Raccoon Foraging in the Tidal Flats of the Coos Estuary

by

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Introduction

Predation has an important influence on the community structure of the intertidal zone. Predators influence the density and distribution of their prey species (Paine, 1969; Peterson, 1982; Summerson and Peterson, 1984). These changes, in turn, can alter competitive interactions among organisms (Paine, 1966, 1969). The effects of marine epibenthic predators (i.e. fish and crabs) and birds on the distribution of prey has been studied in soft sediment tidal flats. Little, however, is known about the influence of terrestrial predators in tidal flats. Although the marine and terrestrial habitats are generally thought of as distinct, the intertidal zone is where organisms of both habitats do interact. Terrestrial mammals such as mink, raccoon, river otters, and mice have been sighted feeding in salt marshes of the Atlantic coast and on the tidal flats in estuaries on the Pacific coast (Ivey 1948; Tyson 1950; Warrick and Wilcox 1981; Arbuckle 1982). At Cape Blanco, in Southern Oregon, raccoons have been seen eating sea urchins in the rocky intertidal (Carlton, Hodder, pers. comm.).

Raccoons feed on estuarine tidal flats as well, although their effects have not been thoroughly examined. Mention of raccoons is found in various estuary and salt marsh studies (Ivey 1948; Tyson 1950; Warrick and Wilcox 1981; Arbuckle 1982), but these studies merely list known prey items, which include crabs, echinoderms (i.e. sea urchins), oysters, clams, mussels, and annelids (segmented worms). There is some evidence that the intertidal habitat may supply important food resources for the coastal raccoon populations (Tyson, 1950). If the raccoons are abundant, they may be important predators in the intertidal zone.

In one freshwater marsh raccoon predation on muskrat kits limited the muskrat population, indicating their importance as predators in freshwater habitats (Dorney 1954). Although raccoons eat a variety of foods, invertebrates, particularly crayfish, and fruits make up a large part of their diet (Tevis 1947; Schoonover 1951; Tester 1953).

In this study I examined the influence of predation by raccoons on the clam population of a tidal flat in Coos Bay. I recorded the number and sizes of clams taken by raccoons, the numbers of raccoons using the study area, and determined whether or not raccoons select a certain species and size of clam and what impact they have on these species. I also developed a raccoon prey species list, and made behavioral observations to determine how the raccoon detects its prey in the sediment.

Methods

I explored the Coos Bay estuary to find raccoon foraging areas (Fig. 1). From these areas I chose a study site. Evidence of raccoon foraging included raccoon tracks, defecation sites, and digs with prey remains. The tracks were easily identified in the sediment surface. The pits left by the raccoons after they had dug up clams or mud-burrowing shrimp were distinct. The relative amount of raccoon activity was assessed by the numbers of tracks and foraging evidence. The locations examined included South Slough, Metcalf Marsh, and a tidal flat at Glasgow, which is a neighborhood of North Bend. I chose the Glasgow tidal flat because of its high raccoon activity and accessibility.

Description of Study Area:

The Glasgow tidal flat is located to the east of the North Bend Bridge, on the Northern bend of the Coos Bay (Figures 1 and 2). A bed of the introduced angiosperm, *Zostera japonica*, grows along the shore extending onto the tidal flat about fifteen meters from the high tide water line (Fig. 3a). Patches of *Carex* grow along the shore, and in places the lower limit of the *Carex* overlaps with the upper limit of the *Zostera* (Fig. 3b). Houses line the bank of the tidal flat. A high bank, or cliff face, forms a sheltered area along half of the study area. A road comes down to the tidal flat just past the last study plot, east of the bridge (Fig. 2). The area is forested with hardwood trees and shrubs, and blackberry bushes are prevalent along the bank. Several large drift logs are scattered along the shore. A sandy beach extends from the bank to the high tide line where there is a mixture of sand and mud (Fig. 3).

Study Plots:

Six permanent plots were staked out at random from the bridge to the access road, at the tidal height of the *Zostera japonica* bed. These plots were located at the same tidal height, and each extended 20 meters parallel to shore and 15 meters from shore (Fig. 2). Each plot was divided into three sections, five by twenty meters each, so that there were three zones. These zones are the upper zone A, a middle zone B, and a lower zone C. This zonation allows detection of differences in predation rates between tidal heights.

Assessment of Raccoon Foraging:

I investigated the study plots for prey remains from mid July to mid August on eleven days. I collected prey remains from the study plots during the early morning low tides so that the kills from the previous night could be recorded before the next high tide moved the shells. This limited the prey census to foraging done after midnight. If low tide occurred before midnight, the following high tide prevented collection of prey remains in the morning. All fresh prey remains found in the plots were collected and recorded by species. I counted only fresh clam shells found next to a recently excavated pit to ensure it was a kill from that night and occurred within the plot.

I distinguished freshly dug shells from older shells by the amount of flesh remaining in the shell and proximity of the shell to a pit. The adductor muscles and part of the mantle remained in freshly eaten shells (Fig. 4). These fleshy pieces disappear over one to two days, enabling the distinction between a fresh shell and a day-old shell. To test this assumption, I monitored fresh shells found between plots during collection series, each spanning a few days. I found within a couple of days the adductor muscle was reduced to a smooth lump, rather than spanning between the valves and most of the mantle was gone. Gradations can be seen between very fresh kills, and day old kills. Fresh kills have much more tissue in them than day old shells that have been washed by water.

I recorded the plot and zone in which each clam shell was found and measured the shell length and width to the nearest millimeter using calipers. I also measured each pit's depth and diameter and its location in the plot using a meter stick and meter tape. To determine the location I measured the distance from the top two plot stakes. Shallow trenches dug by raccoons were measured in a similar way, but several depth measurements were taken along the length of the trench.

Density and Distribution of Clams:

To ascertain if raccoons select a certain species or size of clam, I determined the species and sizes of clams available to the raccoons in the study area. Box cores ($0.25\ m^2$ x 0.30 m) were taken between plots 1 and 2, 3 and 4, and 4 and 5, to examine the species and sizes of clams available to the raccoons. Three randomly located replicate boxcores were taken in each zone, for a total of twenty seven cores. Each core was divided into three 10 cm depth strata, and each layer was sieved through a 2 mm screen. All clams retained on the screen were counted and measured. Measurements were made with calipers to the nearest 0.1 mm. Because the small clams in the top layer were tangled in the *Zostera japonica*, I picked them free of the blades in the lab, while the mid and lower layers were sieved in the field..

Estimation of the Number of Raccoons Using The Study Area:

During the months of November and early December, I made a series of night observations to determine how many raccoons use the Glasgow study area. Because the raccoons forage after sunset, I could not observe actual behavior at Glasgow. Instead, I used a spot light (Beckman "Q-beam") to sight eye-shine from raccoon eyes. Raccoons have a reflective tapetum behind the retina. From the reflection I was able to determine where the raccoons were and how many there were. This light did not appear to significantly disturb the raccoons, which are somewhat acclimated to the presence of light on the tidal flat. Light from traffic on the bridge, passing ships, and houses along shore shines on the tidal flat.

I used two spotting vantages; one was located at the end of the public access road, and the other from the bottom of the stairs (Fig. 2). Most of the spotting was conducted from the bottom of the stairs. I took counts of raccoons between 7 P.M. and 1 A.M., every 20 to 45 minutes. Each spotting lasted 5 to 10 minutes. During this time I swept the beam over the tidal flat three times then recorded the highest count. From the stairs I was able to see eye-shine from the bridge to the access road (Fig. 2). However, to get a more accurate count, the spot light was shone from the access road as well. I found that when the beam was pointed from the stairs, I could see eye-shine from the access road area but I did not always see all of the raccoons. If I used the access road as the vantage point, a larger count resulted. Although I could see eye-shine from the area near the bridge while spotting from the stairs, I did not have a good vantage point from which to monitor the bridge area. As a result, counts from the bridge area may be low.

During July and August, before the spot light was available, observations were made at sunset. Just before sunset, I watched for raccoons entering the tidal flat from a regularly used raccoon trail. I was in a sheltered area near the trail, and remained there until it was too dark to get useful information.

The date, time of sunset, time of low tide, the time, and number and location of the raccoons were recorded for each observation.

Behavioral Observations:

To see raccoon foraging behavior, I observed raccoons foraging in South Slough (Fig. 5). I found that raccoons in the South Slough Reserve forage during the daylight hours as late as ten in the morning. The area is more secluded than the Glasgow tidal flat where raccoons forage only when it is dark. Although the raccoons in South Slough and the raccoons at Glasgow are different populations, the method they use to find prey is similar. I used binoculars to observe raccoons during early morning low tides. A blind was not necessary. I recorded the raccoon's movements, as well as location and the duration of the observation. After a raccoon left the tidal flat, I located foraging pits and prey remains, if possible.

Results

<u>List of Foods Found in Diet of Coastal Raccoons:</u>

Throughout the study I collected various remains of raccoon prey. Raccoons use several different locations, including South Slough, Glasgow tidal flat and Metcalf Marsh. These are tidal flats of Coos estuary. The total species list generated indicates a variety of marine organisms taken by raccoons. The list does not include soft bodied organisms such as annelids, although there is evidence that raccoons do feed on annelids (Tyson, 1950). The species that I found eaten by raccoons include *Cancer magister* Dana (Dungeness crab), *Callianassa californiensis* Dana (mud-burrowing ghost shrimp), *Upogebia pugettensis* Dana (blue mud shrimp), *Cryptomya californica* Conrad (a commensal clam of *Callianassa*), *Macoma nasuta* Conrad (bent-nose clam), *Macoma balthica* L. (small pink clam), *Mya arenaria* L. (soft-shell clam), and *Mytilus spp.*(mussels). Other foods eaten during the summer were discovered in scat located on defecation logs at the study site. In scat I found fruits in season, insects, and small fish bones.

