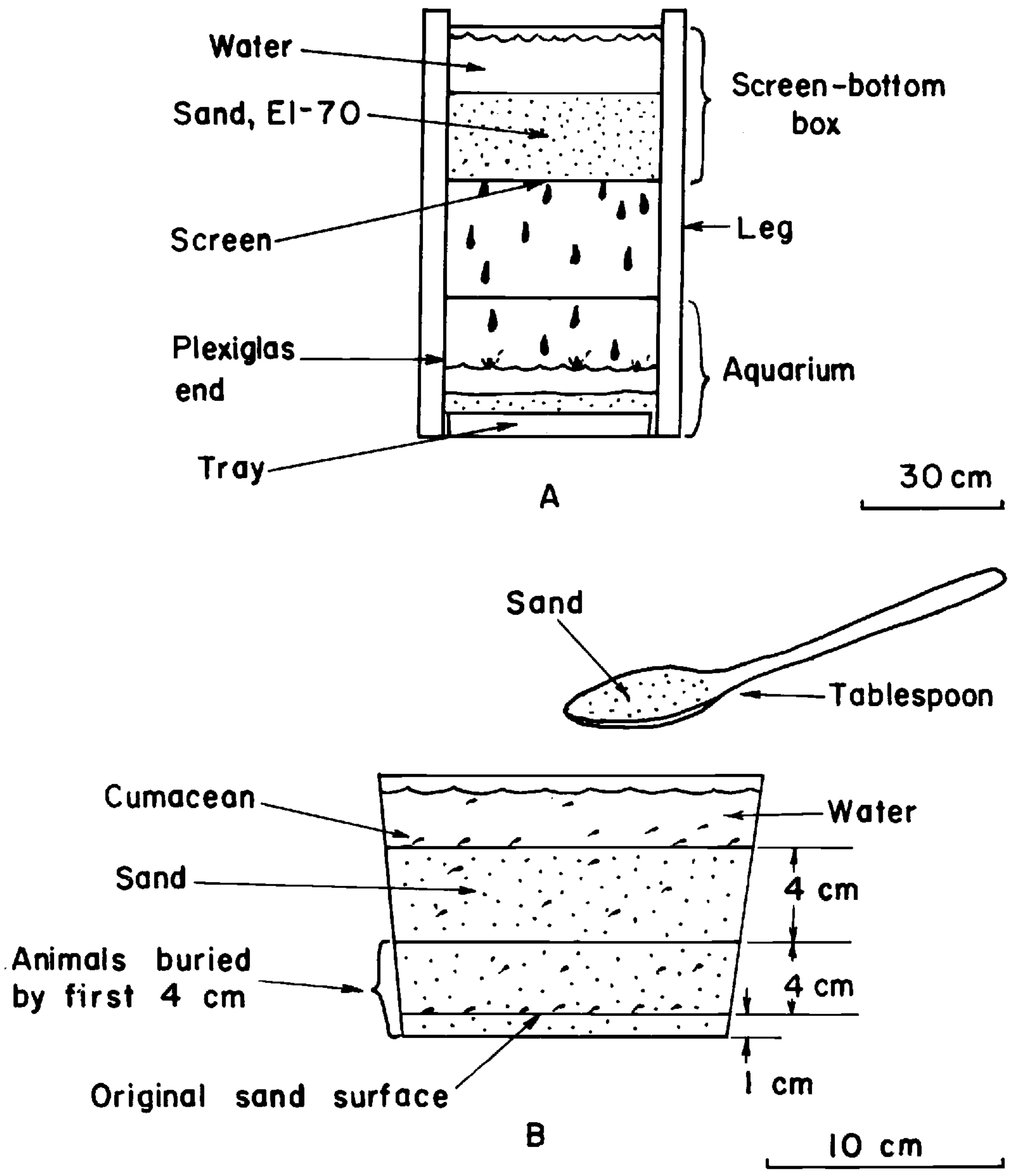

Figure 3. Avoidance of burial apparatus. A- high sedimentation rate, approximately 22 sec/cm. B- low sedimentation rate, approximately 250 sec/cm.

tray in approximately 1.5 minutes. The sand used was white silica El-70 water washed sand, median grain size 0.154 mm. It was not possible to use this method with cleaned natural sand that contained some clay because the clay tended to seal the surface and stop the water from flowing through the sand. This property of impermeability to water is evident to the casual observer who sees shallow puddles in the moist sand that do not drain dry through their bottoms when the tide is out. _Cumella vulgaris_ is found on such water retaining sands.

The aquarium was made just the right size for a 43 cm x 29 cm x 5 cm tray to fit snugly in its bottom. The experimental procedure was as follows. Moist El-70 silica sand was added to a level 4 cm below the top edge of the tray. The tray was filled with filtered bay water. A counted sample of _C. vulgaris_ was put in the tray. A lid with a tray was placed on top of the aquarium to catch sand dripping before the start of the experiment. About 8 liters (2 gal.) of bay water were poured onto the sand in the screen bottomed box. It was allowed to drip into the tray on top of the aquarium until the dripping was rapid and appeared stabilized. Next the aquarium lid and tray were removed so the sand could drip on the animals in the tray in the aquarium. The sand dripped until it was 5 cm or more above the tray edge and the water in the screen bottomed box was gone.

After the sand dripped into the aquarium, the water was siphoned out of the aquarium into a bucket. The aquarium was then set up on blocks, and a tray to catch water and sand was placed under the removable plexiglas end. With the end removed from the aquarium, a sheet of 1/4 in. plywood, cut to the width of the aquarium, was pushed through the sand along the top edge of the tray. The sand above the tray edge was then removed.

The animals in the aquarium were thus separated into those above the tray edge and those below the tray edge. These two groups corresponded to those escaping burial by the first four centimeters of sand added and those buried by the first four centimeters respectively. Animals in the aquarium water and in the tray below the aquarium's removable end were also counted as escaping burial by the first 4 cm of sand. Animals were separated from sand by decanting several times through a 0.124 mm sieve.

The plexiglas end of the aquarium was used to see when the tray was filled with sand so that the time for it to fill could be measured. Due to the turbulence of the water and the uneven filling of the tray, the tray-filling time measurement was less than exact.

The animals used in an experimental run were a mixture of all sizes and both sexes.

2) The above method resulted in a higher percentage of animals buried than had been hoped for. A sedimentation rate which

was high but which buried only a small percentage of the C. vulgaris present was needed to show that the likelihood of burial at lower rates was low.

