FINAL REPORT:
Pre-Reefing Environmental Assessment for the *ex-ORISKANY*

Prepared by

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Executive Summary

The University of West Florida (UWF) conducted a study to examine the distribution and concentration of polychlorinated biphenyls (PCBs) in sediments and key biota on the offshore northern Gulf of Mexico (Gulf) continental shelf off Pensacola, Florida. The purpose of the study was to establish a baseline dataset for comparison of future samples collected from the *ex-Oriskany* aircraft carrier that was sunk as an artificial reef off Pensacola, Florida in May 2006. The sinking of the ex-Oriskany continued a trend in which the northern Gulf has been the most active region in the U.S. in terms of artificial reef creation. In general, goals of reef creation have been 1) enhancing production of reef-dependent invertebrate or fish species; 2) aggregating individuals to increase fishing efficiency; 3) providing divers with increased opportunity to view reef-associated organisms; and, 4) economical disposal of petroleum platforms and ships. In the northern Gulf, a significant percentage of recreational and commercial reef fish landings come from artificial reefs. Therefore, concerns exist about the potential risk that PCBs still onboard the ex-Oriskany will enter the marine foodweb and bioaccumulate in exploited fishes.

The focal point for this study was the *ex-Oriskany* reefing site in the southeast corner of the Escambia East Large Area Artificial Reef Site. Sediments, water column particulates, and biota were sampled in the vicinity of the reefing site and across the shelf. Sampling and analysis followed established standard procedures for each matrix.

Polychlorinated biphenyl content of offshore sediments and water column particulate material was consistently low and below detection limits for most congeners. Several samples of offshore fishes had elevated PCB concentrations. Two samples exceeded the total PCB screening value of 20 $\mu g\ kg^{-1}$ (US EPA, 2000), a king mackerel at 92.1 $\mu g\ kg^{-1}$ and a gag grouper at 22.6 $\mu g\ kg^{-1}$ (values were based on wet weight of skin off fillets). The TEQ screening value for Dioxin-like activity (0.26 ng kg^{-1}; US EPA, 2000) was exceeded by four samples, including the above two fish at 2.31 and 0.47 respectively, and an amberjack at 0.29, and a red grouper at 0.47. The extremely high levels measured in the king mackerel are a cause for concern, and may indicate transport of PCBs from inshore to offshore habitats

Analysis of reef fishes indicated fish length and mass were significantly correlated with PCB concentration. PCB concentration also was significantly but weakly correlated with $\delta^{15}N$, and $\delta^{13}C$. Analysis for all snapper species indicated a relatively strong correlation between trophic position (inferred from $\delta^{15}N$ value) and PCB concentration. Trophic position increased with size/age, which in turn was significantly correlated with PCB concentration, thus indicating bioaccumulation with age.

Overall, levels of PCBs in the biota of the shelf ecosystem were below thresholds of concern for toxicity. However, future comparison work on any effects of PCBs from the sinking of the *ex-Oriskany* should focus on those species that do not include the inshore estuarine habitats as part of their life cycle due to the potential for PCBs from Pensacola Bay to bioaccumulate in muscle tissue of estuarine-dependent reef fishes prior to recruitment to the offshore reefs.

Goal

The University of West Florida (UWF) conducted a study to establish a baseline database of polychlorinated biphenyl (PCB) distribution in sediments and key biota on the nearshore northern Gulf of Mexico continental shelf off Pensacola, Florida. Samples collected and analyzed in this work were obtained prior to the sinking of the *ex-Oriskany* as an artificial reef 25 miles south of Pensacola Bay pass, Florida on 17 May 2006 (Currents, 2006) so subsequent monitoring work may determine any impacts of PCBs potentially released from the reef.

Background

PCBs in the Gulf of Mexico

Studies on persistent inorganic and organic pollutants in the Gulf of Mexico have focused mainly on coastal systems (Kennicutt et al., 1988). Mercury is the only toxicant that has received attention in Florida marine fisheries from a public health perspective. Work has been conducted by EPA (EMAP) and NOAA (Wade et al., 1988) in Gulf estuaries, documenting widespread contamination by trace metals and persistent organics, including PCBs, associated with human activity. The National Oceanographic and Atmospheric Administration (NOAA) also recently tested some organisms in Mississippi Sound as a result of public concern for offshore pollutant transport from hurricane Katrina flooding, and generally found levels of contaminants to be below levels of concern (Krahn et al., 2005).

