BIVALVED SHELLFISH OF SARASOTA BAY:

A FRAMEWORK FOR ACTION

FINAL

Submitted to: Sarasota Bay National Estuary Program
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I. Executive Summary

Stationary bivalved shellfish were selected for a contamination assessment of Sarasota Bay, as an organism which integrates the exposure concentrations of contaminants over a finite period of time (weeks to months). Bivalves, as filter feeders, are exposed to large volumes of water and feed on suspended particulates which typically contain the bulk of chemical contaminants. The resultant tissue concentrations are used as a measure of the present-day chronic contamination exposure, as opposed to the instantaneous or historical conditions deduced from water column and sediment samples.

The study emphasized two recreationally important and edible shellfish, oysters *(Crassostrea virginica)* and hard clams or quahogs *(Mercenaria* spp.), either of which offered a fairly ubiquitous distribution within the study area, or for which a substantial national database existed for contaminant levels. Field and laboratory work was designed to survey the populations of the two species and to determine contamination levels in the edible tissues of these organisms, including pathogenic bacteria, metals, pesticides, and petroleum based polynuclear aromatic hydrocarbons (PAH).

The study originally was structured to evaluate contaminants during both dry and wet seasons, but low rainfall amounts for the year prevented the collection of what might be presumed to be "worst case", summer wet season conditions when contaminants loadings and bacterial populations are maximized. No formal health risk or stock assessment was conducted.

One-quarter of the 169 stations had no clams reported during either sampling, and yields at three-quarters of the stations were very low. Stations where no clams were found were concentrated along the eastern shore of Sarasota Bay and near Midnight Pass. The lowered abundances on the eastern shore have been reported from relatively pristine areas elsewhere and may be linked to physical factors. The lack of clams near Midnight Pass is primarily attributed to episodic low salinity events. Conditions have been favorable for clam sets in the past, but this study cannot establish whether the dead clams observed in the area settled before or after the closure of Midnight Pass. The larger 'chowder' clam

predominates in all areas due to predation, rapid growth rates, and potentially poor or erratic recruitment.

Oysters are also common in the area and are most abundant in the bays and tributaries south of Big Pass. Here, larger watersheds and reduced volume of receiving waters maintain more favorable lowered salinity regimes than in the northern portion of the study area, and consequently exclude predacious molluscs in particular. On the whole, however, oysters are restricted by predation to an intertidal habitat where reduced feeding times produces smaller, less commercially desireable organisms.

Fecal coliforms in water at over half of the stations slightly exceeded the National Shellfish Sanitation Program (NSSP) criteria. No tissue exceeded the NSSP criteria for fecal coliform or total plate counts. Bacterial counts at sampling times did not indicate highly polluted conditions and suggest that the major groups of vibrios and aeromonas are a part of the normal ecosystem and not of human fecal origin.

Oyster tissue metals were more useful for detecting station differences than were *Mercenaria* tissues due to broader ranges encountered. There was no geographic variation for mercury in either species, which implies that mercury is not associated with any major point sources in the study area. Individual stations noted for comparatively high metal content included Hudson Bayou, Bowlees Creek, Phillippi Creek, and South Creek. In relation to Florida Gulf coast values, Sarasota Bay oysters are well above average for lead and the Hudson Bayou concentration exceeded the highest lead value reported for either Florida or the nation.

No station averages of tissue concentrations exceeded Food and Drug Administration (FDA) action levels for mercury. Tissue levels of copper and zinc indicated that oysters in Phillippi Creek, Hudson Bayou, and possibly South Creek may suffer from impairments such as altered shell thickness and abnormal larvae. Sediment concentrations indicate that more extensive impacts could be expected in some areas.

While chlorinated pesticides were evident in many tissue samples, most concentrations were low. No station with detectable pesticides in the spring reported those same compounds during the fall sampling, indicating that sources of pesticides to the study area were intermittent. No pesticide exceeded the FDA action levels, but oysters from Phillippi Creek, Blackburn Bridge, and Hudson Bayou were comparatively high in concentrations of specific pesticides. Trace amounts of the labile organophosphate chlorpyrifos (dursban) were detected in both clam and oyster samples, indicating some influx of pesticides currently in use.

Analyses of shellfish tissues detected no quantifiable levels of PAH, although trace amounts were found at some stations. The compounds present indicate that the PAH were derived primarily from pyrogenic or combustion sources. The stations were distributed broadly and the low concentrations of PAH detected in Sarasota Bay shellfish indicated no chronic petroleum or pyrogenic contamination. Again, sediment concentrations of these compounds indicated that ecological impacts may be expected in some locations.

Feasibility of aquaculture or other commercial efforts within the study area is deemed low for the following reasons: 1) the frequent occurrence of toxic phytoplankton blooms ("red tides") which have closed shellfish beds 37 percent of the time in the last 13 years, 2) the high degree of adverse urban and recreational boating impacts on water quality, 3) the relatively small area of approved waters, 4) the poor shipping characteristics of dominant local *Mercenaria* species, 5) the lack of subtidal oyster habitat and larger individuals in approved areas, and 6) the difficulty of obtaining leases of subtidal State lands.

Resource enhancements at this time can include both seeding of clams and cultch placement for oyster spat to increase the populations, but will not likely result in any direct increase in recreation potential. Harvestable individuals would likely remain low unless 1) salinity regimes were radically restored (oysters), 2) non-point source loadings were reduced, 3) regions nearer tributaries reclassified for harvest, and 4) shore access improved. Reclassification of any areas for additional harvests will not occur without substantial reductions in non-point source loadings of bacteria and other contaminants.

There are, however, valid ecological inducements for these enhancements. As filter feeders, both clams and oysters have the theoretical potential to improve the water clarity of Sarasota Bay, particularly if water clarity impairments are linked to phytoplankton levels. Other benefits of enhancing shellfish populations would include increased biomass of the estuary, support of other species, additional habitat complexity, increased shoreline stability, and reduced sediment resuspension through wave damping.

Research needs noted during this project include the quantification of airborne loads of metals and PAH in relation to surface runoff, relevant for assessing whether conventional non-point source controls can achieve significant reductions in contaminants. Little is known on population dynamics, including recruitment, predation pressures, and harvesting pressure, which should be quantified to manage the resource and protect from overharvest. Mapping of oyster resources should be updated. Historical salinity regimes in the southern study area could be identified by morphological characteristics of current and indian midden oyster shell. If NPS controls improve, a formal contaminant specific health risk assessment and recreational effort assessment will become necessary, as would a true wet season tissue sampling. The suite of analytical compounds should also be further expanded to include selected PCB isomers.

II. Background

On a nationwide basis, the bulk of water quality problems which limit shellfishing are attributed to bacterial and viral contamination, followed by the presence of biotoxins such as those in red tides. Toxic compounds (pesticides, PCB's, and metals) in water or sediments generally account for fewer "use impairments" (NAS, 1991). Current classification of waters by Florida Department of Natural Resources (FDNR) are designed to protect against these hazards, with approximately 3,000 acres within the study area classified as "conditionally approved" (Figure 1).

The areas where shellfish are considered safe for harvest and human consumption by FDNR, however, are considerably smaller than the Class II waters ("suitable for shellfish harvesting and propagation") of the region identified by the Florida Administrative Code. Shellfishing in Sarasota Bay is limited to an area off of the southeastern end of Longboat Key. An additional area in Palma Sola Bay, although 'conditionally approved", has been closed since 1981.

Sources of fecal coliforms which can cause waters to be classified as harvest-limited include urban or non-point source runoff, sewage treatment plants, failed septic systems, industrial wastes, boating activities, agricultural runoff from grazing lands, and fecal material from wildlife, including bird rookeries (Broutman and Leonard, 1988). Stormwater runoff or non-point source impacts are recognized as one of the major water quality problems within Sarasota Bay (FDER, 1988). Within the Sarasota Bay study area, 47 percent of the watershed is currently listed as 'developed', i.e., either residential, commercial, institutional, industrial, transportation, or power or sewage treatment plant land uses. Estimates at build-out are that 82 percent will be similarly classified with concomitant increases in non-point source loadings of some parameters (CDM, 1992).

