From:	Richard Wilson
To:	Rockett, Derek (ECY)
Cc:	Brian Hatfield; Brian Blake
Subject:	Comments on SIZ and EIS for imidacloprid
Date:	Monday, December 01, 2014 12:02:02 PM
Attachments:	SIZ AND EIS COMMENTS.pdf WCSediment comments to work.pdf

---

Derek,

Let me apologize for the length but over the past four decades with my interest in the effects of burrowing shrimp I have accumulated a pile of information. Sediment samples this last summer reaffirmed many of these. In the comments I have tried to maintain a scientific concentration but have to simplify some of the aspects. Granted much is from years of observations both out in the bay or under my microscope. Hope the comments are useful. I have run out of time so please excuse typos.

Keep up the good work as I know you have a tough assignment. To me the understanding of the deleterious impacts of ghost shrimp and Japanese eelgrass to the important benthic sediments and biota is very key to the level of estuary productivity.

DIck

Richard Wilson, Ph.D.
www.baycenterfarms.com
360-875-6172 (V)

Bay Center Mariculture Co.
PO Box 356, Bay Center, Wa. 98527
Ph. 360-875-6172 Fax 360-875-6172
bcfarms@baycenterfarms.com

November 30, 2014

Derek Rockett
Ecology, SWRO Water Quality Program
P.O. Box 47775
Olympia, Washington 98504
Derek.Rockett@ecy.wa.gov

Dear Derek Rockett,

Introduction and History

As a follow up to the comments I submitted to DOE back in April on the control of both Japanese eelgrass and burrowing shrimp further sediment analysis was conducted in the summer of 2014. The first comment report I assume is still posted at DOE and is also viewable on my Flickr site in an album titled, *Comment on the Willapa Benthic*:

https://www.flickr.com/photos/76798465@N00/sets/72157644330726062/

There seemed some question by a few about an oyster grower being unbiased let alone scientifically qualified to offer evidence as to the impacts of and attempts to control burrowing shrimp. So by way of introduction I would like to offer a brief personal vita along with my long history of study with burrowing shrimp. Of importance in this regard is how oyster farming and the associated problems became my eventual focus. Being from Oregon I started in the field of geology at the University of Oregon in Eugene. After graduating was accepted to the highly acclaimed geology program at the university of Michigan at Ann Arbor where I earned a masters and doctorate with nearly equal academic credits in zoology and ecology. I have worked with and under several nationally famous geologists and zoologists. During the graduate period also worked on field crews with the UM museum of natural history. I returned to Oregon as an assistant professor of geology for several years of teaching and extra fieldwork under a NSF grant. Research work in geology and paleontology included fieldwork in Oregon, which was associated with the museum of natural history at the Univ. of Oregon.

Having spent considerable periods of pre-college time at the Oregon coast including on a fishing boat as a deck hand, I wanted to get back to the coastal environment. The ecology of the near-shore environment including the sedimentary processes was a major interest along with my interest in veliger larvae and rearing salmon for release and recapture. For several years I had traveled to investigate sources of both marine and fresh water for rearing various aquatic forms and had focused in on salmonids, crayfish and bivalve larvae. Since water quality and location was key my couple years of search lead me to the eastern side of Willapa bay where the artisanal ground water, the unpolluted Palix River and the brackish marine waters at Bay Center tested out the best possibility. I then developed a business plan that involved implementing a long sought permit from the then Washington Department of Fisheries that would allow the rearing, release and recapture salmon. This we did for three years until abruptly cut off by WDF.

An old deserted cannery on the margin of the Palix River at Bay Center was leased and eventually purchased. Here we set up and started experimenting and building if not the first, one of the earliest oyster and clam hatcheries in Washington. Soon after setting up I was joined by my brother who was a graduate student at Oregon State University working on a doctorate in marine fish physiology. The third partner was my long time friend and mentor, the late Arnold Shotwell professor at the University of Oregon.

In that early stage the main part of our research and development was immediately begun and involved

spawning and researching needed systems to learn how to raise bivalve larvae and most important the steps to isolate and grow concentrated algae cultures to feed the swimming larvae. The site at Bay Center allowed eventual production of set oysters but even though water quality in terms of human caused problems was generally no problem it was mother nature that at times caused rich blooms that could cycle around to bacterial or some phytoplankton harmful to the larval systems. We collected various diatom species and cloned them for culture. This marine water at Bay Center still proves excellent for post set and shellfish growth and today serves our company in this role one it has played for over forty years.

In the mid seventies after several years of raising larvae (often struggling) with the small hatchery the opportunity arose to acquire a long established multigenerational oyster farm which dated back to the turn of the century. We had sold oyster seed to the owner of this farm over the past couple of years. He reached an age and ability where working his beds became difficult. The price of seed and costs to control burrowing shrimp along with aged equipment he gradually gave up and offered us the chance to purchase the oyster beds and equipment. I had observed and investigated the burrowing shrimp control efforts with often very mixed feelings over the use of carbaryl as the means of keeping the intertidal farm areas available to plant and grow oysters. Thus it was critical that before purchase of the oyster farm that we fully investigate scientifically the effects of carbaryl. Much of the farmland we would purchase had been nearly depleted of any oyster crops and through neglect the better productive intertidal oyster grounds had been rendered unusable by burrowing shrimp. I had previously spent considerable effort working to change pesticide type and use in southern Oregon particularly in the orchards of the Medford area. Key tributaries of the Rouge River had been basically rendered uninhabitable to aquatic life and in particular various fish species. I cite this to document my concern for the use of chemicals without consideration of collateral damage. As a long time member of the Sierra Club, Audubon Society (past board member of the SW Washington chapter and avid bird watcher), and many other scientific societies and associations, the use of chemicals was nearly always against my philosophy and for that matter still is. For example, even after leaving Oregon I retained a membership in Cha Smith's NW Coalition for Alternatives to Pesticides group.

At this point the big challenge was to weigh the destruction the two types of burrowing shrimp were imposing on the sediments and benthos against what the application of a pesticide would do to the environment. The purchase was delayed and debated as study proceeded. The principle people in our company had years of scientific experience in zoology, geology, ecology especially in the marine environment. We concentrated on investigating and testing with the purpose to confirm the impacts of carbaryl. We had the necessary scientific tools to do preliminary sampling and analysis. The sedimentary destruction was of major concern and assessment was made on whether it was worth gambling on the long term rebuilding and profitability of oyster farming. Particular attention was paid to the science reports. In short, we discovered that carbaryl which indeed did have short term impacts as noted by the fact it killed ghost and mud shrimp revitalize the benthic. However, the most striking was the revelation we gained through observation and sampling was the longer-term benefits to the benthic sediments and biota. Very notable was the increases in number of species and with microscopes we had the advantage of looking at the incredible micro fauna and flora. These observations became an indicator of what should have been there and had in fact been removed by the burrowing shrimp. Our initial concern was for the benthic phytoplankton recovery after treatment but notice of the increases to the consumer groups could not be missed. Abundance of members in various species also was striking. In fact, extensive areas of the mudflats could be reclaimed and rejuvenated if they had not suffered the burrowing shrimp for extremely long periods. Since we had knowledge of the taxonomic forms normal for the estuary and how change was caused by burrowing shrimp then rejuvenated after carbaryl the contrast was striking. It became obvious periodic treatment benefited other estuary forms such as fish, birds, and eelgrass. Just the arresting of the burrowing shrimp modification of the sedimentary area would trigger recolonization and establishment of the interrelated primary producers and consumer trophic levels. We moved ahead with purchase of the ± 400 acres where today it is in production of not only cyclic oyster crops but areas of high biodiversity and abundance. The oyster bed in the image on the cover of the Draft EIS was included.

The farming of oysters and this interrelated associations of the biological and physical aspects of the

estuary have never ceased to lose my interest. Starting with the birds and fish as a past board member of the Audubon Society and as both a commerical and sport fisherman, guarantee I would continued this personal investigation of the destructive burrowing shrimp over the next 40 years. I helped draft part of the SEIS on carbaryl many years ago. More effort over the next decades as agency folks worried over impacts, continued to hopefully find a non-pesticide means of controlling shrimp. Besides various growers testing alternative means, studies were conducted on the total benthic assemblage in relationship to treating with carbaryl. They nearly always showed increases and a healthy return past post treatment levels which was probably a reflection of recovery from the damage caused by burrowing shrimp. More newly settled crabs existed in a treated farmed oyster bed. Shorebirds used the ground around the oysters that was kept productive to search for invertebrates. Much of this effort was with researchers from WSU and UW. Scientific work was directed at effects of the pesticide carbaryl on various groups of the benthic fauna and flora. For example, many years of research were devoted to impacts on newly settled Dungeness crab. They conducted the work from our shore site and oyster beds near Bay Center. BCM just happened to have ample oyster land we had purchased with good burrowing shrimp populations to set up test areas. I and our crews worked with them as they tested various materials, techniques and possible ways of reducing and controlling burrowing shrimp on the privately owned oyster grounds. For example, I built an injection devise to put ammonium under high-pressure into the sediments. Trying to control shrimp numbers without great disruption of the sedimentary habitat proved difficult and nearly always ineffective. Meanwhile, always protests were noted from those outside and within agencies as new folks replaced those with prior experience. Often new research was required without review of the scientific history. Large amounts of money and time have been spent to control this destructive activity of burrowing shrimp but to little on their total impact on numerous members of the benthic biota. Borrowing shrimp are not restricted to actively farmed oyster beds as thought by many but massive destruction to public lands and resources had and is occurring. No attempt is made to place controls of burrowing shrimp on these public lands. Often the very agencies, which question and attempt to curtail treatment or are wary of public comment, become responsible for letting their mudflats and the biota be decimated. It was hoped that imidacloprid would be judged an improved alternative and easily accepted as an improved method to save and enhance select areas of the benthos not just another toxin to try.

Figure 1. WSU used this tractor to inject and test different types of materials sub surface in at attempt to control burrowing shrimp.

What needs closer scrutiny is what the oyster growers and certain of the agency folks have tried to call attention to is that the burrowing shrimp are extremely detrimental to a majority of the estuary biota not just the oyster crop. The effect is far more extensive than just oysters sinking into the sediment. How do you account for the subtile loss of key stages of a public resources if it can't even be realized such loss is occurring? This seems quite different than an oyster grower's reduction and monetary loss of a planting as they disappear beneath the surface?

Summer Sediment Sampling of Ghost Shrimp Ground and Interpretation

Thus it was somewhat inadvertent that this summer (2014) under the experimental use permit allowed by DOE that BCM decided to treat using an untried granular formula on our commercial size areas. In preparation our company took core sediment samples prior to treating an oyster bed (B111) with a very high density of ghost shrimp. The burrow count was at 60 per square meter. It was an area that we had not

been able to treat over the past decade. The thought was that extra sediment data would add to any results after treatment. The treatment was only partially effective and the sediment data probably irrelevant in the control operation. However, after several days of working through the core samples the results in terms of sediment modification and missing biota were surprising. At this point I decided to sample another oyster bed that I felt physiographically equivalent for comparison to B111. This oyster bed, which unbeknownst to us at the time, was later selected as an image on the Draft EIS cover. Labeled B71 this bed is a seed/harvest area which has received periodic treatment for burrowing shrimp every 5 to 6 years. The importance this will show, in the final analysis, is how critical keeping the burrowing shrimp numbers under control can be. The longer they develop in size and numbers on a bed the greater the damage. Thus, the idea is to keep them from expanding and modifying the sediment composition while replacing the normal inhabitants. The sampling and analysis procedure are attached and posted here:

https://www.flickr.com/photos/76798465@N00/sets/72157649055133359/

This long time personal interest in burrowing shrimp became more focused on the biological impacts the ghost shrimp have on the sediments and the corresponding normal benthos other than oysters. It was obvious a pesticide reduced the population of burrowing shrimp and stabilized the sedimentary area and keeps the benthic biota perhaps reduced but still present. At this time only the ghost shrimp, *Neotrypaea*, is a dominant problem as the mud shrimp, *Upogebia*, populations have been greatly reduced or nearly eliminated by a parasitic isopod. However, we see former areas, which had heavy mud shrimp populations now being occupied and modified by the ghost shrimp. Over the years experience with algal systems and productivity in connection with the sedimentary 'mudflat' ecology has remained important. The thousand plus acres made barren of any sessile forms on the sediment surface and a greatly reduced number of species and abundance within the sediment can be attributed to ghost shrimp. The most important find was the lack of the benthonic diatoms and not surprisingly the primary consumers which depend upon them. These barren acres probably no longer contribute to the primary production of the bay. Not even eelgrass will exist on these shrimpy areas so even their small contribution to the estuary is missing. Samples from our B111 showed high ghost shrimp occupancy rendered the benthic sediments nearly absent of benthos organisms, especially the primary producers, the phytoplankton.

At this point is seemed necessary to put together my understanding of the productivity in the estuary. Guess I found it difficult if not impossible to explain. The weathering, transport, deposition of igneous rock minerals would discourage continuing. I chose to attempt a basic understanding and show the interaction of the atmosphere, hydrosphere and lithosphere for productivity in Willapa Bay as example, the following cut and paste montage is presented (Figure 2). This basic understanding is necessary to realize what the burrowing shrimp remove from the benthic environment. It is drawn from my years of concern of the science of this matter and was underscored by the sediment sampling. I have tried to keep basic scientific information intact and balanced. Hopefully it is not over simplified as most stages have multiple pathways, complex variation and various interactions with the biota. The hope is that eventually key decision makers will understand the damage which has been and is being done by burrowing shrimp occupation.