<u>Shell Collections: Numbers of Bivalves Eaten by Raccoons</u>

Within the study plots, only *Mya arenaria* were found freshly eaten by raccoons, with the exception of five *Macoma balthica* (> 25 mm in length) found in plot 6A. The number of clams taken by raccoons in the upper zone of the study plots was significantly greater (ANOVA, df=2, $P < 0.01$) than the numbers taken from the mid and lower zones of the plots (Figure 6, Table 1).

The average sizes of *M. arenaria* eaten by raccoons were 55.3 ± 0.9 mm in zone A, 56.0 ± 2.6 mm in zone B, and 67.9 ± 1.2 mm in zone C. The average sizes were not significantly different. Clams eaten by raccoons were generally longer than 30 mm. There was no evidence that raccoons picked small (< 20 mm) clams out of the *Zostera japonica* blades or from the sediment scooped out to reach the large *M. arenaria*.

Pits left by raccoons ranged in depth from 6-28 cm, and ranged in width from 3-12 cm, although most of the pits were about 5 cm across and 15 cm deep. The average depth was 15.2 ± 0.3 cm and average width was 5.9 ± 0.1 cm. The average pit area disturbed in zone A was 635.65 $cm^2/100\ m^2$ and the total trench area was 931.5 $cm^2/100\ m^2$. For zone B the difference in pit area is proportional to the difference in numbers of clams taken between zone A and B but trench area was slightly larger. Zone B pit area was 129.0 $cm^2/100\ m^2$ and trench area was 953.27 $cm^2/100\ m^2$. In zone C the pit area was 101.4 $cm^2/100\ m^2$ and the trench area is 282.67 $cm^2/100\ m^2$. The trench area for zone C is a low estimate because one large set of trenches was not measured. The reason for raccoon trenching is unknown. Clam shells were not found next to trenches.

A *Carex* marsh grew above the *Zostera japonica*, and extended down into zone A in some areas. *M. arenaria* were found dug along the edge of the *Carex* or where the blades and rhizomes were thin, no more than about 30 cm into the marsh. Raccoons did not dig clams in dense *Carex*. It is difficult to dig in the *Carex*, because of the tough, dense rhizomes. The two boxcores in which *Carex* was present contained *M. arenaria* and large *M. balthica* in medium to high densities indicating that clams do inhabit the *Carex* marsh. The tough rhizomes and blades probably inhibit the raccoons from digging.

The raccoons tended to remove a number of *Mya arenaria* from a small area rather than spacing their foraging evenly over a larger area. In some areas at the study site, I found extensive digs in the same location over a few days, then the digging in that area would cease. This pattern of *M. arenaria* removal was consistent with foraging patterns of raccoons observed in the field. Raccoons tend to locate prey, then concentrate foraging in that location until no more prey are found.

<u>Bivalves Available to Raccoons At Glasgow Study Site:</u>

Many small bivalves (2-20 mm) were found in the top ten centimeters, most were much smaller than the clams eaten by raccoons. The majority of these small bivalves were, in order of abundance, *Macoma balthica* and *Mya arenaria* (Table 2). *Macoma nasuta* and *Cryptomya californica* were also found in the samples, but in much lower numbers.

The surface of the study area is covered by the blades of an introduced sea grass *Zostera japonica*. Rhizomes of the grass extend about ten centimeters into the sediment. The number of small bivalves found in the samples seemed to have a positive relationship with *Z. japonica* density. Higher numbers of clams were found in dense *Z. japonica* than in thin *Z. japonica* (Table 3). Where the seagrass was absent, no small *M. arenaria* were found. The *Zostera* cover appeared thinner in the lower zone of the study plots and was absent below it. Fewer small bivalves were found in the top ten centimeters of zone C (Table 2).

In the 10 cm to 30 cm depths *M. arenaria* were the most numerous species. Below 10 cm very few *M. balthica*, *M. nasuta* and *Cryptomya* were found (Table 2). Sizes of the clams increased with depth. In the deepest section of the boxcores, 20-30 cm, only a few *M. arenaria* were found, and these were > 40 mm in length.

The boxcore samples revealed that most of the clams greater than 30 mm in length are found in the upper zone, and almost all of these are *M. arenaria*. When comparing the total numbers of *M. arenaria* found in each zone, only the lower zone has significantly fewer *M. arenaria* (Table 4, Fig 7). This would suggest no difference between numbers of *M. arenaria* in the mid and upper zones. However, if the small *M. arenaria* in the top 10 cm are excluded from the totals, significantly more *M. arenaria* are present in the upper zone (Two way ANOVA, $df=2$, $P < 0.01$) than in the two lower zones (Table 5, Figure 8). Of all the *M. arenaria* found in zone A, 26% were > 30 mm, where as only 10% of the *M. arenaria* in zone B were > 30 mm. No *M. arenaria* > 30 mm were found in zone C. Zone A had significantly higher numbers of *M. arenaria* in the size range that raccoons selected in the field (Table 6).

Estimated Impact of Raccoon Predation on *Mya arenaria*:

Raccoons selected the large size classes of *M. arenaria*, which were the least abundant sizes (Figure 9). Figure 9 illustrates the portion each size class contributes to the total population and to the numbers taken by raccoons. Most of the *M. arenaria* were < 20 mm, but none of these were eaten by raccoons. There were few *M. arenaria* from 50 mm to 70 mm, the size selected most often by raccoons (Figure 9). Raccoons have the greatest impact on the population of *M. arenaria* from 50-90 mm because they select these sizes over more abundant sizes (< 40 mm) (Figure 10). The estimated number of *M. arenaria* eaten by raccoons in each size class over a month period was compared to the estimated average number available using the boxcore data. In figure 10 the percentage of *M. arenaria* removed from each size class is given for the two month period of July-August.

Size class distribution differed between zones. A greater portion of the clams in zone A were > 40 mm, than for zone B and C (Figure 9). In the upper zone, the density of *Mya* > 30 mm found in the boxcore samples averaged 5.78 ± 1.9 in 0.25 m^2, or approximately 2300 in 100 m^2. The average number of *M. arenaria* taken from a zone was estimated from the numbers taken over the prey collection period lasting from mid July to mid August. In the upper zone of the study plots raccoons remove an estimated 53 *M. arenaria* from a 100 m^2 per month. In the two months sampled about 4.4% of the total *M. arenaria* > 30 mm were removed by raccoons if the number of nights the tidal flat is available to raccoons is taken into account (night low tides). In the mid and lower zones the density of large *M. arenaria* is much lower, yet the raccoons manage to find large *M. arenaria* in these lower zones. In the mid zone the density of *M. arenaria* > 30 mm is 1 ± 0.4/0.25 m^2 or 400/100 m^2. An estimated 5% of the large *M. arenaria* from zone B, and ~100% from zone C are removed in two months (Table 7). The estimate for zone C may be exaggerated because no *M. arenaria* > 30 mm were found in the boxcore samples. Large *M. arenaria* must be present in zone C in low densities because the raccoons did find *M. arenaria* > 50 mm in this zone. However, raccoons found only 1.3 *M. arenaria*/100 m^2 over eleven days in the lower zone. Their lack of success in finding large clams suggested that there were only a few large *M. arenaria* in the lower zone, and that the density estimate from the boxcore samples was fairly accurate. A larger set of boxcore samples is required for a more accurate assessment of the numbers of large clams in the lower zone and the upper zones.

Estimation of Number of Raccoons Using Study Area:

Raccoons entered the tidal flat just after sunset, and I could tell where they were, and what they were doing. A summary of the results is listed in Table 8. I estimated five to eight raccoons use the study area nightly during the fall. This is an underestimate of the numbers that use the area because of the limitations of the light beam method used to count raccoons and my inability to identify individuals in repeated sightings. Five raccoons were regularly seen foraging in the area, but occasionally eight raccoons were using the area. Raccoons were sighted at the study site 90% of the time. A mother with two young were seen using the study area regularly.

After entering the tidal flat, the raccoons went directly to the water line and continued to move parallel to shore along the water line. Often the raccoons waded into the water, feeling over the bottom with their forepaws. Once prey was located the raccoon stayed in that location for up to fifteen minutes. The raccoons foraged along the edge of the water and followed the water as the tide came in. During low tides that occurred later at night, more raccoons were present after sunset than when low tides ocurred earlier in the evening (Table 8). Because the raccoons forage in shallow water, they have access to prey along the shore even when this area is inundated with water. The raccoons are not limited to lower-low tides only, but have access to prey at higher-low tides as well.

Behavioral Observations:

At the study site in Glasgow, raccoons forage only in the dark. Raccoons in South Slough stay on the tidal flat as late as 10:00 to 11:00 in the morning. The time and location of the South Slough observations are listed in Table 9.

The raccoons did not forage close together, but tended to spread apart about a hundred meters or more. Exceptions were the raccoons traveling in pairs and young foraging with their mother. No more than three raccoons were seen in close vicinity of each other at any one time. This is consistent with the social structure reported in other studies (Chapman, 1982 and Ref. there in). However, raccoons foraging in pairs were seen more frequently than expected. On seven out of eleven sighting days a raccoon pair was seen. A total of 36.4% of the raccoons seen were part of a distinct pair. Pairs were defined as two adult raccoons that remained consistently within one to fifteen meters of each other, did not exhibit aggressive behavior, and left the tidal flat together.

