

**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. MEARNNS, 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. Corresponding 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.

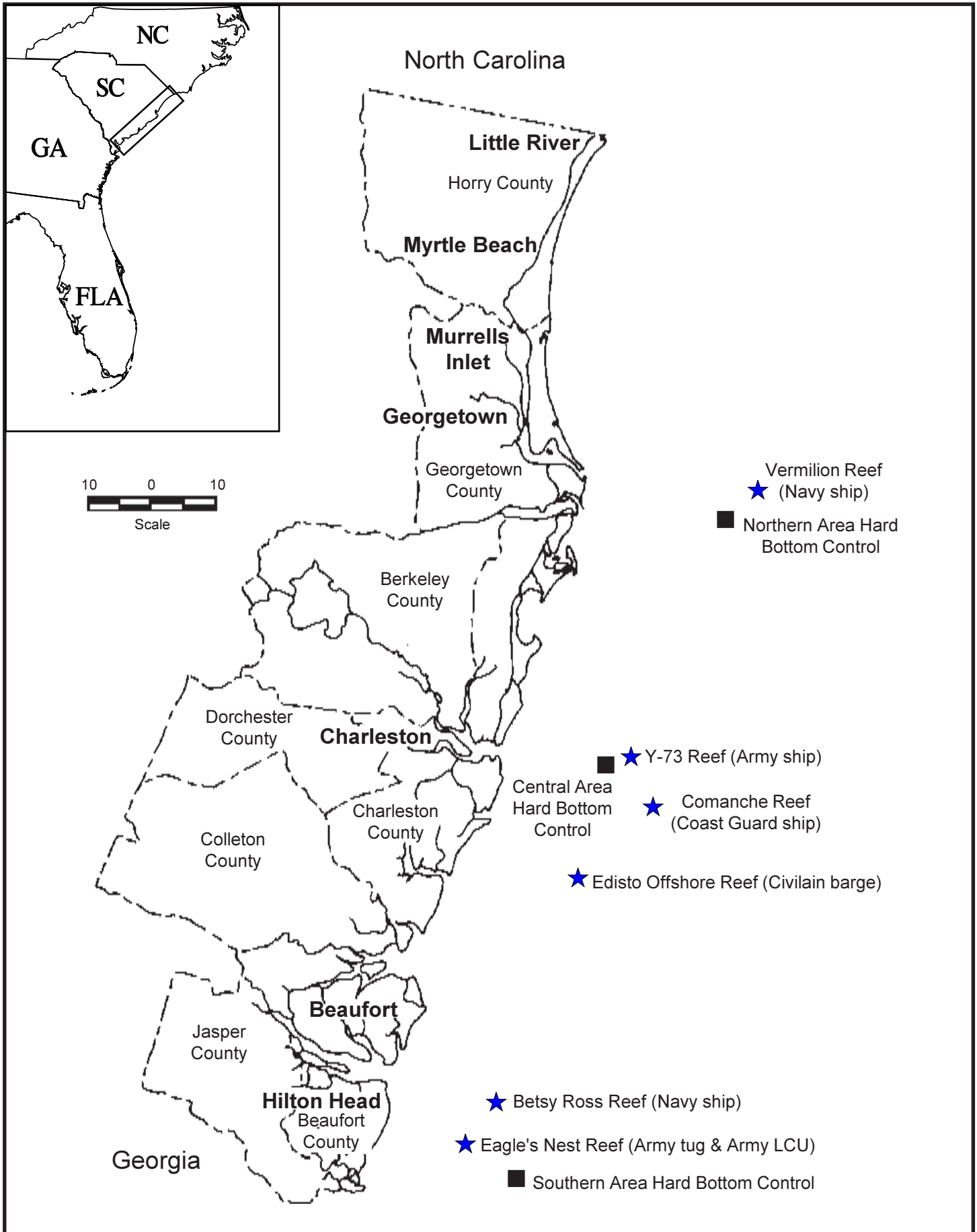


Table 1. Materials analyzed for PCBs

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 <i>Centropristis striata</i>	<LOQ
Gag Grouper <i>Mycteroperca microlepis</i>	ND
Atlantic Winged Oyster <i>Pteria colymbus</i>	235
Atlantic Winged Oyster <i>Pteria colymbus</i>	ND
Turkey Wing <i>Arca zebra</i>	220
Atlantic Hairy Triton <i>Cymatium pileare</i>	<LOQ
Atlantic Hairy Triton <i>Cymatium pileare</i>	<LOQ
Florida Horse Conch <i>Pleuroploca gigantea</i>	124
Shovelnose Lobster <i>Scyllarides nodifer</i>	ND
Sea Cucumber 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)	Comanche Reef	Conc. (ppb)
Hake <i>Urophycis sp.</i>	ND	Black Sea Bass <i>Centropristis striata</i>	ND
Hake <i>Urophycis sp.</i>	ND	Atlantic Winged Oyster <i>Pteria colymbus</i>	ND
Leopard Toadfish <i>Opsanus pardus</i>	<LOQ	Atlantic Winged Oyster <i>Pteria colymbus</i>	ND
Leopard Toadfish <i>Opsanus pardus</i>	<LOQ	Crested Oyster <i>Ostreola equestris</i>	ND
Leopard Toadfish <i>Opsanus pardus</i>	<LOQ	Purse Shell <i>Isognomon sp.</i>	ND
Leopard Toadfish <i>Opsanus pardus</i>	<LOQ	Common American Auger <i>Terebra dislocata</i>	176
Leopard Toadfish <i>Opsanus pardus</i>	ND		
		Edisto Offshore Reef	Conc. (ppb)
Gray Triggerfish <i>Balistes capriscus</i>	<LOQ	Leopard Toadfish <i>Opsanus pardus</i>	179