Despite the lack of attention paid to PCBs along the Gulf Coast, they are of particular concern because of their toxicological effects and their ability to accumulate in biota. Bioaccumulation is manifested as increased body burdens with age and trophic level. Recent work in San Francisco Bay has resulted in a fish consumption advisory for PCB body burdens in top level predatory fish, despite a comprehensive analysis of sediments indicating few areas for concern (http://www.epa.gov/region9/water/dioxin/sfbay.html). Data on Bottlenose dolphins (*Tursiops truncatus*) in the Gulf of Mexico also are instructive in this regard. Males accumulated high concentrations of PCBs in blubber with age (>100 ppm), while females showed much lower and relatively stable levels as a result of depuration by birth of offspring and lactation (<15 ppm; Wells et al., 2005).

Along the northern Gulf Coast, PCBs have been reported from loggerhead turtles (Alam and Bim., 2000), bottlenose dolphins (Johnson-Restrepo et al., 2005; Salata et al., 1995; Watanabe et al., 2000; Wells et al., 2005), and bony and cartilaginous fishes in coastal waters (Geleichter et al., 2005; Johnson-Restrepo et al., 2005; Karouna-Reiner et al., 2007a,b), thus indicating connectivity between estuarine and offshore food webs may serve as a conduit for translocating contaminants, including PCBs, offshore. Analysis of PCBs in other biota in northern Gulf of Mexico offshore environments has been limited and mostly dates to the 1970s. Taxa analyzed include benthic invertebrates (rock shrimp), net plankton (>200 μm), and relatively few fishes (Table 1). Analysis conducted on groupers showed elevated levels in Gulf waters (Figure 1; Giam et al., 1974) It should be noted that quantification of PCBs as Aroclors, as was done in these earlier studies, has been shown to underestimate total PCBs by as much as five fold (Connor et al., 2005).

Table 1. Biota PCB body burdens (µg kg^{-1}) reported from the northern Gulf of Mexico in previous studies.

Species	Location	Wet Mass	Lipid	Reference	Notes
Rock Shrimp	Off Pensacola (30 00.5'; 87 17.5')	6		Giam et al., 1972.	quantified as aroclor 1260
Net Plankton	Off Pensacola (30 00.5'; 87 17.5')	157		Giam et al., 1973	quantified as aroclor 1260
Net Plankton	Off Cape San Blas (29 19.5'; 83 28.0')	1055		Giam et al., 1973	quantified as aroclor 1254
Plankton	Off Pensacola (29 19'; 87 01')	0.1	112.359	Baird et al., 1975	quantified as aroclor 1254
Mesopelagic fish	Off Pensacola (29 19'; 87 01')	0.033, 0.158, 0.040	12.027, 4.313, 3.418	Baird et al., 1975	quantified as aroclor 1254
Plankton	Off Pensacola (29 26'; 87 17')	0.157	19.087	Baird et al., 1975	quantified as aroclor 1254
Grouper	18 samples GOM	33		Giam et al., 1974	quantified as aroclor 1260
Atlantic Croaker	SE of Chandeleur Islands, LA	25±29		Krahn et al., 2005	Sum of PCBs ±SD
Bigeye Tuna	SE of Chandeleur Islands, LA	15±8.8		Krahn et al., 2005	Sum of PCBs ±SD