In Figure 2 the sunlight and nutrients have to come together with the focus on benthic diatoms to represent the phytoplankton as the key starting point of estuary productivity. They seem to enjoy their intertidal experience as often I have found them clinging to small sand grains and dividing. Since they stay when the tide ebbs, I imagine them content with solar radiation and silicic acid found at the sediment surface. Diatoms are interesting and some think more metazoan with their ability to produce urea, but then in plant like fashion combine solar radiation, CO_2 and other nutrients from both air, water and sediments to make carbohydrates, proteins and lipids for numerous species. As noted the diatom frustule (silica shell) leaves them dependent upon a source of useable silicic acid. It results mainly from being a by product of weathering or the chemical action underway upon unstable igneous minerals in the sediment. Some would have the common quartz the major beach sand as a source of silicic acid but if anyone as attempted to watch this mineral break down chemically in nature they were there for a long time.

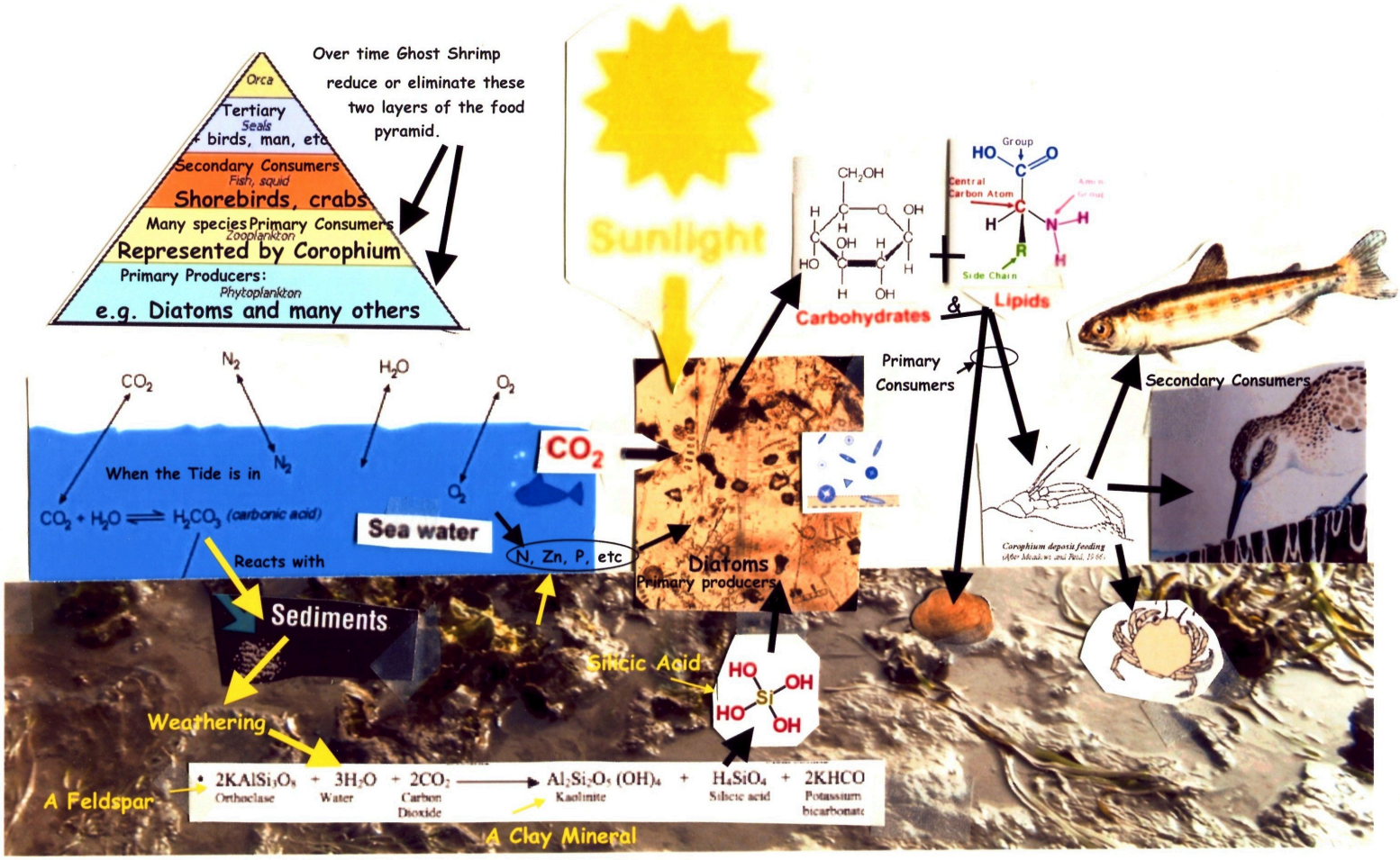


Figure 2. Interaction of the atmosphere, hydrosphere and lithosphere for biological estuary production featuring key roles by the sediments, the sea, the atmospher, the diatoms, the sun, and many consumers.

Continuing on Figure 2 the silicic acid is produced by the normal chemical breakdown of common volcanoclastic minerals, e.g. feldspars (plagioclase and orthoclase), muscovite (mica and biotite - the sparkle in an estuary mud), pyroxenes, olivines, etc. which is aided by the carbonic acid in the marine water. The sampling found the unweathered igneous minerals where present in the estuary samples. Ironically perhaps greater carbonic acid will increase the production of silicic acid and incorporation of the carbon into the diatom and then into primary consumers such as shellfish. Important is amount per time and this is where the grain size of those minerals and thus surface area available plays a role. Figure 2 shows a typical generalized weathering sequence for a feldspar. It is assumed that unless released from the sedimentary layer, as burrowing shrimp would do, the silicic acid supply seeping to the surface is critical to determine diatom abundance. Research seems to differ on limiting nutrients but silicic acid is often indicated as ‘probably’ a very important one. Note: Silicic acid is the general name for a family of chemical compounds containing the element silicon attached to oxide and hydroxyl groups with the general formula illustrated in Figure 2. I have often assumed a major reason for the high productivity beginning with diatoms in Willapa Bay was the composition of the Willapa Hills being basically igneous and sediments derived from earlier volcanic activity. The many small watershed deliver these minerals to the estuary. It is indicated that this source once deposited below base level in the near shore remains a reserve source and a vital nutrient to marine diatoms. The sediment report shows these grains under magnification. The reduced fluvial energy sorts the sediments with large or faster to settle clastics deposited near the stream mouths. Finer sands and silt carry further into the bay. Darker grains are obvious from the more iron and magnesium of basalt type igneous rocks. This buried supply of nutrient baring clastic minerals are being disrupted and reduced by burrowing shrimp as I point out in my comments.

Diatoms and other phytoplankton play their most important role to make the estuary productive. They convert the sun and nutrients into carbohydrates, proteins and lipids. Most should recognize these as key to animal growth and survival. I picked my favorite crustacean, a *Corophiini* I call *Corophium*, a genus which has had the misfortune to have been caught by taxonomists and now has been split into several different genera and species. However, I have used the genus *Corophium* for a long time all are *Corophiini* so both terms will be used, but considered similar as would be their burrowing and importance in the food web. In addition, *Corophium* will also represent many types of primary consumers. The *Corophiini* create a U-shaped burrow and thus they remain when the tidewater leaves the mudflat. This increases their importance and accessibility as a key species in the benthic habitat. There has been considerable research on this crustacean in the Bay of Fundy in regard to shorebirds (the shorebird in Figure 2 is from this work). *Corophium* usually was listed as a detrital feeders due to the fact intact diatoms could not be found in the stomach but it was later determined by using radioactive tracers that this amphipod actually masticates and thus crushes up the diatoms. It is now thought this form is very dependent upon diatoms taking in over 1,000 per hour. It also is dependent upon the diatoms being close to their burrow as it uses its modified antennae to gather them in. If sedimentary surface conditions are favorable the diatoms oblige. Key here is the consumption of diatoms into the diets of many different forms. One example is the path from the diatom with lipids to *Corophium* feeding upon them and then to shorebirds fueling up for long migrational trips. However, *Corophiini* are only one of many primary consumers including other crustaceans, many nektonic larvae such as barnacles, etc. This is a critical stage also for shellfish larvae and adults as the primary food source are those diatoms and other primary producing algae. Those *Corophiini* also leave their burrow especially on occasions when they don't fit any longer or it is an amphipod rutting period. These sojourns allow juvenile crabs and fish such as Dungeness and salmon a high lipid snack. From a personal standpoint, *Corophium* is key to an abundant over wintering shorebird population here on Willapa Bay and specifically the Dunlin. Our Christmas bird count usually records over 10,000 just from the intertidal we can view from Bay Center except when the upper flats were completely covered with Spartina. Shorebirds such as Dunlin don't utilize heavily infested burrowing shrimp ground and as was found in the sediment sampling *Corophiini* are not present. That also indicates burrows not possible and/or diatoms not available.

Shellfish and the people that grow them have called attention to this vital link of the benthic to other important forms such as various decapods (crabs), many fish particularly the juveniles, and of special interest to me many of the shorebirds such as the Dunlin. The burrowing shrimp modify the sediments and disrupt the important marine trophic relationship. They remove the smaller grain sized sediment and thus decrease the potential for nutrient release. The finer sediments support burrowing in allowing sediment burrow integrity, a necessary requirement for forms such as *Corophium*. Of course, this amphipod would not be interested if the sediment surface was not important to the diatoms. The burrowing shrimp seem to constantly bioturbate the sediments as they tunnel and forage through their sandy created sediments. They clean the relatively large grain (actually fine to very fine sand) and research shows they actually consume the smaller grain silt to digest off the organics. These smaller clastics are later eliminated as part of the fecal material outside the burrow opening where they are subject to transport by currents, wind, etc. Important here is this fine fraction of the sediment layer is removed. This reduces chemical reaction on mineral grains and production of usable products such as silicic acid while rendering the increasingly sandy composition to be unusable to support a burrow.

If protection of the marine biota is a top priority in an environmental review or impact statement is seems as much or more attention should be paid to the destruction by the species being targeted for this control. Examples of this were with the destructive Spartina (now under control) and current concern with Japanese eelgrass and ghost shrimp. The true impact they impart on the environment does not seem emphasized. It is far more than harm and mortality to an oyster crop. It is a vital piece of the entire marine biota. At present the oyster growers are the soul group calling attention to and paying the onerous costs in time and money to keep the estuary productive. A good percent of Willapa has been lost to date. It is ironic so much hyper emotion over protecting eelgrass, which the higher *Z. japonica* is a rather opportunistic benthic modifying eelgrass. Eelgrass does little for the other members of the biota in terms of benefit while blocking the valuable primary production of needed sunlight, nutrients and acceptable sediment surfaces (Figure 3).

Why do the oyster growers need to fight this alone? User and interest groups should join in. Bird watchers, crab fisherman and those who pursue salmon should be very concerned. They should discern and look at the true or responsible science of the marine near shore ecology and join in. There is lots of emotion over the use of pesticides but at what cost to the basic production of the estuary. No one likes a pesticide or chemo-therapy but if it remains the only studied viable option to losing valuable lifes should its use not be considered?

Comments on Opposition to Burrowing Shrimp Control:

I take offense at some of those criticizing the proposed use of a very short lived benign treatment such as imidacloprid which replacing another mild short lived pesticide which has been used for over fifty years and has kept Willapa Bay productivity at a good level but not at the potential. Both are chemical compounds duplicated from those of organic origin. I have read a Nigerian bean gave us the carbaryl formula and imidacloprid is similar to a nicotine formula found in tobacco. Both mimic their organic lineage by being short lived and non persistent in the environment. A chemical treatment used perhaps every 5-6 years on specific areas on an area that has held off the disastrous consequences of ghost shrimp taking over more areas of the prime intertidal. Their reference to a chemical soup is not only misleading it is completely false. To my knowledge never has a measurable trace been found in a harvested oyster or clam. The chemical is gone from the sediments and water within a matter of days. No chemical is being used or considered for use is persistent or bioaccumulating. The chemical is applied to the sediment and not on the shellfish. These few people who often-express distain for oyster farmers working their own land and shellfish crops seems self-fulfilling. In one particular case that I find personally troubling, the individual has pilfered the cover of a conservation group, the Sierra Club to promote her unfounded idealism. I have been associated with the Sierra Club as a member for decades and at least in the past they (we) based our discussions on science and the future. This is especially tragic when this individual is supporting and so much a part of a group responsible to subtle long-term damage in Puget Sound by being part of the shore side bulk headed folks. Their modified shorelines are often responsible for run off from skeptics, lawns and driveways. Their real problem is probably with shellfish farmers working their land in sight of their expensive shore side property. Meanwhile, they often block access to the marine areas for the public. We have one self-proclaimed grower who also fought the control of chord grass connected with a shore side motel who just sent out a bulletin on the chemical soup of Willapa. Of course, there is no independent proof of such a claim. He does however, give example of the ignorance as to how his perceived shellfish grow if the algal food supply is reduced or eliminated by burrowing shrimp or an aquatic grass. The folks, who have doubts just as I did years ago, should review the science. They should understand the habitat formation on normal estuary sediments and the shellfish crop. Grab a microscope and look at the dozens of important species that depend on the primary productivity of the benthic sediments, both surface and subsurface. They should educate themselves on how the forms displaced by ghost shrimp activities at one time greatly aided in production for the estuary as they used the sediment to increase in diversity and abundance. It will be these few scientifically compromised individuals attacking the careful use of a long studied control method who stand to be the ones who can take the credit for the collapse of the estuary food chain and its biodiversity. Of course, if they get support from the regulatory folks who should be responsible for ascertaining what the scientific criteria is and thus tayloring their actions to that base. Really important is to realize the real objective is achieved when the application of a long studied and tested control method is used to enhance the habitat. This should also include in depth what would happen if some control method were not used. What is the long-term impact? Is it reversible and what will

be lost if action is not taken? The oyster growers have made this assessment.