Conceivably a low rate of sedimentation could have been produced by some sort of apparatus to drip water over the surface of the screen-bottomed box, but a method easier to set up was used instead. A plastic container 14.9 cm in diameter and 11.1 cm high was cut in two, 5 cm above the bottom and then taped back together (Figure 3B). One centimeter of El-70 silica sand was put on the bottom. Bay water was added to a level of 7 cm above the bottom. A sample of living C. vulgaris was placed in the water and allowed to sink to the bottom. Dry El-70 silica sand was added by gradually sprinkling one level tablespoon of sand every 15 seconds. The time to add 4 cm of sand was noted. This rate was chosen because it was easy to produce and because it was expected to produce a low burial rate. Sand was added until approximately 8 cm deep. The water in the container was then poured into a bucket, the container was placed in a clean tray, the tape was cut, the top half of the container and the sand above the cut was removed by slicing with a metal spatula. The animals above the cut and in the water were counted as escaping burial by the first four centimeters of sediment added. It took approximately 17 minutes to add 4 cm of sand by this method as compared to 1.5 minutes by the previously described method. Animals used with this method were mature or nearly mature.

Swimming Speed

The swimming speed of C. vulgaris was measured by placing single animals in a thin aquarium (Figure 4) which had graph paper on the back. The time for the animal to swim a given number of squares was measured with a hand-operated timer which read to one-hundredth of a second. Reaction time lowered accuracy to about one-tenth second. Swimming speeds were measured at 10.5 C with animals which had been acclimated to 10.5 C for at least three weeks.

Swimming speeds were measured over different distances for different animals as they tended to swim different distances before stopping or turning. Larger animals swam further before stopping than small ones. Approximately four measurements were taken with the animal swimming and four with the animal passively sinking (when they stop swimming, they sink).

Surfacing Ability

One possible way C. vulgaris could survive being buried would be by burrowing back to the surface. The depth of burial in this experiment was kept small because the animals' life style suggested

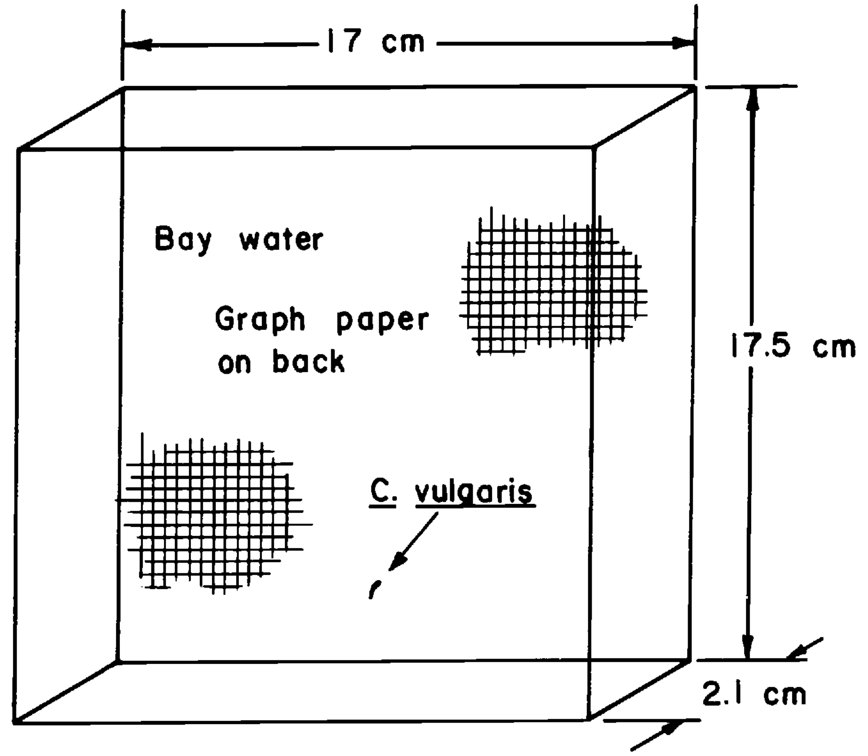

Figure 4. Inside dimensions of swimming speed aquarium.

that they may be poor burrowers. If one shows that they can not survive shallow burial, it stands to reason that they would not be able to survive deeper burial.

Cumella vulgaris was checked for a minimal burrowing ability by placing 100 living animals with less than 5 ml of water in each of two empty 43 cm x 29 cm x 5 cm trays. They were covered with 4 cm of moist cleaned sediment that had set two days in another tray so as to be slightly consolidated rather than a slurry. The sediment was transferred to the tray of animals with a metal spatula. Approximately 7 mm of 31 ppt salinity filtered bay water was poured over the sediment with care to avoid stirring up the sediment and freeing buried animals. In spite of these precautions some of the animals managed to avoid burial. When the moist sediment was added to the tray, they appeared to swim up in the few milliliters of water that were displaced by the sediment as it was added. The experiment was not dependent upon all of the animals being buried though interpretation would have been simpler if they had been. The trays were stored in a cold room at 10.5 C.

After one day part of the water on top of the sediment of one tray was poured into a bucket. The remaining water was swished around the tray to get the cumaceans on the surface into the water and then poured into the bucket. The numbers of dead and living animals in the decanted water were counted separately from those remaining in the tray. The animals remaining in the tray included a few left on the surface which had not been decanted plus those which were buried. Animals in the second tray were removed and counted after the same manner as the first tray after five days.

The above experiment was also performed in a scaled down version in which four samples of approximately 20 _C. vulgaris_ were buried beneath 1 cm of cleaned sediment that was well drained but moist to avoid apparent avoidance of burial in the previous experiment. Two of the samples were examined after six days and two more after thirteen days. Living and dead animals were counted in the water decanted from the surface and recovered from the sediment. The containers used were plastic, 10.1 cm x 10.1 cm 8.9 cm deep. They were kept in a room where the temperature ranged from 15.0-19.4 C with the most common temperature about 17.8 C.

Maximum Buried Survival Time

The simplest way to determine whether or not _C. vulgaris_ can burrow to the surface is to bury it and see what it does. If it dies before reaching the surface, its burrowing ability is insufficient. In order to guarantee that the animals which were unable to burrow to the surface would be dead in a shallow burrowing experiment, it was necessary to determine the maximum length of time _C. vulgaris_ could be expected to live buried.

Cumella vulgaris is epibenthic and therefore has a ready supply of oxygen from the water. When buried, this normal supply of oxygenated water is no longer available. The maximum survival time for buried animals was studied by burying them in sand from which the silt, clay, and particulate organic material had been removed. This procedure insured a maximum porosity to water, a maximum amount of interstitial water and a minimum consumption of oxygen by decaying material. The experiments were run at the middle of the temperature range (10.5 C) of their environment in Yaquina Bay. The minimum temperature would have been preferable because the higher oxygen solubility at the lower temperature might have allowed longer survival times, but a cold room with minimum temperatures was not available.