Of the classification categories, "conditionally approved" and "restricted" require the most state resources to maintain. Lack of resources often dictate that areas remain unclassified and also have resulted in management decisions to downgrade the classification of areas. While FDNR plans a reclassification for this area, expanded opened waters will require a further commitment to continued sanitary monitoring. Statewide, overall trends are for the continued downgrading of classifications, primarily due to increasing recognition of non-point source impacts (Broutman and Leonard, 1988).

Declines in Florida landings of bivalved shellfish have been matched by national declines, and both have been attributed to overharvesting and continuing expansion of areas affected by non-point source pollution (NOAA, 1991). Locally, the commercial fisheries for oysters and clams collapsed in 1967 and 1971, respectively, and clam fisheries in Florida have historically been erratic (Arnold, unpublished manuscript).

The collapse of shellfish fisheries in Florida have often been associated with catastrophic events such as red tides or hurricanes (Steidinger, et al., 1973; Godcharles and Japp, 1973). Locally, overharvest does not seem to be a problem due to the absence of commercial fisheries and low numbers of recreational clammers observed. Recreational harvesting is largely unquantified, however, although thought to be important both in the study area and nationally (Stanley and Dewitt, 1983). A reduced shoreline access produced by a high level of coastal development in the Sarasota Bay study area undoubtedly restricts the recreational clamming (Stevely et al., in press). Quantitative data on recreational harvesting of bivalves is not available.

There are no active shellfishing production leases of submerged lands on the southwest coast (Mr. John Stevely, personal communication). Feasibility of aquaculture or other commercial efforts within the study area is deemed low for the following reasons: 1) difficulty of obtaining leases of subtidal State lands, 2) high degree of adverse urban and recreational boating impacts on water quality, 3) relatively small area of approved waters, 4) poor shipping characteristics of dominant local *Mercenaria* species, and 5) lack of subtidal oyster habitat in approved areas and small sized individuals occurring in intertidal habitats. Ecological or recreationally oriented enhancements, rather than commercially oriented, may be the most effective.

In addition, "red tides" of a dinoflagellate, *Gymnodinium breve*, produces potent neurotoxins (Steidinger, 1983, 1990) which frequently force the closure of the approved shellfishing beds in Sarasota Bay. The bivalves may be only marginally affected except in extreme instances (Tiffany and Heyl, 1978; Roberts et al., 1979), but filter feeding concentrates the toxic phytoplankton (Cummings and Stevens, 1970; Music et al., 1973), and human consumption can produce neurotoxic shellfish poisoning (Baden, 1973).

The west-central region of Florida's coast receives the bulk of the red tide outbreaks, perhaps attributable to current patterns in the Gulf of Mexico. As a direct result, Sarasota Bay shellfish beds have been closed for 37 percent of the time over the past 13 years (1978 through 1991). The bulk of those times were during the fall and winter harvesting months. Closure of beds could also permit the fast-growing *Mercenaria* to grow beyond optimal commercial size.

III. Study Design / Methods and Rationale

To evaluate the contaminant status of an area, water column concentrations are notoriously variable and pose many difficulties in interpretation. Organisms which remain in an area, however, provide an integrating effect and, through depuration, in general reflect only the most recent period, on the order of weeks or months (NOAA, 1989).

Biomonitors, if they tolerate a wide range of pollutants, also should reflect contaminant bioavailabilities and, in some instances, can magnify pollution gradients, making them more readily detectable. Bivalves are particularly well suited for this role due to their feeding strategy, where they filter large volumes of water and associated particulates. The particulates include not only the preferred phytoplankton food items, but also bacteria and viruses, toxic dinoflagellates ('red tide'), inorganic, and detrital particles. The particulate fraction concentrated by filter feeders typically contains not only the bacteria, but also the bulk of the anthropogenic contaminants, specifically toxic metals and organic compounds.

Methods and Rationale - Population Surveys

Population surveys and tissue analyses were performed on two bivalved shellfish, *Mercenaria* spp. and *Crassostrea virginica*, selected for abundance, broad geographic distribution (to permit bay-wide comparisons), recreational interest, and size of existing data base. The hard clam surveyed was described as *Mercenaria* spp. since the dominant local species, *M. campechiensis*, is known to hybridize readily with *M. mercenaria*.

Lack of knowledge on seasonal fluctuations of *Mercenaria*, apparent site specific mortalities (Estevez and Bruzek, 1986), possible erratic recruitment controlled by predation rather than by environmental factors (Mulholland, 1984), and a potentially unstable population, coupled with the potential year round availability of clams for harvest, made two seasonally-based population surveys desireable for *Mercenaria* during the study year. The surveys of *Mercenaria* employed a timed effort approach to mimic recreational shellfishing and avoid impact to grassbeds. Clams found were measured and released. The efficacy of the technique for smaller clams, in particular, was verified with raked quadrats in unvegetated areas and probing in areas with vegetation. The 169 stations were distributed as evenly as possible among the shallow (< 3' below MLLW) areas of Sarasota Bay.

Surveys of oysters primarily consisted of identifying areas of viable and senescent reef (Hines and Belknap, 1986), based on both previous mapping (Mangrove Systems, 1988) and observations during this study. Reef condition and any physical destruction were noted, as was dominant oyster length, the presence of legal sized individuals, and oyster predators.

Methods and Rationale - Tissue Contaminants

Stations for tissue collections were identified with consideration for broad geographic distribution, and, for oysters, endeavored to include the major tributaries to the Sarasota Bay system. Twenty stations were selected, ten for *Mercenaria* and ten for *Crassostrea*. Following each of the two population surveys, two composite tissue samples were collected from each of twenty locations. Collections took place in April and again in November-December 1990. Clams collected from Bishops Point were the only tissues collected from within "conditionally approved" waters. Water column samples were also collected for bacteriological analyses. A total of 80 tissue samples and 40 water samples were analyzed for the entire study.

The original study design called for the collection and analysis of tissues during the dry season, followed by two collections and tissue analyses at some priority subset of stations during a significant storm event of the wet season. Tissue levels of pollutants during the dry season, while not worst case, were to allow for bay-wide comparisons of possible problem areas. Data obtained from tissues collected in the wet season were to represent a 'worst case' scenario, under conditions of maximum runoff and presumably highest pollutant loadings. Low rainfall amounts received during the year forced the redesign of the study, to focus on potential seasonal differences between each of the 20 tissue stations. The two samplings were referred to as a spring and a fall collection to avoid the implication that substantial rainfall occurred.

In the marine environment, one of the most important routes of infectious diseases in humans is through water contact and the consumption of raw shellfish (SCAG, 1988). The pathogens of most concern are associated with human fecal wastes. A number of microbial analyses were selected to provide information on sources of contaminants and severity of contamination. Sample matrices included both shellfish tissues and water column samples.

Aerobic plate counts quantified the entire heterotrophic bacterial population. Total and fecal coliform, and fecal streptococci were used as sewage tracers. A total of seven pathogenic vibrio species were selected for quantification, together with *Aeromonas hydrophila* and *A. sobria*, which are potential human pathogens. The vibrios and aeromonas are indigenous to marine waters, unrelated to the presence of sewage, and have been identified in both approved and prohibited waters (Blake and Rodrick, 1983) with no correlation to fecal coliform levels. E. *coli* are also potential enterotoxic pathogens, and were also selected for enumeration.

Uptake routes of contaminants for bivalves include both from solution and from ingested food particles. Bioaccumulation of chemical contaminants reflects the net results of exposure, uptake, excretion, as well as any degree to which tissue concentrations are "diluted" by increasing size of the organism (Rainbow, 1990). In addition, size or age, seasonal variation in either physiological processes or contaminant loads, sex and reproductive status, temperature and salinity, and the vertical position on the shoreline (Phillips, 1990; NAS, 1980; Paes-Osuna and Marmolejo-Rivas, 1990) can also influence tissue levels.

Bioavailability, the degree to which contaminants are available to biota, also plays a role. In particular for metals subject to uptake from solution, the factors which affect speciation and free ions present (ionic strength, salinity, pH, EH, sulfides, presence of dissolved organics and other chelating agents, suspended sediment) will influence metal bioavailability (McClusky et al., 1986; Ahsanullah and Florence, 1984; Elder, 1988).