One Further Comment on *Zostrea japonica*.

The relationship of meadows of eelgrass on basic production can be shown on the illustration provided. In short, it blocks the primary production that would go to other members of the estuary. The note in the upper right of Figure 3 give reference. It seems difficult to draw in all effects but if the sun is to some degree blocked to the sediment surface while the lithologic character modification inhibits diatoms by blocking nutrients, and changing pH, etc. A good habitat for bacteria and worms which tends to remain in situ. Eelgrass basically contributes little if any benefit to other biotic forms although many claim different. The chemical action or weathering with a different pH is reduced. Competition for other minerals and other needs of a plant are now being reduced by occupation of the eelgrass. The crustaceans and those prey species critical to the estuary would not be feeding within a meadow as the sediment structure and diatom supply would be reduced or absent. E.g. the habitat favorable to the cycle shown above would not happen from the primary producer to higher tropic levels if eelgrass takes up residency and blocks and utilizes the critical components for growth. The image on the cover of the Draft EIS shows the oysters and eelgrass co-existing with barren sediment open to the benthic forms such diatoms and crustaceans *Corophiini*. This is highly productive, protective habitat created by growers (in this

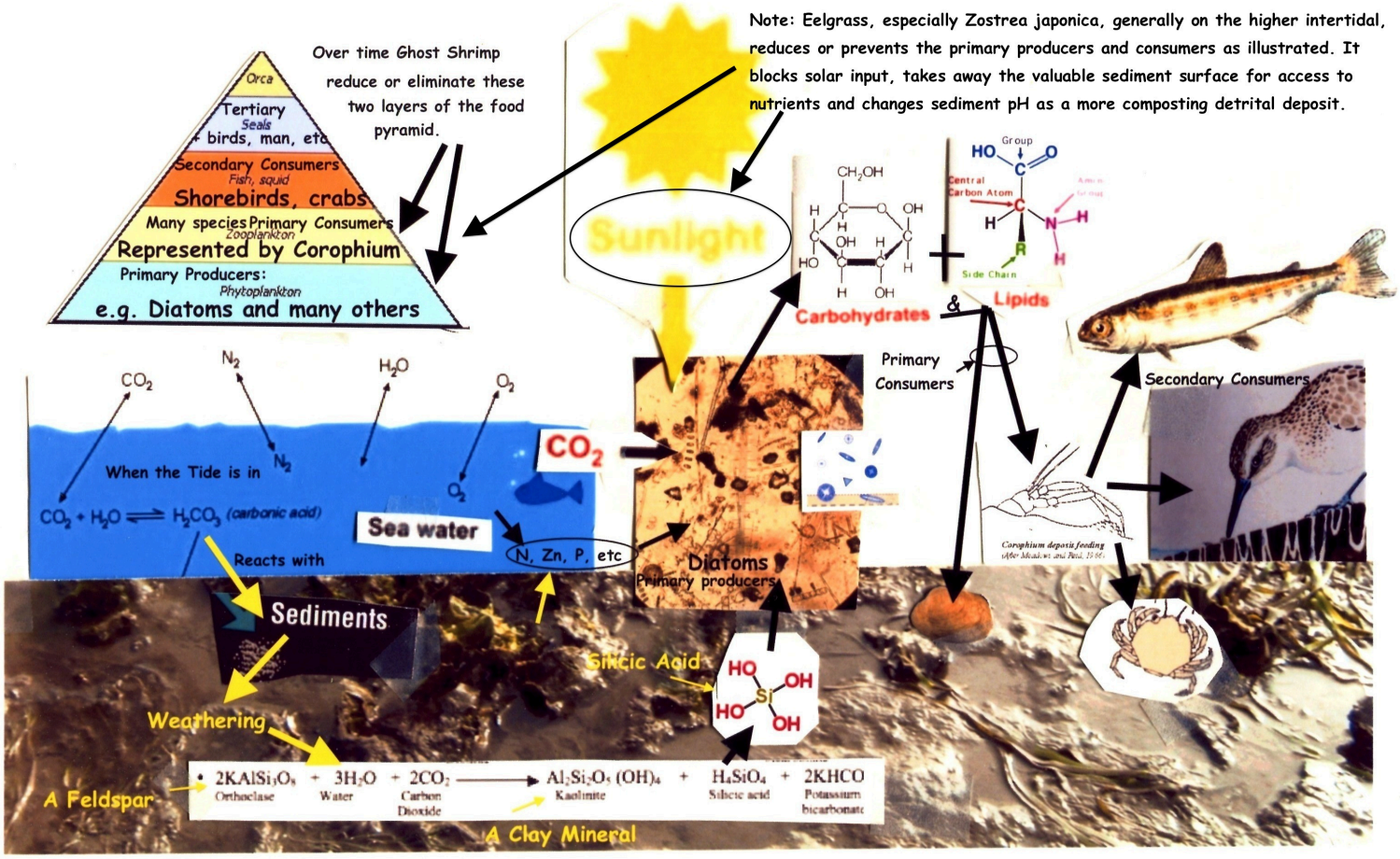


Figure 3. A repeat of Figure 2 but super imposing the impact an eelgrass cover would impart to the basic critical productive cycle. It is hard to find what contribution eelgrass has except to feed one species of goose. Some dabbler ducks might take it in when filtering out invertebrates such as worms.

case our company) by keeping shrimp under control and a welcome sign for other forms excluded by species which expand to be dominant such as burrowing shrimp or eelgrass.

A Final Comment:

I hope that DOE considers the importance the oyster growers have assumed over key intertidal areas in maintaining a high level of biological productivity in their farming practices including burrowing shrimp control. The final EIS should point out the problem with burrowing shrimp is much more than oysters sinking in a bioturbated area with effects extending to much of the important biota and the sediment composition. Furthermore, it should include the realization of the onerous time and expense imposed on shellfish farmers by limitations, testing, etc. Reasonable safeguards would be expected of course, but they should be justified on a strong scientific basis. DOE and other agencies dealing with public resources have to understand and consider the increase in negative impacts to other important members of the fauna and flora so that burrowing shrimp numbers can be reduced periodically on those important intertidal areas. It is also imperative that there is an understanding of why a few individuals are in such strong opposition to burrowing shrimp control and oyster farming. Have these individuals presented verification or proof of the pesticide existence, persistence and impacts especially of a scientific nature? Is this opposition more directed to their hope the practice of shellfish farming will cease? Does DOE in a larger historical perspective point out and compare the advantages of this transition to imidacloprid, a more benign nicotine pesticide, to be used in amounts of less than 7% per acre compared to the one being replaced (carbaryl). In this same overall view it should be noted a sizable portion of Willapa Bay remains productive for a multitude of species largely due to the fifty years of burrowing shrimp control. This ghost shrimp control has not allowed a portion of the benthic to be modified by burrowing shrimp to a barren species poor habitat suitable only for burrowing shrimp, a small clam or two and couple of worms. Should it be appropriate that DOE urge other agencies to start playing an active role (as WDF did several decades ago) in controlling the habitat modification by burrowing shrimp populations. Should the resource agencies perhaps start at the beginning and attempt to determine the extent of this overall degradation? How much of the natural production has been lost? Should attempt at reclaiming part of the thousands of public acres which have been rendered non productive by burrowing shrimp be attempted? Should enhancing habitat for such species as decapods, fish and shorebirds be a priority of our public agencies? Does their possible lack of understanding of ghost shrimp impacts inhibit this?

Overall I think the serious damage to the nearshore habitat where the ghost shrimp take over, needs to be understood and proper actions taken to maintained at levels which do not eliminate valuable members of the biota. It seems regulations should be promulgated on the premise of helping maintain environmental productivity and not on how to keep control methods minimum or even eliminated because of perceived problems.

Respectively,

Richard L. Wilson, Ph.D.
President, Bay Center Mariculture Co. (BCM)

Comments on the sedimentary environment of Ghost shrimp occupied mudflats

by Richard Wilson, Ph.D.

Prologue: Sediment samples were taken to gather background data prior to applying a granular formulation of clay and imidacloprid on an oyster growing area, B-111. This barren, once productive oyster growing area had, over time reached a high density of *Neotrypaea californiensis* as evidenced with over 60 burrows per square meter. Purpose was to examine sediment composition and the benthic inhabitants with emphasis on the surface dwelling diatoms and fossorial arthropods and mollusks to perhaps gain insight to aid in making the treatment more effective. Examination of sediment samples showed a surprising homogeneity to the fine sand fraction with a corresponding near absence of silt, clay and organics. The benthos included a few small annelid worms and a clam species but the near absence of arthropods (e.g. crustaceans) and diatoms. This extremely sparse to absent biotic assemblage and a surprising homogeneous clastic sediment prompted additional tests for comparison on a similar nearby oyster growing area, B-71. This farmed area has received periodic (± 5 year) treatment for burrowing shrimp (mud shrimp *Upogebia*) over the past forty years. The contrast was unmistakable and Ghost shrimp, *N. californiensis,* are implicated in disrupting and modifying the benthic sediments that in turn excluded the base of the estuary food web - the primary benthic producers and grazers.

Part I: The upper benthic sediment and associated biota on a burrowing shrimp area:

Often there is not a chance or the time taken to examine an area for what might be characteristic of long term burrowing shrimp domination of a benthic sedimentary area. This is made more remarkable when it is realized there are thousands of intertidal acres in Willapa Bay that fit into this category. Treatment by shellfish growers usually has to take place before a period of years has passed and the area occupied by Ghost shrimp becomes unusable for a majority of the normal benthic inhabitants. Thus, the purpose here was to pick a high burrowing shrimp burrow count oyster growing area to take surface sedimentary samples to examine this critical upper 10-15 centimeters of these sediments. Our oyster bed B-111 had a northern extension which had not been treated for several years.

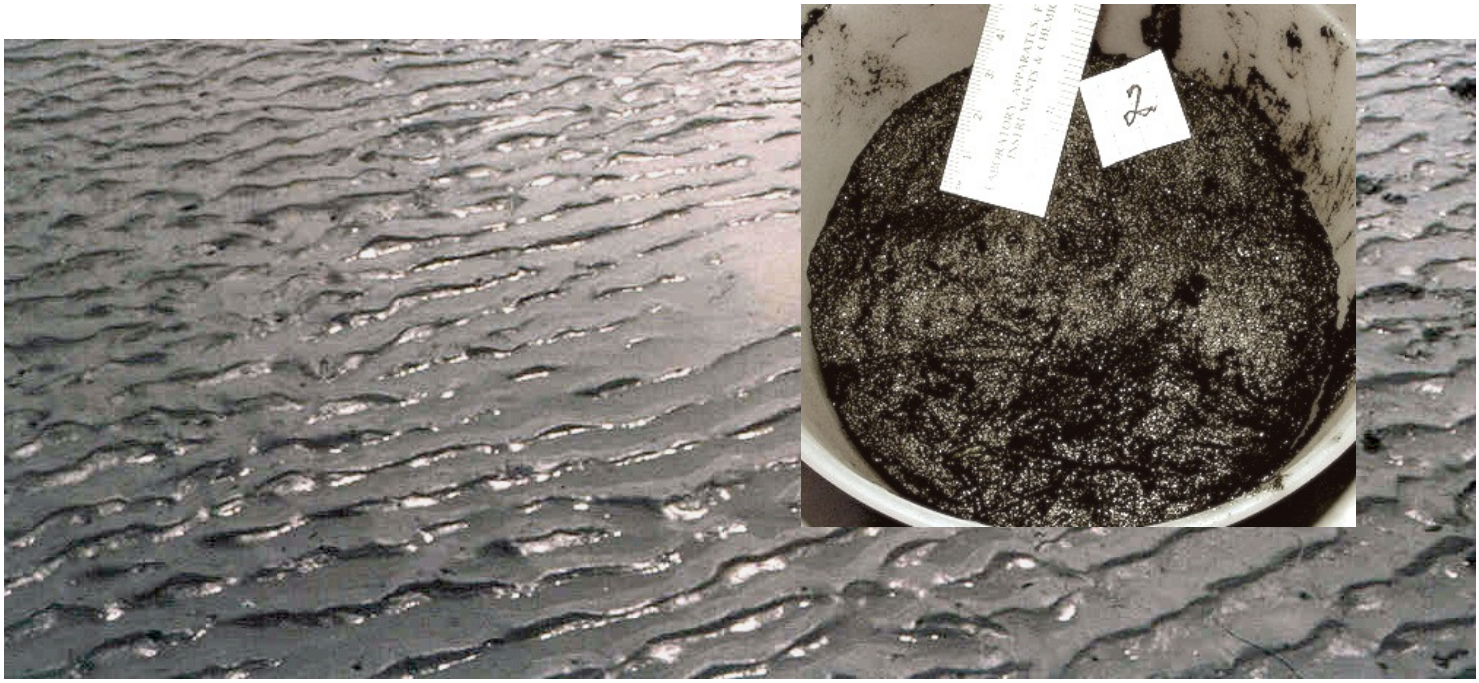


Fig 1. Sediment surface and one of the core samples from B-111. Surface showed a couple of possible burrows which probably were from the worms found when screened (Fig. 5). Note the sandy sediment and the reflective muscovite (mica) minerals on the surface.