The conditions chosen to produce a maximum buried survival were basically an educated guess at the time they were made. The correctness of the choice of conditions was later partially justified by the surfacing-ability experiment data. In the surfacing-ability experiment, detritus, but not silt and clay, was removed from the sediment, therefore it was less porous. Lower survival in the less porous sediment is consistent with the hypothesis that oxygen availability is the critical factor.

One might expect that removing fines and detritus from the sediment would also remove their food and cause them to starve. This view is not supported by the data. In almost all trials of the buried-survival time experiment the percentages of animals buried shallowly and recovered alive was higher than for those buried deeply. The sediment and the amount of food present were uniform throughout. If food availability were of primary significance, one would have expected lower rather than higher survival in the generally more crowded surface layers. Also *C. vulgaris* feeds in fine sand by cleaning the surfaces of sand grains, rather than by feeding on the silt, clay, and detritus which were removed (Wieser, 1956). In the surfacing ability experiment in which silt and clay and their associated bacteria were not removed, survival of buried animals was lower than in the maximum buried survival time experiments.

Since no direct tests were made on the tolerance of *C. vulgaris* to low oxygen levels, no unequivocal statement can be made that they die from insufficient oxygen when buried. But the results of the experiments are consistent with what one would expect if oxygen availability is of significance.

The experiment was run as follows. Moist, cleaned, silt and clay-free sand and *C. vulgaris* were alternately added to 8 plexiglas tubes (21 cm long x 5.1 cm inside diameter with a rubber stopper in one end) to 12.7 cm deep with about 2 cm of bay water above the sediment surface. Because of the ability of C. vulgaris to avoid burial this procedure resulted in animals throughout the sediment. A more uniform distribution of animals might have been obtained if moist sand and animals had been mixed before adding the sand to the tubes. The tubes were stored at 10-11 C. After 12 hours the sediment in two tubes was extruded and divided into 2.5 cm layers. The animals in the layers were removed by decanting and the number of living and dead counted. This procedure was repeated with other tubes at 24, 48, and 96 hour intervals.

The sand used in this experiment was prepared by decanting the silt and clay out of cleaned sediment previously prepared.

Abrasion Resistance

Once, when trying to get animal-free sediment without changing the particle size distribution, some moist sediment with added water was mixed in a cement mixer for an hour expecting to grind up all of the animals. Afterwards many animals were found remaining in the sediment. The following technique to measure abrasion resistance is a direct result of that experience. Such a measurement is significant when considering the fate of animals which are dredged from the bottom. They must survive passage through pipe line or hopper-dredge pumps or drag line buckets before any ability to burrow to the surface can do them any good. Also if one wishes to recover corpses of cumaceans buried in dredging spoil (to estimate fatalities for example) one must have some confidence that the animals were not broken into unrecognizable pieces in the process of being dredged. Evidence of abrasion resistance gives confidence that the vigorous stirring of water and sand involved in decanting animals from the sediment does not kill them and bias results.

To measure abrasion resistance, samples of one hundred live _C. vulgaris_ were mixed with sediment for one-half hour in a 3 cubic foot cement mixer at 25 rpm. To estimate the density of the slurry in the mixer, the volume and weight of the sediment added to the mixer was measured (about 3.8 liters weighing about 7.8 kg). The mixer was run one-half hour with the sediment before adding animals in an attempt to uniformly oxygenate it. No effort was made to measure the Eh of the sediment, but it was a uniform light brown after mixing. Oxygenation was done to ensure that any animals dying would be dying from abrasion rather than a lack of oxygen. Next the animals were added to the mixed sediment in a measured volume of water, about 250 ml. The animals were then decanted from the sediment and put in trays, 43 cm x 29 cm x 5 cm, of cleaned sediment and bay water at 10.5 C, 24.3 ppt salinity.

After one week they were separated from the sediment in the trays by decanting. Dead and living animals were counted and the dead were preserved. Living animals were returned to trays for an additional week after which they were removed and counted again. Animals were not counted until a week after mixing so that weakened animals might die. Death of still animals was defined as the lack of response when pushed by a teasing needle.

Mancas were not used in the experiment because they could be confused with mancas released from marsupia during the experiment. It was suspected that including mancas in preliminary experiments accounted for more living animals after mixing than were originally placed in the mixer.

Because of the length of the experiment, some animals molted in the trays. Empty molts were distinguishable from dead animals by their hollow look and by the presence of a separation on the dorsal surface between two segments near the carapace through which the molting animal left its old shell.

Decomposition Buried

If one wished to do a field experiment to determine how many *C. vulgaris* were victims of burial, there are several things it would be useful to know. The buried *C. vulgaris* should not be collected and counted until they had no chance of making it to the surface, either by burrowing or by the reworking of the sediments by currents. Therefore the cumaceans should not be collected until they have been buried long enough to die. The maximum time *C. vulgaris* can be expected to live buried at 10.5 C was determined previously to be around four days. In this experiment dead C. vulgaris were buried in their habitat and not recovered until enough time had passed so that a living animal would have probably died. It was hoped to demonstrate that some of the corpses of animals which died shortly after burial in other experiments would still be collectable if one did not collect them until the slow-to-die had died.

One should not assume that the loss rate of buried dead animals in this experiment is useful for predicting the loss rate at another time, place, or season as the number and activity of decomposers and predators and the amount of sediment reworking is extremely variable. The purpose of the experiment was to show that one should not assume off-hand that the corpses are not recoverable after a few days burial and to show the possibility of estimating the loss rate in the field to help in estimating the total number of burial victims from the number of recoverable corpses.

Since C. vulgaris can not surface after being buried as shallowly as 4 cm (surfacing experiment), one might take cores immediately after burial of the cumaceans and assume that all animals recovered from below 4 cm are going to die. In doing this one neglects those that may have made the surface as a result of reworking of the sediment and those buried less than 4 cm.

Field decomposition was measured as follows. Fifty-animal samples of C. vulgaris, killed by freezing, were injected 7.6 cm (3 in) beneath the sediment surface in the area where collected, near the Oregon State University Marine Science Center small-boat pier. To minimize disturbance of the sediment, the animals were injected into the sediment with a #15 needle on a syringe (Figure 5). A 0.5 cm long piece of stainless steel sewing pin with a plastic head was put in the end of the needle before injecting the animals to keep sand from plugging the needle. To get the pin out of the end of the hypodermic needle under the sediment, the needle was shoved 8.9 cm (3.5 in) into the sediment and then withdrawn to 7.6 cm (3 in). The pin served as a marker to later verify that cores to recover the animals had been taken in the right location should it happen that no animals were recovered. The animals were injected exactly half way between two stakes which were 122 cm (48 in) apart. The distance between the animals and the stakes was to minimize disturbance of the sediment at the burial sites by the stakes. The stakes were above water only during the lower-low tide of the day, which occurred at night during this experiment minimizing the chances of their being disturbed by passers-by. Out of ten stakes, only one was lost.