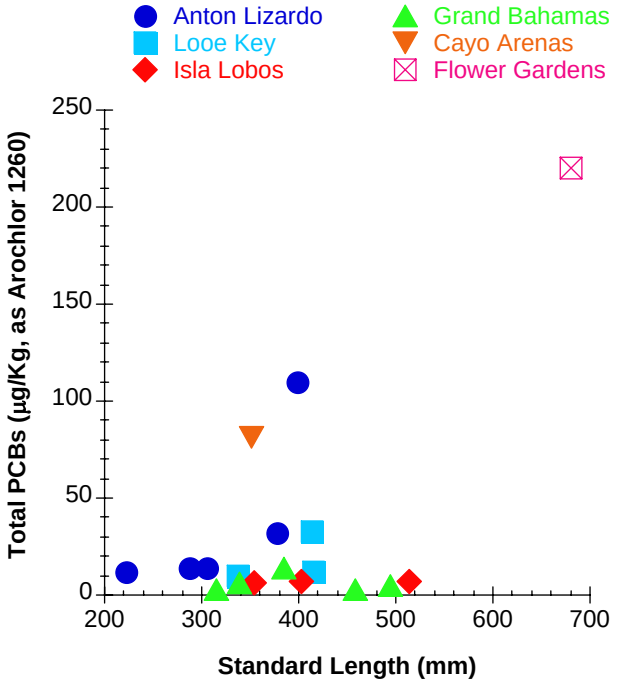

Figure 1. PCB body burdens in groupers reported by Giam et al. (1974) from the Gulf of Mexico, Florida Keys, and Bahamas. The only sample close to the northeastern Gulf of Mexico is the Flower Gardens, which is likely impacted by coastal Louisiana and Texas.

PCBS in Pensacola Bay

The Center for Environmental Diagnostics and Bioremediation (CEDB) at the UWF has been engaged in a study of fish and shellfish tissue loads in the Pensacola Bay estuarine system. PCB contamination in the system originates from industrialized areas of the Bay (Lewis et al., 2001, 2002) but predominantly from a spill documented in 1969 in the Escambia river (Duke et al., 1970; Karouna-Renier et al., 2007a,b; Nimmo et al., 1975; Oliver et al., 2001). Among other fishes, high levels of PCBs have been recorded in mullet, croaker, and red drum, which make annual spawning runs into the Gulf of Mexico thus raising concern about inshore to offshore transport of PCBs (Karouna-Renier et al., 2007a,b; Snyder et al., unpublished data).

PCBs on the ex-Oriskany

The goal of this investigation was to establish a baseline of PCB content and distribution in various partitions of the offshore environment so any impact of PCBs from the sinking of the *ex-Oriskany* as an artificial reef might be assessed. PCBs remaining on the ship, as well as their potential leach rates into the environment have been investigated and reported (George et al., 2006). Other documents pertaining to PCBs and the *ex-Oriskany* reef, including modeling of potential environmental and human health impacts can be found on the US EPA server: http://www.epa.gov/Region4/air/lead/PCBWebPage.htm

Artificial Reefs and Fisheries in the Gulf of Mexico

The northern Gulf of Mexico has been the most active region in the U.S. in terms of artificial reef creation. Reefs consisting of a variety of materials have been deployed in Gulf waters since World War II for myriad purposes (Bohnsack and Sutherland, 1985; Minton and Heath, 1998; Stone, 1986). In general, goals of reef creation have been 1) enhancing production of reef-dependent invertebrate or fish species; 2) aggregating individuals to increase fishing efficiency; 3) providing divers with increased opportunity to view reef-associated organisms; and, 4) economical disposal of petroleum platforms and ships no longer in service (Baine, 2001; Kasperzack, 1998; Okechi and Polovina, 1995; Seaman, 2000). Perhaps the single most cited reason for reef creation has been increasing fishing opportunities or efficiency on the Gulf's inner (i.e., < 25 miles offshore) continental shelf. For example, since 1995 nearly 60% of the Gulf's recreational red snapper harvest has come from Alabama and the Panhandle of Florida, areas where reef fishes are predominantly targeted over artificial reefs (Minton and Heath, 1998; Shipp, 1999).

Study Area

The site where the *ex-Oriskany* was sunk is in the southeast corner of the Escambia East Large Area Artificial Reef Site (LAARS). The predominant sediments in this area are silica-quartz sands that constitute part of the Mississippi-Alabama-Florida (MALFLA) sand sheet (Curray 1960; Ludwick 1964). Off Pensacola, MALFLA sediments generally are low in organic matter (< 5 %) and are well-sorted (Dufrene, 2005). Areas of high carbonate concentration are concentrated in patches of shell rubble throughout the region, but few natural hardbottom (i.e., reef) areas exist on the shelf. The most extensive areas of natural reef habitat occur at depths greater than 100 m out to the shelf break (~200 m depth) (Gittings et al. 1992, Schroeder et al. 1988).