The focus of this investigation was simply on what comprised the sediment after a long term occupation by the burrowing shrimp, *Neotrypaea californiensis* and what impact might be noted on other expected biotic elements in this sedimentary 10-15 cm (± 4-6 inches) intertidal zone. This included the very important sediment interface (surface) which normally would support the benthic diatoms, as well as, the shallow smaller burrowing crustaceans, bivalves and others. Random cores (Fig. 1) were taken at various sites over the two acre area and brought intact to where screens and microscopes were available. Each core (12.4 cm diameter) to ± 10 cm deep that would represent a volume of ± 1,200 cc or 1.2 litter (73.6 cu inches). The six cores were kept intact in a plastic (Fig.1) container and refrigerated until being analyzed.

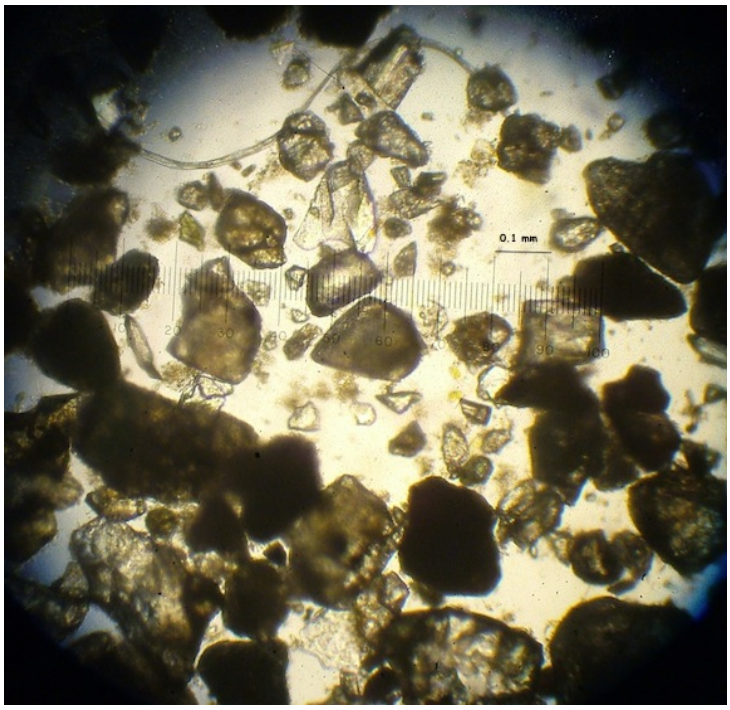


Fig. 2. Surface scraping on sedimentary sample from B-111. Note the range of grain sizes with very little organic debris and no obvious diatoms (100X).

Surface samples of the sediment core were taken and the small scraped residue samples were diluted and placed in a 1 cc Rafter cell and examined at 100X. The surface texture was of a sandy nature and not the soft organic interface expected. A photomicrograph was taken (Fig. 2) and showed basically a range of sand and silt grains and the near absence of any substantial organic activity or remains. These clastic fragments reflect a similarity to the entire core except the presence of a few silt size

Fig. 3. Burrow casings probably a polychaete. These were very fragile and no occupant was found. Samples in the second part of this report from an oyster growing area B-71 found similar burrows with the polychaete worm inside (Fig. 14). 1/4 graph paper scale.

fragments not seen in later tests. There appeared to be little or no living phytoplankton or micro zooplankton as would be expected on the surface. Effort was made to search through several scraped surface samples under 100 X but no live diatoms were noted. A few empty diatom tests were seen later buried in the upper ten percent in the Imhoff test (Fig. 8) and were most likely the result of the burrowing shrimp action. They probably became buried along with the organic debris.

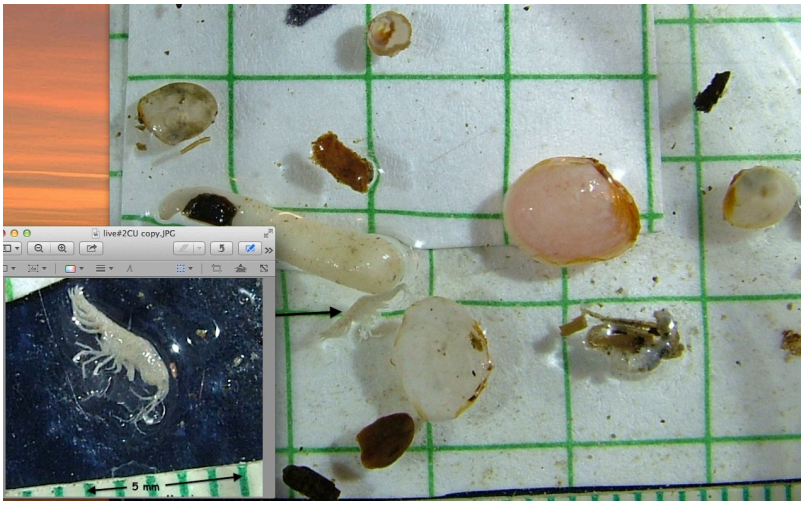


Fig. 4. Additional clams and a gammarid amphipod *Ampithoe* (insert) from sample 2 which contained the burrow casings thought to be from polychaete worms (Fig. 3).

The next tests would involve screening the cores in such a manner as to carefully retrieve any fragile organic remains. The first mesh was an 18 mesh screen which would retain objects and sediment at around one millimeter and larger. The second mesh was a stainless steel screen with 0.0117 inch or ± 300 microns opening used to retain material of at least 0.5 mm or larger. The screening method was alternately submerging and lifting from the water thus washing away successive layers of the sediment sample without moving any larger particles and risking breakage. Virtually no sediment was retained on the 1 mm mesh. Fig. 6 shows the sedimentary remains retained on the 0.5 mm screen. Each 1.2 liter core would yield ± 20 cc of this size or less than 2% by volume.

Fig. 5. Living forms from one of the six cores which had the highest abundance of worms and clams from B-111.

The residue on the 1 mm and 0.5 mm screens was sorted for living (and dead if identifiable) biotic forms. All except sample (#2) had a very similar assemblage which consisted of small worms and clams. Fig. 5 shows the greatest number of worms in any sample as most had only two to four individuals. One core sample was unique in having multiple pieces of polychaete worm burrow casings but no live worms were noted (Fig. 3). Samples from a second test area B-71 had similar borrow cases occupied with polychaetes (Fig. 12).

These worm burrow fragments were from sample #2 of which the surface photo shown in Fig. 1 did not appear to give any sign of the active worm surface features as pointed out later on B-71 (Fig.12).

Samples were screened initially to the 1 mm size into the 0.5 mm screen. After considerable time screening and sorting all samples from B-111 basically only two types of living forms were found in the residue. The dominant animal type were the worms (Fig. 5). Two or three small types of probably annelid worms were present in each core. It seemed each core (1.2

liter) had two or so small (shell width 3-8 mm the largest individual was in Fig. 5) bivalves (cf. *Macoma*). Only one gammarid amphipod, *Ampithoe* (identification by John Chapman, OSU) was found in all the residue from six cores (Fig. 4). No burrows were observed in the sedimentary core as was seen later in the samples from B-71. Fig. 6 shows a sample of what was retained from a core on the 0.5 mm screen which over 95% of the sediments passed through. It consisted basically of clastic fragments with some organic debris (vegetation) which when combined made up a volume of around 2 cm per each 1.2 liter sediment core. There was a small but variable number of organisms and remains on the 1 mm screen which included several of the worms and clams (examples Figs. 4 and 5). One core had the broken burrow pieces (Fig. 3) while another of the six exposed a 2 cm buried dead Japanese oyster drill, *Ocinebrellus inornatus*. At this stage the lack of animal and plant forms in or on the sediment layer being tested was surprising and finding out why seemed worth trying. It appears probable that the increase and takeover by *N. californiensis* results in physical and biological changes that limit or exclude the majority of the expected benthic types.

Fig. 6. Clastic sediment and bits of detritus on the 0.5 mm screen. Quartz, micas and plagioclase feldspar, pyroxene, fragments mainly.

Fig 7. Imhoff Cone supported in graduate and after two hours the slow to settle organic matter seen in Fig. 8 still in suspension.

At this point in the testing the samples had indicated the burrowing shrimp had engaged in habitat modification resulting in the noticeable lack of diatoms on the surface and no obvious sign of burrowing by worms and crustaceans. The sediment modification which appeared would not allow burrow construction to last for forms such as *Corophium* will become obvious when the Imhoff cone separates various sediment components. This could be a result of sediment type and composition change along with continued surface disruption. At this point what was becoming obvious was the extremely small number and abundance of benthic species on this intertidal with a high long term burrowing shrimp occupancy. Still a question remained of why and it became obvious that sedimentary characteristics might give a clue. Also, there still seems to be a need to verify that the sampling methods used were sufficient to recover an adequate sample of faunal and flora members. That became the incentive to use an Imhoff cone to better discern the sediment composition. It was also decided to sample another oyster area to compare not only the benthos but the sampling methods for confirmation of the testing procedure.

Part II. The Imhoff cone and the sediment composition.

The sedimentary residue which had passed through both the one and 0.5 mm screens was saved to further analyze. There appeared to be no obvious organic component, smaller clastic fragments or clay minerals in this sandy sedimentary residue. Use of the Imhoff cone (see image Fig. 16) to differentiate the heavier clastics from the lighter material by a differential called settling velocity. Settling velocity basically involves the size, specific gravity and shape of the components. The sediment which had been screened and saved in a bucket was mixed and a random sample with some water made into a slurry and a 100 cc volume was extracted. The one liter Imhoff cone (Fig. 7) was preloaded with ±700 ml of water and the stirred diluted 300 ml sediment sample quickly added while stirring. A little twisting of the cone for a few seconds and then the

mixture was allowed to settle over night. Some of the finer materials took over 12 hours to settle into the thin top layer. A fine mesh screen (400 mesh) under a plastic barrier had been placed over the small bottom opening of the cone to avoid any sediment from escaping. After 12 hours the plastic was removed but the fine mesh left on to let water drip from the cone which allowed all components to remain layered. It took over 12 hours to drain the nearly one liter of water. Sampling of the various levels was then undertaken.

The Imhoff analysis is by volume and rate of settlement determines the position of the various fractions. Fig. 8 is a composite of two photomicrographs at 200x of this soft fluffy upper layer diluted in water. The left image is down about 10% into the sample and the right view is material from the surface (Fig. 7).
This upper approximately 10 ml (10% of the sample) shown in Fig. 8 was an extremely fine matter and for the most part appeared as organic detritus or waste.

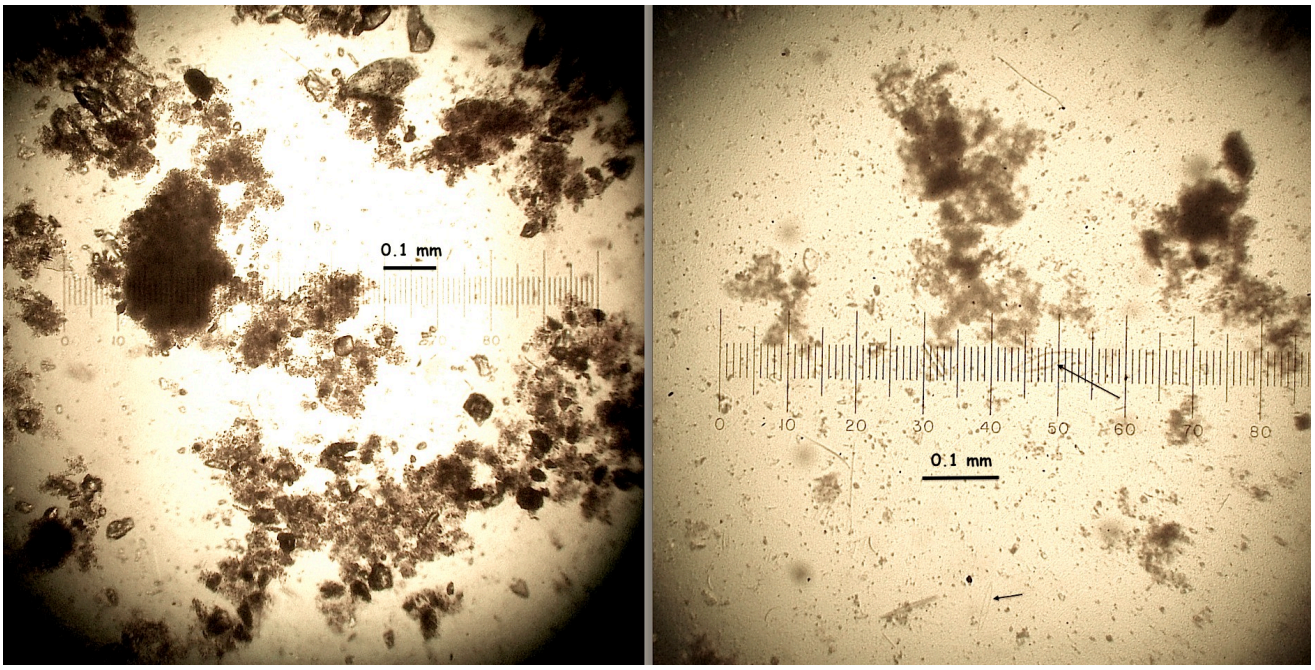


Fig. 8. Finer material appearing to be mostly organic (debris or waste) extracted from last to settle fraction of the sediment sample. Image on left lower in the cone showing few possible silt/clay size non organic particles and on the right a fluffy organic textured matter. There were a few empty diatom tests mixed in (arrows) and probably were buried within the sediment mix.