Animals were recovered by taking 12.7 cm (5 in) in diameter, 14.6 cm (5.75 in) deep cores with a two pound coffee can from which

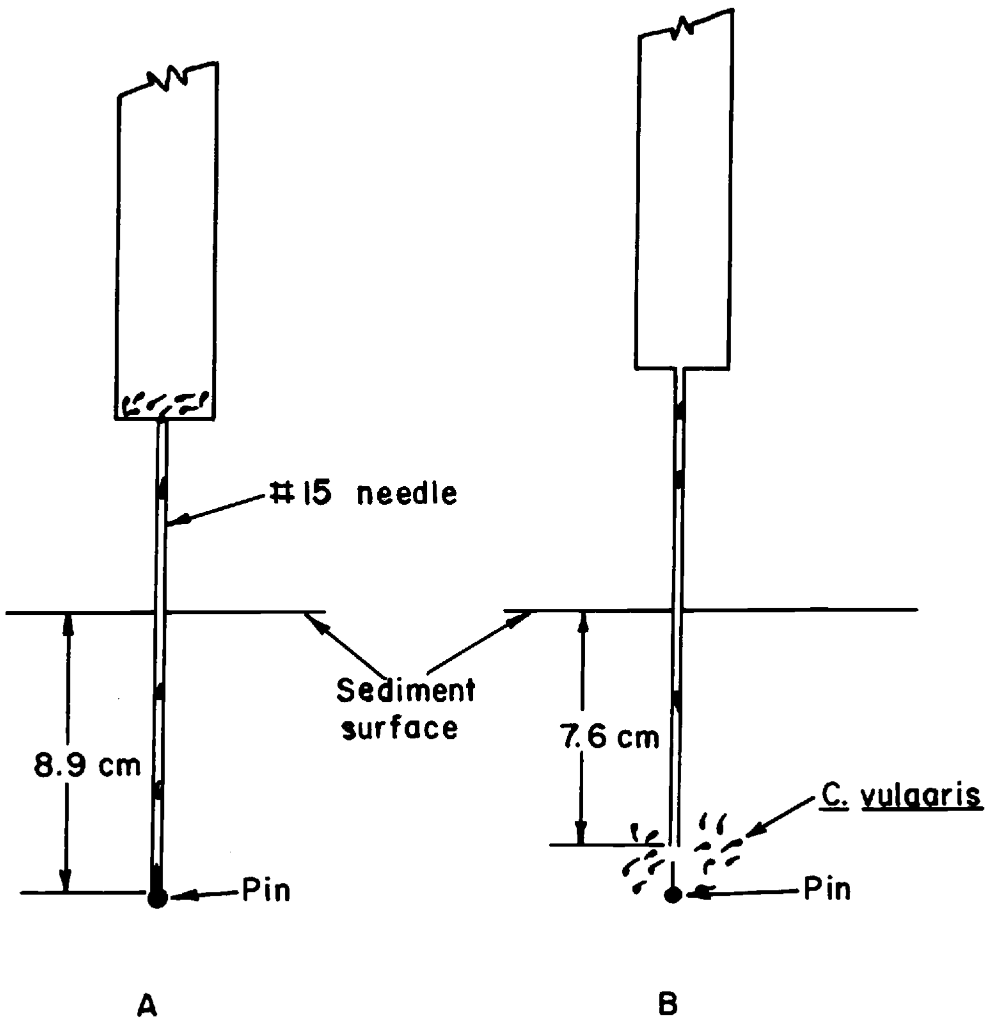

Figure 5. Injecting dead C. vulgaris into the sediment. A- syringe injected to 8.9 cm, then, B- withdrawn to 7.6 cm to remove pin from tip before injecting cumaceans.

the bottom had been removed. The can was pressed into the sediment until the top was flush with the sediment surface. To remove any naturally occurring C. vulgaris, approximately the top two centimeters were spooned off the top and put into a plastic bag. The rest of the sediment in the can was then spooned into another bag. The animals were removed from the sediment by decanting through 0.295 mm and 0.124 mm sieves successively. Since there was a large amount of detritus to look through with both sieve fractions and because of the large number of animals recovered with the coarser sieve, approximately half of those buried, the smaller sieve fraction was not counted. This omission may have resulted in the loss of small animals and those which had been broken by decomposition. But since the animals recovered by the coarse sieve were sufficient to show that corpses may be recoverable after several days of burial and since there was no intention of producing accurate recovery rates for future use, counting the small sieve fraction was not considered worth the time required.

To check for C. vulgaris otherwise buried, two control cores were taken approximately one foot from one of the animal burial sites.

RESULTS

Avoidance of Burial

Using the method where wet sand and water were dripped into an aquarium adding 4 cm of sand in 1-1.5 minutes, burial percentages in three trials were 66%, 61%, and 45% (Table 1). The method of sprinkling dry sand into a container so that it took 15-19 minutes to add 4 cm of sand produced burial percentages of 11%, 13% (Table 1). In one case when 4 cm of sand was added in 1.4 minutes, only 6.8% of the animals were buried below 4 cm. This result was considered aberrant and was not used.

Table 1. Avoidance-of-burial data. Numbers of animals buried by the first 4 cm of added sediment.

Time to add 4 cm, min.	# recovered below 4 cm	Total recovered*	% buried below 4 cm
1.0	294	443	66.4
1.3	843	1382	61.0
1.5	151	399	44.5
15.0	9	82	11.0
19.0	9	69	13.0

* Initial number of animals somewhat larger due to losses in recovery.

Swimming Speed

Immature and female _C. vulgaris_ were found to swim upward a few millimeters to a few centimeters and then stop swimming to sink passively. They swam up at speeds ranging from 0.3 to 1.5 cm/sec. The larger the animals, the higher the swimming speed tended to be (Figure 6). Mature males, which have four pairs of pleopods with exopodites for swimming compared to the two of mature females, swam at speeds ranging from 2-5 cm/sec. Only mature males were observed actively swimming horizontally at the very surface of containers of water. They swam very fast and erratic courses.

Sinking speeds of both sexes and immatures ranged from 0.2-1.6 cm/sec, with the larger animals sinking faster than the smaller ones (Figure 7).

Surfacing Ability

Cumella vulgaris is not consistently able to burrow through as little as 4 cm of partially consolidated sediment. One and five days after burial of 100 animals in each of two trays, 32 and 67 dead were recovered (Table 2).