There are several modes of detection the raccoons use to find prey on the tidal flats. The raccoons use both sight and olfactory signals to locate prey in the sediment. These two detection methods are difficult to differentiate by observation alone because the postures are similar. Tactile detection is used when the surface of the mud is covered by seagrass or water. Raccoons have highly sensitive skin on their front feet which they use to explore holes, crevices, and any surfaces they can not directly see (Chapman, 1982). Even when they can see what they are touching, they often rely entirely on touch to explore while looking at something else.

When raccoons are in water, they use their forepaws to search the bottom. Raccoons often wade or swim, but they do not submerge their heads. In *Zostera marina* beds the raccoons move slowly, carefully feeling over the area with forepaws. Raccoons pat the surface of the blades and push the blades aside while searching for prey in a *Zostera* bed. When searching an area free of seagrass, raccoons sweep their noses across the ground in front as they walk. As raccoons move along they make shallow exploratory scoops in the sediment with their forepaws. In this manner they may distinguish siphon holes from other holes seen on the surface of the sediment. From my observations, scent is clearly used to detect prey; the raccoon investigates a small area with nose to the ground, then pauses and seems to follow a scent with its nose in a straight line. Thus they appear to use both sight and scent to detect prey.

Detection and Capture of *Callianassa* and *Cryptomya*:

To capture *Callianassa*, the raccoons scoop out the top of the burrow entrance, then thrust the full length of their front legs down into the burrow, up to the shoulder. Sometimes both front legs are put into the burrow. If the shrimp escapes, the raccoon puts its forepaws down the adjacent entrances, as if trying to intercept the escaping shrimp. Sometimes the raccoon thrusts its forepaw directly into the burrow, without widening it.

Raccoons most likely use a visual cue to locate occupied *Callianassa* burrows. Although the burrow entrances are conspicuous, one burrow may have several entrances. The raccoon must choose entrances which contain the shrimp rather than putting its forepaw down every burrow hole, which is energy-expensive. In the field, only certain entrances were dug out, not every one. This indicates a selection of the occupied burrows by the raccoons. It is possible that the raccoons see the shrimp just below the entrance of the burrow because these shrimp spend much of their time in the upper part of the burrow (Posey, 85).

Raccoons seem to be fairly successful in capturing these elusive *Callianassa*. At one location I found the remains of five *Callianassa*, and a few *M. nasuta* and *Cryptomya*, in a small area after a raccoon had been foraging in the location for about ten minutes. Most of the *Callianassa* found were males, which I identified by the enlarged cheliped. Usually only the tail portion of *Callianassa* is eaten, leaving the carapace, head and chellae.

The bivalve *Cryptomya* is taken from *Callianassa* burrows. *Cryptomya* live in the *Callianassa* burrows, and are found while the raccoon searches for the shrimp in its burrow. *Cryptomya* remains were found only next to *Callianassa* burrows, and often with remains of shrimp.

<u>Detection of *Macoma nasuta* and *Mya arenaria*:</u>

Macoma nasuta may be found by detection of the siphon retracting into the siphon hole. Siphon retraction into the hole results in a slight movement of the sediment and a water stream. Raccoons inspecting the sediment with forepaws possibly detect these slight movements of the retracting siphon. The *M. nasuta* siphon holes are small and difficult to find in the sediment. Raccoons may use exploratory shallow digs to determine the location of siphon holes. In *Zostera marina* beds, where there is a lot of water trapped between the blades, the siphon may be on the surface, and the raccoon could feel the siphon retracting into the burrow when disturbed. I found both *M. arenaria* and *M. nasuta* dug in the

Zostera marina, indicating the raccoons are able to locate the clams under the seagrass.

In contrast to the small siphon diameter of the *Macoma*, *M. arenaria* siphons are fairly wide and the siphon holes easily detected on unvegetated surfaces. It is possible that the raccoons locate *M. arenaria* by their siphon holes. The number of siphon holes seen on the surface was lower than the number of *M. arenaria* found in boxcore samples, indicating there are more clams in the sediment than siphon holes on the surface. (At boxcore site 1, *M. arenaria* siphon holes were counted before the boxcore was dug, then compared to the number of large *M. arenaria* found. About 3-8 siphon holes were counted for zone A samples but 10-20 *M. arenaria* were found below 10 cm.) In dense *Zostera japonica*, siphon holes are difficult to find. If raccoons find *M. arenaria* by their siphon holes only, they would dig up only those clams with detectable siphon holes.

There are other ways of detecting the *M. arenaria* besides sighting siphon holes. As the water goes out the *M. arenaria* tend to leave their siphons in the upper part of the burrow (field observation). When disturbed, the siphon retracts, sending up a jet of water. A dramatic squirt does not always occur, but the retracting siphon can be felt as the sediment moves slightly, and the movement makes a distinctive sound. Raccoons have keen hearing and it is possible that they can hear the retraction of the siphons and feel the movement as they walk over the sediment. In shallow water, raccoons might detect the water stream from siphons with their forepaws. Locating clams by detecting the exhalent siphon streams, or retracting siphon, would explain the tendency of raccoons to forage along the water line.

Discussion

The numbers of raccoons using the tidal flats and the amount of time they spend foraging there indicate the importance of the tidal flats as a food resource to raccoons. Although the degree to which raccoons depend on the tidal flats for food is problematic to quantify, it is possible to attain an estimate of the numbers using a tidal flat and the amount of time they spend foraging there. I accomplished this to some extent.

The impact raccoons have on a particular prey species was easier to quantify. The raccoons remove substantial numbers of large *Mya arenaria* in the upper intertidal. Although only *Mya arenaria* were eaten by raccoons in the study plots, there is no evidence that they prefer *M. arenaria* over the native bivalve species. Raccoons eat what is available to them if they can detect it and it is large enough. In South Slough raccoons eat *Macoma nasuta* and *Cryptomya* in addition to *M. arenaria* because these species are available in South Slough. At the study site the apparent preference for *M. arenaria* was explained by its availability. *Mya arenaria* is the most abundant large (> 30 mm) species, and therefore the only available bivalve of suitable size. *Macoma balthica* and small *M. arenaria* are more numerous than large *M. arenaria*, but are not eaten because they are too small. The greater density of *M. arenaria* in the upper zone was responsible for the higher numbers of *M. arenaria* removed in this zone compared to the lower areas.

The selection of large bivalves over medium (20-30 cm) and small (<20 cm) bivalves makes sense energetically. Large and medium *M. arenaria* were found at similar depths (10-20 cm). A raccoon expends the same amount of energy digging for medium and large bivalves but receives more energy from the larger bivalves. Only the small bivalves are found in the top 10 cm. Although they are not very deep and may be easier to dig than the large bivalves, small clams may be too difficult to handle and eat. In addition, a raccoon would have to spend a longer time foraging for small bivalves than for large bivalves to attain the same energy. A raccoon would have to find many small clams to equal the volume of one larger clam. It is difficult to pick the small clams from the sediment and the *Zostera* blades, and they are not readily seen from the surface.

The selection of large *M. arenaria* may occur because the siphon holes are easier to detect than the siphon holes of smaller clams. It is impossible to select large clams from the surface except by examining the width of the siphons and siphon holes. The larger *M. arenaria* have wider siphons and thus more distinct siphon holes. A smaller bivalve, *Cryptomya*, is easily found because it inhabits the *Callianassa* burrows. *Cryptomya* were the only small clam eaten on a regular basis. This finding indicates that small clams, above a minimum size of 20 mm, are eaten if they are easily found.

Selection of larger *M. arenaria* resulted in a removal of the least abundant size classes (Figure 6). The removal of substantial numbers of the larger *M. arenaria* may limit the numbers of these size classes. An estimated 6 to 8 percent of the *M. arenaria* > 30 mm are removed in a summer (three months), from the mid and upper zones. The number of nights that the tidal flat was available to the raccoons was taken into account for this estimate. Recall that the estimate is based on early morning low tides when part of the low tide occurs during daylight to allow shell collections. The impact of raccoons on other species is probably not as dramatic because foraging is concentrated in the relatively narrow zone close to shore where there are few large native bivalves. Within this narrow upper zone *M. arenaria* predominate, but decline in abundance at lower tidal heights. The higher tidal areas are exposed more of the time, enabling raccoons to reach *M. arenaria*. *Macoma nasuta* and *Cryptomya californica* are found in a few boxcores in zone C, suggesting these native species are present lower than the study plots. The introduction of *Mya arenaria* from the Atlantic coast provides coastal raccoons with a more accessible bivalve prey species than the native species because *M. arenaria* is a large clam inhabiting areas accessible to raccoons.

The relationship between small bivalve density and *Zostera japonica* density may explain, in part, the high numbers of adult *M. arenaria* close to shore. In areas devoid of seagrass, the density of the small bivalves dropped and small *M. arenaria* were absent. The presence of seagrass may be important in determining where the young *M. arenaria* settle and survive. Hydrodynamics may play a part in determining pattern of *M. arenaria* settlement. Young *M. arenaria* are moved by currents, which influences where the adult is located (Matthielssen, 1960). After *Mya* reach a certain size, they are no longer entrained by currents

(Matthielssen, 1960). The physical barrier created by the shoots and blades, may trap the small bivalves in the seagrass.

In addition to "collecting" the larval clams, seagrass may increase survival chances of the small clams. In several studies the presence of seagrass inhibited epibenthic predators (i.e. fish, crabs and snails) (Peterson, 1982; Summerson and Peterson, 1984). Higher densities of macrofauna (animals large enough to see) were found inside seagrass meadows than outside. The predators feed on exposed sediment, causing lower densities of prey species outside the seagrass beds (Peterson, 1982; Summerson and Peterson, 1984).