Since the remaining 85-90% of the sediment in the Imhoff cone turned out to be relatively uniform fine to very fine sand (100 to 400 micron in size) the origin of the organic debris could be from activities of the Ghost shrimp. In Fig. 2 the surface sample had some of this type of material and it indicated also the random occurrence of the material. In general, it seems the very low proportion of non clastic and for that matter small minerals (e.g. clay) or smaller clastics (silt) give evidence how throughly sedimentary particles had been reworked and graded for size. This activity would move the finer and lighter material to the surface where tidal currents or wave action could remove. The compositional lack of certain sedimentary size fractions and organics will be better illustrated when a comparable sample is analyzed from an oyster bed where the burrowing shrimp have been controlled and kept to much lower numbers (B-71, Fig. 16).

In sampling down through the various layers which had settled into the Imhoff cone it was noted that the mud like ooze comprising the thin top layer changed relatively fast to the noticeable granular material which comprised the other 90% or the volume. Since the sediment mixture had been graded through the 0.5 mm screens rock grains were from that size and smaller. The near absence of a silt size fraction is again noted.

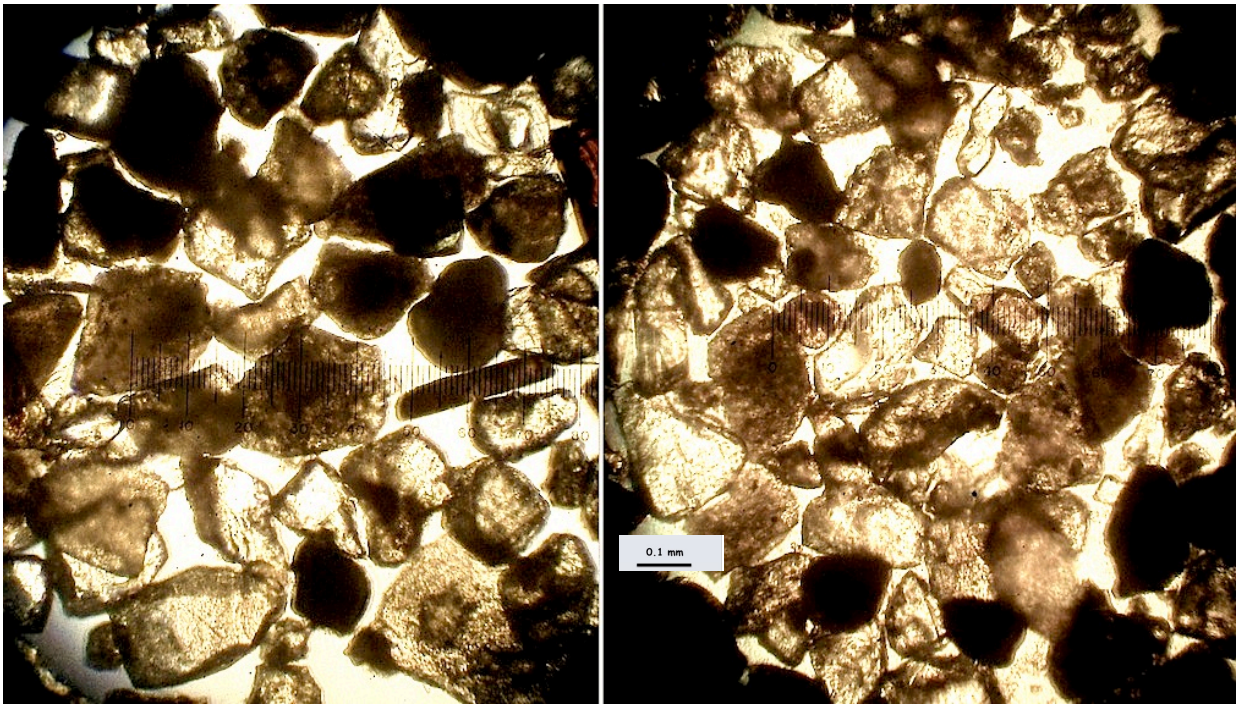


Fig 9. Photographs under magnification of settled grains in the Imhoff cone. On the left are the first to reach the bottom and the right represents more of the center to upper (50-67 ml) volume. Ninety percent of the sediment volume was basically the same fine to very fine sand with little or no silt size.

The clastic mineral fragments were primarily quartz, plagioclase feldspar, muscovite and biotite (micas) and other mafic minerals from the typical weathering of igneous rock types or reworked sediments from earlier erosion and deposition. The weathering reaction assumed to still be underway is probably a very important aspect of an estuary like Willapa. With exception of the quartz the other minerals should be chemically breaking down down into positive ions of Ca+, Mg+, Na+, Fe+, Al+ and the very important H4SiO4 (silicic acid) and the negative bicarbonate, HCO3- that hooks up with those positive ions. The aluminum and silicate should be converting into an aluminum silicate mineral called clay. This important chemical breakdown would be lessened with the removal of the smaller size particles which due to surface exposure would be a big contributor to the nutritive minerals.

Deposition on both oyster beds (B-111 and B-71) tested was sedimentary material in large part from the combined transport by the Niawiakum and Palix rivers with origin in the Willapa Hills uplift. Due to the gravitational gradient change at sea level the sediment transport dynamics would put limits on size and type of mineral grains. The relatively unworn grains, especially the quartz was a sign of the short transport and little reworking. Of importance again on B-111, is the absence of the silt/clay fractions expected to be an incorporated part of estuary sediments. This was really noticed and confirmed later in the upper deposit in the Imhoff samples from B-71 (Fig. 16) where over 40% of the sample was silt/clay size.

The photomicrographs in Fig. 9 are from the upper middle and lower areas of the Imhoff cone. It is obvious in Fig. 9 that there is little change in sediment size from the first to settle (left image) to middle upper sand portion in the right image. Fig. 9 images through the microscope at 100 X and these two fractions comprise 85-90% of the total sedimentary volume including the small amount greater than 0.5 mm. Some darker larger Mafic (Fe-Mg) mineral type fragments appear in the lower portion (left side) but those also are in part biotite a very platy mafic sheet like mica with a slower settling velocity. It was observed that the 90% clastic fraction with most grains 75 to 300 microns (0.075 to 0.3 mm) settled quickly and almost simultaneously.
The Imhoff cone did separate out the intermixed organic material with a proportion of silt and probably clay from the predominately fine sand sediment. This is a sedimentary habitat most likely modified to this

homogeneous fine sand state by the burrowing shrimp to fit their type of existence. Any finer material, e.g. clay which could be formed from chemical breakdown of the mineral grains, is probably carried from the sediments by the burrowing shrimp. Those finer clastics and clay of course would make it harder to liquify the sediments suitable for Ghost shrimp to move through and clean or consume the smaller grains. It is assumed this assemblage of uniform sand grains would allow water flow and a corresponding filtration and entrapment of organics (phytoplankton) from the brackish estuary water.

It also is noted that the initial limits on size of the clastics was a function of the energy of the intertidal river transport. The loss and continual extraction of finer components of the sedimentary deposit by Ghost shrimp is to the benefit and feeding habits of this larger crustacean. Ghost shrimp burrow or more properly create a series of tunnels in the liquified sand and probably do not depend on utilizing the surface but rather stay underground to graze or consume small particles for the organic coating in the sand of their burrow area. In contrast many of the other important burrowing crustaceans, annelids, etc, depend on a burrow with casing to the surface to graze or filter. This factor alone would make it difficult for beneficial burrows to be constructed due to incompetency of the sediment caused by the lack of finer components. This would restrict certain forms such as the Amphipods *(e.g. Corophium and Ampithoe)* and the smaller burrowing worms that were seen in later samples from B-71. Even though on B-111 over twenty times the volume of sediment was sorted these forms (with exception of one amphipod) were not found. Two major possibilities of this are seen in the examination of the cores; the elimination of the diatoms and sediment reliability for burrowing both of which are modified sedimentary conditions created by Ghost shrimp.

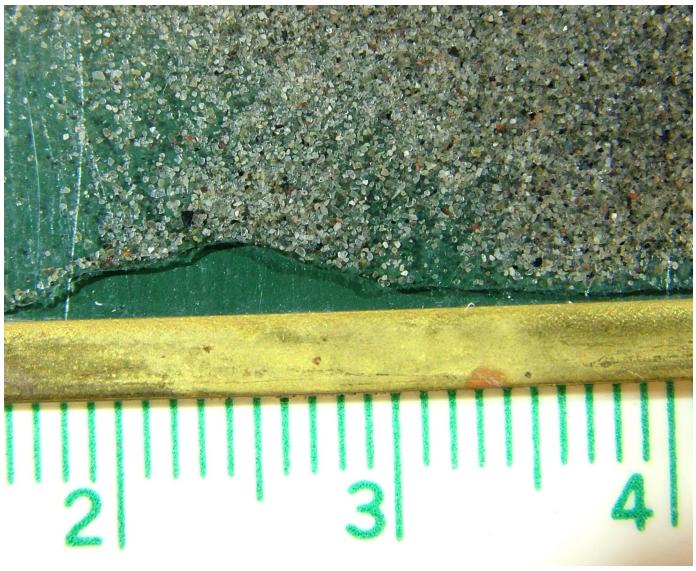


Fig. 10. Camera view of the sediments at the 50% or 50 ml area of the 100 ml sample from B-111 the high burrowing shrimp area. Scale in centimeters

Fig. 10 was added to give a perspective of the sand grain size at middle of the Imhoff and representative of ninety percent of the sedimentary mass. As can be noted in the photomicrographs the sand mixture has a mineral diversity (not all quartz) and relatively uniform size indicative of the depositional history from origin in the watershed to deposition on the oyster bed.

The presence of the assumed annelid worm types appeared to be free living without a noticeable burrow on B-111. The one clam species apparently is able to survive in the bioturbated habitat. The Ghost shrimp modified sediment composition without the finer clastics and clay would be less likely to support burrows or near surface habitat for any invertebrates. The lack of a diatom flora on the sediment surface, besides taking away the overall diatom abundance takes away the habitat possibly for important forms such as *Corophium*. Constant reworking and removal of a nutrient production and storage capability in the upper most sediments further makes the Ghost shrimp area unwelcome to important components of the estuary such as benthic phytoplankton and those zooplanktonic forms which prey on it. It is assumed the few worms in the samples from B-111 were utilizing the organic matter (waste) and associated bacteria within the burrowing shrimp habitat.

This sedimentary environment modified by burrowing shrimp impacts the volume of the nutrient and food for the entire bay. A nutritive and stable substrate is necessary for primary production of phytoplankton and aquatic vegetation and especially diatoms with a need for nutrients, minerals and soluble silicate in a sunny location sunlight. The burrowing shrimp seem to reduce or eliminate a sediment surface that would fulfill that

need. A noticeable reduction or lack of submerged aquatic vegetation within a fine sand on longer term Ghost shrimp dominated areas leaves the sediment surface barren.

Part III: Discussion: The biota of the Ghost shrimp area on B-111:

The outstanding aspect of these samples from an area with the long term occupancy of by Ghost shrimp as measured by a population of 60 burrows per square meter is the low abundance or absence of what is usually considered a normal biota associated with the upper benthic sedimentary zone. It starts with the lack of diatoms on the sedimentary surface during a low tide. The surface scrapings yielded little suggesting that sedimentary disruption occurs during the period it is covered with the tide. Characteristically diatoms would be clinging to objects on the surface like the sand grains but if the surface is being constantly reworked and cleaned by burrowing shrimp this habitat seem eliminated. All usual benthic forms including eelgrass would find existence difficult on the areas of the shrimp occupation. On the margins of B-111 sparse growth of eelgrass remain but are missing from the central part of this turbulent sedimentary environment. With the absence of a primary source of diatoms the next levels of the food web have little or no reason to be present. Energy for the estuary flows from the sun to the phytoplankton and from there to groups like crustaceans and other invertebrates such as shellfish. Instead of a usual more diverse bivalve fauna only a small clam (cf. *Macoma, Fig. 4*) seems able to adapt to the liquified sediment created by burrowing shrimp. No hardshell, gaper, cockles or butter type clams .. not even juveniles. A host of crustaceans under normal circumstance would be using the upper few centimeters of the benthic sediments and as mentioned often the real key high lipid food source, *Corophium* is missing from all samples from B-111. In a non-shrimp infested area this amphipod would normally be present at over 10,000 individuals per sq. meter. A few additional clams and only one crustacean in Fig. 4, the gammarid amphipod, *Ampithoe*, identified by John Chapman at OSU and not *Corophium.*

There were a few small worms, ± 5 per each 1.2 liter sample ranging in size from 1-4 cm. This small number could reflect the sparse amount of organic detritus and instability for burrowing assuming they were detrital feeders.

