**Levels of PCBs and Heavy Metals in Biota Found on ex-Military Ships Used as Artificial Reefs**

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## ABSTRACT

Resident fish and invertebrates were collected from several ex-military ships which had been sunk as artificial reefs and from naturally occurring "hard bottom" reef sites in order to determine the levels of PCBs and heavy metals present and to assess whether or not any environmental or human health concerns existed as a result. Tissues were analyzed for PCBs, chromium, cadmium, lead, copper, nickel, and manganese. Although PCBs were found in many samples, levels were not elevated at artificial reef sites and all values detected were well below the FDA action level of 2.0ppm. Similar concentrations of certain heavy metals were also detected, again with no apparent trends among sites. There do not appear to be increased levels of PCBs or heavy metals in biota on or around military ships sunk as artificial reefs and the risk to human health appears no greater than that posed in any naturally occurring hard bottom area.

# INTRODUCTION

Marine artificial reefs play an important role in most Atlantic and Gulf coast states by significantly enhancing recreational fishing and sport diving opportunities in coastal and offshore waters. From the earliest days of artificial reef development, many states have relied upon the use of surplus vessels (ships, boats, barges, etc.) to provide suitable, stable and affordable materials from which to construct these reefs. As of 1994, over 650 vessels had been reported sunk on permitted reef sites by Atlantic and Gulf coast marine artificial reef programs, with many of the ships and smaller craft having been former U.S. military property (GREGG and MURPHEY, 1994).

In recent years, concerns have been raised by the U.S. Environmental Protection Agency (EPA) regarding the possibility of the introduction of polychlorinated-biphenyls (PCBs) into the marine environment through the sinking of former military ships as U.S. Navy exercise targets and as marine artificial reefs. MEARNS, et al (1988) provides a thorough review of PCB contamination concerns and findings from an historical basis.

The PCBs of concern to the EPA are now known to exist in many different components on ex-U.S. Navy vessels. Formerly approved methods and levels of cleaning ex-Navy vessels for sinking as exercise targets or marine artificial reefs are no longer acceptable to the EPA based on the determination in recent years that many materials onboard, such as water-tight gaskets, cable insulations, paints and other heat resistant components may contain some levels of PCBs. This has led to a restriction on the Navy's use of ships as exercise targets and halted the sinking of Navy ships as marine artificial reefs.

The South Carolina Department of Natural Resources (SCDNR) has been active in the development of marine artificial reefs along the South Carolina coast since 1972, with many artificial reefs constructed from surplus U.S. Navy, U.S. Army and civilian vessels. Based on the concerns raised by the EPA over sinking ex-Navy ships, the SCDNR wanted to assess whether or not past artificial reef construction activities have unknowingly resulted in the placement of PCBs into the marine environment through the introduction of PCB-containing components onboard ships and other vessels sunk as marine artificial reefs. Additionally, the SCDNR wished to learn if PCBs and/or certain heavy metals could be found in the tissues of marine organisms which were permanent or temporary residents of artificial reefs constructed from such vessels and, if so, the extent of environmental or human health concerns which existed as a result.

Although not a primary focus of this study, the question of the release of various trace or heavy metals by artificial reefs was also considered. Ship hulls were not viewed as potential sources of harmful metals since they were constructed of steel, however, the hull and interior paints of some vessels and certain installed ship components and equipment were possible sources.

## METHODS AND MATERIALS

During routine artificial reef monitoring activities, over 100 samples of reef materials, resident invertebrates and resident finfish were collected from several locations along the South Carolina coast, including permitted artificial reefs and naturally occurring "hard-bottom" reefs ranging in water depths of 80 to 110 feet (24 to 34 meters) (Figure 1). Artificial reef structures chosen for this study were primarily ex-military (U.S. Navy and U.S. Army) vessels having been submerged from 3 to 17 years at time of sampling. Corresrponding hard-bottom control sites were located approximately 3 to 5 miles from the artificial reef sites, close enough to be of similar depth and with similar fish communities.

All vessel component and invertebrate samples were collected by SCUBA divers, while finfish samples were taken by a combination of methods, including pole-spear, hook-and-line and fish traps. Finfish species known to be long-term residents of artificial reefs were targeted when available, as well as resident species which are commonly landed and consumed by recreational anglers. Recreational size limits were adhered to in order to approximate a typical angler's catch and to insure comparisons of similar size and age. Any available shellfish and crustaceans were targeted when available. Samples were sealed in plastic bags and frozen immediately for transport to the laboratory for preparation and analysis.