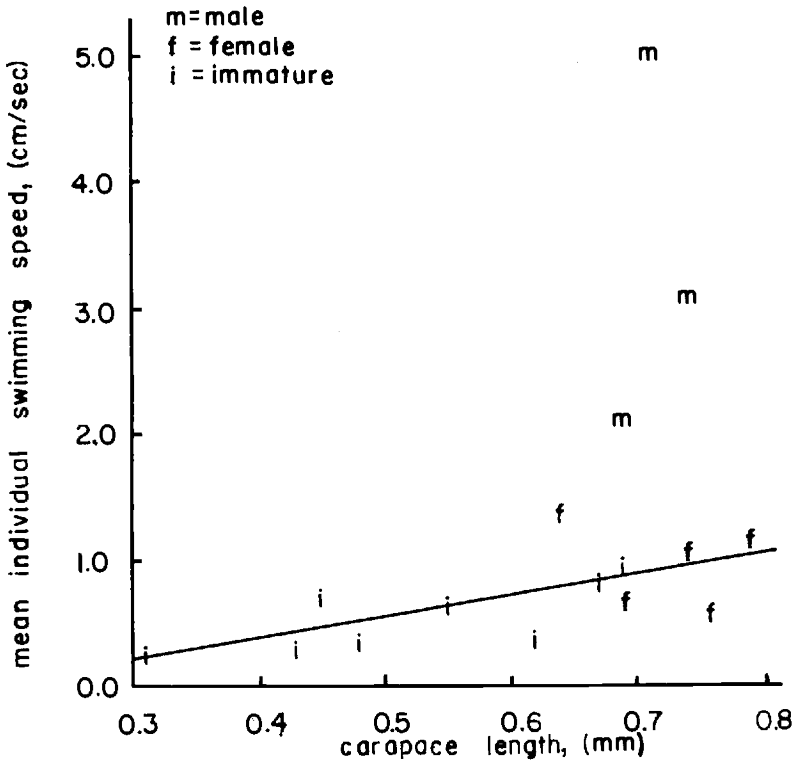

Figure 6. Swimming speed versus carapace length. Coefficient of determination for linear regression, $r^2 = 0.43$, males excluded.

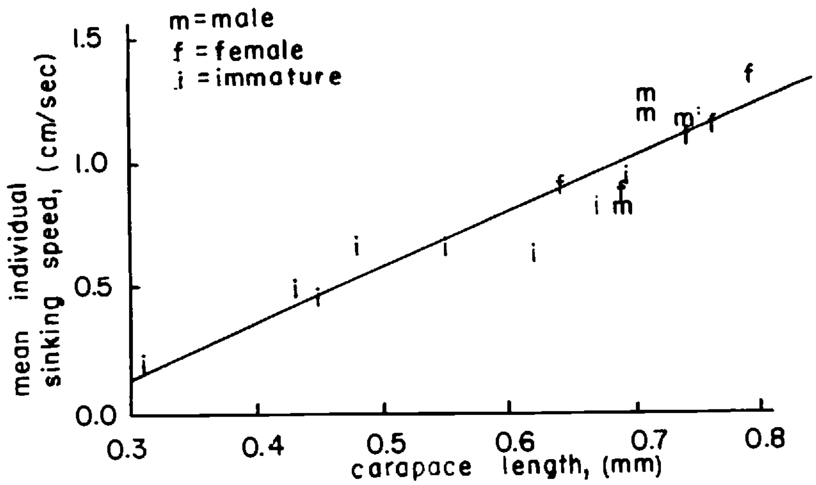

Figure 7. Sinking speed versus carapace length. Coefficient of determination of linear regression, $r^2 = 0.85$. Sinking speed (cm/sec) = -0.517 + 2.196 x carapace length (mm).

Table 2. Surfacing ability. Survival of animals, 100, buried 4 cm.

time in tray	buried 4 cm		not buried*		
	1 day	5 days	7 days	7 days	7 days
# starting	100	100	100	100	100
# recovered	87	86	95	96	92
# alive	55	19	91	96	88
# dead	32	67	4	0	4

* data from abrasion-resistance experiment.

In the abrasion resistance experiment 100 animals were put in each tray on top of the sediment instead of being buried. Significantly more dead were recovered in trays were animals were buried, 32, 67, than in trays where animals were not buried, 4, 0, 4.

The data from the experiments with animals buried 1 cm turned out to be inconclusive.

Maximum Buried Survival Time

The results of burial of C. vulgaris in tubes of clean, clay-free sand are shown in Table 3. Dead animals showed up within 24 hours at the 10.2-12.7 cm (4-5 in) level. The LD-50 burial time under the conditions of the experiment was between one and four days for animals deeper than 2.5 cm in the sediment. After four

Table 3. Animals recovered different periods after burial in clean sand (#dead/# alive).

depth buried cm	hours buried									
	12	12	24	24	48	48	96	96	96	96
0-2.5	0/28	0/19	0/24	0/19	0/18	0/15	0/30	0/23	3/47	1/40
2.5-5.1	0/3	0/4	0/4	0/1	5/0	0/3	1/0	1/0	0/0	1/1
5.1-7.6	0/3	0/17	0/13	0/6	20/0	2/7	5/0	5/0	6/1	3/2
7.6-10.2	0/16	0/11	0/13	1/12	25/6	4/1	4/0	4/0	2/0	11/4
10.2-12.7	0/13	0/28	1/24	2/7	23/10	1/2	5/0	0/0	1/0	5/0
Total 2.5-12.7	0/36	0/60	1/54	3/26	73/16	7/13	15/0	10/0	9/1	20/7
% dead below 2.5 cm	0	0	1.8	10.3	82.0	35.0	100	100	90	74.1

days of burial, nearly all of the animals recovered from deeper than 2.5 cm had died. The near lack of dead buried less than 2.5 cm could have several explanations. Perhaps there were very few animals buried shallowly (many animals were observed swimming above the sediment and they were included in the 0-2.5 cm fraction). Or the shallowly buried worked their way to the surface in this sediment (fine sand without clay or silt). Or the shallowly buried take longer to die than four days under the experimental conditions. No dead were observed in the 0-2.5 cm fraction until the fourth day and then only a few.

It is possible that the death rate was a function of depth of burial, as the first few deaths appeared at the greatest depths and no deaths appeared in the shallowest fraction until the fourth day. To make a depth effect clearer, one would need to repeat the experiment using trials with burial times between 24 and 96 hours.

