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DISTRIBUTION OF THE INVASIVE INDO-PACIFIC GREEN MUSSEL, *PERNA VIRIDIS*, IN KINGSTON HARBOUR, JAMAICA

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ABSTRACT

In February 1998, green mussels were first observed during the collection of mangrove roots from Kingston Harbour on the south coast of Jamaica by researchers at the University of the West Indies, Mona. Preliminary observations of its morphological characteristics identified the mussel as *Perna viridis*, and this was confirmed by reference to the retractor muscle scars on the inside of the shells and ultimately by chromosome number. Prior to the first sighting in Jamaica, *P. viridis* was seen in Trinidad (1990), and subsequently in Tampa Bay, Florida (1999). A preliminary survey of 29 random sites was carried out in July 1999, which revealed that the mussel had established itself at numerous sites around the Harbour. Ten of these sites were monitored monthly for one year from February 2000 to January 2001 for mussel density, physicochemical parameters, suspended solids, microalgae, and gut contents. Densities varied throughout the year and appeared to be affected by salinity, substrate availability and removal by persons. Analysis of the gut contents of several of these mussels revealed the presence of four species of toxic microalgae, as well as a large amount of organic material. Further studies aimed at following the spread of this invading species are in progress.

Introduction of new species of organisms into commercial harbors such as Kingston Harbour is quite often by means of ballast water that is released by ships upon entry into the harbor. This water would have been taken up from the port of origin where the organism was growing. The introduction of species into an ecosystem can result in displacement of native species. Such new species will tend to compete with native species primarily for space and food, and may lead to the reduction in numbers or even total displacement of the native species.

Perna viridis (Linnaeus, 1758), the Indo-Pacific green mussel, belongs to the Phylum Mollusca, Class Bivalvia and the Family Mytilidae. Another important member of this family is the cold-water bivalve *Mytilius*, which is the primary edible mussel.

Geographical distribution was once used as a taxonomic tool to differentiate the various species of *Perna*. However, more precise methods are now used based on morphological characteristics, such as coloration, hinge teeth and scars from the adductor muscle attachment (Siddall, 1980). Confirmation of the identification of *P. viridis* is now even more accurately done using cytological analysis, where the chromosome number is elucidated. The diploid number of *P. viridis* is 30, i.e., 15 pairs of homologous chromosomes. The most closely related species is *P. perna*, which has a diploid number of 28 (Ahmed, 1974 as quoted in Vakily, 1989).

Perna viridis has several planktonic larval stages that are very motile. The penultimate larval stage, the veliconcha, has a locomotory organ (velum), which allows it to remain free swimming for up to 20 d (Bayne 1976 as quoted in Vakily, 1989). The final larval stage, the pediveliger, has a pedal organ that it will use to attach to suitable substrate when it is found. Once attached, it will produce byssal threads to secure itself to the substrata. This stage is often referred to as spat. It is very likely that ballast water released from a ship into Kingston Harbour could have contained the larval stages of *P. viridis*,

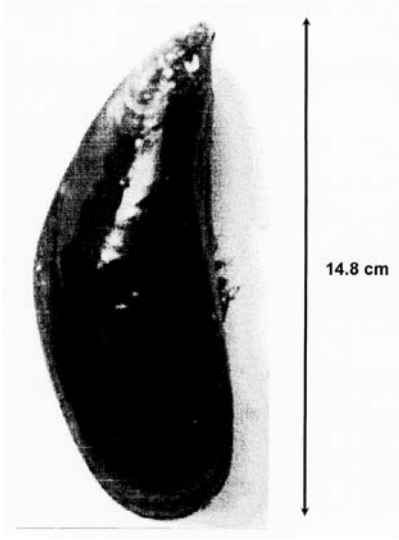

Figure 1. Specimen of *Perna viridis* collected March 2000 from a wharf piling at Greenwich Farm (GF) in Kingston Harbour.

which subsequently settled out of the water column as spat to various sites around the harbor.

Perna viridis, and other mussels, are filter feeders. They use gills for both gaseous exchange and feeding. Food particles are first trapped and then channeled into the digestive system. *Perna* spp. thrives in areas such as estuaries and bays, which contain a high concentration of organic matter.