Only muscle tissue from finfish was used, while the soft parts of crustaceans and shellfish were prepared. Small sections of several sponges and one echinoderm were processed in their entirety. Where possible, samples were analyzed for PCBs and metals, however, some shellfish samples were too small to be subdivided. The suite of PCBs run included the following aroclors: 1221, 1248, 1254, and 1268. The basic PCB methods used were reported in MATHEWS (1994) and were a refinement of techniques used in MARCUS and MATHEWS (1987) with some variations.

The PCB extractions were performed as for pesticides with methanol, isopropanol, and acetone (2:1:1 v:v), but the extract plus water used for the final concentration was adjusted to a pH of 2 with HCl. The limit of quantitation (LOQ) was 100ppb for the PCBs, although they were detected at much lower concentrations. Non-detection values (ND) were 10ppb.

The only change in the metals analyses from methods used and reported in MATHEWS (1994) was in the use of an inductively-coupled plasma (ICP) instrument as opposed to an atomic absorption (AA) spectrophotometer. Chromium, cadmium, lead, copper, nickel, and manganese were run. Metal LOQs were 100ppb for all metals except cadmium, which was 50ppb. Non-detection values (ND) were one-tenth of LOQ. At least one sample was split and analyzed both spiked and unspiked with each batch of ten samples for quality control purposes in addition to reagent blanks for PCBs and metals. All PCB and metal concentrations were calculated as wet weight (ww).

## RESULTS AND DISCUSSION

### PCBs

Three of the seven vessels from which biological samples were collected were found to have materials onboard which contained PCBs (Table 1). Thorough stripping of all seven of these vessels during pre-sinking cleaning resulted in a scarcity of accessible materials potentially containing PCBs, making it impractical or unsafe to attempt to locate additional suspect materials in internal spaces on several of the vessels. While the cables and gaskets retrieved from three vessels clearly had PCBs remaining in them, ranging in concentrations of 1.3ppm to 24.5ppm, the original concentrations of PCBs in these materials at their time of submergence is unknown. It should be noted that higher concentrations of PCBs could possibly be obtained from these materials through the use of more vigorous extraction methods.

From the wide variety of resident reef organisms collected, 80 tissue samples were analyzed for PCBs (Tables 2 through 5) yielding PCB concentrations ranging from 0 to 0.337ppm in finfish and 0 to 0.235ppm in mollusks. Only 19 of the organisms sampled (4 finfish, 14 mollusks and 1 echinoderm) were found to contain PCBs in concentrations above the 100ppb ww LOQ, with all being well below the USFDA alert action level of 2.0ppm ww.

While it is apparent that PCBs exist in the tissues of some organisms collected from sunken vessels, no significant differences in PCB concentrations were detected (Kruskal-Wallis one-way ANOVA, $p=0.268$) between biological samples taken from vessels found to contain PCB-laden materials and those taken from natural "hard-bottom" control sites or target vessels where the presence of PCBs in onboard components was possible but not confirmed. Levels of PCBs encountered in organisms from both target vessels and control sites fall within ranges of PCBs encountered in finfish and mollusks in other studies along the Atlantic Coast and elsewhere (MEARNS et al., 1988), and do not indicate that the artificial reef structures examined represent potential "hot spots" where PCBs are being bioaccumulated.

Although not strictly comparable due to species differences, the mean value of 0.098ppm ww (based on all values above and below the LOQ) for PCBs encountered in bivalves from target vessels is somewhat higher than the grand national median of PCBs in the 1986 NOAA Mussel Watch Survey of 0.015ppm ww (NOAA, 1987). The mean and range of PCB values for bivalves taken on artificial reefs, however, are still well below the 2.0ppm FDA action level and, it should be noted, the bivalve species found on the artificial reefs are not targeted for human consumption. Adequate bivalve samples were not located on control sites for comparative purposes.

The mean PCB concentration obtained from finfish sampled on target vessels was 0.050ppm. This value is half that of the nationwide average of approximately 0.10ppm detected in estuarine fish between 1972 and 1979 (BUTLER and SCHUTZMANN, 1978), and also less than a 1976-77 survey mean (0.88ppm) of fish encountered in U.S. inland waters (SCHMITT et al., 1985). While it could be argued that many of the finfish sampled were not permanent residents of any site from which they were collected, it is felt that at least the toadfish (*Opsanus pardus* and *O. tau*) were a reasonable representative of a finfish species with a broad-ranging diet that tended to remain closely associated for life with artificial or natural reef structure. Of the 14 toadfish sampled only one had a PCB concentration above the 100ppb LOQ. No fish sampled at any site approached the FDA 2.0ppm action level.