Besides being a function of burial depth, survival time might also be a strong function of porosity (influences oxygen and water flow through the sediment), organic content (influences food and oxygen availability in the sediment), consolidation (affects ability to move limbs for respiration and feeding), sediment clay content (affects compactness and porosity of the sediment), and temperature (affects metabolic rate of cumaceans and decomposers in sediment). Since my interest was in the greatest length of time _C. vulgaris_ could survive under a combination of optimal conditions, I made an educated guess of what an optimal combination of conditions would be, and then used those. The correctness of the choice was partially verified by the approximately 50% death rate after only 24 hours for animals buried 4 cm in the surfacing-ability experiment compared to no dead recovered after 24 hours shallower than 7.6 cm in the maximum buried survival time experiment.

Resistance to Abrasion

Abrasion resistance of *C. vulgaris* proved to be high (Table 4). One week after being mixed for one-half hour in a sediment slurry, 91.7% of the original animals were recovered and 97% of the recovered animals were alive. It is safe to say that very few animals will be killed by the decanting process used to separate them from sediments.

Decomposition of Corpses

Four samples with their plastic-head-pin markers were recovered approximately 4-1/4 days after the December 16, 1975 burial of five samples of fifty dead *C. vulgaris* each. One sample was not recovered because one of the two locating stakes was gone. From the other four sites, 28, 28, 22, and 33 out of fifty animals were recovered. Two control cores had 1 and 2 *Cumella vulgaris.*

Table 4. Abrasion resistance derived by counting the number of dead and living animals after mixing one-half hour in a slurry. All samples started with 100 animals.

sample number	Total recovered after		Total recovered alive after		% of recovered animals alive after	
	one week	two weeks	one week	two weeks	one week	two weeks
1	95	94	91	87	96	92
2	96	93	96	88	100	95
3	92	90	98	82	96	91

The animals recovered in the cores below the surface may have been shoved down by the corer walls. Or they may have been previously buried there. It is not felt that they represent normally living individuals at the depth of recovery because of the poor survival of buried individuals in the lab.

In spite of the small size of *C. vulgaris*, corpses may remain in the sediment available for collecting for several days.

DISCUSSION

Several aspects of the behavior of *C. vulgaris* under conditions simulating sedimentation from dredging have been studied. These basically are short-term results and represent the behavioral processes of the cumacean as outlined in the upper portion of the conceptual model (Figure 2). No attempt had been made to deal with the possible long-term effects of sedimentation over a habitat of *C. vulgaris* (bottom portion of Figure 2), but some speculation concerning long-term behavior is included at the end of the discussion.

The responses of *C. vulgaris* to the physical processes studied, are discussed by topic as outlined in the conceptual model and an attempt is made to relate their laboratory behavior to dredging situations.

Avoidance of Burial

During dredging, suspended sediments may be carried by currents and deposited over a large area. The chances of avoidance of burial by *C. vulgaris* over this area of low-level sedimentation appear good on the basis of the avoidance-of-burial experiment. Suspended-sediment deposition would be at low, long-period rates rather than at the high impulse rates found at a spoil dumping site. Hopper dumping is probably of little concern, however, because it would be virtually impossible to dump such a load directly over a colony of C. vulgaris which is generally restricted to water less than 10 m deep.

Since in the avoidance-of-burial experiment only a little more than 10% of the C. vulgaris were buried in the first 4 cm of sediment at the relatively high sedimentation rate of 0.2 cm/min, one would not expect a large proportion of the cumaceans to be buried by the probable slower rate of deposition of suspended sediment.

When the problem of avoidance of burial was first considered, it seemed that swimming speed would be a good measure of an epibenthic animal's ability to avoid burial. This idea seemed logical because if an animal could swim up faster than the bottom was rising due to sedimentation, it should be able to avoid burial. Yet, with a sedimentation rate of 2.7 cm/min, 56% of the animals were buried by the first four centimeters even though the swimming speed of the smallest, slowest life stage, the manca, was measured at 15 cm/min. It therefore seems their ability to avoid burial in the experimental situation was determined by something other than their clear-water swimming ability. One possibility might be that under the downfall of particles their swimming speed is greatly lowered. Moving objects going in opposite directions tend to get in each other's way and slow each other down.

Alternatively, perhaps avoidance of burial is limited by the speed at which they can get out of the sediment to begin swimming. _Cumella vulgaris_ normally rests horizontally just beneath the sediment surface with only its head exposed. If one assumes a surface-escaping speed which is markedly lower than its swimming speed, then they could be buried by any sedimentation rate greater than its surface escaping speed before it had a chance to make use of its faster swimming speed.

If the above hypotheses are correct, one would expect that animals swimming when high sedimentation began would have a better chance of avoiding burial than those resting on the bottom.

In the large areas of suspended-sediment deposition, the animals probably would not have any trouble avoiding burial. But in areas where above normal sedimentation rates occurred, such as spoils areas, _C. vulgaris_ survival might be increased if they could be induced to swim. One method to make them swim in shallow water would be by "blowing" them off the bottom with the prop wash of the dredge. Should a population of _C. vulgaris_ somehow exist in a hopper-dredge spoil area, a maneuver which might be amenable with the operation of a twin screw dredge and the above ideas would be a 180° pivoting turn over the dumping site by backing down on one screw while going forward with the other before dumping the hoppers. The turn would not be an extra one as the dredge needs to turn to return to the dredging site. This maneuver might be objectionable, however, from the standpoint of some other species because of the extra sediment suspended.

A possibility exists that the ability of C. vulgaris to avoid burial might be used to separate it from detritus. The slow and careful addition of detritus free sediment to a container containing a thin layer of detritus and animals could force all of the living epibenthic animals to the new detritus free sediment surface. After the detritus has been buried by a few centimeters of clean sediment, the water and upper most sediment could be removed and the detritus free animals separated by decanting.

Swimming Behavior

The swimming speed and behavior of C. vulgaris is dependant on many factors. Mature males have more highly developed swimming legs (Figure 1) and swim faster than females and immatures (Figure 6). The males are the only ones observed to swim horizontally and downward as well as swimming upward. To go down, females and immatures stop swimming and sink. Males may go down either by sinking or by actively swimming. Only males have been observed swimming rapid erratic courses at the water surface in an aquarium. Some other species of cumacea have been observed to have swarms of males at the surface (Foxon, 1936; Corey, 1969; Gnewuch and Croker, 1973), but only the males of C. vulgaris have been observed to follow this behavior.

Possibly the swimming behavior of males is associated with mating. Gnewuch and Croker (1973) observed fast erratic swimming by a mature male cumacean, Mancocuma stellifera, immediately prior to mating with a female which had just molted to its brooding form.

All stages, manca and older, can swim. Eggs and developmental stages preceding the manca are carried in the marsupium of the female and thereby maintain the advantages of mobility also.