The water column over the shelf off Pensacola is subjected to a seasonal pycnocline driven by annual warming of the surface water and seasonally high rainfall. Surface currents also display seasonal variation, with shorter term shifts due to wind effects. Relatively weak east and west current velocities that were estimated from wind (greater) and Loop current forcings (lesser) with satellite tracked drifters resulted in little net annual movement, yet periodic strong winds can result in dramatic westward movement (He & Weisberg, 2002; Sturges et al., 2001;Yang et al., 1999). Wind driven currents from tropical storms may track the wind directional changes as storms pass (Sturges et al., 2001). Deeper water movements are less well understood, but at the depth of the *ex-Oriskany* reef are thought to mirror wind driven surface water movement with Ekman effects on direction. Any effect of strong currents on the dispersal of biota and the PCBs they might contain is poorly known.

Materials and Methods

All sampling was conducted with field data sheets initiating a chain of custody paperwork trail that followed each sample. Powder-free latex gloves were worn when handling all samples and sampling equipment. Specimen contact with plastics was avoided. Any evidence or question of contamination (e.g., ice water entry into sample bags, etc.) resulted in discarding those samples.

Sediments

Sediment samples were obtained using a Shipek grab sampler with a stainless steel sampling scoop (Figure 2), which was pre-cleaned by scrubbing with mild detergent in seawater and then rinsed with seawater, rinsed with alcohol, and finally rinsed with double-deionized H_2O (DDH_2O). The area sampled was .04 m^2 with a bite depth of 10.2 cm and a sample volume of 3000 ml. The sampler was deployed from the *R/V Wilson* (offshore transect) or the *R/V Seahorse* (inshore stations). Three replicate samples were obtained at each station. The sampler was cleaned as described above after each sample. For a given sample, latitude and longitude were recorded when the sampler hit the bottom. The sampler was unloaded and the sediment in the scoop was mixed, sub-sampled using pre-cleaned stainless steel spoons, and transferred to duplicate pre-labeled certified clean sample jars (500 ml). The remainder of the sample was placed in a plastic ziplock bag. Aliquots of sediment samples were used for elemental (C, N, S, & P) and stable isotope ($\delta^{13}C$, $\delta^{15}N$, and $\delta^{34}S$) analysis, determining carbonate content, and particle size analysis. Samples for elemental and stable isotope analyses were acidified to remove carbonates prior to analysis. Jars for PCB analysis were kept at 4°C or below (on ice) and frozen (-20°C) upon return to the lab until shipment for analysis.

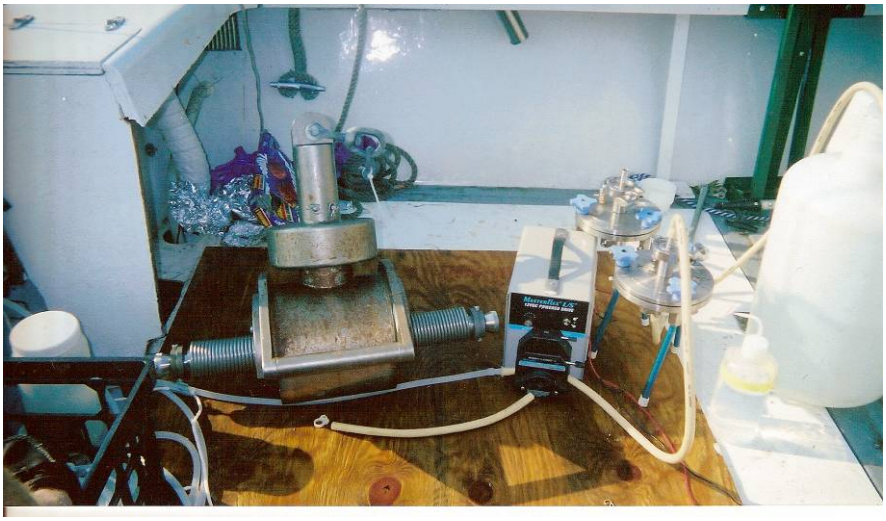

Figure 2. Shipek grab sampler for sediments (left) and filtration manifolds for water column particulates (right).

Stations for sediment collections are listed in Table 2 and mapped in Figure 3. A transect was established from just east of the proposed sinking site (30° 2.467'N, 87° 0.417'W) to south of the Tenneco Rig reef site located to the southwest (29° 59.733'N, 87° 05.111'W). Eight stations were set at exponentially increasing distances from 0.1 nm east and west of the *ex-Oriskany* sinking site, to roughly follow bathymetric contours in the direction of westerly current flow. Two additional stations were established between the *ex-Oriskany* site and the pass to Pensacola Bay, one in the Escambia artificial reef zone at approximately 8 nm offshore (30° 11.553N, 87° 14.41W) and one approximately 3 nm offshore near the outermost channel marker for the pass (30° 16.367N, 87° 17.274W; Figure 3).