These findings suggest that even with PCBs remaining in some materials onboard vessels years after sinking, these compounds are not being bioaccumulated in artificial reef organisms to a greater degree than they are among organisms found on non-artificial reef sites. The presence of PCBs in bivalves collected on target reef vessels appears to represent no direct health risk to artificial reef users due to their low values and, more importantly, because none of these species is typically consumed by humans. Of the 23 finfish sampled which are commonly consumed by fishermen, two of the three samples in which PCBs above the 100ppb LOQ were detected came from natural "hard-bottom" control sites and all quantities detected were relatively low. Thus, from the samples taken in this study, fish caught on sites other than artificial reefs represented the greatest degree of PCB exposure through direct human consumption.

## Heavy Metals

Results of the metals analyses from the same tissue samples taken for the PCB work are found in Tables 6 through 9. No samples of man-made materials on the vessels were run as for PCBs. Although individual tissue samples may be moderately high in a particular metal, no clear correlation of high metal levels and a particular type of sample site (control versus ship reef) exists. Table 10 summarizes mean concentrations of metals encountered in the samples and compares them to international action limits established for chromium, cadmium, lead and copper (NAUEN, 1983). No similar limits were found for nickel and manganese.

While the mean cadmium concentration in bivalve samples taken from ship reef sites (1.547ppm) is about three times the international action limit (0.500ppm), the mean level for cadmium in control site bivalves (1.400ppm) was equally high. Previous work off South Carolina (MATHEWS and BELL, 1994) also revealed no significantly higher levels of cadmium or lead in sessile invertebrate and fish tissues sampled on automobile tire reefs versus "hard-bottom" control sites.

Much higher levels of lead were found in some gastropods removed from artificial reefs when compared to low numbers for bivalves and fish off the same site. This is most likely attributable to these organisms grazing directly on the painted surfaces of the ships and ingesting minute quantities of lead-rich paint in the process. In examining other organisms, no indication of bioaccumulation of lead in higher trophic levels exists.

As in the case of PCBs, these results indicate that while high levels of certain metals may be encountered in some individual organisms from artificial reef ships, the same or closely-related organisms taken from natural hard-bottom areas are also likely to yield similar results. The data from this study suggest that artificial reefs constructed from ex-military and other ships offer no higher degree of environmental risk associated with the bioaccumulation of heavy metals than might be experienced on natural hard bottom reef locations. The degree of human health-related risk is also equally low.

## CONCLUSIONS

The presence of PCBs and heavy metals in organisms from natural and artificial reefs attests to the fact that these substances are present in marine waters. However, the relatively low values detected and the similarity in values between sites indicates more of a general background level rather than any particular area of increased contamination. The presence of these chemicals may, in fact, be universal. As stated by MEARNS et. al., (1988) in their historical assessment of PCB contamination ". . . they persist and are still found in terrestrial, aquatic, and marine plants and animals throughout the United States and the world." The levels detected in this study clearly do not indicate increased hazards around the military ships used as artificial reefs. The risk to human health appears no greater there than that posed in any naturally-occurring area.