Carex may provide additional protection for bivalves by inhibiting raccoon digging. Above the study plots was a *Carex* marsh. Digging occurred only in thin *Carex* and not in dense *Carex*. The bivalves do inhabit areas where *Carex* grows. Raccoons would probably forage in *Carex* as well as *Zostera* except that *Carex* is too difficult to dig in. The rhizomes were very difficult to dig through using a shovel, and it must be difficult work for raccoons.

While removing prey the raccoons dig pits and trenches. Pits in the *Zostera japonica* beds are from ten to twenty-five centimeters deep. These are short-lived in sediment without vegetation, but in the *Zostera* beds, pits will last for several days. The effects of this disturbance is not known. The digging does remove rhizomes and displace small clams possibly making them vulnerable to other predators.

The diet of tidal flat raccoons is similar to the diet of raccoons foraging in fresh water. Both the inland raccoon and the coastal raccoon feed on aquatic invertebrates, fruit, and insects. The way raccoons detect prey is also consistent with observations of raccoons foraging in freshwater streams where they rely on their forepaws to detect prey in water (Tevis, 1947; Chapman, 1982). These similarities are expected since they are the same species, but coastal raccoons use a habitat different from the inland freshwater systems at least part of the time. Coastal areas are available only during low tide, and the salinity and topographies are different from fresh water streams and lakes. Although there are similarities between the diets, raccoons also prey on marine organisms very different from those encountered in freshwater systems, such as sea urchins and large crab species. At Cape Blanco, an exposed rocky coast habitat in Southern Oregon, raccoons feed on sea urchins (Carlton and Hodder, pers. comm.) indicating that raccoons are not limited to the tidal flats of estuaries. The ability to adapt to the coastal environments is not surprising because raccoons are described as intelligent, omnivorous, and adaptable (Chapman 1982).

I did not determine the proportions of each food in the diet. A study of stomach content of coastal raccoons in southwest Washington suggested that marine invertebrates constitute the entire diet of coastal raccoons in that area (Tyson, 1950). Fruit and other plant material was not found in this study. However, stomach content varies depending on what the raccoon had eaten just before it was taken for analysis. If the raccoons were sampled only in the intertidal, then they would have mostly invertebrates in their stomachs, although they may have eaten fruit hours before. In scat, I found a lot of fruit, and some insects and seeds, indicating raccoons feeding in the intertidal habitats also eat fruit. Similarly, studies done on inland raccoons indicate that plant matter is important in the diet. Although crayfish constituted from 30% to 66% of the scat volume, the next most important food was fruit or corn (Schoonover and Marshall, 1951; Tester, 1951; Dorney, 1954). The proportions of invertebrate and plant matter in scat varied with location and season, suggesting the diet changes to suit availability. It is inaccurate to use these volumes as an estimate of importance in the diet because shell material is not always ingested and soft-bodied organisms are not identifiable in the scat. However, scat analysis studies are useful for attaining further information about the variety and of items eaten, seasonality of different foods, and how often these are eaten.

Drift logs serving as defecation sites for raccoons are readily found on the tidal flat. In future studies these scat collections could be examined more thoroughly to determine other foods eaten seasonally. The proportion of crustaceans, mollusks, and soft-bodied organisms in the diet cannot be determined by this method because the amount ingested does not directly correspond to the amount eliminated.

Human activity in areas may affect when raccoons forage regardless of the low tide schedule. In South Slough, raccoons foraged on the tidal flat during morning low tides in the day light, where as they foraged only during dark hours at the Glasgow tidal flat. This difference in behavior is most likely explained by the relatively low level of human activity in South Slough compared to Glasgow. At Glasgow there are houses along the shore, many with dogs. In the South Slough, however, there are few houses near the shore, and the area around it is well forested. In more secluded tidal flat areas, raccoons may have more foraging time because they are not limited to foraging during low tides that occur at night.

My observations of raccoons suggest they form lasting pairs. Pairs were seen during the summer and fall, which was not during the spring mating season. Reasons for the formation of pairs is not clear. Supposedly, raccoons do not form mating pairs, but remain promiscuous during the mating season (Chapman, 1982). In one study, a pair observed included a male and female (Tevis, 1947). If pairs are comprised of a male and female staying together beyond mating season, raccoons may form longer lasting bonds than previously assumed.

The social behavior, and foraging behavior of raccoons on the tidal flats was partially revealed in this study. The results indicate that raccoons are important as tidal flat predators. However, further investigation of the effects of raccoons on their prey populations is needed before conclusions about the impact of raccoons on intertidal species can be made. This study is a useful preparation for a longer study that would reveal seasonal changes in foraging, possible tidal cycle adaptations of raccoons, and long term effects on prey species. Investigations of other terrestrial mammals that potentially use the intertidal habitat would increase our understanding of the interaction between the coastal terrestrial ecosystem with the intertidal ecosystem.

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The report mentions raccoons as a predator of *Mya arenaria* on the East Coast.

Chapman, Joseph A., and George A. Feldhammer, Ed. Wild Mammals of North America. Baltimore: The Johns Hopkins University Press, 1982.

This book gives general information on the biology, behavior, and distribution of *Procyon lotor*. It also provided references to papers on raccoons.

Dorney, Robert S. 1954. Ecology of Marsh Raccoons. *Journal of Wildlife Management* 18(2): 217-225.

This is a study on the impact of raccoons in a freshwater marsh. The research emphasized the numbers of certain prey taken by raccoons. Muskrat young (kits) were taken in significant numbers.

Ivey, R. DeWitt. 1948. The Raccoon In The Salt Marshes of Northeastern Florida. *Journal of Mammalogy* 29(3): 290-291.

This study of raccoons in a coastal salt marsh listed a daily activity pattern, which suggested an adaptation to the tidal cycle, being active at low tide, and inactive at high tide. The raccoons fed on crustaceans and mollusks.

Light, S.F. Intertidal Invertebrates of the Central California Coast. Los Angeles: University of California Press, 1954.

Paine, Robert. 1966. Food Web Complexity and Species Diversity. *Amer. Naturalist* 100: 65-75.

Paine, Robert. 1969. The *Pisaster-Tegula* interactions: Prey Patches. *Ecology* 50(6): 950-961.

These two papers discuss predation as a contributor to the intertidal zonation. In particular the relationship between the zones of *Pisaster* and *Mytilus*.

Peterson, C.H. 1982. Clam Predation by Whelks (*Busycon* spp.): Experimental Tests of the Importance of Prey Size, Prey Density and Seagrass Cover. *Marine Biology* 66: 159-170

Peterson, C. H. 1986. Enhancement of *Mercenaria mercenaria* densities in seagrass beds: Is pattern fixed during settlement season or altered by subsequent differential survival? *Limnol. Oceanogr.* 31: 200-205.

Studies of differential survival of clams outside the seagrass beds versus inside. The studies suggest the seagrass bed is a protection against predation by certain epibenthic predators.

Schoonover, Lyle J. and William H. Marshall. 1951. Food Habits of the Raccoon(*Procyon lotor hirtus*) in North-Central Minnesota. *Journal of Mammalogy* 32(4): 422-428.

The paper provided information on the diet of inland raccoons in freshwater systems. The data suggests that crayfish, grasshoppers and juneberries were the most important foods at the time of the study.

Sharp, Ward M. and Louise H. Sharp. 1956. Nocturnal Movements and Behavior of Wild Raccoons at a Winter Feeding Station. *Journal of Mammalogy* 37(1): 170-176.

This study on the nightly feeding behavior of raccoons at a feeding station provided information on nocturnal patterns of raccoons. Corn was available for raccoons at the station.

Summerson, H.C., and C.H. Peterson. 1984. Role of predation organizing benthic communities of a temperate-zone seagrass bed. *Marine Ecology Prog. Ser.* 15: 63-77.

Tester, John R. 1953. Fall Food Habits of the Raccoon in the South Platte Valley of Northeastern Colorado. *Journal of Mammalogy* 54(4): 502-503.

The paper provided information about the diet of inland raccoons in freshwater systems. It gives evidence that crayfish, grasshoppers and corn were most important at the time of the study.

Tevis, Lloyd Jr. 1947. Summer Activities of California Raccoons. *Journal of Mammalogy* 28(4): 323-332.

This is a good series of night observations of raccoons fishing for crayfish in streams and pools.

Tyson, Edwin L. 1950. Summer Food Habits of the Raccoon in Southwest Washington. *Journal of Mammalogy* 31(4): 448-449.

A study of stomach contents of coastal raccoons found exclusively marine invertebrates in the stomachs of 29 raccoons. They took a range of crustaceans, including beach inhabiting crabs, mussels, fish, and annelids.

Warrick, Sheridan F., Elizabeth D. Wilcox. Big River: The Natural History of an Endangered Northern California Estuary. Santa Cruz: Environmental Field Program, University of California, 1981.

This estuary study found a number of mammals using the estuary, and feeding on marine invertebrates. The list included mink, raccoons, river otters and meadow mice.