If one compares the swimming speed of C. vulgaris (0.2-5.0 cm/sec.) with that of a modest one-knot tidal current (51.5 cm/sec.), it becomes obvious that it does not maintain its position in the estuary by swimming against the current. To avoid being washed from its habitat it would need to either swim only during the slack tide or when the currents are flowing towards its habitat.

If the latter case is true, it would be interesting to determine what factors must be met before they will swim when a current is flowing. One of many possible behaviors might be that they swim if the salinity deviates from their normal range. Salinity changes might be detected by their effects on water excretion rates. There are many conceivable behavior patterns which would enable them to use the currents which might be examined in an attempt to find how it is that they remain in a desirable habitat. The possibility that they just do not swim when a current is flowing should of course be checked first.

I have observed undisturbed _C. vulgaris_ swimming only in the dark. Swimming in the light is rare unless they are somehow disturbed. Large portions of samples of _C. vulgaris_ have been observed to swim under lighted conditions when in a container overcrowded with animals, in a container which had just been shaken, or in a petri dish with no sediment into which they could settle. When disturbed in the above ways many swam towards the light.

Burrowing (Surfacing) Ability

Cumella vulgaris gave only poor evidence of an ability to burrow back to the surface after being buried 4 cm. After one day 32 out of 100 were dead. After five days 67 out of 100 were dead. The abrasion resistance experiment animals were used as controls as they were placed on the surface of identical trays of sediment for seven days. Only 0-4 animals were recovered dead in these trays. Such large numbers dead after burial compared to animals not buried indicates a poor ability to survive burial and suggests a poor burrowing ability. If they had been able to burrow to the surface they should have survived.

The possibility that C. vulgaris might be able to surface when buried by a slurry was not examined. Because of the fluid nature of a slurry it is suspected that they might be able to swim to its surface.

One problem they may have when buried is in knowing which way is up. Their eye, which is the most obvious organ to use when swimming, could be useless when buried.

Cumella vulgaris may die from a lack of oxygen when buried. The death rate of shallowly buried animals in the surfacing-ability experiment was much higher than in the maximum buried-survival-time experiment. After 24 hours in the upper 4 cm, approximately 37% of the animals in the surfacing experiment died compared to none buried 5 cm in the survival-time experiment. The sediment of the surfacing experiment included fine sand, silt, and clay and therefore had a much lower porosity to water and oxygen than the silt and clay free fine sand of the survival-time experiment. Many other possible causes of death of buried animals must be considered besides a lack of oxygen, however, including hydrogen sulfide poisoning, local build up of excretory products, starvation, or inability to respire or feed because they are restrained by the sediment.

Buried-Survival Time

The buried-survival-time experiment showed that subsurface life is not for *C. vulgaris*. After four days of burial most animals deeper than 2.5 cm had died (Table 3). This experiment did not make clear how long animals buried less than 2.5 cm could survive. It is suspected that they might survive longer.

The only sedimentation associated with dredging that would be high enough to bury *C. vulgaris* would be dumping of spoils. But *C. vulgaris* is usually found in water 10 m or shallower and spoils are usually dumped deeper. If spoils were dumped in shallow water and used as fill for land development, some animals would be buried, but the effect on their population of the burial would be of little consequence compared to the loss of habitat.

Clammers might affect *C. vulgaris* by burying them. The effect of heavy clamming is hard to assess from present data. If the sediment piled on the surface in clamming is eroded away during the next high tide, the buried animals may be uncovered before they die.

Sediment Selectivity

There are several ways in which dredging might make the sediment surface unsuitable for *C. vulgaris*. The surface could be raised so much that it dries more during low tides. *Cumella vulgaris* is not found on sediment that dries at any time during the tidal cycle (Wieser, 1956). A very thin layer of sediment deposited from dredging could make an area unsuitable if it had a median particle diameter greater than 0.35 mm, the coarsest sediment upon which *C. vulgaris* has been reported (McCauley et al., 1977) or if it formed a poorly consolidated layer of silt and clay.

Cumella vulgaris is able to sense more about a sediment than its particle size. Wieser (1956) showed its ability to discern sediment which has been dry recently even though it was wet when contacted. Such an ability might help *C. vulgaris* to avoid getting stranded in the upper reaches of the intertidal area where the sand dries during low tides. He proposed that it remains on unsuitable sediments for shorter times and swims sooner when on those sediments which are unsuitable. As a result *C. vulgaris* tends to accumulate on the preferred sediment even if its search movements are random rather than directed.

Wieser (1956) proposed that *C. vulgaris* might discern a recently dried sediment by the effect the drying had on the diatoms, bacteria and organic film attached to sand grains on which they feed. Assuming that Wieser's hypothesis is correct, dredging might temporarily change the attractiveness of large areas to *C. vulgaris*. Dredging causes large quantities of buried channel sediment to be suspended and then redeposited over large areas. This recently buried sediment might have a different or less abundant flora and fauna than that on which C. vulgaris normally feeds.

Suspended sediment from dredging would likely have less unicellular algae than the sediment which it covered. Two factors would contribute to lower algae levels in dredged sediment. One would expect surface algae to be less abundant in the dredged channel than on the tidal flats because the depth of the normally murky bay water in the dredged channel blocks light. Also as one goes down in the sediment the algae would decrease from a lack of light (Grontved, 1962), and the algae in the freshly deposited sediment would be diluted with algae-free subsurface sediment. Similarly bacterial count goes down very rapidly as one goes down into the sediment. Sediment dredged from 10-20 cm deep may have two orders of magnitude less bacteria than sediment from the surface (Peterson, 1973; Zobell and Feltham, 1942; Wood, 1965).

When on sediment with a median diameter greater than 0.15 mm, C. vulgaris is an epistrate feeder (Wieser, 1956). It revolves sand grains with its mouth parts, cleaning off food. The surface of the sand grain can serve as a food source because diatoms and bacteria live there. Even though organic particulate detritus is abundant in the sediment, C. vulgaris feeds on sand-surface microfauna. Since much of the dredged material is from channels and from below the sediment surface, it will have much lower levels of microfauna than the intertidal and shallow-water surface sediments on which C. vulgaris is normally found. Therefore deposition of just a few centimeters of dredged sediment might replace an abundant food supply with a temporarily much sparser one.

The large areas over which the sediment settles might decrease in attractiveness until it acquired a normal surface covering of microfauna. If the attractiveness of the sediment was greatly lowered there could be several different consequences. 1) Cumella vulgaris would swim more frequently and therefore be more subject to predation and to transportation out of the area by currents. 2) Their numbers might go down temporarily in the area of sedimentation due to their moving elsewhere and then go back up after a normal grain surface microfauna was reestablished. 3) If dredging were for an extended period, the return of normal surface microfauna might be delayed long enough to decrease the cumacean "seed" population.