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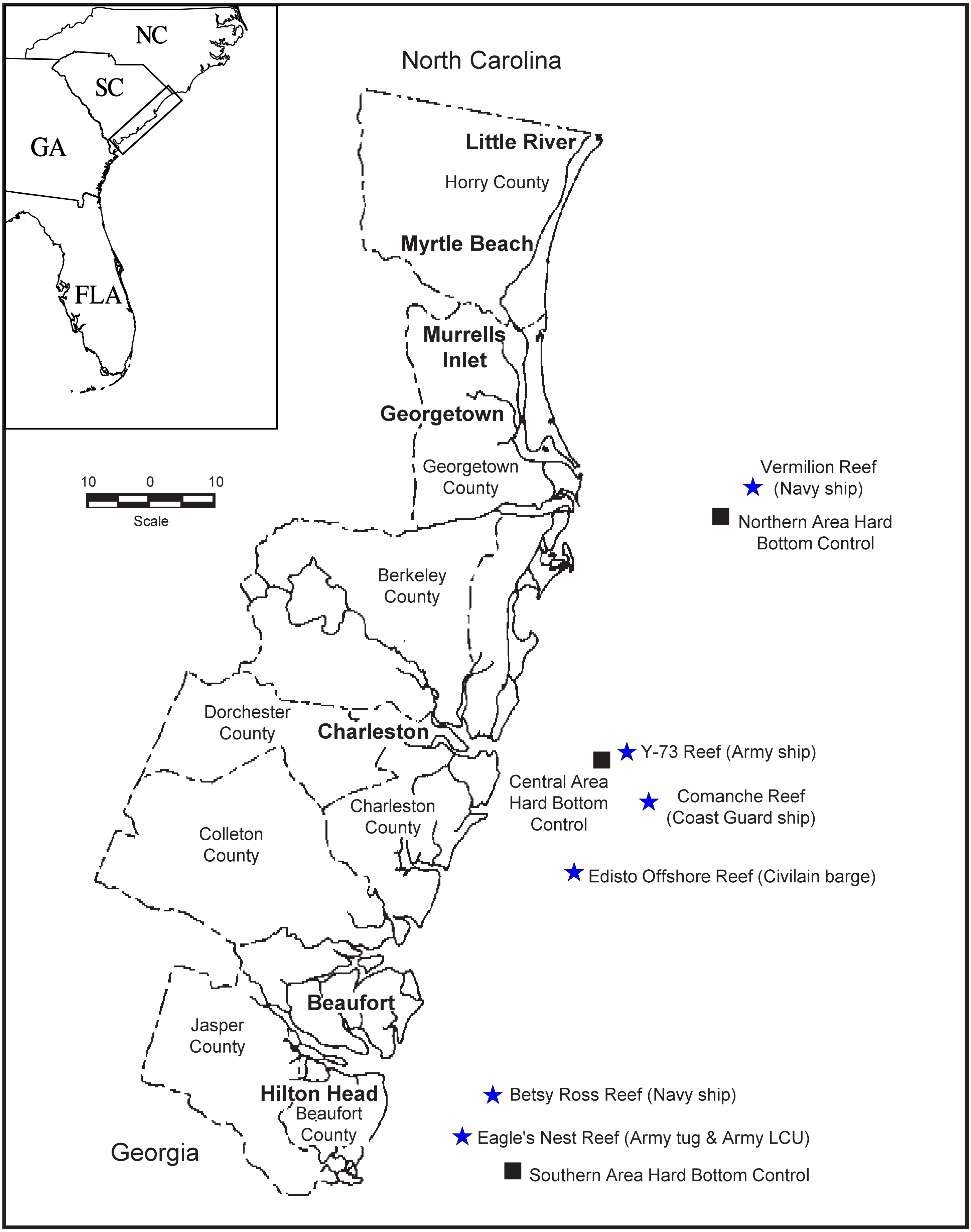
Figure 1.



NC
SC
GA
FLA
10 0 10
Scale
North Carolina
Little River
Horry County
Myrtle Beach
Murrells Inlet
Georgetown
Georgetown County
Berkeley County
Dorchester County
Charleston
Charleston County
Colleton County
Beaufort
Jasper County
Hilton Head
Beaufort County
Georgia
Vermilion Reef (Navy ship)
Northern Area Hard Bottom Control
Y-73 Reef (Army ship)
Central Area Hard Bottom Control
Comanche Reef (Coast Guard ship)
Edisto Offshore Reef (Civilain barge)
Betsy Ross Reef (Navy ship)
Eagle's Nest Reef (Army tug & Army LCU)
Southern Area Hard Bottom Control

**Table 1. Materials analyzed for PCBs**

| Reef | Material | Conc. (ppb) | Years submerged |
|---|---|---|---|
| ex-USS Vermillion | Cable Insulation | 7330 | 8 |
| Eagle's Nest ex-Army Tugboat | Cable Insulation | 24500 | 3 |
| | Rubber Gasket | 4450 | 3 |
| Eagle's Nest ex-Army LCU | Cable Insulation | 15500 | 3 |
| | Rubber Gasket | 4730 | 3 |
| | Rubber Gasket | 1330 | 3 |
| | Cloth Gasket | 5050 | 3 |

**Table 2. North area artificial reef samples analyzed for PCBs.**

| Vermillion Reef | Conc. (ppb) |
|---|---|
| Black Sea Bass<br>*Centropristis striata* | <LOQ |
| Gag Grouper<br>*Mycteroperca microlepis* | ND |
| Atlantic Winged Oyster<br>*Pteria colymbus* | 235 |
| Atlantic Winged Oyster<br>*Pteria colymbus* | ND |
| Turkey Wing<br>*Arca zebra* | 220 |
| Atlantic Hairy Triton<br>*Cymatium pileare* | <LOQ |
| Atlantic Hairy Triton<br>*Cymatium pileare* | <LOQ |
| Florida Horse Conch<br>*Pleuroploca gigantea* | 124 |
| Shovelnose Lobster<br>*Scyllarides nodifer* | ND |
| Sea Cucumber<br>Holothuroidea | 109 |