The greatly reduced benthic biota probably is important for the burrowing shrimp to achieve preferred habitat of uniform sand for sediment liquefaction in which to forage. This would preclude familiar benthic forms that rely on attaching to stable objects or animals on the sedimentary interface such as attached algae, barnacles, diatoms, crustaceans and dozens of other species. In the cores from B-111 there was virtually a total absence of these expected members of the benthic biota in the high density area where these tests were preformed.

Fig. 11. Oyster Bed B-71 with two year old oysters that were planted this one section.

Part IV. Comparison with a more normal benthic:

The sampling of the sediment with a high occupancy of Ghost shrimp on B-111 resulted in a rather bleak, sterile and non-productive benthos and not at all like would be expected in the lower intertidal in a highly productive estuary. To gain a better perspective on whether this was abnormal relative to other more seemingly productive benthic areas another growing area with very few burrowing shrimp and much different surface characteristics was sampled (Fig 11). Trying to keep as many parameters similar things such as; sediment source, elevation, proximity to rivers, etc., oyster bed B-71 was sampled by coring. This area is about a kilometer east and directly across the Palix River from B-111. It is a long time farmed area with the different

parts of the bed planted and used as both seed and grow-out area plus in certain seasons or particular years can be utilized for harvest. Often both removal methods are used with 'picking' the thick seed crop to transplant and within a year or so dredge for harvest those which were left. It is an area that burrowing mud shrimp larvae have reliably settled onto and thus has had control on about a five year rotation over at least the past forty years. B-71 has been farmed with successive crops being planted as one is harvested and yet appears as a healthy habitat including micro and macro biota along with the oyster crop (Fig. 11).

As with the earlier tests, cored samples were placed in plastic containers then brought in and refrigerated. Since the purpose was to observe to compare with prior samples on B-111 analysis again began with examination of the surface (Fig. 12 - image of the core) showed a striking contrasting to those cores from the high shrimp area on B-111(Fig. 1). Numerous small borrows (arrows on Fig. 12)

Fig. 12. Sample #8 from B-71 with sedimentary burrow holes marked on a quarter section which will be screened. Larger worm locations marked with 'W' and the excavated burrows shown on the insert image.

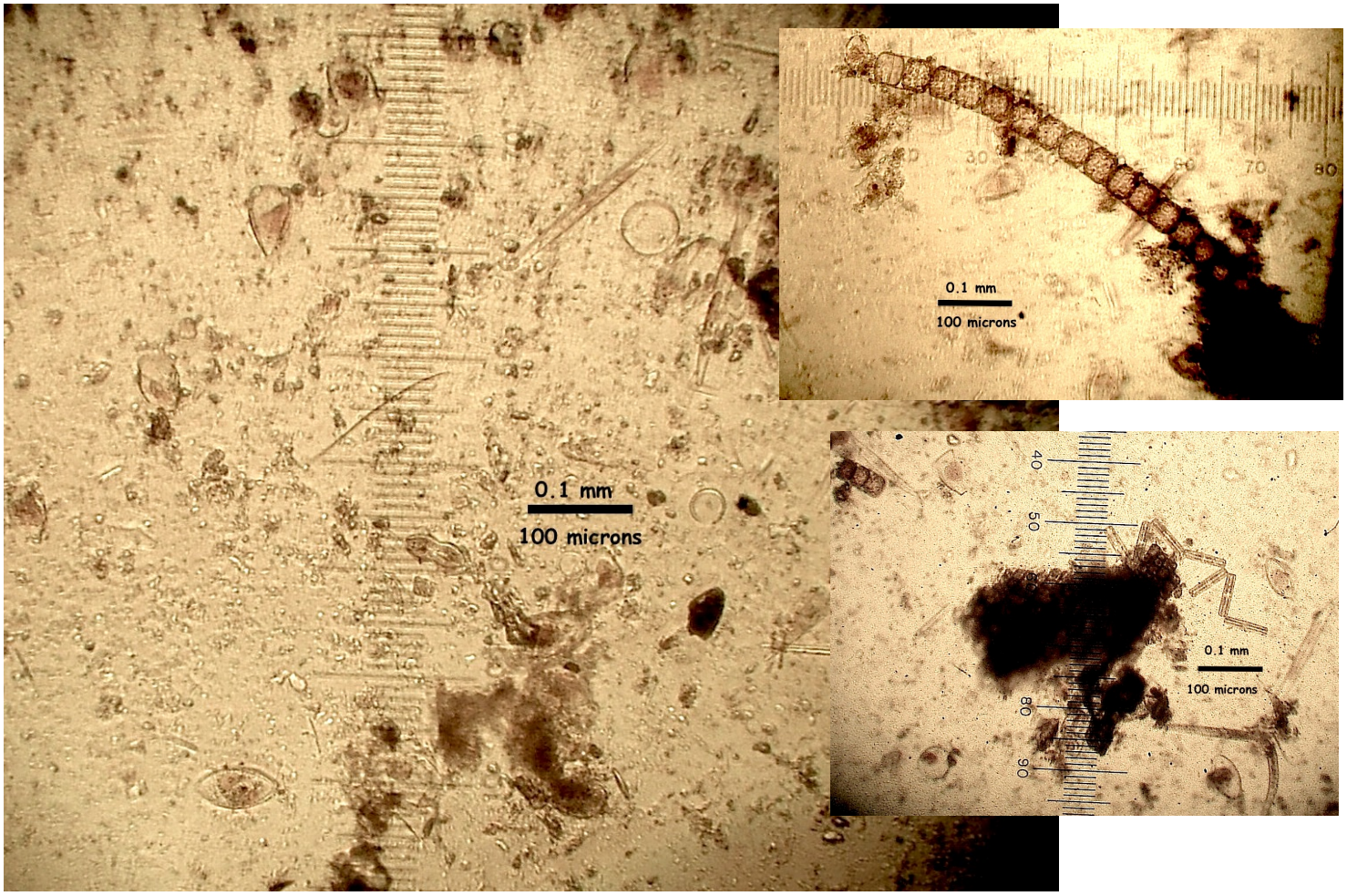


Fig. 13. A composite of photomicrographs of the diluted scraped surface of the sedimentary core from B-71. Obvious are larger diatoms and other phytoplankton but numerous smaller forms are present in the background.

seemed to be present of which some will prove to be crustaceans and others small worms. Some smaller holes without occupants where not verifiable as to animal type. These openings were not present in those cores from B-111 with the heavy Ghost shrimp population. Also, the dimpled areas (marked with a 'W" Fig. 12) indicate the presence of polychaete burrows with the occupants still in it and which the casings were extracted..

Perhaps the most important examination step in this study has turned out to be most contrasting between the two test areas. This was that very shallow surface sample (a scraping) from the sediment cores. Being sought was the organic life such as benthic diatoms and other phytoplankton attached to the sediment surface. It has been known diatoms utilize the intertidal mudflat surface between tides to combine sun light and nutrients and most important to divide.

There was nothing very precise or quantitative about scraping a little of the soft dark brown colored surface material and place into a microscope slide and dilute out with additional water. A damp scouring pad would probably have worked well but just a small spatula collected an adequate sample. Since the surface samples from the heavy shrimp occupied bed showed no live phytoplankton from the surface (especially diatoms) this test was important even if just presence or absence is recorded. Examination under both 100X and 200X at various locations on the Rafter cell showed a rich organic accumulation on the sediment surface after the tide had ebbed off the bed (Fig. 13). This will prove an important contrast to the samples from B-111 (Fig. 2).

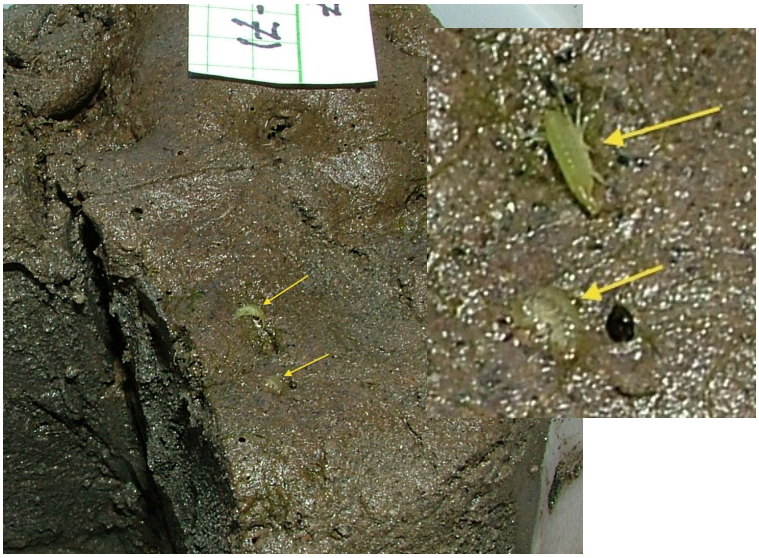


Fig. 14. Gammarid amphipod *Ampithoe* out of burrow for a visit. Both emerged while the adjacent quarter was being cut for screening. Note that no crustacean activity was seen in the many samples from B-111 .

Screening and sorting followed the procedure as described in the previous tests from the heavy shrimp occupied area on B-111. Noting the extensive signs of animals instead of sorting the total 1.2 liter cores they were quartered for sub samples (Fig 12 is marked and Fig 14 cut). The larger dimpled areas marked with 'W's (Fig. 12) indicate the location of larger worm burrows. Insert image are the burrows screened from the core(insert on Fig. 12). It was noted that worms occupied many of the very small holes while of the larger ones held one of the two amphipods, *Corophium* and *Ampithoe* (Fig.s 14 and 15). In Fig. 14 those small amphipods crawled out of burrows while the core was being sampled. When the sample was sorted on the 0.5 mm size screen several *Corophium* were dislodged from their burrows (Fig. 15). The core in Fig. 14 had a small strand of submerged aquatic vegetation (cf. *Ulva*) attached to a shell fragment. The worms in this habitat (B-71) seemed to utilize burrows or at least were seen emerging from small holes in contrast to B-111 where they appeared to just exist in the unstable sand environment.

Fig. 15. *Corophium*, the most abundant amphipod even though sampling depth was only around 10 cm.

Part V. Imhoff separation of sample from B-71.

A random sediment sample from B-71 that had passed through the 0.5 mm screen was mixed as a slurry and added to the one liter Imhoff cone and allowed to settle overnight. This followed the procedure used on B-111 except as an additional final step the resulting separation was allowed to firm up by letting the water slowly work through to produce a firm consolidated core that would allow sampling without layers mixing. Also the discovery that a digital image could show this layering was made (Fig. 16).

Photomicrographs of the separated clastics and smaller sizes at various levels were taken under 100X and set back on as inserts. The two images on the left side of the Imhoff tube (Fig. 16) are of the fine upper fraction which settled last and accounted for around 45% of the total volume. These have a high percent of silt size minerals and a scale of this clastic size

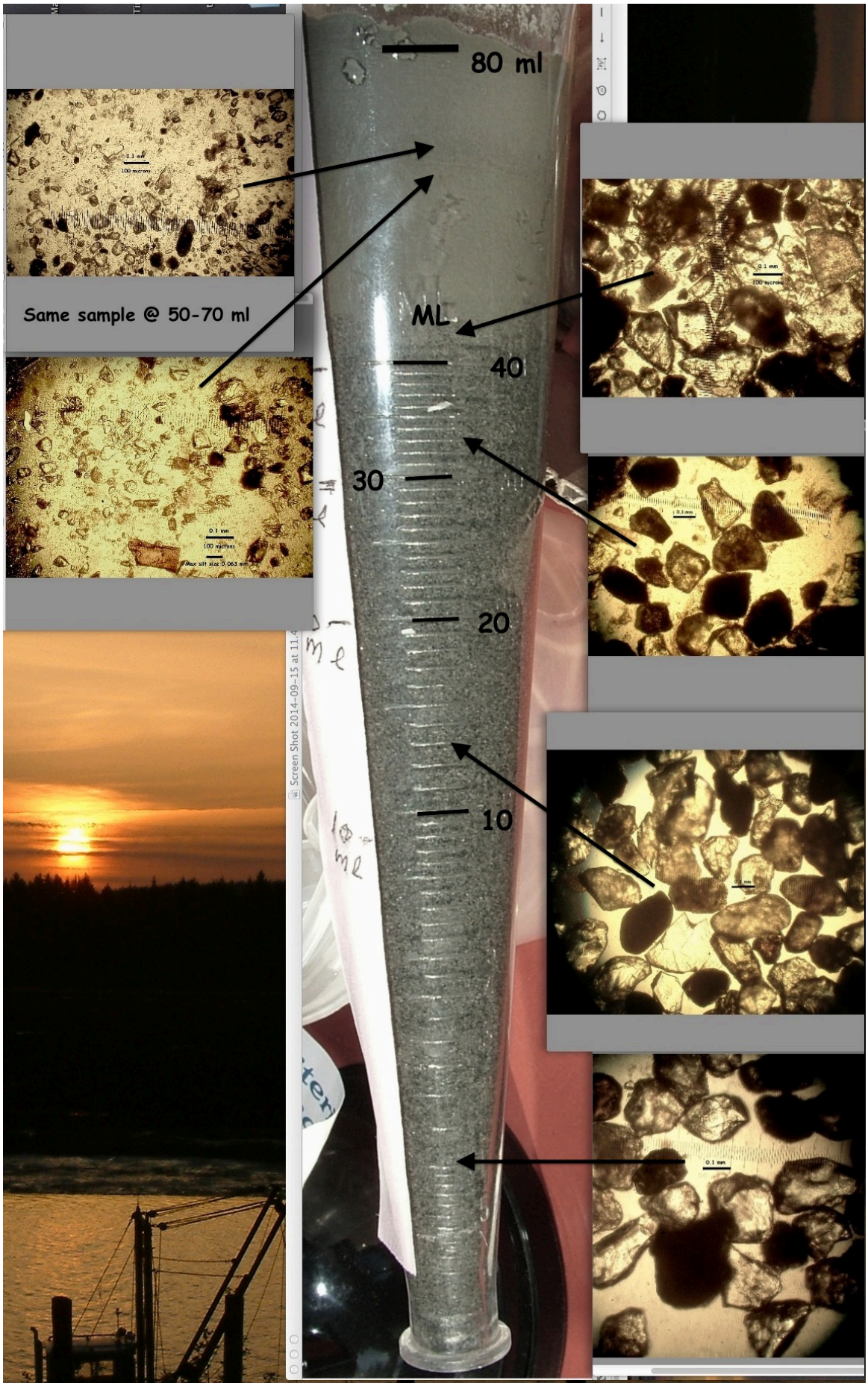


Fig. 16. Imhoff cone and the settled 80 ml sample of sediment after it passed through 0.5 mm screen.