Table 2. Locations of sediment grab samples

Sample ID	Latitude °N	Longitude °W	Depth m
ORISKE-3	30.0416	87.0069	65.2
ORISKE-2	30.0418	87.0069	65.2
ORISKE-1	30.0411	87.0064	65.2
ORISK1-3	30.0399	87.0073	65.2
ORISK1-2	30.0397	87.0074	65.2
ORISK1-1	30.0400	87.0075	65.2
ORISK2-3	30.0368	87.0085	59.7
ORISK2-2	30.0371	87.0077	59.7
ORISK2-1	30.0388	87.0087	59.7
ORISK3-3	30.0370	87.0122	63.4
ORISK3-2	30.0369	87.0123	63.4
ORISK3-1	30.0369	87.0120	63.4
ORISK4-3	30.0344	87.0160	62.5
ORISK4-2	30.0344	87.0160	62.5
ORISK4-1	30.0344	87.0161	62.5
ORISK5-3	30.0276	87.0261	59.4
ORISK5-2	30.0277	87.0260	59.4
ORISK5-1	30.0278	87.0259	59.4
ORISK6-3	30.0145	87.0466	53.3
ORISK6-2	30.0146	87.0467	53.3
ORISK6-1	30.0147	87.0465	53.3
ORISK7-3	29.9875	87.0869	54.3
ORISK7-2	29.9876	87.0869	54.3
ORISK7-1	29.9878	87.0866	54.3
EZAR8-3	30.1925	87.2402	21.6
EZAR8-2	30.1926	87.2402	21.6
EZAR8-1	30.1926	87.2402	21.6
PCOB-3	30.2728	87.2879	12.5
PCOB-2	30.2728	87.2879	12.5
PCOB-1	30.2728	87.2879	12.5