Perna viridis (Fig.1) is commercially harvested in India, Thailand, Malaysia and the Philippines, and is cultured in the latter three countries (Vakily, 1989). *Perna viridis* is also known to be an important biofouling organism (Thompson et al., 1994). The mussels tend to clog pipelines used to transport seawater into industrial plants to cool turbines, such as those of companies that produce electricity. These pipelines have to be constantly cleared, resulting in very expensive maintenance costs. Colonization by *P. viridis* has been shown to also foster a microhabitat for other fouling organisms such as barnacles (Thompson et al., 1994).

Agard et al. (1992) reported the first observation of *P. viridis* in Trinidad around the Point Lisas Port in mid-1990. Since then it has spread along the entire coast of the Gulf of Paria, presumably via the prevailing water currents. Specimens have been seen colonizing hard substrates such as pier walls and wharf pilings, as well as soft bottom beds at Point Lisas and La Brea. They have since also invaded the Caroni Swamp, colonizing the mangrove roots. By 1995, this mussel had appeared along the Venezuelan coast and appears to be out-competing the native brown edible mussel, *P. perna* (Segnini de Bravo et al., 1998).

Perna viridis was first seen in Jamaica on mangrove roots at Kingston Harbour in February 1998. In July 1999, specimens of the mussel were found in the water uptake structures of TECO Gannon Station Power Plant in the Hillsborough Bay portion of Tampa Bay Florida (Ingrao et al., 2001). Since then, surveys have shown that the mussel has

extended its range as far north as John's Pass in St. Petersburg and as far south as Boca Grande, Florida.

In this report, we confirm the presence of this species, examine its distribution patterns and its feeding habits as it establishes itself in Kingston Harbour, the principal and largest maritime harbor in Jamaica (Goodbody, 2003).

Materials and Methods

Three different aspects of the biology of this mussel in Kingston Harbour, namely identification, distribution and nutrition were examined.

Identification

The species was first identified based on morphological characteristics (Siddall, 1980). The shell color in both the juveniles and the adults was compared. Forty mussels were dissected also to examine the scar patterns left from the adductor muscle.

Cytological confirmation of the species was then done in collaboration with D. Hicks (Lamar University, Texas). Specimens between 30–40 mm were collected and the gill tissue dissected and isolated. They were then prepared using a modified colchicine-Giesma technique (Holland et al., 1999 as per Ingrao et al., 2001), in which specimens were first placed in 0.05% colchicine solution for a period of 12 hrs and then placed in a hypotonic solution of 0.8% sodium citrate for 40 min. Replicates of the gill tissue were then fixed twice in freshly prepared solutions of three parts ethanol and one part glacial acetic acid for 20 min. periods. Finally, they were stored in freshly prepared mixtures of the identical fixative solution and sent off for cytological analysis (as per Ingrao et al., 2001).

Distribution

In July 1999, a preliminary survey was carried out at 29 random sites around Kingston Harbour to observe the absence, or presence of the mussel. Ten of these sites were selected to study distribution patterns and are called 'distribution sites.' The positions and the names of these sites are given in Figure 2. A key to the names of the sites, as well as the type of substrate that the mussels are found on, is in Table 1.

The density was monitored monthly over a one yr period (February 2000 to January 2001) at each of these ten distribution sites. Sites showed variation in the type of substrate on which the mussels were found; hence, the density was ascertained using slightly different techniques. For flat substrates, such as pier walls and seagrass beds, a 20×20 cm quadrat was employed. With cylindrical surfaces, such as mangrove prop roots and wharf pilings, only a defined upper segment was counted using a reference pole. Three random counts were done at each of these sites, and the mean of these values expressed per unit surface area. Simultaneously with the sampling, several physicochemical parameters were also taken using a Hydrolab multi-parameter data logger. These parameters included salinity, dissolved oxygen and temperature.

Nutrition

Enumeration and Identification of Phytoplankton.—Samples taken from the water directly surrounding the mussels were collected from ten of the 13 study sites (Fig. 2) using 250 ml plastic bottles. Three of the ten distribution sites (GSP, HB and PS) were not used in this aspect as the mussel density was too low for extraction, or absent. Three other sites were then chosen to replace these sites and are outlined in Table 2 (see also Fig. 2).