Toxicity varies with compound, life stage, and size of the particular organism, with embryos and larvae being notably more sensitive to contamination (Viarengo, 1989). Toxicity effects can be evidenced through either biochemical or whole animal responses (growth, morphology, or activity). Half lives, or the time period required for half of the body burden of contaminant to be excreted, are typically longer for metals than for organochlorines or hydrocarbons (Phillips and Segar, 1986).

A number of effects have been linked to metals, as oysters, clams, and other bivalves have been reported to exhibit reduced growth and larval toxicity, the formation of abnormal larvae for several bivalve species (Marten et al., 1981; MacInnes and Calabrese, 1978), reduced fecundity, reduced filtration rates or burrowing behavior (Bayne et al., 1985; McGreer, 1979), and impaired settlement and survival (McGreer, 1982). Metal detoxification strategies, particularly for oysters, frequently allow high concentrations of certain metals to be accumulated as the metals (copper and zinc, in particular) are sequestered by metal binding proteins or in granular form (Mason, 1988).

Sarasota Bay is fortunate in that there are, in comparison to other estuaries within the National Estuary Program, comparatively few industrial point source discharges. One of the major problem sets identified in the nomination document, however, was stormwater runoff. Pollutants characteristic of stormwater include metals, toxic organic compounds, and petroleum products. Marinas and boating operations can contribute metals to the environment, as well. Metals selected for tissue contaminant analyses were as follows: arsenic, cadmium, copper, lead, mercury, and zinc. These elements were selected due to the national databases available on shellfish tissue levels, presence in urban runoff, and toxicity information available (both for bivalves and humans).

Chlorinated pesticides are persistent, lipid-soluble, synthetic chemicals that are toxic to a wide variety of aquatic organisms, as well as humans, and in some instances are carcinogenic. Sublethal effects of chlorinated pesticides create stress on bivalves through interference with enzyme pathways (Engle et al., 1972). Eggs and larvae are more susceptible than juveniles and adults (NOAA, 1990a). The chlorinated pesticides have been replaced with less persistent, yet often more toxic organophosphate and carbamate pesticides. These pesticides generally do not persist in the marine environment for years; however, they do persist for weeks to months and may have a short-term impact following local applications and stormwater runoff. Dursban or chlorpyrifos, for instance, is identified as a potential hazard for benthic species (Schimmel et al., 1983).

Pesticides selected for contamination assessment included representatives from three classes of chemicals (carbamate, organophosphate, and chlorinated pesticides) that are used in Sarasota and Manatee Counties. These indicators were the organophosphates chlorpyrifos (dursban), used for domestic and industrial insect control and dibrom (naled), used as a mosquito adulticide; and the carbamate bendiocarb (ficam) used on turf and ornamental plants (Agricultural Chemicals Handbook, 1989). In addition to these pesticides currently in use around the Bay, residues of persistent chlorinated hydrocarbon pesticides (e.g., DDT and derivatives, chlordane, BHC) were monitored.

Although no major oil spills have been observed in Sarasota Bay, there likely is a chronic influx of petroleum (consisting of roughly 40% PAH) from tributaries bringing stormwater runoff from an urban watershed and spillage from a number of marinas. Of greatest concern are the polycyclic aromatic hydrocarbons (PAH) which include both toxic and carcinogenic substances (NAS, 1985). Summaries of PAH input to aquatic environments attribute 73 percent to petroleum spills, 21 percent to atmospheric deposition (generally of combustion products), 3 percent to wastewaters and surface runoff, with 1 percent from biogenic sources (Eisler, 1987).

Sources of PAH may be from either petroleum or combustion (petrogenic or pyrogenic). Both sources may be from human activities, such as oil spills and combustion of fossil fuels, or from natural occurrences, such as oil seeps and forest fires (Farrington, 1980; NAS, 1985). The predominant source can be distinguished by the mix and types of compounds present. Petroleum-derived PAH contain more of the smaller compounds (two and three rings) with alkyl substitution on the rings (Farrington, 1980). Combustion sources are characterized by unsubstituted three to five ring compounds as many substitution groups are removed in the combustion process. Combustion sources predominantly include fluoranthene and pyrene (NAS, 1985).

The lower molecular weight PAH (2 to 3 rings) are generally acutely toxic but noncarcinogenic, while the 4 to 7 ring higher molecular weight compounds are less toxic but carcinogenic, mutagenic, or teratogenic (Eisler, 1987). The low molecular weight toxic compounds include anthracenes, fluorenes, naphthalenes, and phenanthrenes, while the carcinogenic compounds include benzo(a)pyrene (Kennish, 1991).

As a whole, PAH are not biomagnified within the food chain due to rapid degradation, depuration, and the low absorption in higher organisms (Jakim and Lake, 1978). Seasonal increases in PAH tissue concentrations coincide with periods of lipid storage for spawning (Marcus and Stokes, 1985). Pyrogenic PAH are apparently tightly bound (Farrington, 1985) or incorporated in sediment particles and not readily available for biological accumulation, while petrogenic PAH occur in dissolved and colloidal suspensions, more readily available for biological uptake.

Analytical techniques for all contaminant analyses were detailed in both the project EPA-Approved Quality Assurance Plan and the Draft Final Report.

IV. Results

Population Surveys - Results

There was little seasonal variation apparent in abundance (Figure 2) or size of clams. The distribution of *Mercenaria* varied with sediment and vegetation type, being most numerous in sandy mud and in sparse *Halodule* beds. Clams were most abundant on the western shore of Sarasota Bay (largely in the "conditionally approved" area), western Anna Maria Sound, and New Pass where up to 35 individuals could be found in a 30 minute effort. Clam abundance was not significantly correlated with the quarterly water quality data collected under the National Estuary monitoring program.

Approximately one-third of the stations sampled had no clams during any one survey, and roughly three-quarters of the stations reported less than 5 animals during the field work (Figure 2). No clams were found during either survey at one-quarter of the stations.

In the Midnight Pass area (Figure 3) numerous mature and intact, but dead, clams showed evidence of some abrupt change in environmental factors other than predation. Prolonged periods of reduced salinities during the wet season are a likely explanation for the death of these organisms. Low current velocities experienced by any area near the tidal null zone may also have contributed by providing insufficient food. The presence of the mature (although dead) individuals, however, indicates that conditions are favorable for settlement and growth during past times. It could not be determined, however, whether the initial settlement of the dead individuals pre- or post-dated the closure of Midnight Pass.

The large number of stations on the east side of Sarasota Bay with no clams found (Figure 3) is not easily explained. It is reported that this pattern of more clams on the west side of bays is common on the Florida west coast, however (Don Hesselman, personal communication), and could be associated with bathymetry, associated wave energies, sediment type, or predation.

Predacious molluscs were observed primarily in the northern portion of the study area. The less valuable, larger 'chowder' clam predominates due both to predation, rapid growth rates, and potentially poor or erratic recruitment. The smaller, although still large, mean clam lengths <100 mm were found at stations roughly in the area of passes (Figure 4): Longboat Pass; New and Big Passes; and in the far south portion of the study area near Venice Jetties. These may represent more recent sets of cohorts. Smaller sized clams also were noted in shell or coarse substrate, while larger individuals were found in sand.

The rapid growth habits of *Mercenaria* and intense predation on juveniles undoubtedly bias populations towards larger individuals. However, even allowing for this and assuming that the individuals less than 50 mm are less than two years old (Jones et al., 1990), it is apparent that recruitment rates are relatively slow. The quantitative effect of harvest pressure on these and on *Mercenaria* populations elsewhere is relatively unknown.

The extent of recreational clamming was not a portion of this study, but clammers were observed or reported during the survey in four areas, New Pass, Pansy Lagoon, Selby Gardens area, and the north end of Palma

Sola Bay. Bay access is relatively easy at these locations, but all sites are in prohibited shellfishing areas. Much of the harvested organisms may be used for bait in finfishing.