ND = None Detected

<LOQ = PCB detected but below limit of quantitation

**Table 3. Central area artificial reef samples analyzed for PCBs.**

| Y-73 Reef | Conc. (ppb) |
|---|---|
| Hake<br>*Urophycis sp.* | ND |
| Hake<br>*Urophycis sp.* | ND |
| Leopard Toadfish<br>*Opsanus pardus* | <LOQ |
| Leopard Toadfish<br>*Opsanus pardus* | <LOQ |
| Leopard Toadfish<br>*Opsanus pardus* | <LOQ |
| Leopard Toadfish<br>*Opsanus pardus* | <LOQ |
| Leopard Toadfish<br>*Opsanus pardus* | ND |
| Gray Triggerfish<br>*Balistes capriscus* | <LOQ |
| Atlantic Winged Oyster<br>*Pteria colymbus* | <LOQ |
| Atlantic Winged Oyster<br>*Pteria colymbus* | ND |
| Atlantic Winged Oyster<br>*Pteria colymbus* | ND |
| Turkey Wing - Engine room<br>*Arca zebra* | 158 |
| Turkey Wing - Hull<br>*Arca zebra* | ND |
| Lion's Paw Scallop<br>*Nodipecten nodosus* | <LOQ |
| Lion's Paw Scallop<br>*Nodipecten nodosus* | ND |

| Comanche Reef | Conc. (ppb) |
|---|---|
| Black Sea Bass<br>*Centropristis striata* | ND |
| Atlantic Winged Oyster<br>*Pteria colymbus* | ND |
| Atlantic Winged Oyster<br>*Pteria colymbus* | ND |
| Crested Oyster<br>*Ostreola equestris* | ND |
| Purse Shell<br>*Isognomon sp.* | ND |
| Common American Auger<br>*Terebra dislocata* | 176 |

| Edisto Offshore Reef | Conc. (ppb) |
|---|---|
| Leopard Toadfish<br>*Opsanus pardus* | 179 |
| Leopard Toadfish<br>*Opsanus pardus* | <LOQ |
| Atlantic Winged Oyster<br>*Pteria colymbus* | 211 |
| Atlantic Deer Cowrie<br>*Cypraea cervus* | 225 |
| Atlantic Deer Cowrie<br>*Cypraea cervus* | ND |

ND = None Detected

<LOQ = PCB detected but below limit of quantitation

**Table 4.  Southern area artificial reef samples analyzed for PCBs.**

| Eagle's Nest Tugboat | Conc. (ppb) |
|---|---|
| Black Sea Bass<br>*Centropristis striata* | 102 |
| Sheepshead<br>*Archosargus probatocephalus* | <LOQ |
| Gray Triggerfish<br>*Balistes capriscus* | <LOQ |
| Leopard Toadfish<br>*Opsanus pardus* | ND |
| Atlantic Winged Oyster<br>*Pteria colymbus* | 108 |
| Atlantic Winged Oyster<br>*Pteria colymbus* | 168 |
| Atlantic Winged Oyster<br>*Pteria colymbus* | <LOQ |
| Arc Shell<br>*Anadara  sp.* | 173 |
| Common Slipper Shell<br>*Crepidula fornicata* | 185 |

| Eagle's Nest LCU | Conc. (ppb) |
|---|---|
| Atlantic Winged Oyster<br>*Pteria colymbus* | 190 |
| Crested Oyster<br>*Ostreola equestris* | ND |
| Common Slipper Shell<br>*Crepidula fornicata* | 232 |

| Betsy Ross Reef | Conc. (ppb) |
|---|---|
| Turkey Wing<br>*Arca zebra* | ND |
| Turkey Wing<br>*Arca zebra* | ND |
| Turkey Wing<br>*Arca zebra* | ND |
| Sponge<br>*Haliclona  sp.* | ND |
| Sponge<br>*Ircinia  sp.* | ND |