Three ml of Lugol's iodine solution was added to each water sample for immediate preservation and staining of the microalgae in the samples for later identification and enumeration (Vollenweider, 1969; Steidinger, 1979). The gut contents from three small and three large mussels from each of the

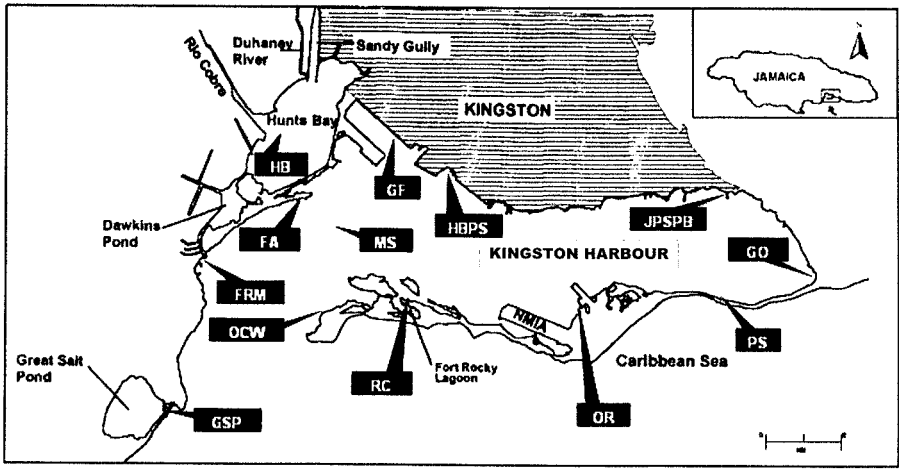

Figure 2. Map of Kingston Harbour showing sampling sites for monitoring of *Perna viridis* establishment GSP, Great Salt Pond; FRM, Forum Hotel; FA, Fort Augusta; HB, Hunt's Bay; HBPS, Hunt's Bay Power Station; JPSPB, Jamaica Public Service Power Barge; GO, Gypsum Office; PS, Palisadoes Strip; OR, Old Airport Runway; OCW, Old Coal Wharf; MS, Mammee Shoal; GF, Greenwich Farm; RC, Refuge Cay.

ten sites were washed using filtered seawater into separate bottles containing two ml of Lugol's solution.

Lugol's preserved site water and gut contents were gently homogenized by inversion and 10–100 ml aliquots of each used to fill settling chambers. The chambers were left to stand overnight to allow settling of the phytoplankton before examination. Examinations were conducted using a Leitz Labovert (model no. 020-435.025) inverted microscope (Utermohl, 1958). Phytoplankton cells were identified and enumerated from 50 random fields of view to remove the edge effect in the settling of phytoplankton cells (Sangren and Robinson, 1984). The presence/absence of microalgae in both the gut contents and water samples was recorded and the number of cells per liter of any potentially toxic species was determined.

Estimation of Suspended Solids.—One-liter water samples were taken from each of the ten distribution sites (see Table 1) adjacent to the mussels (or suitable substrate in the case of Hunt's Bay), which were used to determine the total amount of suspended solids present. This was done by vacuum filtering the sample through Whatman 1 mm glass fiber filters. The filters were then dried and weighed to determine the total suspended solids.

Table 1. Sampling stations around Kingston Harbour, their abbreviations (symbol) and the substrate type on which *Perna viridis* was found.

Distribution Sites	Key (Symbol)	Substrate found on
Great Salt Pond	GSP	Mangrove roots
Forum Hotel	FRM	Submerged rocks
Fort Augusta	FA	Wharf pilings
Hunt's Bay	HB	Absent
Hunt's Bay Power Station	HBPS	Wharf pilings
Jamaica Public Service Power Barge	JPSPB	Wharf pilings
Gypsum Office	GO	Pier wall
Palisadoes Strip	PS	Mangrove roots
Old Airport Runway	OR	Mangrove roots
Old Coal Wharf	OCW	Wharf pilings