Oysters are also common in the area, and were most abundant in the more enclosed bays south of Big Pass. Phillippi, North, Catfish and South Creeks flow into shallow Roberts Bay, Little Sarasota Bay and Blackburn Bay and this freshwater is undoubtedly responsible for lowered salinity and nutrient input favorable for oyster survival. In addition, the watershed contributing to the southern portion of the study area is roughly double that which drains to Sarasota Bay. Figure 5 illustrates the areas where oyster bars or reefs were observed. It is clear in the figure that oysters were more abundant in the southern portion of the study area. The high levels of predators *(Melongena)* noted throughout the study area, however, restricts oysters to an intertidal habitat in many regions. As a result, the oysters which feed less than subtidal populations are smaller and less commercially and recreationally desireable.

Bacteriological Contaminants - Results

Fecal coliforms in water never exceeded 64 per 100 ml, with over half of the stations slightly exceeding the National Shellfish Sanitation Program (NSSP) criteria of 14 per 100 ml. No tissues NSSP criteria of 230 fecal coliform or 50,000,000 total plate count per 100 g tissue. The maximum tissue concentrations were 100 fecal coliform per 100 g tissue and 51,000 organisms per 100 g for total plate counts.

During the two sampling periods in 1990, all bacterial counts in both tissue and water column samples remained exceptionally low in Sarasota Bay. This may have resulted from the relatively low rainfall that occurred during this sampling year. Rainfall deficits were over 15" below normal for calendar year 1990 in the Manasota Basin, and 22" below the eight year period of record at the City Island gaging station. Additionally, as sampling was delayed in anticipation of increased rainfall amounts, the study was not conducted during the warmest portion of the year, when ambient bacterial counts are expected to be at a maximum.

Although fecal coliform standards for waters (14 per 100 ml) were slightly exceeded at many stations, only one, Bishops Point, was within a "conditionally approved" area. Counts at this station were 32 and 16 per 100 ml during spring and fall respectively. The fecal coliform water standard is apparently a conservative value since none of the tissues were in excess of the 230 per 100 g standard for tissue. Only the waters at the South Creek station were below the standard during both sampling events.

Bacterial counts at sampling times did not indicate highly polluted conditions or for that matter the presence of high numbers of vibrios unrelated to pollution. Of the vibrios, the most frequently identified were *V. alginolyticus*, *V. parahaemolyticus* and *Aeromona hydrophila*, with *V. vulnificus* occurring only in the spring and at selected stations in the water column and oyster tissue samples. Results suggest that the major groups of vibrios and aeromonas are a part of the normal ecosystem and not of human fecal origin.

The low levels of vibrios are also a likely result of sampling during the spring and fall rather than during the warmer months when bacterial populations are typically at a maximum. While specific dose-response information is generally lacking for vibrio infections, the vibrio counts determined during this study are approximately four orders of magnitude less than either total vibrios or *V. vulnificus* alone as documented at a Gulf Coast oyster processing plant (Ruple et al., 1989).

The erratic counts of total coliform bacteria may indicate that some non-human inputs may be significant at some locations, but the low levels of fecal coliform and fecal streptococci found prevented the use of fecal coliform to fecal strep ratios to gain information on sources of fecal matter.

<u>Metals - Results</u>

No consistent seasonal variation in tissue metal concentrations was observed, although this result may differ under years with more rainfall. Comparisons between species support other literature in that Sarasota Bay oysters are noted for high concentrations of copper and zinc. Copper and zinc oyster maxima were 20 or more times higher in oyster tissues than in the maximum clam tissue concentrations, and is attributed to species-specific physiological strategies for metal detoxification. Lead concentrations were slightly higher in clam tissues than in oysters.

There were significant variations between stations for all metals and each species, with the exception of mercury. Since the ability of shellfish to bioaccumulate mercury has been extensively documented, it can be inferred that mercury is not associated with any major point sources or loadings from the basins represented by stations within this study. Z Oysters typically displayed a larger range between stations than did *Mercenaria*, with geographic variation most pronounced for copper, lead, and zinc, and the least for arsenic and cadmium.

Oyster tissues in Sarasota Bay were evaluated by comparison with the oyster tissue data base developed by the National Oceanic and Atmospheric Administration's National Status and Trends Program (NS&T) (NOAA, 1989). Data from the NOAA program include dry weight tissue metal values for oysters collected in 1986-1988 from 20 stations located along Florida's Gulf coast.

In relation to Florida Gulf coast values, Sarasota Bay oysters are lower than average in cadmium and mercury, average for arsenic, slightly above average for copper and zinc, and well above average for lead. The Sarasota Bay Hudson Bayou concentration of 6.9 µg/g exceeded the highest lead value reported (5.4 µg/g) for either Florida or the nation (Figure 6). Metal concentrations in clam tissues were similar to other urban areas.

Individual stations are noted for their comparatively high arsenic (South Creek and Siesta Bridge), copper (Hudson Bayou), lead (Hudson Bayou and Bowlees Creek), and zinc (Phillippi Creek, Hudson Bayou, and South Creek) concentrations. In comparison, oysters from Palma Sola Creek and Perico Bayou were low in overall metal concentration. For clam tissues, those gathered from the Phillippi Creek estuary were highest in lead, mercury and zinc, while those from near Selby Gardens were highest in cadmium and copper. Arsenic concentrations in clams were highest in tissues collected off of Bishops Point. Clams from the northeast side of the Manatee Avenue Bridge were the lowest overall in metals percentages.

Overall, tissue metal concentrations were most notable in Hudson Bayou, Phillippi Creek, and South Creek. Tissue concentrations of zinc and lead do not correlate particularly well with predicted loads from the various basins, which may reflect varying bioavailability of metals, or unknown point sources.

No station averages of tissue concentrations exceeded Food and Drug Administration (FDA) action levels for mercury, while only the clams at the Selby Gardens station exceeded the unofficial NSSP recommendations for cadmium, for those metals which FDA addresses. Almost all of the clam stations, however, and some of the oyster sites exceeded the more restrictive Canadian action levels for lead.

There is a comparative lack of data sets in which biological effects data (mortality, physiological processes, reproductive impairment, or other sublethal effects) are presented together with tissue concentrations, most being evaluated as a function of water column or sediment concentrations. Long, et al., (1991) have compiled this information for oysters. Tissue levels of copper and zinc indicated that oysters in Phillippi Creek, Hudson Bayou, and possibly South Creek may suffer from impairments such as altered shell thickness and abnormal larvae. Sediment contaminant concentrations indicate that ecological impacts may be greater than can be defined from tissue concentrations alone (Chapter ***).

Toxic Organics - Results

Oysters and clams from the majority of the sites sampled throughout Sarasota Bay in spring and fall 1990 did not contain substantial pesticides, yet low levels of chlorinated pesticides were evident. Most concentrations were low, near the detection limits. Of the station averages of the pesticides detected, the highest concentrations were usually contained in oysters, but these organisms were also more directly exposed, as stations were preferentially near the mouths of tributaries. For the study as a whole, eight of the 18 pesticides under analysis were found in shellfish. No station with detectable pesticides in the spring reported those same compounds during the fall sampling, indicating that sources of pesticides to the study area were intermittent rather than continuous. Sources could be associated with the resuspension of older contaminated sediments, as during dredging operations, or with the new applications of approved carbamates or organophosphates.

No pesticide exceeded the applicable FDA action levels. A greater variety of pesticides was detected in the fall samples than from those collected in spring. Dieldrin was the most prevalent compound during the study (occurring in the most number of samples), followed by B-BHC, τ-BHC, and p,p'-DDE.

The oysters collected in the spring from Phillippi Creek, however, did contain DDE in concentrations equal to 7 percent of the FDA action level of 5,000 ng/g. This level was considered high in relation to the 1986-1988 NS&T data for the southwest Florida coast (NOAA, 1989). *Mercenaria* from Blackburn Bridge contained approximately 12 percent of the FDA action level for chlordane. One sample of oyster tissue from Hudson Bayou contained 5 percent of the total DDT (the sum of all DDT, DDE, and DDD) allowed by FDA during the fall sampling.

Notable concentrations of p,p'-DDE were found in oysters collected from the mouth of Phillippi Creek during the spring and from Hudson Bayou in the fall, with lower concentrations of dieldrin, chlordane, BHC and the organophosphate pesticide, chlorpyrifos. Phillippi Creek represents the largest watershed basin within the study area and the loadings are probably high. The Hudson Bayou watershed, while small, is highly developed with both residential and commercial areas and was also exceptional for metal contaminants in oysters.