(0.063 microns) for silt is shown in the lower image. This volume of this size range of silt and into clay were basically absent in B-111. Many of the particles in this size range would most likely be ingested (if the research is correct) and after a stomach cleaning would be put outside on the sediment surface as a component of the fecal pellets. The size and volume change in the Imhoff cone image (Fig. 16) is just above the 40 ml level.

The fine to very sand fraction comprised 50-60% from B-71 (Fig. 16 images on the right) in contrast to this size of very fine to fine sand on B-111 at a volume of close to 90%. The mineral types except for quartz would still be undergoing chemical change (weathering) and most are much softer and with cleavage to aid in breaking down. The very fine sand and silt/clay component when mixed with the relatively larger sand grains, should create a very fine substate suitable for burrowing forms with a fixed burrow casing. This sediment makeup would also serve to incorporate and hold minerals derived from fluvial deposition as well as those being formed in situ.

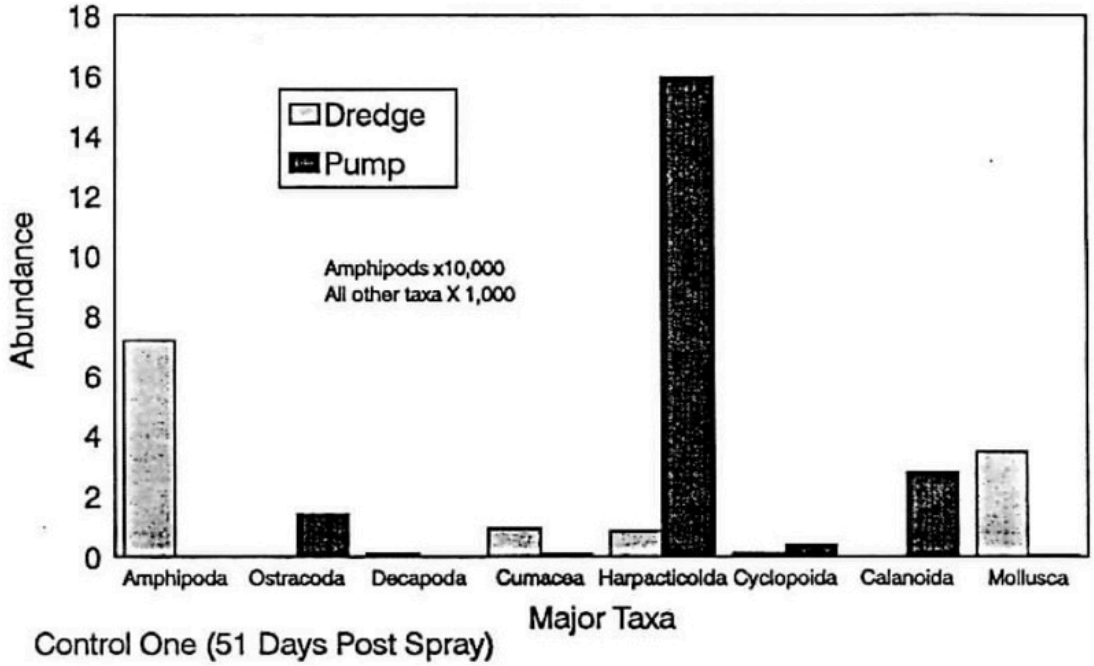


Fig. 17. Brooks, 1993. Comparison of the van Veen dredge and sediment surface pump for sampling the benthos. Numbers represent six samples combined of the major taxa collected. His two sampling methods pointed out the fossorial vs those forms on or just above the surface.

Brooks in 1993 in an extensive sampling and comparison of benthic arthropods and bivalves for the EPA data call in for the environmental impact statement for shrimp control gave a reasonable comparison or at least an expectation of abundance of arthropods and bivalves that could be expected in the sampling (Fig. 17). His report details the various species and provides a good reference especially with the van Veer dredge which would capture invertebrates at about the depth of the cores in this report. Thus, when basically no arthropods and only a few small clams on the burrowing shrimp site, B-111 it is far below the numbers Brooks showed on another nearby oyster bed. The numbers from Brooks's samples help assess what was missing and perhaps the limitations on this study as to volume screened. The major emphasis here was the sedimentary comparison and the presence and or absence of those important diatoms.

The smaller burrowing crustaceans were probably more numerous than were found but again the presence and absence is what proved important. The sediment samples from B-111 showed a much reduced benthos in both number of species and abundance.

Part VI. Discussion of burrowing shrimp bioturbation.

What began as a curiosity about the upper benthic sediment composition and the associated benthos on a burrowing shrimp area became a bit more revealing. Generally, it is thought that Ghost Shrimp just soften the ground and those on the surface sink and those constructing a static burrow find it difficult or impossible. The sedimentary test results in this report seem to support and verify the role being played by the burrowing shrimp in sediment modification and the resulting reduced or eliminated benthic biota.

The habitat and life mode of thalassinidean shrimp and in particular *Neotrypaea californiensis* has been the subject of many reports. Feldman, et al., 2000, has a very complete bibliography of the work on *Neotrypaea californiensis* on the west coast and in particular Willapa Bay. Most report similar burrowing and living conditions; rather tenuous burrows with numerous branches and turnaround spaces, usually two openings which are assumed for water circulation, and restriction to sedimentary bottoms with sand and finer material to maintain the burrow structure but they are constantly adding new branches into sedimentary adjacent areas. The ghost shrimp sift and mine through the sandy sediment to extract organic detritus. It has been difficult to find definition of what the authors mean by detritus but seems algae and bacteria mixture which has been entrapped in the sandy burrowing area are a possibility. At this point different interpretations are found in the burrowing and foraging process. It is not made clear but seems the ghost shrimp pick up and clean or ingest the organic matter on the sand grains and ingest smaller grains later putting the fecal pellets outside the burrow in the surface. By doing this repeatedly the type of sediment profile on B-111 is understandable. Repeatedly putting finer silt, clay and non digestive matter on the surface as fecal pellets where currents and wave action would disperse. This would fit the sediment condition on B-111.

Other reports verify other aspects such as the semi-permanent burrow morphology and the decrease in fine sediment and organics as the samples from B-111 showed. Many authors point out the contrast with the mud shrimp which has a more permanent burrow and do not deposit feed but pump in water to catch algae, etc. Others report observation of the ghost shrimp spending a larger percent of the time near the opening of their burrow. Feldman, et al., report on work by Witbaard and Duineveld who report the size of lithologic particles (assumed to be silt, clay, etc.) in the fecal pellets ingested while feeding as usually < 50 microns (0.05 mm) with 12-30 microns typical but larger that 70 microns rejected. This was from another species of burrowing shrimp, *Callianassa subterranean* **(***Neotrypaea californiensis* was *Callianassa californiensis)* but most certainly the same or very similar size range for the ghost shrimp of Willapa Bay. Looking at the sediment breakdown (Fig. 9) this is the missing size range (silt and smaller) of the clastic component on B-111. This could also help account for the sandy mounds often found around the burrow openings where the feces is deposited.

One interesting possibly is indicated that might involve the ghost shrimp pumping seawater down into the maze of burrow structures and having the organic debris, algae, etc. hang up on the sand grains to be later mined by the ghost shrimp. This also would aerate the living area burrow maze for *N. californiensis* while the fine sand would allow water being forced into the burrows to flow up and out through the sand.

Sedimentary bioturbation by continual burrowing and removal of the finer sedimentary particles by feeding was shown by the sedimentary components found on B-111. It would also account for the greatly reduced benthic fauna and flora, especially the phytoplankton such as diatoms. Removal of the finer clay and silt would make the primarily sand far less cohesive and static burrows hard or impossible to maintain. Some authors have proposed that the ghost shrimp enhance the benthic and increase faunal numbers by making the sand less compact but this seems not the case here. Some of those judgements depend on what is considered important to the benthos. The burrowing shrimp create an area without the primary productivity by the marine flora such as phytoplankton and eelgrass.

Part VII Comments of key benthos groups.

A couple notes seem appropriate on key groups impacted by the sediment modification. At the base and of primary importance are the diatoms and other benthic phytoplankton. Diatoms are important for the production of important lipids (fatty acids) so vital to the food chain. Sunlight and lipid production on the mudflats is a key relationship and should be studied as such. Several researchers have reported that diatoms have the cellular mechanisms for nutrient utilization in the environment leading to the finding that diatoms have a functional urea cycle. This animal-like urea cycle enables the diatoms to efficiently use carbon and nitrogen from the environment. The smaller components of a normal sedimentary composition would have the smaller silt and clay sizes that were found missing on B-111. The sampling indicated the smaller clastics, clay and some organics are removed by the burrowing shrimp. Smaller grains and clay entrapment of nutrients would not be available for diatoms in a shrimp dominated sediment. Also, the bioturbation would discourage surface dwelling by diatoms but benefit the Ghost Shrimp by getting the diatoms into the sand mixture they control.

The crustaceans and probably most of the small grazer invertebrates rely on phytoplankton especially diatoms. This probably includes burrowing shrimp although reports have them foraging on detritus. It is well known that key crustaceans such as *Corophium* (Fig. 18) are big consumers of diatoms. Perhaps their burrowing and remaining during the tidal retreat was to be within reach of the surface diatoms. Diatoms as their major prey was disputed for a time as diatom remains (tests) could not found in their stomachs. Then radioactive tracers where used and the discovery made that this amphipod actually has 'mandibles' and capable of crushing diatoms as it foraged. *Corophium* a major food item for shore birds, fish and crabs in the juvenile stage, etc. is dependent upon benthic diatoms close by its burrow. In addition, burrowing shrimp create a difficult to impossible sediment composition for *Corophium* to maintain a stable burrow with proper sedimentary composition.

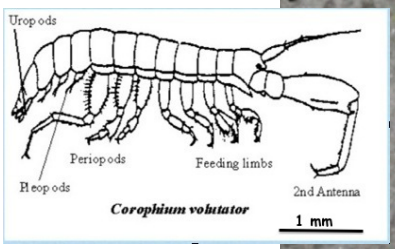
The only bivalve, the small clam which is probably genus *Macoma,* ranging in size from 2 to 8 mm, were present at about two per liter in samples on B-111 in the shrimp infested area. Equated back, each core represented an area of one eighty third of a square meter. Thus the samples would indicate an abundance of of about 160 clams per square meter. From Brooks work the number of these small clams appear to be around 500 per sq. meter in the control #1 of his study. Care must be taken in comparing Brooks work with samples from B-111. The main concern is that the area Brooks sampled was at that time impacted with the mud shrimp, *Upogebia,* which digs a static U shaped burrow and pumps seawater through to collect organic material on its seta to ingest and that small commensal clam might benefit by this service. However, the clam was present on B-111 just not as abundant as Brooks found which could be testing methods or tester.

Part VIII. The impact to key food chains:

The sediment analysis showed the burrowing shrimp modify and impact the sedimentary environment when their numbers are allowed to increase over time. That in turn removes the valuable role the sediments have in supporting many members of the estuary biota and the overall productivity of the area and bay. Using other examples of important estuary food chain relationships Fig. 18 was relabeled to fit Willapa Bay with all of the stages and taxa observed have been observed. Expanding on the predators feeding on *Corophium*, or other crustaceans and zooplankton which have utilized diatoms could just as well be young Dungeness crab or juvenile salmon among dozens of other familiar examples. If the diatoms might get sidetracked and avoid a benthic grazer as they drift off with the tide could be they get filtered out by other invertebrates such as an oyster or clam. Dozens of different taxa could be substituted into the sequence in Fig. 18 illustrating a key relationship production and predator prey relationship in Willapa Bay.