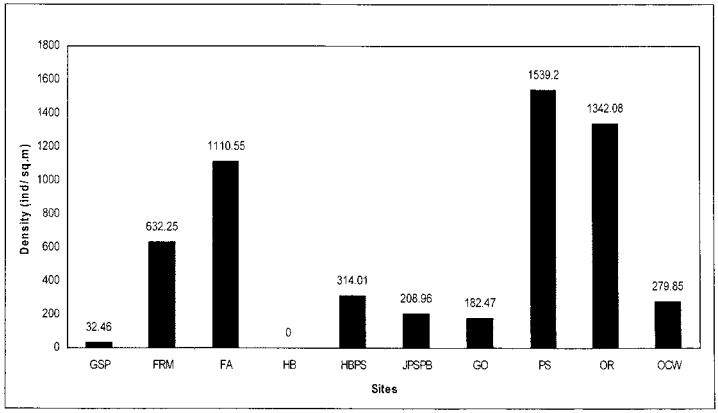

Figure 3. Average density over one year period (February 2000 – January 2001) for each study site. GSP, Great Salt Pond; FRM, Forum Hotel; FA, Fort Augusta; HB, Hunt's Bay; HBPS, Hunt's Bay Power Station; JPSPB, Jamaica Public Service Power Barge; GO, Gypsum Office; PS, Palisadoes Strip; OR, Old Airport Runway; OCW, Old Coal Wharf.

Results

The brilliant green color of the entire shell in the juveniles and the green margin of the predominantly brown shell seen in the adults were the initial characteristics used to identify specimens as belonging to the species *P. viridis*. The scar patterns of the anterior and posterior portions of the adductor muscle left on the inside of the shell when dissected, however, were of particular importance. The muscle was completely separated into two components supporting the claim that specimens belonged to the genus *Perna*. Cytological evidence confirmed that the mussel seen in the Harbour was *P. viridis* as observation of prepared gill tissues revealed the presence of 30 chromosomes in the cells of the animal.

Perna viridis has been observed growing densely on several types of substrata around Kingston Harbour. These include wharf pilings, (wooden, metallic and concrete), mangrove prop roots, pier walls, submerged rock faces, seagrass beds, muddy bottoms of mangrove areas, logs, metal drums, rubber tyres and abandoned boats.

Specimens were present at all sites except Hunt's Bay. The densities at the various sites varied and the data on average monthly densities show that high densities were observed in two sections of the Harbour, one including the FA and FRM sites and the other, the PS and OR sites; all other sites having lower densities (see Fig. 3).

The highest density of adult mussels was observed on the mangrove roots of a stand of *Rhizophora mangle* behind the Old Airport Runway (OR), where a density of 1342.08 individuals m^{-2} was recorded. The largest individual mussel recorded was 15.2 cm in length and this was collected from a wharf piling at Greenwich Farm (GF) in July 2000. Graphs of average monthly densities at individual sites did not show much fluctuation throughout the year with the exception of the site in the Great Salt Pond (GSP) and the site near the Old Runway (OR). At the GSP site, peak densities were recorded in July and December with troughs in February–March and September–October. At the OR site, a single peak was recorded in February, which leveled off during the rest of the year (see Fig. 4).

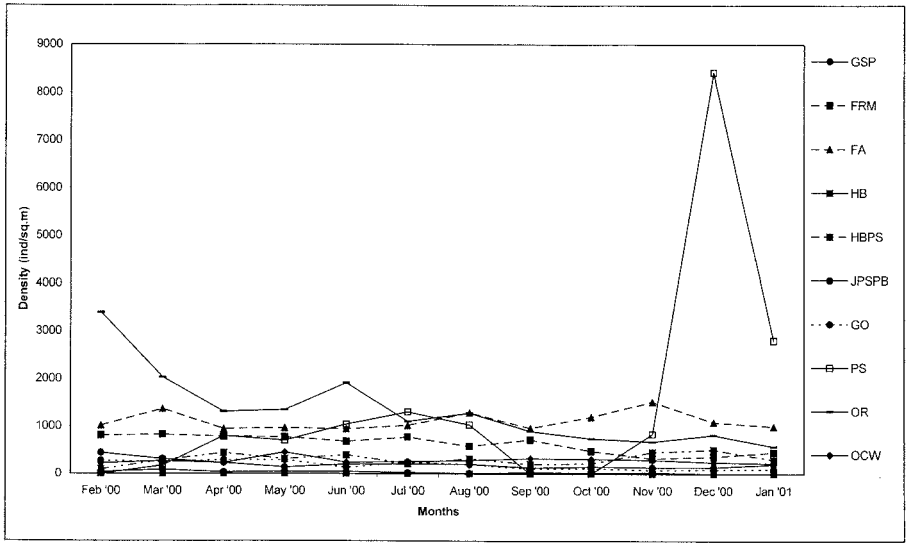

Figure 4. Change in monthly densities over one year period (February 2000 – January 2001) for each study site. GSP, Great Salt Pond; FRM, Forum Hotel; FA, Fort Augusta; HB, Hunt's Bay; HBPS, Hunt's Bay Power Station; JPSPB, Jamaica Public Service Power Barge; GO, Gypsum Office; PS, Palisadoes Strip; OR, Old Airport Runway; OCW, Old Coal Wharf.