During the fall, trace amounts of the labile organophosphate chlorpyrifos (dursban) were detected in three clam samples and one oyster sample, indicating some influx of pesticides currently in use. Only one clam sample, from the Manatee Ave. site, however, contained quantifiable amounts of chlorpyrifos, averaging 5 ng/g.

The concentrations of total chlorinated contaminants (pesticides from the EPA 608 series) in shellfish tissue averaged over the two seasonal sampling episodes are illustrated Figure 6 for oyster tissue samples. Oysters exhibited greater concentrations of pesticides and residues were detected at 5 of the 10 sites sampled, with the greatest amounts found at Phillippi Creek and Hudson Bayou. This ranking was again primarily the product of concentrations of single compounds, p,p'-DDE for both locations. Pesticide contamination was detected in five of the ten clam sampling sites, with the greatest amount found at the Long Bar site (due to the heptachlor levels found). Blackburn Bridge clams were the next most contaminated overall, again due to a single compound (α-chlordane).

The concentrations of p,p'-DDE in Phillippi Creek oysters during the spring sampling represent anomalously high amounts relative to other shellfish samples throughout the southwest Florida coast (NOAA, 1989), but are still well below the 5,000 ng/g FDA Action Level for fish. The fact that p,p'-DDE was not found in oyster samples from the same site during the subsequent collection, however, indicates no continuous contamination problem. Sediment contaminant concentrations, however, indicate that ecological impacts from pesticides and PAH may be greater than can be defined from tissue concentrations alone (Chapter ***).

The predominance of DDE is indicative of long-term contamination from DDT pesticides applied to the watershed more than 20 years ago. Periodic disruption and erosion of contaminated soil or resuspension of contaminated sediments would cause the inconsistent pattern of minute amounts of DDT metabolites to be found. Due to low precipitation throughout 1990, and correspondingly lower inputs of stormwater to the Sarasota Bay system, the tissue analyses presented here do not represent a maximum contaminant scenario. It is quite possible that during a wetter season or immediately following a major rainfall, influx of current-use pesticides in stormwater runoff would be greater and tissue concentrations proportionally greater.

Analyses of shellfish tissues detected no quantifiable levels of PAH (greater than 50 ng/g dry weight), although trace amounts (between 15 and 50 ng/g) were found at some stations. The stations were broadly distributed and the low concentrations of PAH detected in Sarasota Bay shellfish indicates no chronic petroleum or pyrogenic contamination and subsequent bioaccumulation.

Sarasota Bay shellfish PAH compounds were derived primarily from pyrogenic sources, rather than from direct input from petroleum products. Primary sources would include atmospheric deposition of PAH-containing particles from automobile and boat engine exhaust, coal and oil combustion industrial processes and forest fires, as well as used crankcase oil washed into the estuary with stormwater runoff. Since many of the PAH in estuaries come from stormwater runoff, a better understanding of the impact from runoff could be gained from monitoring the PAH composition of stormwater at select runoff sites and at select shellfish beds following a major rain event.

Because of dry conditions throughout 1990, the environmental conditions represent a minimum case scenario for stormwater-derived contaminants. In general, the results are indicative of estuarine environments with no consistent, widespread influx of petroleum contamination. PAH analyses in shellfish collected at periodic intervals following a major rain event are needed to provide a better assessment of stormwater-derived PAH in shellfish.

V. Management Recommendations and Research Needs

The coliform standard and resulting classification of waters appears to be effective in limiting human exposure to toxic contaminants as well. The most contaminated sites in the study area were in areas currently unapproved or closed to shellfish harvesting and in areas adjacent to tributary mouths. The lack of wet season and therefore potentially worst case data during this study, however, should be recognized.

As shellfish in Sarasota Bay generally do not appear to be grossly polluted, recommendations for bacterial (fecal organisms only) and toxic compound control and reduction were based on reducing non-point source (NPS) loadings of particulates. Specific watersheds (Hudson Bayou and Phillippi Creek) could obviously benefit from these techniques more than others. An evaluation of the airborne loads of metals and PAH in relation to surface runoff would indicate whether conventional non-point source controls (retention, detention, other surface water management strategies) would achieve significant reductions. Continued restrictions on dredging practices and solids control during these activities would protect shellfish from intermittent exposures to older contaminated sediments. Improved application practices of pesticides could reduce the amounts of recent material reaching the estuary.

Development of biologically based sediment criteria would afford the best protection to the bivalved species, but species-specific thresholds must be developed. These thresholds must extend beyond conventional acute and chronic toxicity assessments, and help to define the ecological impacts of these toxic compounds. The criteria might be applied bay-wide or may be restricted to areas designated for shellfish harvesting, recruitment areas, or seed beds. Incidentally, human consumers might also receive additional protection if sediment concentrations and shellfish tissue concentrations are monitored and controlled.

As vibrios are apparently endemic to the estuarine environment, controlling human exposure to these pathogens will continue to focus on education of at-risk individuals, primarily those with blood, liver, or immunological disorders. Existing Sea Grant informational pamphlets are useful. Approaches may be considered to area physicians and/or health specialists. Information pamphlets could be incorporated into the existing recreational fishing license or boat registration programs. The comparatively low levels of vibrios found reduces the priority of this effort somewhat.

More extreme measures could include the development of a recreational shellfishing licensing program for distribution of information and generation of revenue, information made available at public access points, and restricting the harvest of *Mercenaria* during warm months when *Vibrio* counts are expected to be high. The first of these measures is certain to be unpopular and does not seem justified in view of the low *Vibrio* counts observed. An ecological aspect of vibriosis which deserves attention is the etiology of vibriosis on juvenile shellfish. Infestations can rapidly devastate an aquaculture facility and could play a role in limiting stocks.

While harvest pressure for human consumption appears low within the study area, any enhancement in this resource may generate additional interest and pressure. Currently, harvest pressure in approved areas does not reduce the population below that in other areas of the Bay, or prevent (through the removal of reproductive adults) the occurrence of smaller individuals. (If recruitment is higher in this region from environmental factors, this generalization may not hold for other regions of the Bay if they are reclassified in the future.)

Some recreational harvesting in unapproved areas, for bait or consumption, was observed during the surveys. An examination of densities of clams as a function of public access points, however, demonstrated no consistent pattern which would indicate that populations are reduced as a function of harvesting by shore based shellfishermen. Those areas with no clams reported appeared instead to reflect regional environmental conditions, and there is no obvious justification for reducing access to protect populations.

Overall, there is a lack of information on population dynamics, including recruitment, predation pressures, and harvesting pressure, which should be quantified to manage the resource and protect from overharvest. Recruitment rates are reported to be highly erratic and may be a function of environmental variables (of either the water column or the sediments/substrate) coupled with physiological requirements. Currents also play an undoubted role in larval distribution. The degree of predation and harvest pressure which the various ages of a stable population can support is difficult to assess, but of interest in managing this resource.

Activities related to the oyster resource would be to update the spatial mapping. Much of the information included in the Sarasota County Habitat Trend Analysis (Mangrove Systems, 1988) on oyster reefs appears outdated, and the Manatee County portion of the study area is unmapped.

Any NPS controls implemented for particulate and toxics removal would also act to improve the detention of stormwaters and increase the dry season base flow. The restoration of altered flows would be very beneficial to oyster populations in the southern portion of the study area. During historical times, freshwater flows to the Bay were in general less variable, as larger wetland and pervious areas provided for runoff attenuation and the controlled delivery of higher base flows to the estuary. Increasing impervious areas have increased the speed with which runoff occurs and freshwater pulses occur on a short term basis. As a result, there is less water to provide for dry season or base flows and a smaller salinity gradient is maintained between storm events.

The Phillippi Creek area was apparently impassable due to oyster bars prior to the construction of the Intercoastal Waterway. Opening this channel has most likely decreased flushing times, increased salinities within the Bay, and permitted the increased invasion of oyster predators such as *Melongena*. Removal of existing bars, even if senescent, should be discouraged from the standpoint of preventing further flow or flushing alterations. In addition, reef removal would reduce the available preferred substrate for oyster spat settlement. Additional support for flow restoration could be found from a determination of the paleoenvironment in the study area by the use of morphological characteristics of current and indian midden oyster shell. Although more technically complex, creation of off-channel oyster bars which could divert freshwater flows into areas less well flushed might also serve to increase the duration and extent of low salinity habitat.