ND = None Detected

<LOQ = PCB detected but below limit of quantitation

**Table 5. Control samples analyzed for PCBs.**

| Northern Control Site | Conc. (ppb) |
|---|---|
| Black Sea Bass<br>*Centropristis striata* | <LOQ |
| Bank Sea Bass<br>*Centropristis ocyurus* | <LOQ |
| Leopard Toadfish<br>*Opsanus pardus* | <LOQ |
| Scorpionfish<br>Scorpaenidae | <LOQ |

| Central Control Site | Conc. (ppb) |
|---|---|
| Black Sea Bass<br>*Centropristis striata* | ND |
| Black Sea Bass<br>*Centropristis striata* | ND |
| Black Sea Bass<br>*Centropristis striata* | ND |
| Black Sea Bass<br>*Centropristis striata* | ND |
| Black Sea Bass<br>*Centropristis striata* | ND |
| Black Sea Bass<br>*Centropristis striata* | ND |
| Black Sea Bass<br>*Centropristis striata* | <LOQ |
| Black Sea Bass<br>*Centropristis striata* | <LOQ |
| Black Sea Bass<br>*Centropristis striata* | 337 |
| Gag Grouper<br>*Mycteroperca microlepis* | ND |

| Central Control Cont. | Conc. (ppb) |
|---|---|
| Scamp<br>*Mycteroperca phenax* | ND |
| Scamp<br>*Mycteroperca phenax* | 116 |
| Red Grouper<br>*Epinephelus morio* | <LOQ |
| Leopard Toadfish<br>*Opsanus pardus* | <LOQ |
| Leopard Toadfish<br>*Opsanus pardus* | <LOQ |
| Leopard Toadfish<br>*Opsanus pardus* | <LOQ |
| Leopard Toadfish<br>*Opsanus pardus* | ND |
| Gray Triggerfish<br>*Balistes capriscus* | ND |
| Queen Angelfish<br>*Holacanthus ciliaris* | ND |
| Shovelnose Lobster<br>*Scyllarides nodifer* | ND |
| Florida Horse Conch<br>*Pleuroploca gigantea* | 100 |
| Crested Oyster<br>*Ostreola equestris* | ND |

| Southern Control Site | Conc. (ppb) |
|---|---|
| Oyster Toadfish<br>*Opsanus tau* | ND |
| Oyster Toadfish<br>*Opsanus tau* | ND |

ND = None Detected

<LOQ = PCB detected but below limit of quantitation

**Table 6.** **North area artificial reef samples analyzed for metals. Concentrations are in ppm.**

| Vermillion Reef | Chromium | Cadmium | Lead | Copper | Nickel | Manganese |
|---|---|---|---|---|---|---|
| Black Sea Bass *Centropristis striata* | ND | ND | 0.903 | 0.211 | ND | ND |
| Gag Grouper *Mycteroperca microlepis* | 0.797 | 0.389 | 1.160 | 0.286 | * | * |
| Atlantic Winged Oyster *Pteria colymbus* | ND | 0.698 | ND | 0.313 | ND | 1.910 |
| Turkey Wing *Arca zebra* | ND | 0.759 | 0.221 | 0.605 | ND | 1.340 |
| Atlantic Hairy Triton *Cymatium pileare* | 0.115 | ND | 0.149 | 4.380 | ND | 0.962 |
| Atlantic Hairy Triton *Cymatium pileare* | 0.109 | ND | ND | 6.150 | ND | 1.070 |
| Florida Horse Conch *Pleuroploca gigantea* | ND | 0.128 | ND | 5.830 | ND | 2.670 |
| Shovelnose Lobster *Scyllarides nodifer* | ND | 1.060 | ND | 4.420 | ND | 0.294 |
| Sea Cucumber Holothuroidea | 0.120 | ND | 0.167 | 0.147 | ND | 0.538 |