AQUACOP and de Gaillande (1979) are quoted by Vakily (1989) as considering the optimum salinity for *P. viridis* to be 30. However, salinity appears not to be the only limiting factor in the distribution of the mussel in Kingston Harbour. Although *P. viridis* is absent from Hunt's Bay (HB) where the average salinity for the entire year was 27.70, the mussel was not present in high densities at sites such as the Great Salt Pond (GSP) where the average salinity was 33.80 (see Fig. 5). Fort Augusta (FA) showed the highest salinity value of 34.96, while the lowest salinity value of 25.10 was seen at Hunt's Bay (HB).

The site water and gut water samples of both the large and small mussels were found to contain various species of dinoflagellates, diatoms and blue-green algae. Amongst the microalgae found in both site water and gut water samples were four potentially toxic microalgal species that are known to cause shellfish poisoning in humans; *Dinophysis caudata* (all sites), *Prorocentrum minimum* (four sites), *Prorocentrum mexicanum* (two sites), *Prorocentrum lima* (one site). Concentrations of these algae ranged from 20–600 cells/liter in the site water samples. Very high concentrations of organic material were present in the water at all sites and large amounts were found in the stomachs of *P. viridis*.

The total suspended solids, which give an indication of the organic load, showed slight variation between sites with the exception of Hunt's Bay (HB), which showed a relatively high value of 0.058 g L^{-1} of suspended solids (see Table 3).

Discussion

Species of organisms introduced into an ecosystem will compete with the native species primarily for space and food. Where the introduced species out-competes the native species, reduction of the numbers and even total displacement of the latter follows.

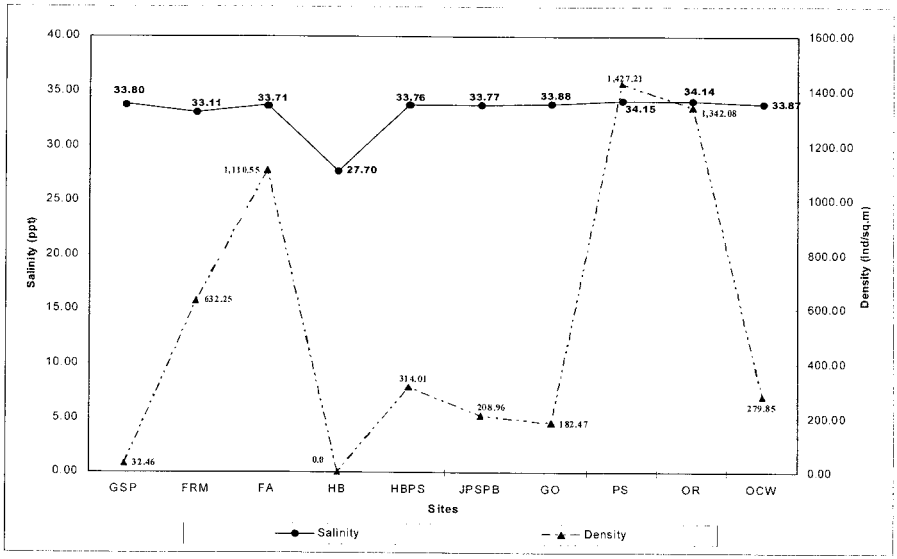

Figure 5. Average density over one year period (February 2000 – January 2001) for each study site, with corresponding salinity values. GSP, Great Salt Pond; FRM, Forum Hotel; FA, Fort Augusta; HB, Hunt's Bay; HBPS, Hunt's Bay Power Station; JPSPB, Jamaica Public Service Power Barge; GO, Gypsum Office; PS, Palisadoes Strip; OR, Old Airport Runway; OCW, Old Coal Wharf.

In Kingston Harbour, only two species of bivalves other than *P. viridis* were present in significant numbers. These were the mangrove oyster, *Crassostrea rhizophorae*, and the so-called 'flat oyster', *Isognomon alatus*. Both of these species are intertidal, but *P. viridis* is for the most part sub-tidal, so that its interaction with the other two bivalve species appears to be somewhat limited, and they occupy different zones of the substrata (Fig. 6). This may be a major reason why the spread of *P. viridis* throughout Kingston Harbour was so great.