If NPS controls improve, with a potential expansion of the approved shellfish harvesting area, a formal health risk assessment and recreational effort assessment will become more pertinent. In addition, a wet season tissue sampling would become essential to quantify what could be worst case tissue contaminants. The suite of analytical compounds could be further expanded to include selected PCB isomers, since some of these highly toxic compounds were observed in sediment samples.

Resource enhancements at this time can include both seeding of clams and clutch placement for oyster spat to increase the populations, but these activities should be coupled with small scale investigation to determine optimum locations, timing, or rates of success. These enhancements will be difficult to evaluate economically, and, due to limited approved waters and limited oyster habitat, they will not likely result in any direct increase in recreation potential. For oysters in particular, harvestable individuals would likely remain low unless 1) salinity regimes were radically restored, 2) subtidal growth habits were encouraged, 3) non-point source loadings were reduced, 4) regions near tributaries reclassified for harvest, 5) sufficient monitoring was supported to guarantee sanitary quality.

There are, however, valid ecological inducements for these enhancements. As filter feeders, both clams and oysters have the theoretical potential to improve the water clarity of Sarasota Bay, particularly if water clarity impairments are linked to chlorophyll or phytoplankton levels. The size preferences of shellfish should be compared to dominant phytoplankton species in the region for predicting improvements. Other benefits of enhancing shellfish populations would include increased biomass and productivity of the estuary, and the support of other species which prey on larval bivalves. Expanding oyster reefs could also provide additional habitat complexity particularly suited to invertebrate fauna and juvenile fish, increased shoreline stability, and reduced sediment resuspension through wave damping.

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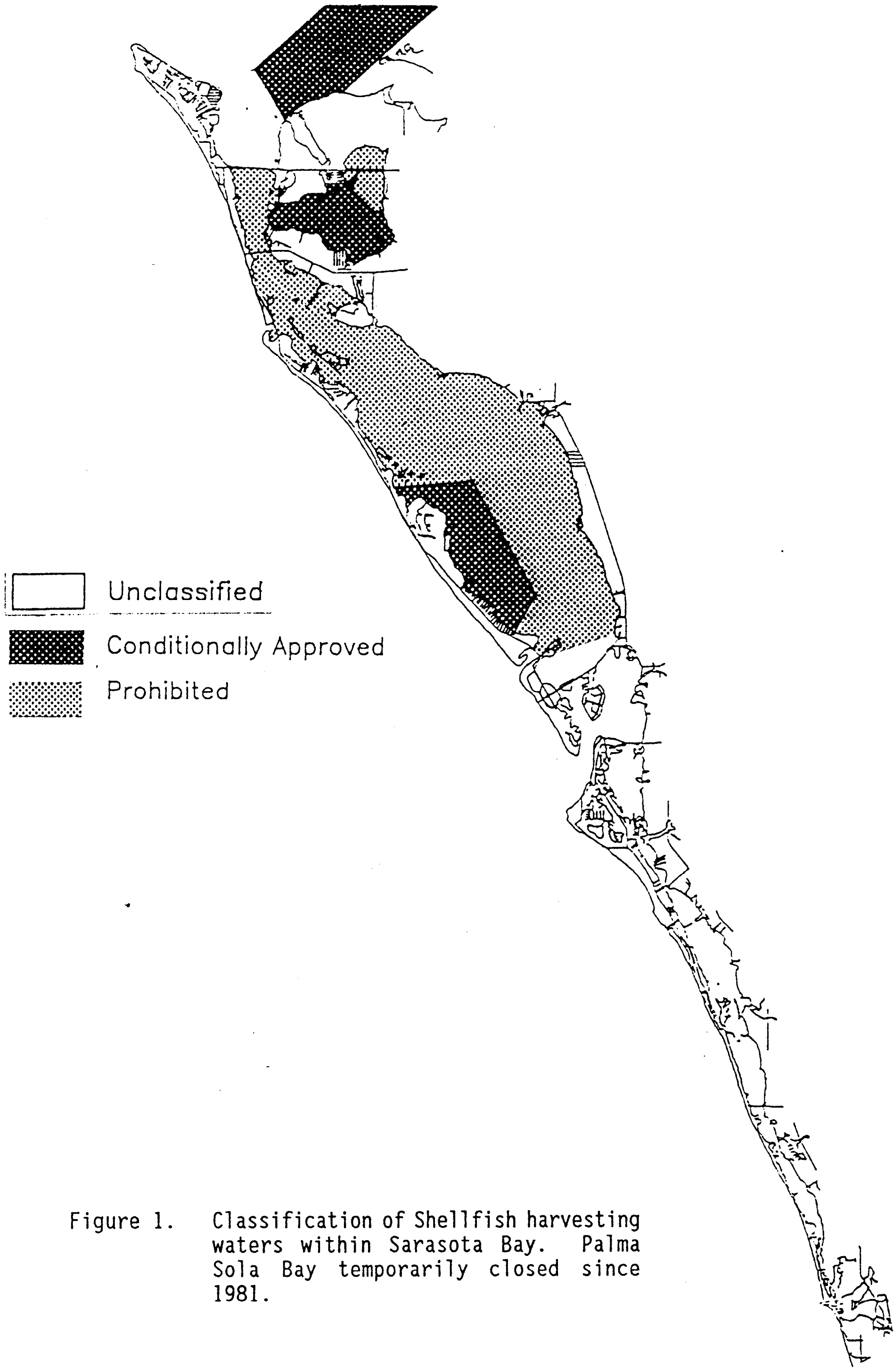


Figure 1. Classification of Shellfish harvesting waters within Sarasota Bay. Palma Sola Bay temporarily closed since 1981.

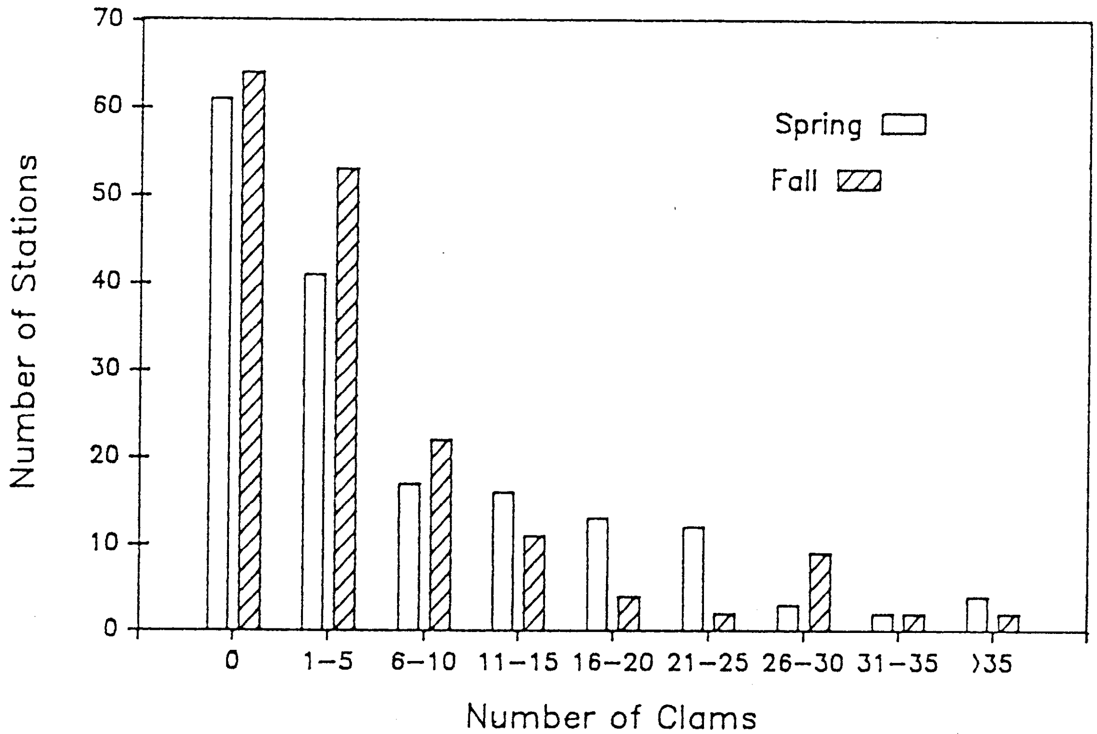


Figure 2. Results of clam population survey, abundance, during the spring (dry) and fall (wet) seasons.