Figure 1: Coos Estuary

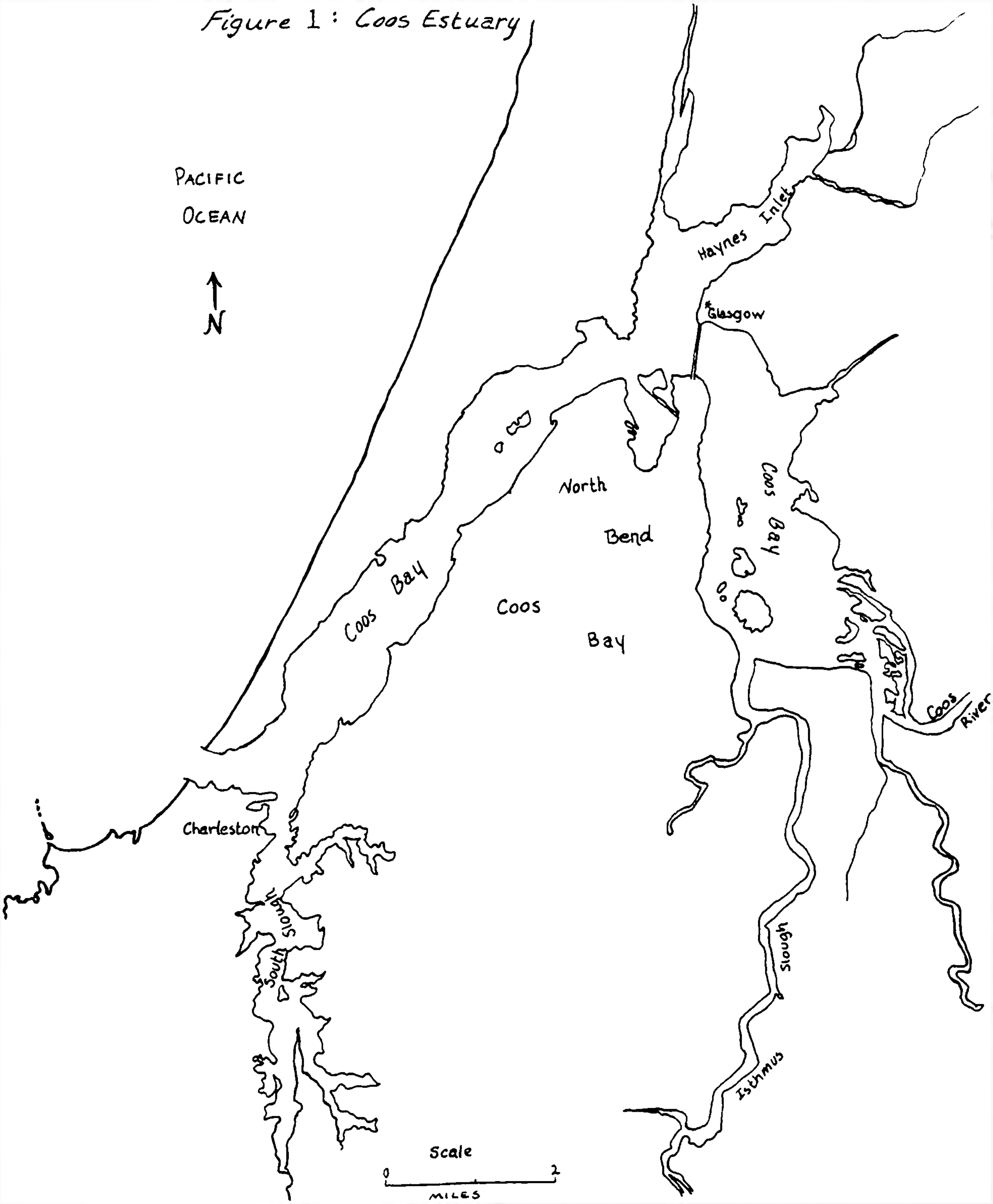


Figure 2: Study Area

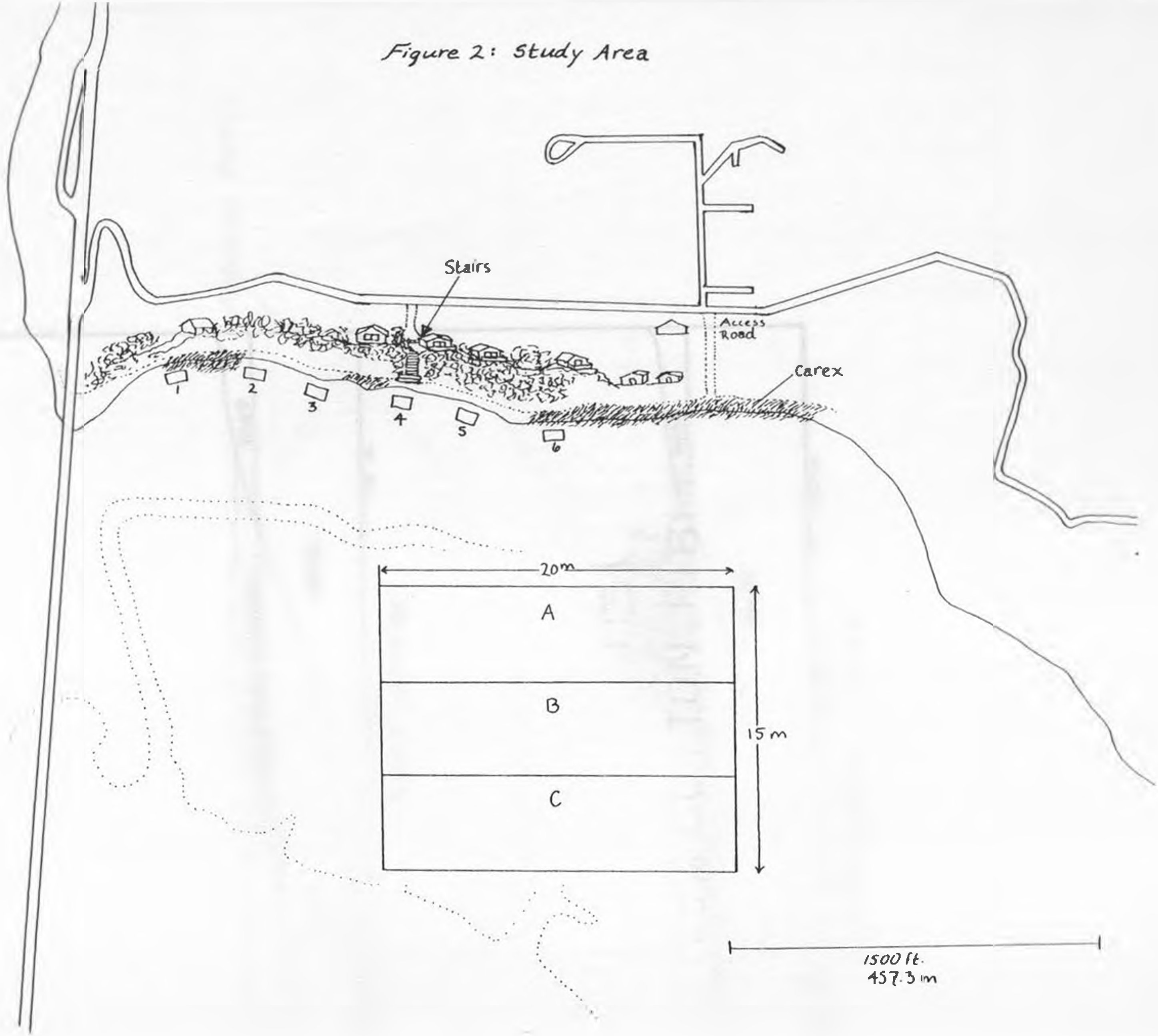


Figure 3: Cross section of the Glasgow Tidal Flat

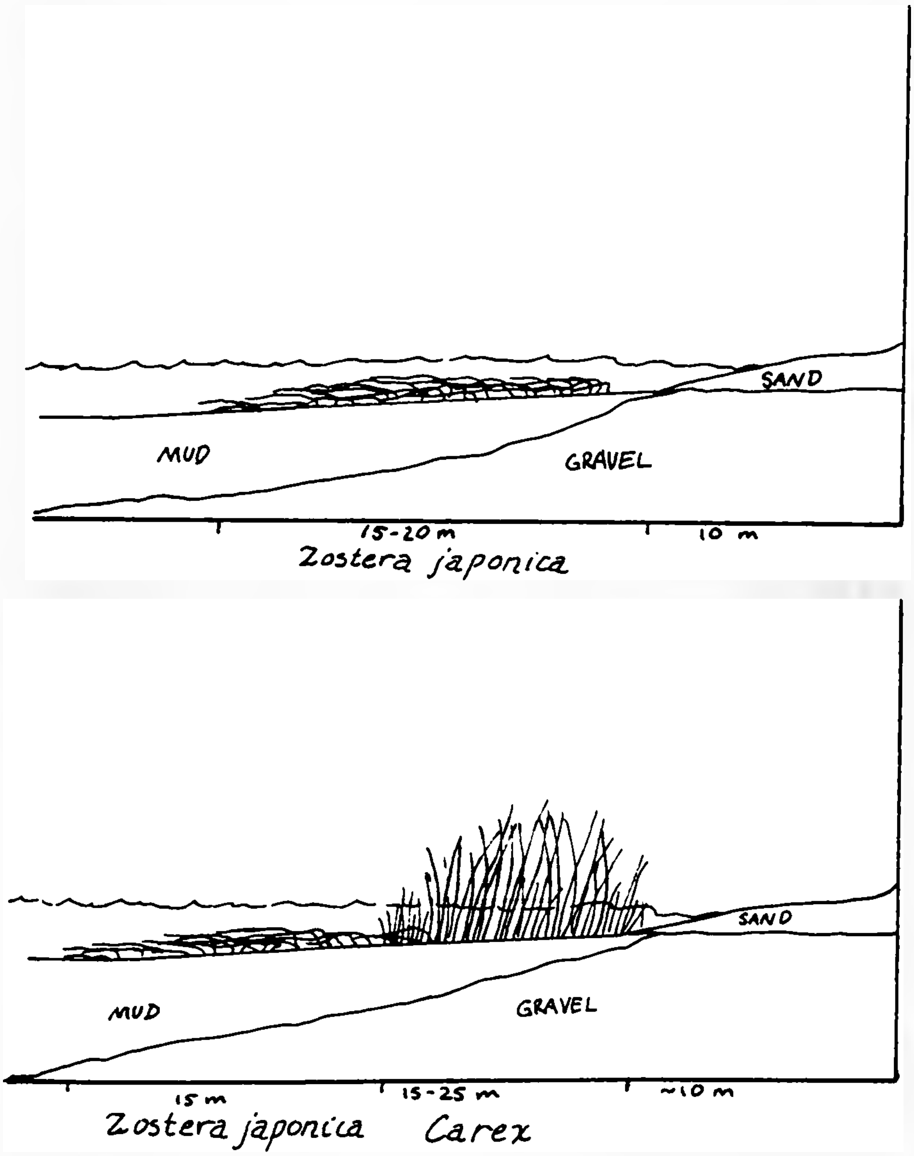
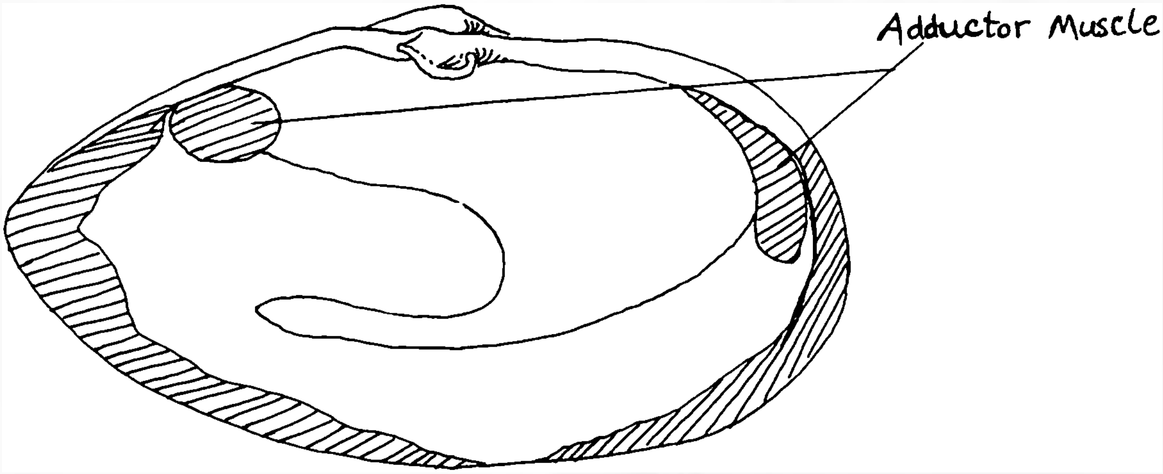


Figure 4



▨ Areas of Remaining tissue on the shell of A freshly eaten *Mya arenaria*