The preceding is speculative and should at least be checked by preference experiments in which mixed sediment from cores taken in the channel are compared to surface sediment from the animal's normal habitat. Following the lead of Wieser (1956) and Chang and Levings (1976), such preference experiments should be straight forward to perform.

Abrasion Resistance and Decomposition Time

Two aspects of *C. vulgaris* which are useful to know when designing experiments are abrasion resistance and decomposition time.

These animals showed a high resistance to being broken up or killed when sediments were mixed. The results of the abrasion resistance experiment could not be interpreted as originally planned, to suggest that *C. vulgaris* would not be broken up in passing through a hopper dredge sediment pump, because the energy level of mixing may be much higher in a pump than in a cement mixer. This one factor might make abrasion damage more severe, even though exposure time is shorter and the sand content is lower.

It does appear likely that *C. vulgaris* would survive milder forms of abrasion such as prop wash and current stirring of surface sediments. For experimenting with live animals it is useful to know that they are tolerant of abrasion involved in techniques used to separate them from the sediment.

The decomposition rate of buried *C. vulgaris* observed was slower than one would expect considering what a small mouthful they would make for many animals and considering the large numbers of bacteria in estuarine mud. Under some situations at least, corpses may remain identifiable and collectible for several days. In experiments where animals are allowed to die, the fact that they take several days to decompose beyond recognition allows one to locate and count them and know where they died even though it has been several days since they died.

Bay Development

Dredging is not the only activity of man that can affect the habitat of C. vulgaris. Any of man's activities that increase the load of various materials such as silt, fertilizer, organic materials, and toxins in the water run the risk of damaging the environment. Dredging encourages development and unless pollution control is improved, pollution increases along with development and will eventually reach levels that damage the estuarine environment.

Intertidal and shallow water areas are normally brightly lighted during the day at low tide. Dredging encourages bay front building development. Densely shaded areas under structures extending over the bay may have an aberrant ecology and certainly will have reduced primary productivity because of low light levels.

CONCLUSIONS

1. It is unlikely that sedimentation due to dredging will bury *C. vulgaris*.

2. Sedimentation rates higher than 0.25 cm/min are necessary to bury 50% of *C. vulgaris* with 4 cm of added sediment.

3. *Cumella vulgaris*, once buried, is a poor burrower. Burial by as little as 4 cm of sediment may be fatal.

4. Females and immatures swim at speeds of 0.25 to 1.5 cm/sec, depending upon size and factors undetermined. Mature males swim at speeds up to 5 cm/sec.

5. Sinking speeds of *C. vulgaris* in water varied from approximately 0.2 to 1.6 cm/sec. Their sinking speed is proportional to their size.

6. They are highly resistant to abrasion when mixed in a slurry of sediment and water.

7. Under some conditions dead *C. vulgaris* can be buried four days and still be recoverable and recognizable.

8. Dredging is more likely to affect *C. vulgaris* by destruction of suitable habitat than by burial.

BIBLIOGRAPHY

Armstrong, L. R. 1965. Burrowing limitations in Pelecypoda. Veliger 7(3):195-200.

Birkett, L., and A. D. McIntyre. 1971. Treatment and sorting of samples. Pages 156-168 in N. A. Holme and A. D. McIntyre, eds. Methods for the Study of the Marine Benthos. Blackwell Scientific Publications. Oxford, 334 p.

Chang, B. D., and C. D. Levings. 1956. Laboratory experiments on the effects of ocean dumping on benthic invertebrates. I. Choice tests with solid wastes. Can. Fish. Mar. Service Tech. Rpt. 637. 65 p.

Corey, S. 1969. The comparative life histories of three Cumacea (Crustacea). Cumopsis goodsiri (Van Beneden), Iphinoe trispinosa (Goodsir), and Pseudocuma longicornis (Bate). Can. J. Zool. 47:695-704.

Dixon, A. Y. 1944. Notes on certain aspects of the biology of Cumopsis goodsiri (Van Beneden) and some other cumaceans in relation to their environment. J. Mar. Biol. Assoc. U.K. 26:61-71.

Foxon, G. E. H. 1936. Notes on the natural history of certain sand-dwelling cumacea. Ann. Mag. Nat. Hist. series 10, 17: 377-393.

Gnewuch, W. T., and R. A. Croker. 1973. Macroinfauna of New England marine sand; I. The biology of Mancocuma stellifera Zimmer, 1943 (Crustacea: Cumacea). Can. J. Zool. 51(10): 1011-1020.

Grontved, J. 1962. Preliminary report on the productivity of micro-benthos and phytoplankton in the Danish Wadden Sea. Medd. Danmarks Fish. Hav. 3(12):347-371.

Hart, J. F. L. 1930. Some cumacea of the Vancouver Island region. Contr. Can. Biol. Fish. (n.s.) 6:23-40.

Jones, M. L. 1961. A quantitative evaluation of the benthic fauna of Point Richmond, California. Univ. Calif. Publ. Zool. 67(3):219-317.

Jones, N. S. 1963. The Marine Fauna of New Zealand; Crustaceans of the Order Cumacea. N. Z. Oceanogr. Inst. Mem., no. 23. 81 p.

McCauley, J. E., R. A. Parr, and D. R. Hancock. 1977. Benthic infauna and maintenance dredging: a case study. Water Research 10:(in press).

McKnight, D. G. 1969. A recent, possibly catastrophic burial in a marine molluscan community. N.Z. J. Mar. Freshwater Res. 3:177-179.

Peterson, P. E. 1973. Factors That Influence Sulfide Production in an Estuarine Environment. M. S. thesis. Oregon State University. 97 p.

Schulenberger, E. 1971. Responses of Gemma gemma to a catastrophic burial (Mollusca: Pelecypoda). Veliger. 13(2): 163-170.

Wieser, W. 1956. Factors influencing the choice of substratum in Cumella vulgaris Hart (Crustacea, Cumacea). Limnol. Oceanogr. 1(4):274-285.

Wieser, W. 1959. The effect of grain size on the distribution of small invertebrates inhabiting the beaches of Puget Sound. Limnol. Oceanogr. 4:181-194.

Wood, E. J. 1965. Marine Microbial Ecology. Reinhold Publishing Company, New York. 243 p.

Zimmer, C. 1943. Cumaceen des Stillen Ozeans. Arch. Naturgesch. 12:130-174.

Zobell, C. E., and C. B. Feltham. 1942. The bacterial flora of a marine mud flat as an ecological factor. Ecology. 23(1): 69-78.