Atlantic Winged Oyster <i>Pteria colymbus</i>	<LOQ	Leopard Toadfish <i>Opsanus pardus</i>	<LOQ
Atlantic Winged Oyster <i>Pteria colymbus</i>	ND	Atlantic Winged Oyster <i>Pteria colymbus</i>	211
Atlantic Winged Oyster <i>Pteria colymbus</i>	ND	Atlantic Deer Cowrie <i>Cypraea cervus</i>	225
Turkey Wing - Engine room <i>Arca zebra</i>	158	Atlantic Deer Cowrie <i>Cypraea cervus</i>	ND
Turkey Wing - Hull <i>Arca zebra</i>	ND		
Lion's Paw Scallop <i>Nodipecten nodosus</i>	<LOQ		
Lion's Paw Scallop <i>Nodipecten nodosus</i>	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)	Eagle's Nest LCU	Conc. (ppb)
Black Sea Bass <i>Centropristis striata</i>	102	Atlantic Winged Oyster <i>Pteria colymbus</i>	190
Sheepshead <i>Archosargus probatocephalus</i>	<LOQ	Crested Oyster <i>Ostreola equestris</i>	ND
Gray Triggerfish <i>Balistes capriscus</i>	<LOQ	Common Slipper Shell <i>Crepidula fornicata</i>	232
Leopard Toadfish <i>Opsanus pardus</i>	ND		
		Betsy Ross Reef	Conc. (ppb)
Atlantic Winged Oyster <i>Pteria colymbus</i>	108	Turkey Wing <i>Arca zebra</i>	ND
Atlantic Winged Oyster <i>Pteria colymbus</i>	168	Turkey Wing <i>Arca zebra</i>	ND
Atlantic Winged Oyster <i>Pteria colymbus</i>	<LOQ	Turkey Wing <i>Arca zebra</i>	ND
Arc Shell <i>Anadara sp.</i>	173	Sponge <i>Haliclona sp.</i>	ND
Common Slipper Shell <i>Crepidula fornicata</i>	185	Sponge <i>Ircinia sp.</i>	ND

ND = None Detected

<LOQ = PCB detected but below limit of quantitation

Table 5. Control samples analyzed for PCBs.