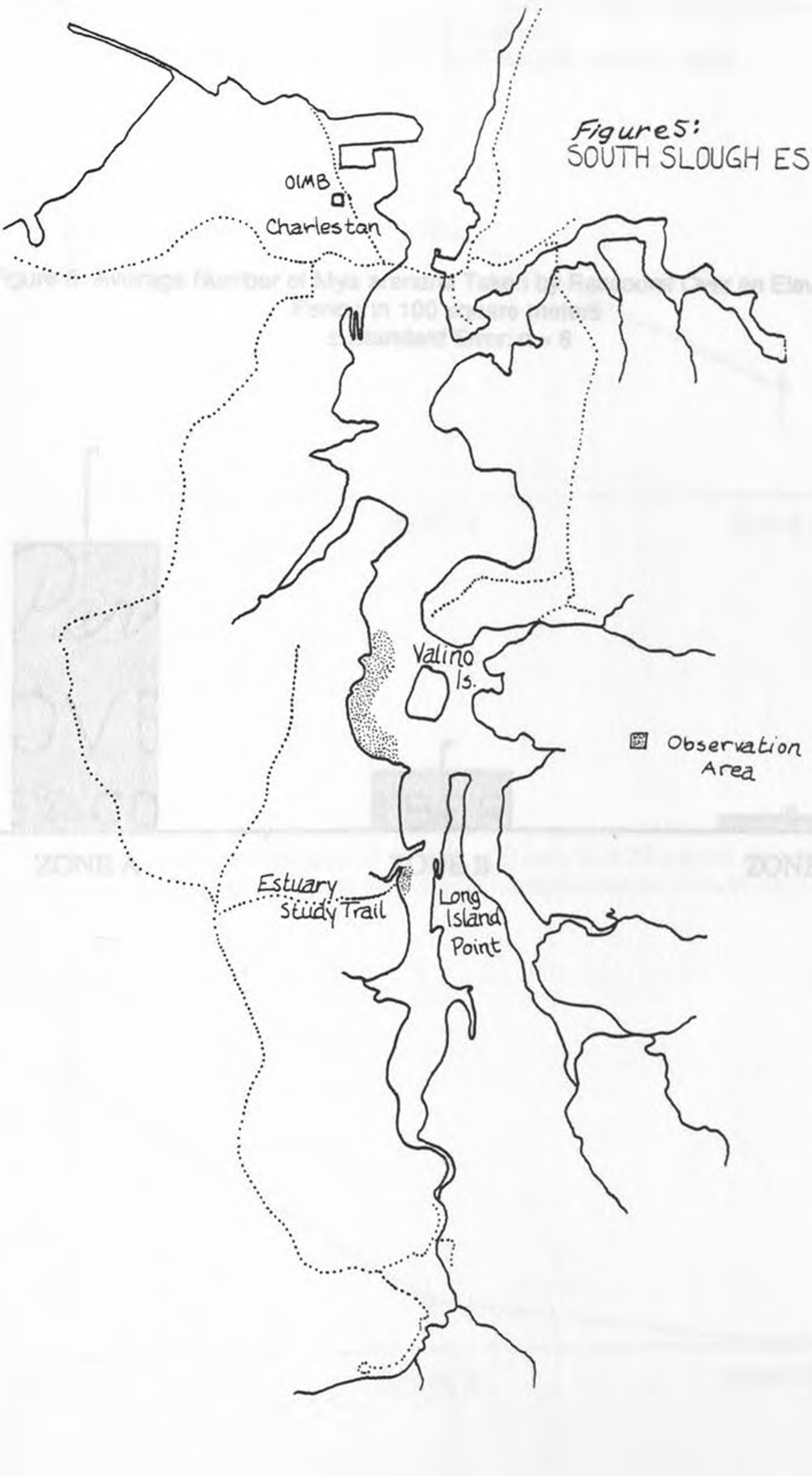


Figure 5:
SOUTH SLOUGH ESTUARY

Figure 6: Average Number of Mya arenaria Taken by Raccoons Over an Eleven Day Period in 100 square meters
± Standard Error; n = 6

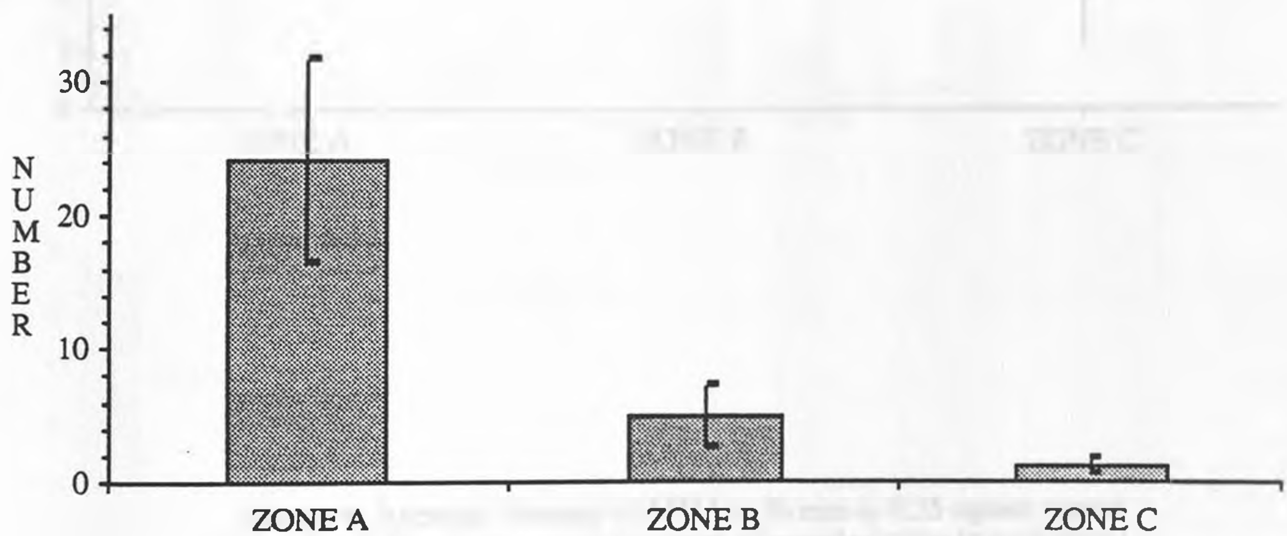


Figure 7: Average Number of MYA Found in 0.25 square meters
All Depths Combined
± Standard Error; n = 9 x 0.25 square meters / zone