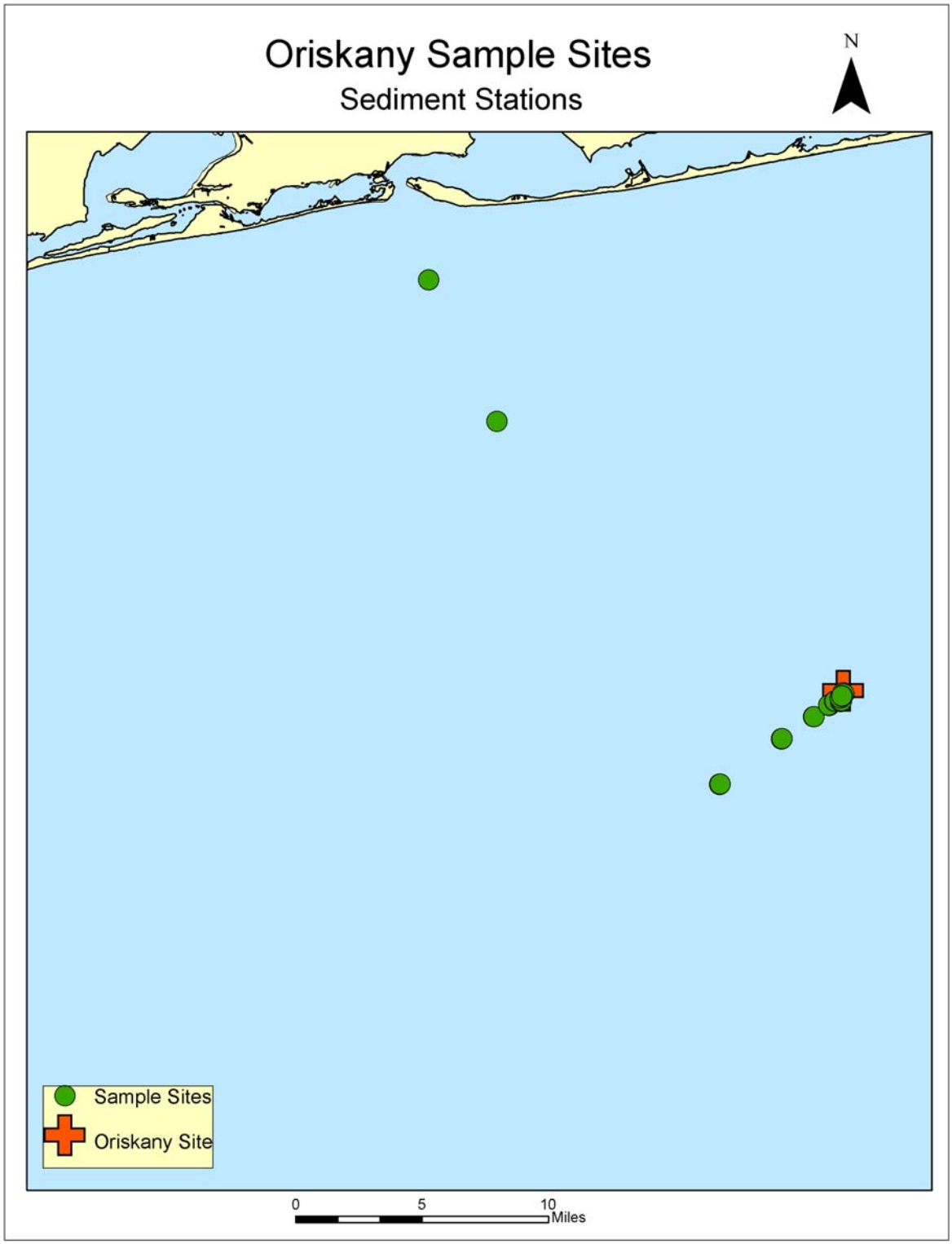

Figure 3. Location of sediment sampling stations with respect to the *ex-Oriskany* reefing site. Three replicate grabs were made at each station.

Water Column Particulates

Stations for water column particulate collections are listed in Table 3. Water column particulates were collected on 142 mm diameter Whatman GF/F filters with a nominal pore size of 0.7µm, inclusive of some bacteria and all particles of larger size up to 0.95 cm. Filters for collections were pre-cleaned by ashing at 500°C for one hour, weighed, and placed into individual labeled foil envelopes. Particulate material was collected from 10 m off the bottom at all sites. A lead weighted cable carried 3/8 inch ID silicon tubing to depth. Water was pumped up the tubing by a DC powered peristaltic pump (Masterflex). Three void volumes of the tubing were passed prior to sample collection. Sample water was sent through a stainless steel 142 mm filtration manifold (Millipore Corporation; Figure 2) for the collection of particulate material. Filtrate was collected and the volume recorded. Filters were folded, placed back into their respective envelopes and stored at <4°C until returned to the laboratory for frozen storage (-20°C). Sample filters were oven dried at 50°C and the dry weight recorded. Dried filters were shipped for PCB analysis. Three replicate filters were obtained at each station. The filtration manifold was cleaned after each sample by scrubbing with mild detergent in seawater, followed by a seawater rinse, an alcohol rinse, and a final DDH_20 water rinse.

Table 3. Locations and quantities of water column particulate samples.

Station	Latitude °N	Longitude °W	Sample Depth m	Volume Filtered l	Filtrate Dry Mass g	Dry Mass g l^{-1}
ORISKO	30.0411	87.0069	63.4	50	0.25	0.0050
ORISKO	30.0411	87.0069	63.4	50	0.088	0.0018
ORISKO	30.0411	87.0069	63.4	25	2.992	0.1197
ORISK_TENECO	29.9956	87.0852	50.8	60	1.583	0.0264
ORISK_TENECO	29.9956	87.0852	50.8	60	1.9	0.0317
ORISK_TENECO	29.9956	87.0852	50.8	55	1.707	0.0310
EZAR8	30.1926	87.2402	22.8	25	1.934	0.077
EZAR8	30.1926	87.2402	22.8	30	3.807	0.1269
EZAR8	30.1926	87.2402	22.8	30	0.653	0.0218