Northern Control Site	Conc. (ppb)	Central Control Cont.	Conc. (ppb)
Black Sea Bass <i>Centropristis striata</i>	<LOQ	Scamp <i>Mycteroperca phenax</i>	ND
Bank Sea Bass <i>Centropristis ocyurus</i>	<LOQ	Scamp <i>Mycteroperca phenax</i>	116
Leopard Toadfish <i>Opsanus pardus</i>	<LOQ	Red Grouper <i>Epinephelus morio</i>	<LOQ
Scorpionfish Scorpaenidae	<LOQ	Leopard Toadfish <i>Opsanus pardus</i>	<LOQ
Central Control Site	Conc. (ppb)	Leopard Toadfish <i>Opsanus pardus</i>	<LOQ
Black Sea Bass <i>Centropristis striata</i>	ND	Leopard Toadfish <i>Opsanus pardus</i>	<LOQ
Black Sea Bass <i>Centropristis striata</i>	ND	Leopard Toadfish <i>Opsanus pardus</i>	ND
Black Sea Bass <i>Centropristis striata</i>	ND	Gray Triggerfish <i>Balistes capriscus</i>	ND
Black Sea Bass <i>Centropristis striata</i>	ND	Queen Angelfish <i>Holocanthus ciliaris</i>	ND
Black Sea Bass <i>Centropristis striata</i>	ND	Shovelnose Lobster <i>Scyllarides nodifer</i>	ND
Black Sea Bass <i>Centropristis striata</i>	ND	Florida Horse Conch <i>Pleuroploca gigantea</i>	100
Black Sea Bass <i>Centropristis striata</i>	<LOQ	Crested Oyster <i>Ostreola equestris</i>	ND
Black Sea Bass <i>Centropristis striata</i>	<LOQ	Southern Control Site	Conc. (ppb)
Black Sea Bass <i>Centropristis striata</i>	337	Oyster Toadfish <i>Opsanus tau</i>	ND
Gag Grouper <i>Mycteroperca microlepis</i>	ND	Oyster Toadfish <i>Opsanus tau</i>	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 <i>Centropristis striata</i>	ND	ND	0.903	0.211	ND	ND
Gag Grouper <i>Mycteroperca microlepis</i>	0.797	0.389	1.160	0.286	*	*
Atlantic Winged Oyster <i>Pteria colymbus</i>	ND	0.698	ND	0.313	ND	1.910
Turkey Wing <i>Arca zebra</i>	ND	0.759	0.221	0.605	ND	1.340
Atlantic Hairy Triton <i>Cymatium pileare</i>	0.115	ND	0.149	4.380	ND	0.962
Atlantic Hairy Triton <i>Cymatium pileare</i>	0.109	ND	ND	6.150	ND	1.070
Florida Horse Conch <i>Pleuroploca gigantea</i>	ND	0.128	ND	5.830	ND	2.670
Shovelnose Lobster <i>Scyllarides nodifer</i>	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 <i>Urophycis sp.</i>	ND	ND	ND	ND	ND	0.125
Leopard Toadfish <i>Opsanus pardus</i>	ND	ND	ND	ND	ND	ND
Atlantic Winged Oyster <i>Pteria colymbus</i>	ND	3.680	ND	0.991	ND	3.280
Turkey Wing <i>Arca zebra</i>	0.101	1.280	ND	0.750	ND	8.000
Turkey Wing <i>Arca zebra</i>	0.121	3.640	0.321	1.770	0.100	2.700
Lion's Paw Scallop <i>Nodipecten nodosus</i>	ND	2.690	0.195	0.156	ND	0.788
Comanche Reef	Chromium	Cadmium	Lead	Copper	Nickel	Manganese
Black Sea Bass <i>Centropristis striata</i>	ND	ND	ND	0.090	ND	ND
Atlantic Winged Oyster <i>Pteria colymbus</i>	ND	0.551	0.305	0.580	ND	2.230
Common American Auger <i>Terebra dislocata</i>	ND	ND	1.230	13.600	ND	1.360
Edisto Offshore Reef	Chromium	Cadmium	Lead	Copper	Nickel	Manganese
Leopard Toadfish <i>Opsanus pardus</i>	0.937	ND	0.644	0.473	1.850	29.200
Leopard Toadfish <i>Opsanus pardus</i>	0.197	ND	0.744	0.340	ND	2.270
Atlantic Winged Oyster <i>Pteria colymbus</i>	ND	0.275	ND	0.287	ND	0.966
Atlantic Winged Oyster <i>Pteria colymbus</i>	1.620	1.980	1.800	2.030	1.530	2.800
Florida Spiny Jewel Box <i>Arcinella cornuta</i>	0.101	0.970	0.222	0.953	0.408	0.546
Atlantic Deer Cowrie <i>Cypraea cervus</i>	0.329	0.500	0.711	6.830	ND	2.670