ND = None Detected

* Not Analyzed

**Table 7. Central area artificial reef samples analyzed for metals. Concentrations are in ppm.**

| Y-73 Reef | Chromium | Cadmium | Lead | Copper | Nickel | Manganese |
|---|---|---|---|---|---|---|
| Hake<br>*Urophycis sp.* | ND | ND | ND | ND | ND | 0.125 |
| Leopard Toadfish<br>*Opsanus pardus* | ND | ND | ND | ND | ND | ND |
| Atlantic Winged Oyster<br>*Pteria colymbus* | ND | 3.680 | ND | 0.991 | ND | 3.280 |
| Turkey Wing<br>*Arca zebra* | 0.101 | 1.280 | ND | 0.750 | ND | 8.000 |
| Turkey Wing<br>*Arca zebra* | 0.121 | 3.640 | 0.321 | 1.770 | 0.100 | 2.700 |
| Lion's Paw Scallop<br>*Nodipecten nodosus* | ND | 2.690 | 0.195 | 0.156 | ND | 0.788 |
| **Comanche Reef** | **Chromium** | **Cadmium** | **Lead** | **Copper** | **Nickel** | **Manganese** |
| Black Sea Bass<br>*Centropristis striata* | ND | ND | ND | 0.090 | ND | ND |
| Atlantic Winged Oyster<br>*Pteria colymbus* | ND | 0.551 | 0.305 | 0.580 | ND | 2.230 |
| Common American Auger<br>*Terebra dislocata* | ND | ND | 1.230 | 13.600 | ND | 1.360 |
| **Edisto Offshore Reef** | **Chromium** | **Cadmium** | **Lead** | **Copper** | **Nickel** | **Manganese** |
| Leopard Toadfish<br>*Opsanus pardus* | 0.937 | ND | 0.644 | 0.473 | 1.850 | 29.200 |
| Leopard Toadfish<br>*Opsanus pardus* | 0.197 | ND | 0.744 | 0.340 | ND | 2.270 |
| Atlantic Winged Oyster<br>*Pteria colymbus* | ND | 0.275 | ND | 0.287 | ND | 0.966 |
| Atlantic Winged Oyster<br>*Pteria colymbus* | 1.620 | 1.980 | 1.800 | 2.030 | 1.530 | 2.800 |
| Florida Spiny Jewel Box<br>*Arcinella cornuta* | 0.101 | 0.970 | 0.222 | 0.953 | 0.408 | 0.546 |
| Atlantic Deer Cowrie<br>*Cypraea cervus* | 0.329 | 0.500 | 0.711 | 6.830 | ND | 2.670 |
| Atlantic Deer Cowrie<br>*Cypraea cervus* | 0.231 | 0.631 | 0.400 | 5.700 | ND | 2.030 |

ND = None Detected

**Table 8. Southern area artificial reef samples analyzed for metals. Concentrations are in ppm.**

| Eagle's Nest Tugboat | Chromium | Cadmium | Lead | Copper | Nickel | Manganese |
|---|---|---|---|---|---|---|
| Black Sea Bass *Centropristis striata* | 0.203 | ND | 0.137 | 0.126 | ND | 0.214 |
| Sheepshead *Archosargus probatocephalus* | 0.138 | ND | 0.204 | 0.204 | 0.286 | 0.516 |
| Gray Triggerfish *Balistes capriscus* | 0.133 | ND | 0.156 | 0.210 | 0.102 | 0.207 |
| Hake *Urophycis sp.* | 0.442 | 0.266 | ND | 0.889 | * | * |
| Leopard Toadfish *Opsanus pardus* | 0.995 | 0.279 | ND | 0.232 | * | * |
| Atlantic Winged Oyster *Pteria colymbus* | ND | 0.571 | 0.253 | 1.250 | ND | 2.750 |
| Atlantic Winged Oyster *Pteria colymbus* | 1.110 | 3.650 | 1.130 | 2.010 | 0.838 | 7.200 |
| Atlantic Winged Oyster *Pteria colymbus* | 0.260 | 1.080 | 0.942 | 1.110 | * | * |
| Ark Shell *Anadara sp.* | 0.242 | 2.940 | 0.181 | 0.246 | ND | 59.400 |
| Common Slipper Shell *Crepidula fornicata* | 3.770 | 0.212 | 54.500 | 12.400 | ND | 34.800 |
| Convex Slipper Shell *Crepidula convexa* | 0.710 | 0.218 | 11.900 | 9.180 | * | * |
| **Eagle's Nest LCU** | **Chromium** | **Cadmium** | **Lead** | **Copper** | **Nickel** | **Manganese** |
| Atlantic Winged Oyster *Pteria colymbus* | ND | ND | ND | 0.714 | ND | 1.250 |
| Atlantic Winged Oyster *Pteria colymbus* | 0.114 | 2.940 | 0.145 | 0.637 | ND | 2.280 |
| Crested Oyster *Ostreola equestris* | ND | ND | ND | 104.000 | ND | 2.530 |
| Common Slipper Shell *Crepidula fornicata* | 1.100 | 0.505 | 0.842 | 4.100 | ND | 12.100 |
| Common Slipper Shell *Crepidula fornicata* | ND | ND | 0.380 | 7.700 | ND | 24.600 |
| **Betsy Ross Reef** | **Chromium** | **Cadmium** | **Lead** | **Copper** | **Nickel** | **Manganese** |
| Turkey Wing *Arca zebra* | 0.894 | 0.982 | 0.798 | 1.150 | * | * |
| Turkey Wing *Arca zebra* | 0.497 | 0.709 | 0.818 | 1.550 | * | * |