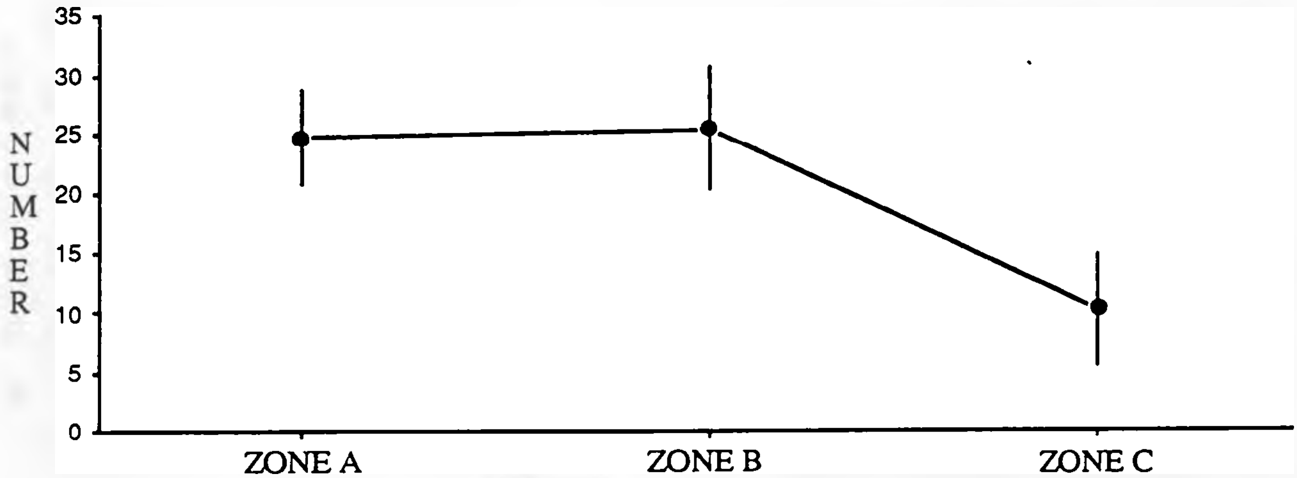


Figure 8: Average Number of MYA > 30 mm in 0.25 square meters
n = 9 x 0.25 square meters (number of samples taken in each zone)

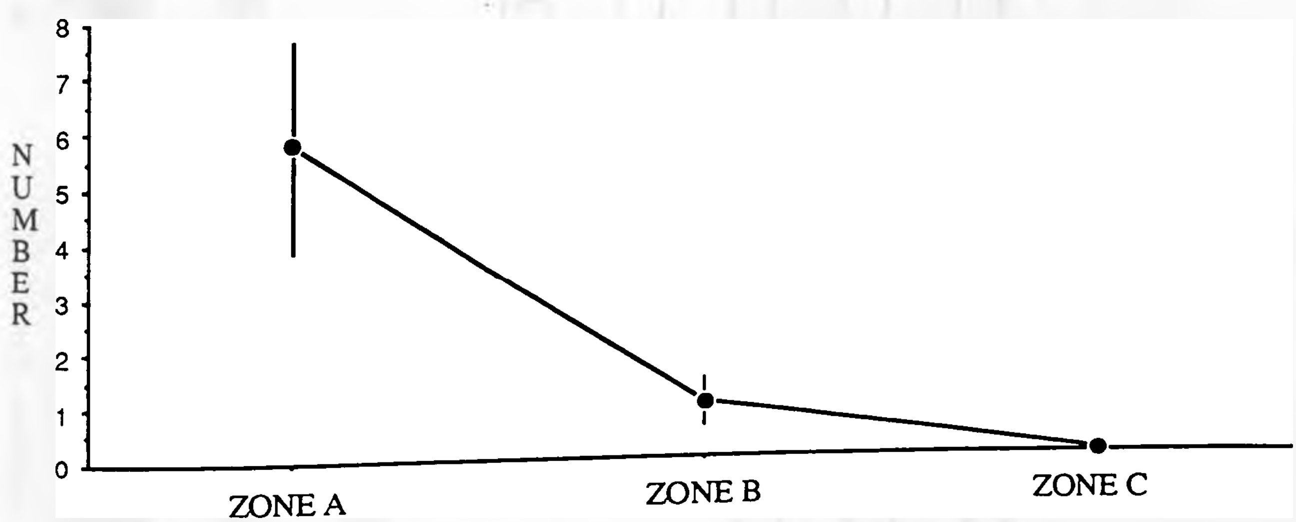


Figure 9: Distribution of Mya arenaria Size Classes in the Population and in The Raccoon Diet
Population data comes from boxcores and diet data comes from shell collections.