Atlantic Deer Cowrie <i>Cypraea cervus</i>	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 <i>Centropristis striata</i>	0.203	ND	0.137	0.126	ND	0.214
Sheepshead <i>Archosargus probatocephalus</i>	0.138	ND	0.204	0.204	0.286	0.516
Gray Triggerfish <i>Balistes capriscus</i>	0.133	ND	0.156	0.210	0.102	0.207
Hake <i>Urophycis sp.</i>	0.442	0.266	ND	0.889	*	*
Leopard Toadfish <i>Opsanus pardus</i>	0.995	0.279	ND	0.232	*	*
Atlantic Winged Oyster <i>Pteria colymbus</i>	ND	0.571	0.253	1.250	ND	2.750
Atlantic Winged Oyster <i>Pteria colymbus</i>	1.110	3.650	1.130	2.010	0.838	7.200
Atlantic Winged Oyster <i>Pteria colymbus</i>	0.260	1.080	0.942	1.110	*	*
Ark Shell <i>Anadara sp.</i>	0.242	2.940	0.181	0.246	ND	59.400
Common Slipper Shell <i>Crepidula fornicata</i>	3.770	0.212	54.500	12.400	ND	34.800
Convex Slipper Shell <i>Crepidula convexa</i>	0.710	0.218	11.900	9.180	*	*
Eagle's Nest LCU	Chromium	Cadmium	Lead	Copper	Nickel	Manganese
Atlantic Winged Oyster <i>Pteria colymbus</i>	ND	ND	ND	0.714	ND	1.250
Atlantic Winged Oyster <i>Pteria colymbus</i>	0.114	2.940	0.145	0.637	ND	2.280
Crested Oyster <i>Ostreola equestris</i>	ND	ND	ND	104.000	ND	2.530
Common Slipper Shell <i>Crepidula fornicata</i>	1.100	0.505	0.842	4.100	ND	12.100
Common Slipper Shell <i>Crepidula fornicata</i>	ND	ND	0.380	7.700	ND	24.600
Betsy Ross Reef	Chromium	Cadmium	Lead	Copper	Nickel	Manganese
Turkey Wing <i>Arca zebra</i>	0.894	0.982	0.798	1.150	*	*
Turkey Wing <i>Arca zebra</i>	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 <i>Centropristis striata</i>	0.125	ND	0.115	0.230	ND	0.336
Bank Sea Bass <i>Centropristis ocyurus</i>	0.144	ND	0.111	0.195	0.130	0.237
Leopard Toadfish <i>Opsanus pardus</i>	ND	ND	0.257	0.392	ND	0.749
Scorpionfish Scorpaenidae	ND	ND	0.144	ND	0.117	ND
Florida Spiny Jewel Box <i>Arcinella cornuta</i>	0.452	1.400	0.417	1.690	0.672	1.260
Common American Auger <i>Terebra dislocata</i>	0.539	1.630	0.508	11.400	4.500	238.000
Central Control Site	Chromium	Cadmium	Lead	Copper	Nickel	Manganese
Black Sea Bass <i>Centropristis striata</i>	0.137	ND	0.118	0.118	ND	ND
Black Sea Bass <i>Centropristis striata</i>	ND	ND	ND	0.144	ND	0.111
Black Sea Bass <i>Centropristis striata</i>	0.263	ND	ND	0.256	0.118	0.248
Black Sea Bass <i>Centropristis striata</i>	0.318	ND	ND	0.114	0.116	ND
Gag Grouper <i>Mycteroperca microlepis</i>	0.196	ND	ND	0.162	ND	ND
Scamp <i>Mycteroperca phenax</i>	ND	ND	ND	0.169	ND	ND
Scamp <i>Mycteroperca phenax</i>	0.149	ND	ND	0.172	0.141	ND
Red Grouper <i>Epinephelus morio</i>	0.097	ND	ND	0.247	0.100	ND
Hake <i>Urophycis sp.</i>	0.460	0.341	ND	0.050	*	*
Leopard Toadfish <i>Opsanus pardus</i>	ND	ND	ND	0.163	ND	0.109

Table 9. Cont.

Central Control Site	Chromium	Cadmium	Lead	Copper	Nickel	Manganese
Leopard Toadfish <i>Opsanus pardus</i>	0.090	0.115	ND	0.358	0.109	0.403
Leopard Toadfish <i>Opsanus pardus</i>	0.201	ND	ND	0.081	ND	0.131
Gray Triggerfish <i>Balistes caprisus</i>	1.400	ND	ND	0.124	0.136	0.215
Queen Angelfish <i>Holacanthus ciliaris</i>	0.552	ND	ND	0.143	0.298	ND
Shovelnose Lobster <i>Scyllarides nodifer</i>	0.109	1.670	ND	1.590	ND	0.594
Florida Horse Conch <i>Pleuroploca gigantea</i>	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).