The distribution of the mussels around Kingston Harbour was uneven. This is believed to be due directly, or indirectly to local conditions with respect to one or more of the following factors; salinity, food availability, substrate limitation, the presence of pollution and other environmental factors.

Salinity fluctuations as well as low water circulation (flushing) appear to be the factors most likely responsible for the absence of the mussel from Hunts Bay (HB). Hunts Bay is somewhat isolated from the greater harbor, with much less marine traffic as well; these factors would decrease the spread of *P. viridis* in the Bay. However, optimal conditions seem to exist at PS, OR, FA and to some extent FRM and these sites support high densities of mussels. Preliminary observations suggest that oil pollution may be affecting the density of mussels at the HBPS site, raised seawater temperatures due to outflows from

Table 2. Additional sites used for nutrition analysis, their abbreviation and the substrate on which *Perna viridis* was found.

Site	Key (Symbol)	Substrate found on
Mammee Shoal	MS	Seagrass bed
Greenwich Farm	GF	Wharf pilings
Refuge Cay	RC	Mangrove roots

Table 3. Average values for total suspended solids (TSS) for the ten distribution sites.

Site	GSP	FRM	FA	HB	HBPS	JPSPB	GO	PS	OR	OCW
TSS	0.032	0.029	0.030	0.058	0.030	0.030	0.030	0.029	0.029	0.028

the electricity generating plant may be affecting JPSPB and pollution by dust from the Gypsum Quarry might be negatively affecting the population at the GO site. At GSP, the pond is partially cut off from the Greater harbor. In general, water flows out of the pond except at high tide and this could limit the ability of the mussel to migrate into the pond leading to low population densities. At OCW, persons have been observed removing mussels on a regular basis for fish bait. It is possible that this activity may have limited the densities at this site. The PS site showed an extremely high average monthly density although specimens were absent for several months of the year. This result is due to the high numbers of juveniles taking over once the mussel establishes itself. These juveniles are densely packed, but do not colonize this site long enough to reach the adult stage.

The presence of toxic microalgal species in the gut of the mussel is cause for concern. In some countries, concentrations of *P. lima* ranging from detectable to 500 cells L^{-1} results in the imposition of restrictions on the shellfishery (Anderson, 1996). Values were found to be in excess of this standard. This mussel has great potential to a sustainable and lucrative resource for Jamaica; however, proper depuration procedures must first be carried out before the mussel can be put on the local and export markets. The large amount of organic matter present in the water at all sites and in the guts of specimens of *P. viridis* suggests that this represents the major food source and explains why the densities of *P. viridis* in Kingston Harbour are so high.

Given the large size of the existing population, it is not necessary at this point in time to culture these mussels. Commercial exploitation seems feasible using management strategies for the removal of the mussel that ensure they are safe for human consumption and

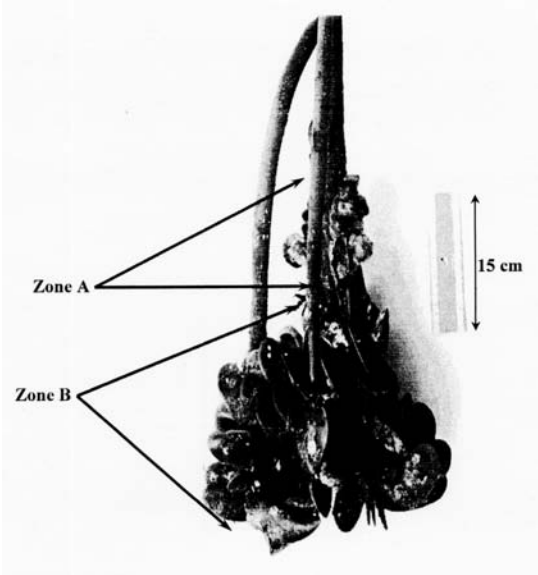

Figure 6. Prop root of red mangrove, *Rhizophora mangle* showing zonation in colonization of bivalves; Zone A: *Crassostrea rhizophorae* and *Isognomon alatus*; Zone B: *Perna viridis.*

also that the numbers are not so drastically reduced that the resource is lost. Should the numbers decline then farming could be contemplated.

Acknowledgements

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