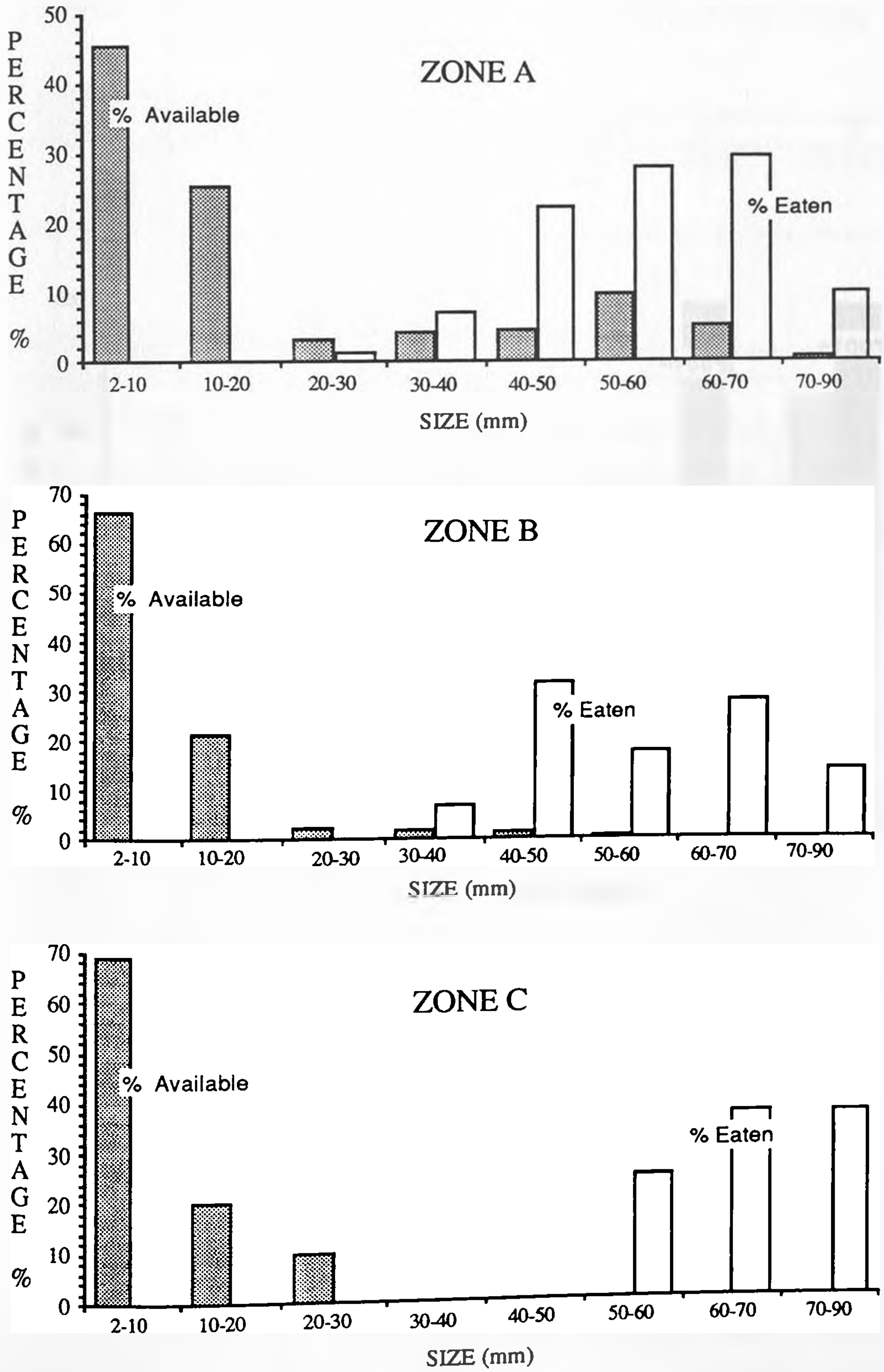


Figure 10: Estimate of the Percentage of Clams Taken By Raccoons over 2.5 Months

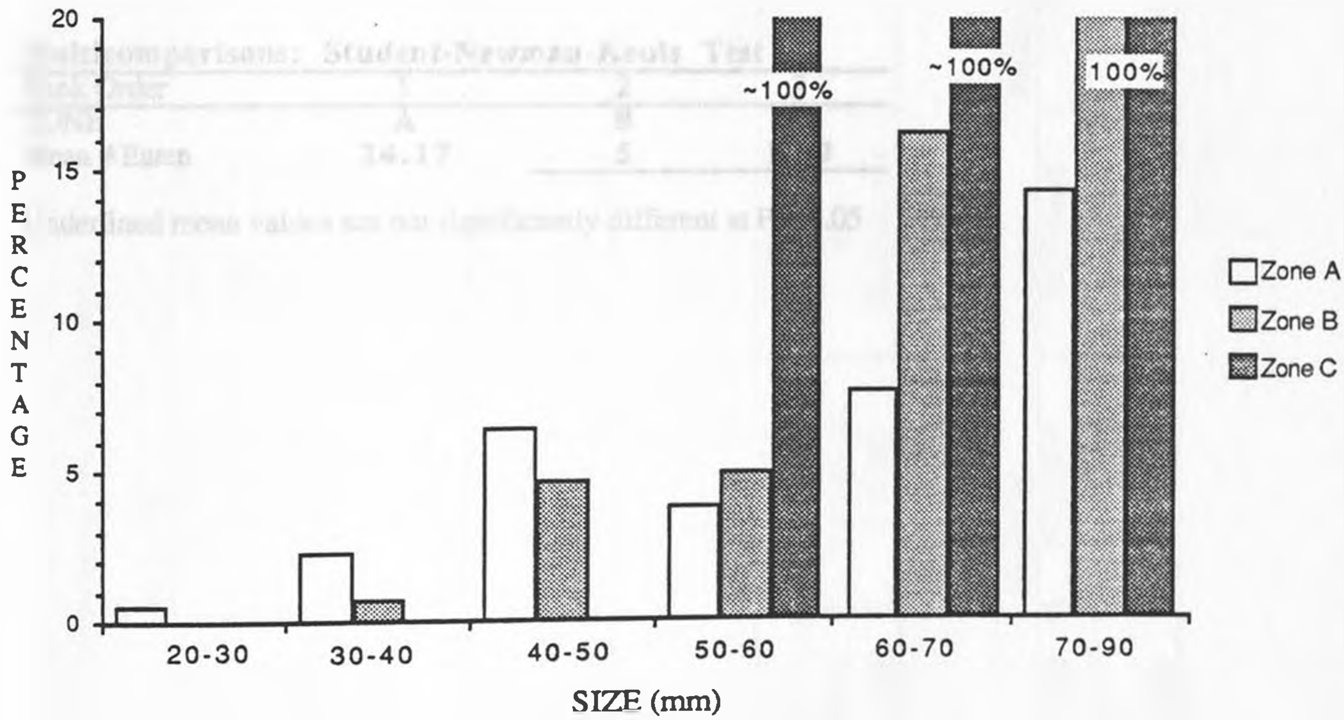


TABLE 1: ANOVA of Mya arenaria Eaten in Each Zone in 11 Days During the Months of July and August

Comparing All Zones

Source of Variation	df	MS(variance)	F	P
ZONE	2	902.165	7.08	P<< 0.01
ERROR	15	127.478		
TOTAL	17			

Multicomparisons: Student-Newman-Keuls Test

Rank Order	1	2	3
ZONE	A	B	C
Mean # Eaten	**24.17**	5	**1.33**

Underlined mean values are not significantly different at P = 0.05

TABLE 2: AVERAGE NUMBER AND SIZES OF BIVALVES FOUND IN 0.25 SQUARE METERS
Numbers in Parentheses are the Standard Error Values

MACOMA BALTHICA

DEPTH	0-10 CM		10-20 CM		20-30 CM	
ZONE	NUMBER	SIZE (mm)	NUMBER	SIZE (mm)	NUMBER	SIZE (mm)
A	180.22 (15.92)	7.48 (0.09)	1.44 (0.53)	18.89 (2.92)	0	0
B	202.22 (20.48)	7.31 (0.1)	1.78 (0.8)	10.69 (1.88)		
C	149.78 (37.74)	7.18 (0.05)	0.78 (0.36)	12.95 (4.18)		

MYA ARENARIA

DEPTH	0-10 CM		10-20 CM		20-30 CM	
ZONE	NUMBER	SIZE (mm)	NUMBER	SIZE (mm)	NUMBER	SIZE (mm)
A	17.11 (3.72)	8.43 (0.43)	6.89 (2.2)	43.09 (2.17)	0.88 (0.58)	63.85 (3.81)
B	25.22 (4.9)	8.99 (0.45)	2.33 (0.76)	33.23 (3.45)	0.11 (0.11)	43.4
C	9.89 (4.4)	8.67 (0.54)	0.33 (0.33)	24.67 (2.49)	0	0

MACOMA NASUTA

DEPTH	0-10 CM		10-20 CM		20-30 CM	
ZONE	NUMBER	SIZE (mm)	NUMBER	SIZE (mm)	NUMBER	SIZE (mm)
A	0.67 (.67)	8.36	0.11 (0.11)	13.5	0	0
B	6.67 (3.64)	7.36 (0.85)	0.11 (0.11)	40		
C	9.56 (4.29)	12.45 (1.23)	1 (0.88)	38.29 (4.48)		

CRYPTOMYA

DEPTH	0-10 CM		10-20 CM		20-30 CM	
ZONE	NUMBER	SIZE (mm)	NUMBER	SIZE (mm)	NUMBER	SIZE (mm)
A	0.11 (0.11)	5	0	0	0	0
B	0	0	0	0	0	0
C	0.56 (0.24)	9.43 (1.1)	1 (0.67)	11.46 (0.69)	0.44 (0.44)	14.15 (2.96)

TABLE 3: The number of Zostera japonica shoots counted in a 10 cm x 10 cm sample taken from the boxcore indicated, and the number of bivalves found in the top 10 cm of the sample.

SAMPLE #	NUMBER OF SHOOTS	M. arenaria	M. balthica
A1	62	12	236
A2	51	17	152
A3	7	0	110
B1	70	17	213
B2	67	13	315
B3	30	17	101
C1	0	0	91
C2	0	0	65
C3	25	6	142

TABLE 4: Two Way ANOVA of the Numbers of M. arenaria in Boxcores ALL DEPTHS INCLUDED

Source of Variation	df	MS	F	P
SUB GROUPS	8	446.09		
SITES (A)	2	309.59	2.30	NS
ZONES (B)	2	712.70	5.30	0.025
AxB (INTERACTION)	4	381.04	2.84	NS
ERROR	18	134.37		
TOTAL	26			

Student-Newman-Keuls Multiple Comparison of Means

Rank Order	1	2	3
ZONE	**B**	**A**	**C**
Mean	**25.78**	**24.78**	**9.89**

Underlined mean values are not significantly different at P = 0.05.

TABLE 5: Two Way ANOVA of the Numbers of M. arenaria in Boxcores EXCLUDING M. ARENARIA IN TOP 10 CM

Source of Variation	df	MS	F	P
SUB GROUPS	8	60.93		
SITES (A)	2	46.37	3.32	NS
ZONES (B)	2	127.26	9.12	0.005
AxB (INTERACTION)	4	35.04	2.51	NS
ERROR	18	13.96		
TOTAL	26			

Student-Newman-Keuls Multiple Comparison of Means

Rank Order	1	2	3
ZONE	**A**	**B**	**C**
Mean	**7.67**	**2.56**	**0.33**

Underlined mean values are not significantly different at P = 0.01.

TABLE 6: Two Way ANOVA of M. arenaria > 30 mm

Source of Variation	df	MS	F	P
SUB GROUPS	8	38.06		
SITES (A)	2	23.59	2.94	NS
ZONES (B)	2	85.81	10.68	0.001
AxB (INTERACTION)	4	21.43	2.67	NS
ERROR	18	8.04		
TOTAL	26			

Student-Newman-Keuls Multiple Comparison of Means

Rank Order	1	2	3
ZONE	**A**	**B**	**C**
Mean	**5.78**	**1**	**0**

Underlined mean values are not significantly different at P = 0.01

TABLE 7: SIZES AND NUMBERS OF MYA KILLED BY RACCOONS OVER ELEVEN DAYS AND THE ESTIMATED NUMBER TAKEN IN TWO MONTHS IN 100 SQUARE METERS

ZONE	NUMBER (Standard Error)	SIZE (mm) (Standard Error)	Number Taken in 2 Months	Number Available > 30 mm	% Of Aailable Mya Taken in 2 months
A	24.17 (7.62)	55.31 (0.93)	100	2300	4.40%
B	5 (2.31)	55.99 (2.57)	20.5	400	5.10%
C	1.33 (0.61)	67.88 (1.19)	5.4	0	100%

Table 8: Summary of Eye Shine Counts

Date	Lowtide Time	Sunset Time P.M.	Sighting Time	Number Raccoons
Nov. 12 1989	6:42 P.M.	5:00	6:30-9:30	0
Nov. 13	7:30 PM	4:47	6:20-9:30	3
Nov. 14	8:20 PM	4:47	6:15-9:30	3
Nov. 17	10:50 PM	4:42	10:15-12:45	8
Nov. 28	7:38 PM	4:32	until 11:30	0
Nov. 29	6:40 AM		4:50 to 5:45 A.M.	5
Dec. 5	12:30 A.M.	4:30	9:20-12:30	6
Jul. 7 1989	10:20 P.M.	8:40	9:25 to 9:56 P.M.	3- 5
Aug. 3 1989	8:30 P.M.	8:20	9:25 to 9:56 P.M.	5, including two young w/mother

Table 9: Summary of Observations of Raccoons Foraging in South Slough

Location	Date	Lowtide Time	Observation Time A.M.	Number Raccoons Observed	Prey Items If able to find
Polyprop. Line and Oyster Stakes	7/19/89	8:05 A.M.	6:45-7:05	1	Callianassa 5, M. nasuta Cryptomya
South Slough Study Trail	7/20/89	8:45 A.M.	6:45-8:00	5	
Oyster Racks	7/21/89	8:55 A.M.	7:45-8:55	3	
Oyster Racks	8/2/89	7:50 A.M.	6:30-7:10	2	

Table 10: Prey Species Eaten by Raccoons at Different Locations

Location	Habitat Type	Prey Species listed in Order of Relative Frequency Taken
Glasgow	Tidal Flat	*Mya arenaria, Callianassa californiensis, Cryptomya californica, Macoma nasuta, Cancer magister, Mytilus.*
South Slough	Tidal Flat	*Callianassa californiensis, Cryptomya californica, Macoma nasuta, Mya arenaria, Upogebia pugettensis.*
Metcalf Marsh	Tidal Flat	*Mya arenaria, Macoma nasuta*