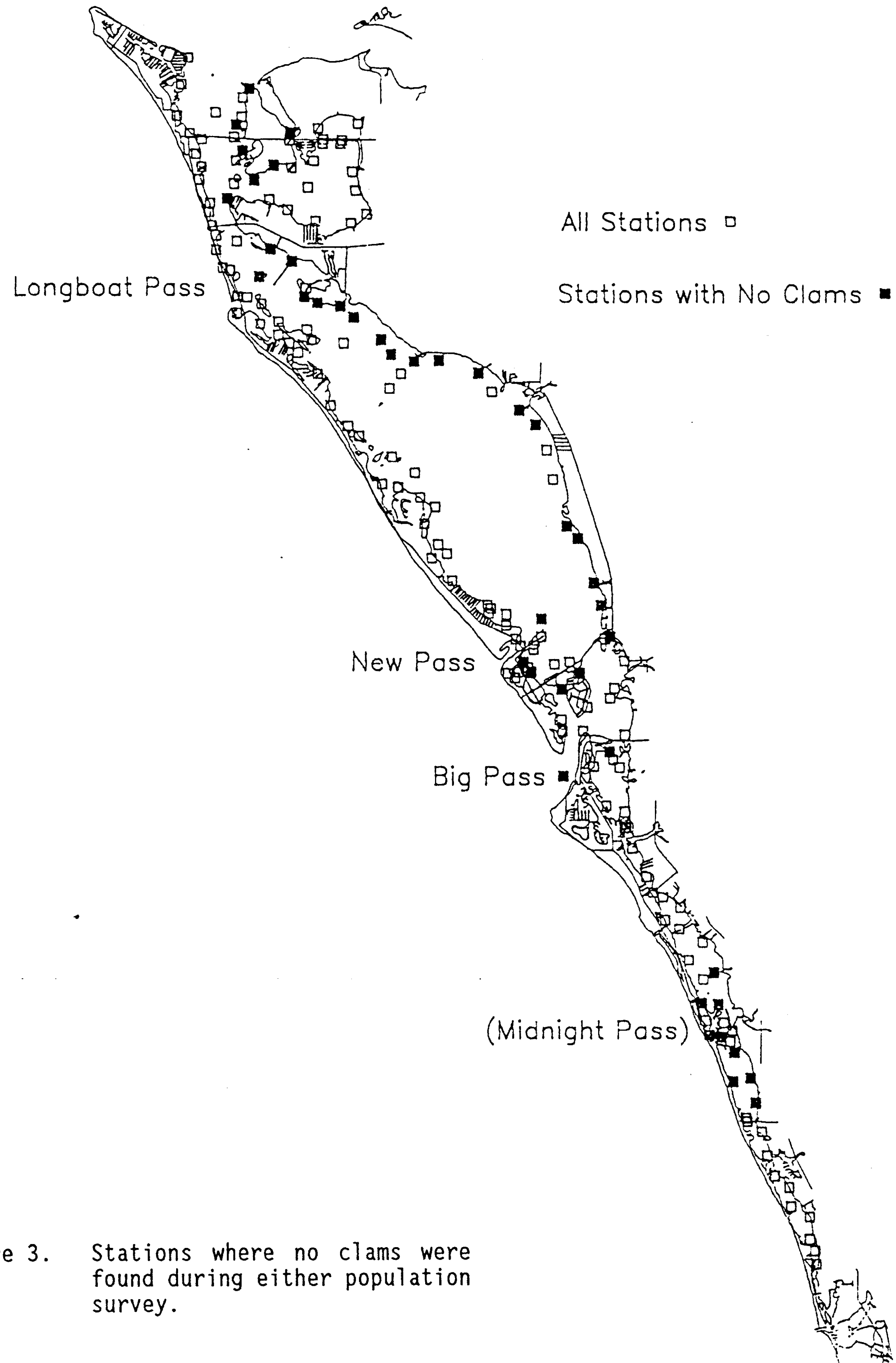


Figure 3. Stations where no clams were found during either population survey.