Often a mudflat if not modified by the bioturbation by Ghost Shrimp becomes a more reducing environment and a somewhat different nutrient path in a more reducing environment starts from the sedimentary layers. A decomposing environment might have diatoms replaced with bacteria and worms feeding on them. Fig. 19 refers to the darker reducing high sulfide mudflat and it can be the smell of organics and nutrients being

recycled. Often this layer is below the upper oxygenated benthic where perhaps a rich diatom assemblage is providing a feeding base for part of the estuary. Fig. 19 illustrates a somewhat simplified (after modification to Willapa Bay) portrayal of another feeding sequence. Worms feeding on the bacteria then become food for a shore bird. Note longer beak for deeper depth than the shorter Dunlin stand-in in Fig. 18. Diatoms can utilize the carbon and nitrogen according to some and quickly divide and create blooms. All part of the rich mudflat. A common occurrence of this is under meadows of eelgrass where currents and flushing do not remove the decaying grass and they become bacterial/worm habitat. This habitat is distinct from the diatom crustacean food web but could exist close to each other. However, in both of these general examples whether the rich diatom solar lipid nutrient rich sediment surface or the recycling of organic material in the sulfide environment both can be disrupted and eventually eliminated by Ghost Shrimp.



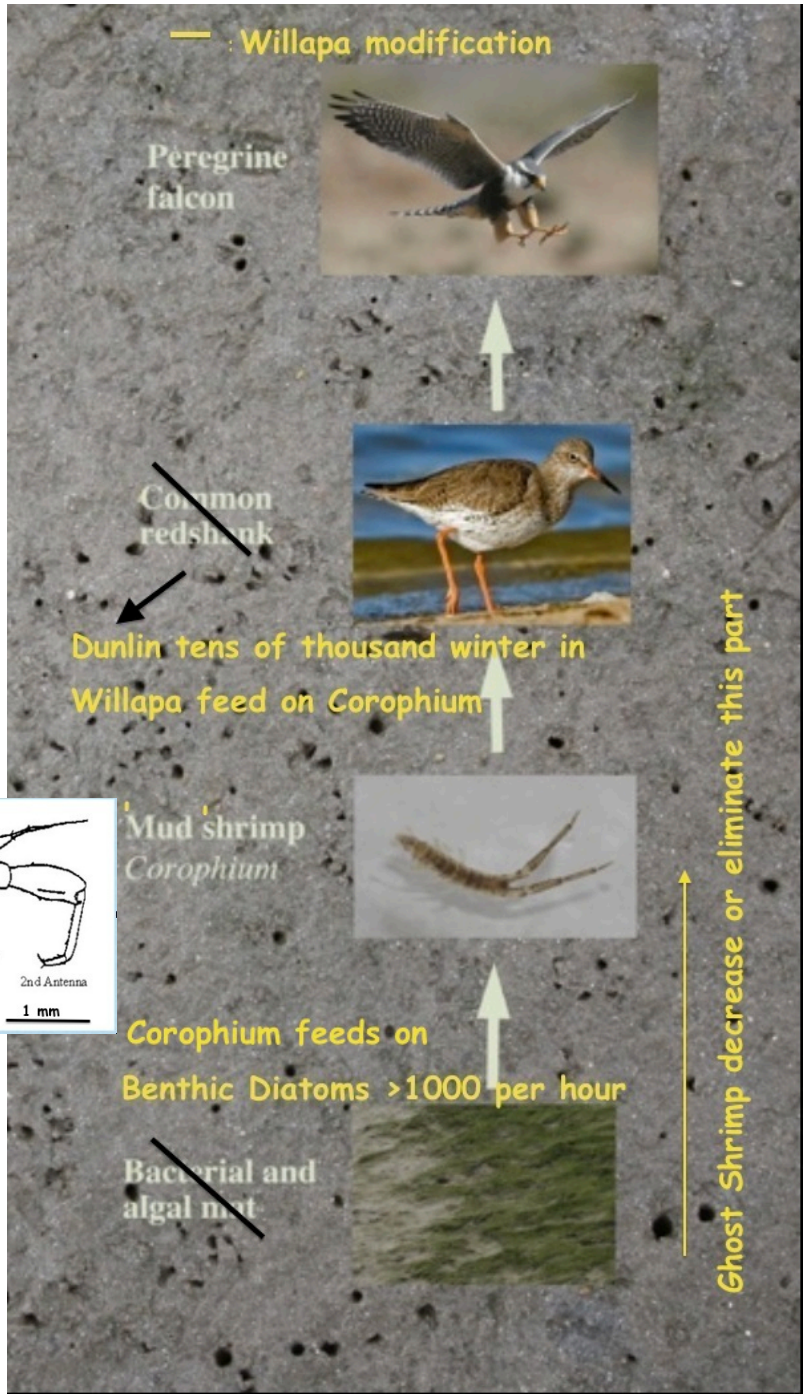


Fig. 18. One of many important food chain relationships in Willapa Bay negatively impacted by burrowing shrimp. This one is most important to the overall health of the Willapa Bay and has been greatly decreased by burrowing shrimp.

Why it matters and other questions:

When starting the first part of this project it was just to explore certain parameters that seem to change with high burrowing shrimp occupancy and perhaps give a better clue as to how to control. It was more out of curiosity of what and how the area was changed as indicated by the sediments. It was perhaps why virtually none of the more common surface features and characteristics associated with a productive benthic seemed to be missing. Why no eelgrass, or shallow clams such as cockles and steamers? Why did the Dunlins, Dowitchers, and many other shorebirds not utilize burrowing shrimp areas for feeding and instead land and use the oyster planted areas to probe the sediments? Why is it difficult to walk without sinking deeply into the soft sandy mud. Why just the obvious burrows of the larger shrimp and the absence of other smaller sedimentary surface features? What and how many changes can *Neotrypaea californiensis* cause?

Have the thousands of acres dominated by burrowing Ghost Shrimp really removed a majority of the important biotic elements important for overall estuary productivity from those areas and thus a big percent from the estuary as a whole? How much more productive would the estuary be if shrimp had not been allowed to expand to the levels of today? How could this be assessed or at least gain some idea as to the magnitude of degradation. Oyster growers know the high burrowing shrimp occupation render surface habitat impossible and is accompanied by poor growth. They also know that it impacts more than just the bivalves they are cultivating. They know how much land, which was once used for shellfish culture, has been rendered unusable by burrowing shrimp.

That vital nutrient and productive organic and sedimentary zone has been compromised by the burrowing shrimp. It should be protected as oyster growers do in controlling shrimp. Note that in Willapa there are thousands of acres not being used to grow oysters which have been taken over by burrowing shrimp and may run to 25% of the total intertidal. The land being used to grow oysters remains the productive intertidal of the bays with an abundant number of natural species. These mudflats keep the essential food chains intact as the burrowing shrimp tend to change it. What happens if *Neotrypaea californiensis* cannot be controlled on the oyster growing areas?

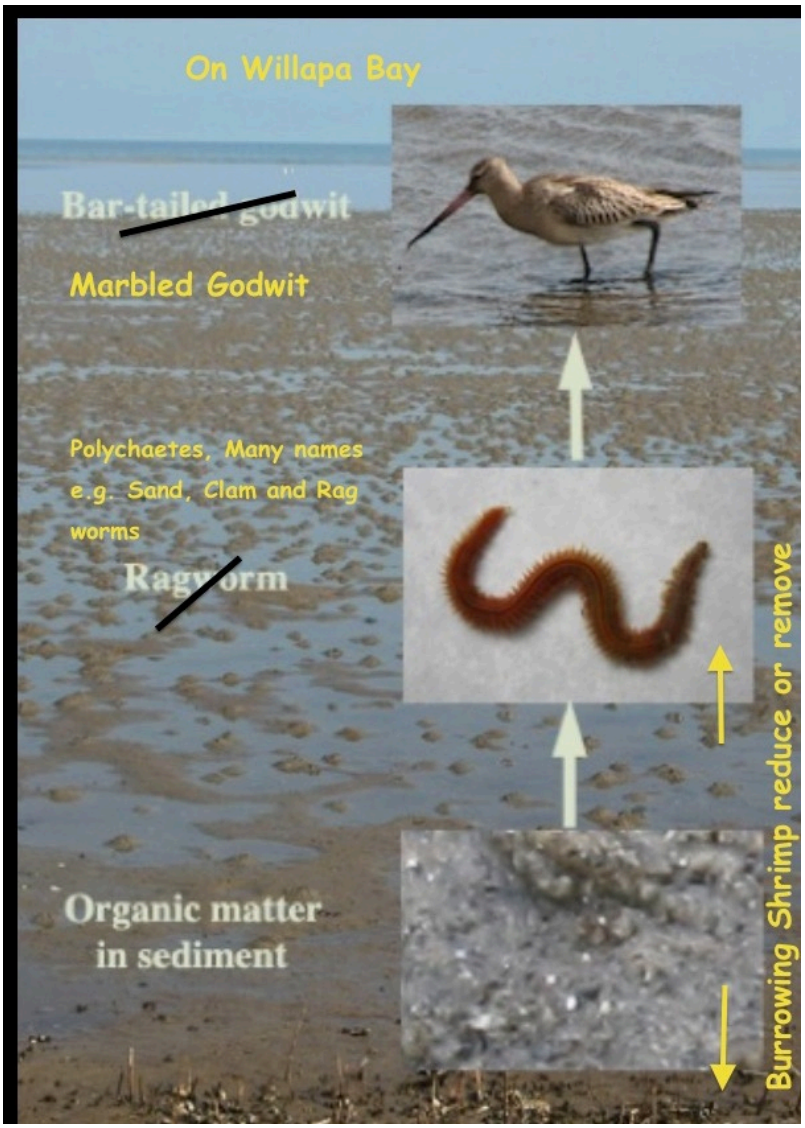


Fig. 19. Example of food chain relationships in Willapa Bay negatively impacted by burrowing shrimp. The tests showed organic material was nearly non existent in the shrimp infested area but on the oyster bed B-71 the large worms were abundant.

It should be a major concern on how the benthic sediments could again achieve the important mixture of the very fine sand and silt, clay and organic material after some components are removed by burrowing shrimp. What needs assessment is whether the burrowing shrimp modify the sediments to a point of not being able to return to a productive intertidal. With important oyster growing areas oyster growers make an effort to not let the shrimp modification proceed past a certain point as has happened to thousands of acres most under public ownership and control. It was indicated in these tests this sand, silt, clay, organic mixture is key to the bay production from benthic phytoplankton and the micro zooplankton grazers. Sediments move seaward in an estuary gradually being transported by tidal currents and wind toward the mouth of the bay. This rate of transport depends upon composition and without the finer clastics this transport becomes easier. Loss of the finer silts, clay, weathering clastics, and organics by action of the burrowing shrimp again impose deleterious and irreversible impacts to the ecology of the estuary.

In short, *N. californiensis* eventually modifies the sedimentary habitat to limit or exclude the primary producers and grazers which in turn are key to the estuary health. Juvenile salmon and Dungeness crab stand to be shorted on their nursery phase with the estuary being unable to support their prey. Why do the agencies which are charged with the custodial duties of the state owned tidelands not take this into consideration? If the destructive nature of the burrowing shrimp are allowed to go unchecked or untreated there will continue to be a decline in productivity. What if oyster farmers had not fought and spent large sums of money to control the burrowing shrimp on thousands of acres over the past 50 years. There most likely would today be a sizable percentage of the productive intertidal areas of Willapa Bay converted to largely a non productive barren sand flat. Some would say the burrowing shrimp are beneficial to the bay but this is a very misguided opinion and should have a through scientific debate. Much of the intertidal area is under care of public agencies who have not come to realize how they have allowed it to degrade into non productive nearly sterile sand flats by allowing the Ghost Shrimp to dominate and modify. It should be the agencies which take a lead in reversing the trend of increased burrowing shrimp degradation instead of blocking and limiting the shellfish growers from doing their part. They could do their own testing and learn what is happening. The rather simple tests and obvious findings as reported here can be easily replicated and actions taken on the results. All that is needed is some pragmatic science to cut through the idealistic stagnation in the regulatory realm.

A quote by Bob Sundstrom on KPLU, Bird Note: *"But that mudflat fragrance offers an important clue. Mudflats are rich in nutrients, such as decomposing organic matter and minerals. Mudflats, far from wastelands, support a bounty of life, such as foraging sandpipers called Dunlin."* and he continues; *"Mudflats also support a bounty of bird life. Millions of shorebirds follow shorelines and their mudflats each spring and fall, where they feast upon those tiny creatures hidden beneath the mud's surface, a banquet that powers the birds' continent-spanning migrations."*

Amen, but the Ghost Shrimp, *N. californiensis,* over time modifies the sedimentary habitat to exclude important primary producers and grazers which in turn are key to this estuary's health and productivity through its food web.

RLW

References in part:

Brooks, Kenneth M., (1993). A special monitoring study to assess long-term ramifications and exposure to carbaryl in an estuary as required by EPA. EPA Carbaryl Data Call In. p. 56, Sec.158.490 Wildlife and Aquatic Organisms, Footnote #7. Rept. pp. 1-53.

Feldman, K. L., Armstrong D. A., Dumbauld B. R., DeWitt T. H., & Doty D. C. (2000). Oysters, Crabs, and Burrowing Shrimp: Review of an Environmental Conflict Over Aquatic Resources and Pesticide Use in Washington State's (USA) Coastal Estuaries. Estuaries. 23, 141-176.
Published by: Coastal and Estuarine Research Federation Stable URL: http://www.jstor.org/stable/1352824