ND = None Detected * Not Analyzed

**Table 9. Control samples analyzed for metals. Concentrations are in ppm.**

| Northern Control Site | Chromium | Cadmium | Lead | Copper | Nickel | Manganese |
|---|---|---|---|---|---|---|
| Black Sea Bass *Centropristis striata* | 0.125 | ND | 0.115 | 0.230 | ND | 0.336 |
| Bank Sea Bass *Centropristis ocyurus* | 0.144 | ND | 0.111 | 0.195 | 0.130 | 0.237 |
| Leopard Toadfish *Opsanus pardus* | ND | ND | 0.257 | 0.392 | ND | 0.749 |
| Scorpionfish Scorpaenidae | ND | ND | 0.144 | ND | 0.117 | ND |
| Florida Spiny Jewel Box *Arcinella cornuta* | 0.452 | 1.400 | 0.417 | 1.690 | 0.672 | 1.260 |
| Common American Auger *Terebra dislocata* | 0.539 | 1.630 | 0.508 | 11.400 | 4.500 | 238.000 |

| Central Control Site | Chromium | Cadmium | Lead | Copper | Nickel | Manganese |
|---|---|---|---|---|---|---|
| Black Sea Bass *Centropristis striata* | 0.137 | ND | 0.118 | 0.118 | ND | ND |
| Black Sea Bass *Centropristis striata* | ND | ND | ND | 0.144 | ND | 0.111 |
| Black Sea Bass *Centropristis striata* | 0.263 | ND | ND | 0.256 | 0.118 | 0.248 |
| Black Sea Bass *Centropristis striata* | 0.318 | ND | ND | 0.114 | 0.116 | ND |
| Gag Grouper *Mycteroperca microlepis* | 0.196 | ND | ND | 0.162 | ND | ND |
| Scamp *Mycteroperca phenax* | ND | ND | ND | 0.169 | ND | ND |
| Scamp *Mycteroperca phenax* | 0.149 | ND | ND | 0.172 | 0.141 | ND |
| Red Grouper *Epinephelus morio* | 0.097 | ND | ND | 0.247 | 0.100 | ND |
| Hake *Urophycis sp.* | 0.460 | 0.341 | ND | 0.050 | * | * |
| Leopard Toadfish *Opsanus pardus* | ND | ND | ND | 0.163 | ND | 0.109 |

**Table 9. Cont.**

| **Central Control Site** | **Chromium** | **Cadmium** | **Lead** | **Copper** | **Nickel** | **Manganese** |
|---|---|---|---|---|---|---|
| Leopard Toadfish *Opsanus pardus* | 0.090 | 0.115 | ND | 0.358 | 0.109 | 0.403 |
| Leopard Toadfish *Opsanus pardus* | 0.201 | ND | ND | 0.081 | ND | 0.131 |
| Gray Triggerfish *Balistes capriscus* | 1.400 | ND | ND | 0.124 | 0.136 | 0.215 |
| Queen Angelfish *Holacanthus ciliaris* | 0.552 | ND | ND | 0.143 | 0.298 | ND |
| Shovelnose Lobster *Scyllarides nodifer* | 0.109 | 1.670 | ND | 1.590 | ND | 0.594 |
| Florida Horse Conch *Pleuroploca gigantea* | 0.105 | ND | 0.091 | 45.300 | ND | 1.910 |

ND = None Detected

* Not Analyzed

**Table 10. Mean concentrations (ppm) of heavy metals found in samples.**

| | Chromium | Cadmium | Lead | Copper |
|---|---|---|---|---|
| **International action limit** | **1.000** | **0.500** | **0.500** | **15.000** |
| **Target Fish** | 0.320 | 0.078 | 0.329 | 0.255 |
| **Control Fish** | 0.229 | 0.025 | 0.041 | 0.173 |
| **Target Bivalves** | 0.266 | 1.547 | 0.386 | 6.374* |
| **Control Bivalves** | 0.452 | 1.400 | 0.417 | 1.690 |
| **Target Gastropods** | 0.636 | 0.219 | 7.011** | 7.587 |
| **Control Gastropods** | 0.322 | 0.815 | 0.300 | 28.35*** |

* Concentration values were not normally distributed. Eliminating the single outlying value (104) leaves a mean of 0.950 ppm.

** Two specimens were analyzed while attached to chips of lead hull paint. Eliminating these values leaves a mean of 0.464 ppm.

*** Mean consists of only two values (11.4 and 45.3 ppm).