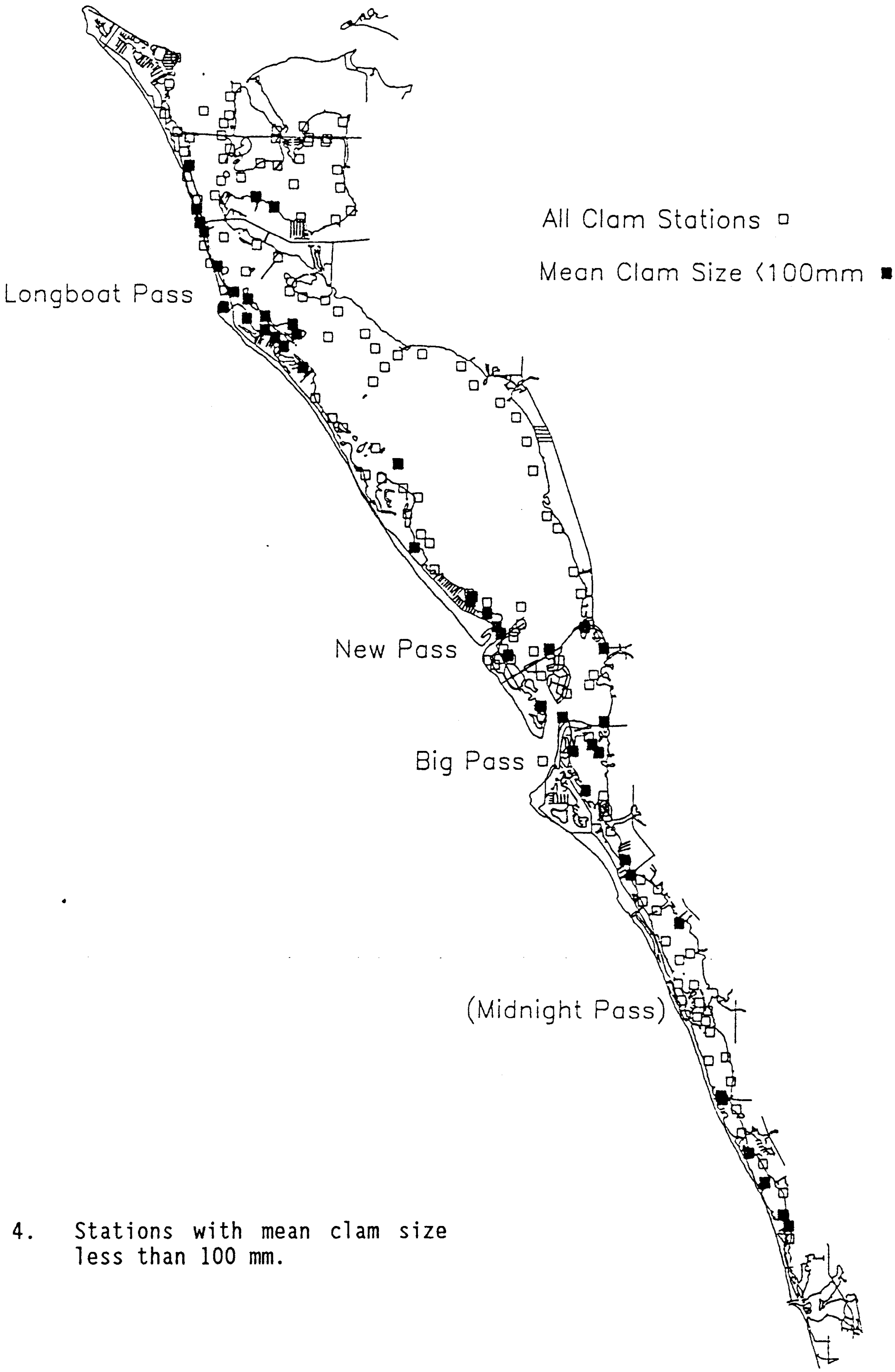
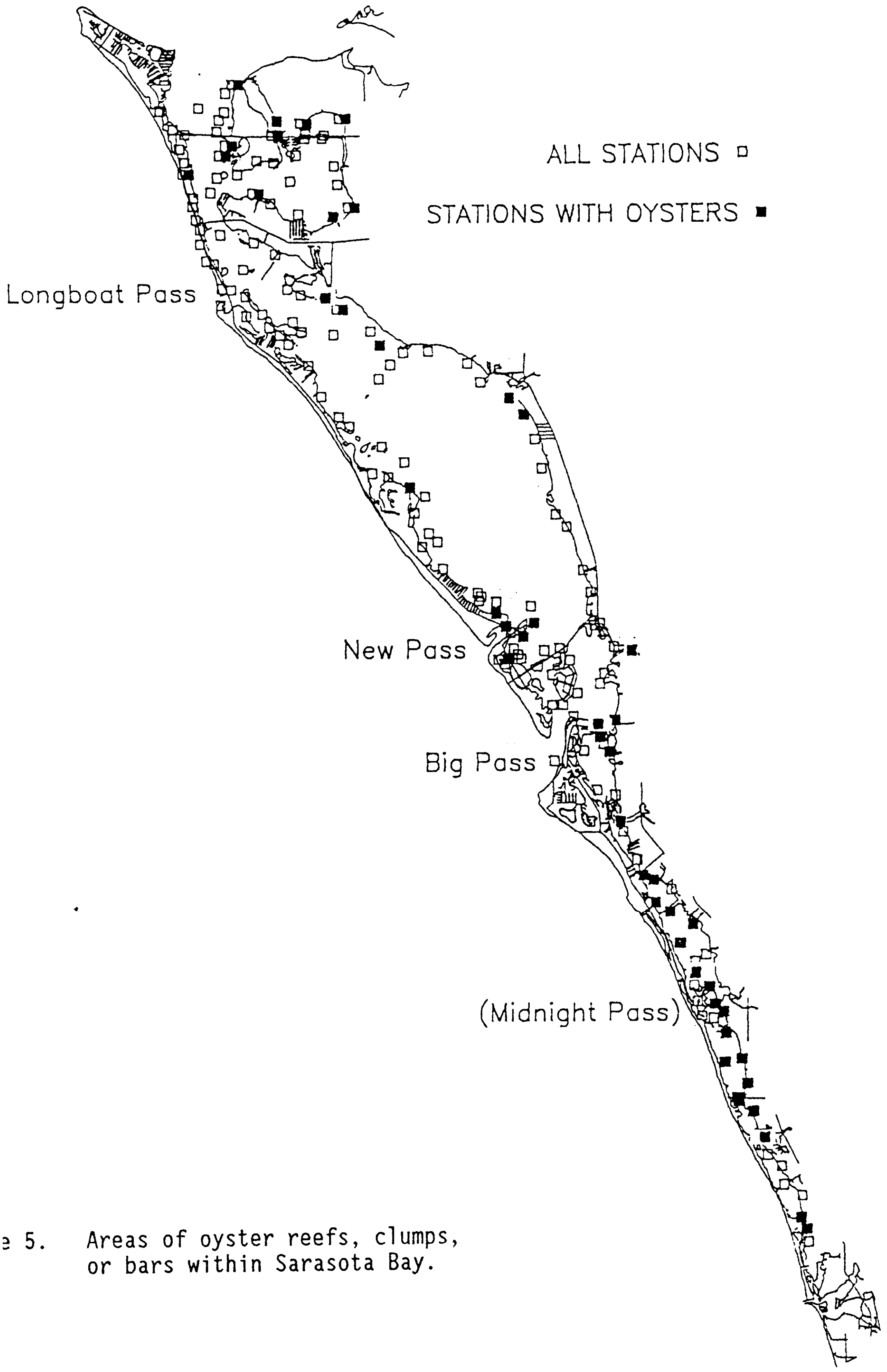


Figure 4. Stations with mean clam size less than 100 mm.



e 5. Areas of oyster reefs, clumps, or bars within Sarasota Bay.

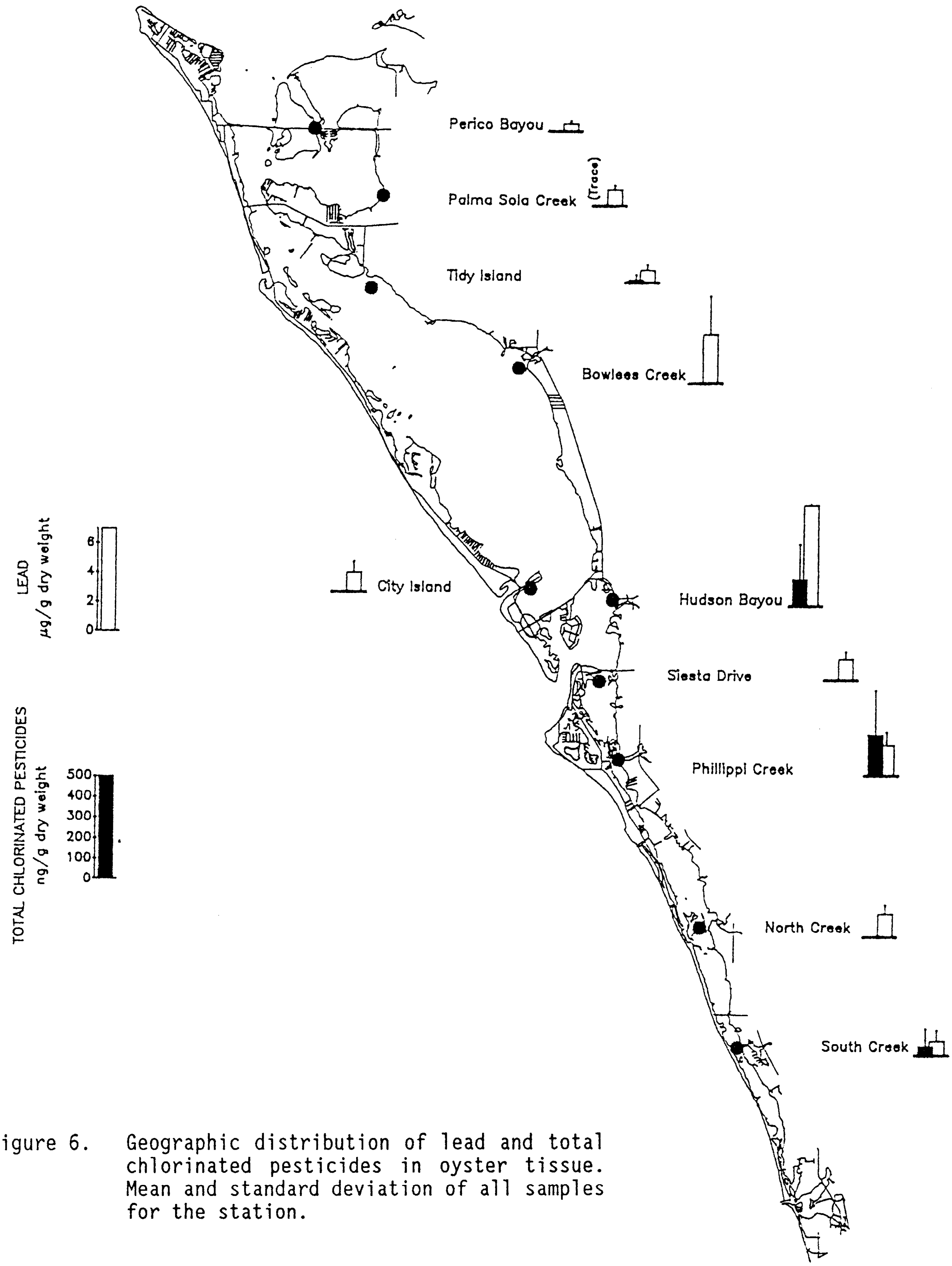


Figure 6. Geographic distribution of lead and total chlorinated pesticides in oyster tissue. Mean and standard deviation of all samples for the station.