Fish and Invertebrate Samples

Fish and invertebrate samples were collected with a trawl and with vertical hook and line gear (Table 4, Figure 4). Hook and line sampling of fishes occurred on April 6-7, 2006 onboard the chartered *F/V Dorado* and on May 16, 2006 onboard the chartered *F/V Total Package*. Sampling onboard the *Dorado* occurred at known artificial reef sites off Pensacola (Table 4, Figure 4). Fishing rods were rigged with either two-hook bottom rigs (n = 4 fishers) or sow rigs (n = 2 fishers). The terminal tackle of two-hook bottom rigs was 3-0 straight shank hooks baited with cut squid or menhaden. Sow rigs consisting of two 5-0 straight shank hooks snelled 10 cm apart to a 1.5-m leader and baited with a whole round scad. Sampling onboard the *Total Package* was similar to the *Dorado* except that it occurred farther offshore and over natural hardbottom versus artificial reefs (Table 4, Figure 4). The hook types used also were slightly different. On two-hook bottom rigs, terminal tackle was 10-0 circle hooks. A single 12-0 circle hook was tied to the end of sow rigs. Bait was similar for both rig types to that used on the *Dorado*.

Trawl samples were collected on April 20, 2006 with a 10-m wide otter trawl towed behind the National Marine Fisheries Service's *R/V HST*. The trawl was fished on the seafloor for approximately 20 minutes at six sites that ranged in depth from 18.8 to 84.4 m (Fig. 4). Trawls

were retrieved with a hydraulic winch and then catches were dumped from the cod end of the trawl onto a sorting table.

All specimens were placed on foil when brought on board. Total length was recorded (if appropriate) and specimens were wrapped in foil then enclosed in ziplock bags for storage at <4°C until returned to the laboratory for processing. Each bag was labeled externally with an indelible marker in addition to Sample Identification Labels enclosed in the bag. All materials used in sample processing were washed in mild detergent, rinsed in tap water, rinsed with alcohol, and rinsed in DDH_2O water. Sterile, powder-free gloves were used and changed between samples.

Length of all fish and invertebrate specimens was re-measured in the lab, and their total mass recorded. All specimens were handled on aluminum foil, which was changed for each sample. Whole scallops were removed from shells and homogenized into a composite sample. Sand dollars were homogenized whole. Chitinous pens were removed from squid bodies and the remainder was homogenized whole. Stainless steel fillet knives were used to remove fish muscle tissue and skin was removed from all samples. Total fish fillet mass was recorded, with the goal of providing 200 g of tissue for PCB analysis. When single fish did not produce ≥200 g of muscle tissue, composites of muscle tissue dissected from more than one similar-sized fish were homogenized. Tissue from each sample (composite or individual fish) was homogenized in a FossTeactor tissue homogenizer, which was cleaned as described above before each sample. Sample homogenates were transferred to pre-labeled, certified clean 500 ml jars. Homogenates were stored at -20°C until shipment for PCB analysis. Aliquots of homogenates also were transferred to small vials and dried for elemental and stable isotope analysis. Otoliths and stomachs were dissected from fish carcasses after the removal of fillet samples. Left and right sagittal otoliths were removed from the braincase with steel chisels and forceps and stored in centrifuge tubes or small plastic ziplock bags. Stomachs were extracted and fixed with 10% buffered formalin in plastic bottles for gut content analysis. After at least 48 hours, stomach samples were removed from formalin and preserved in 70% isopropanol.

Table 4. Fish and invertebrate sample collection data.

Date	Sampling Station	Latitude °N	Longitude °W	Depth m	Sampling Gear
4/6/2006	Tenneco Rig AR Site	29.9955	87.0851	48.8	Hook and Line
4/6/2006	Tenneco Rig AR Site	29.9984	87.0864	53.3	Hook and Line
4/6/2006	Chevron Rig AR Site	30.0712	87.0358	39.6	Hook and Line
4/6/2006	Chevron Rig AR Site	30.0780	87.0874	30.5	Hook and Line
4/6/2006	Chevron Rig AR Site	30.0672	87.0922	30.5	Hook and Line
4/6/2006	Santa Rosa II AR Site	30.0817	87.1946	26.2	Hook and Line
4/6/2006	Santa Rosa III AR Site	30.0830	87.1743	25.9	Hook and Line
4/6/2006	Santa Rosa I AR Site	30.0578	87.1982	28.0	Hook and Line
4/7/2006	Concrete Culverts AR Site	30.2017	87.2392	21.9	Hook and Line
4/7/2006	I-10 Bridge Rubble AR Site	30.1963	87.2385	24.4	Hook and Line
4/7/2006	Navy Barge AR Site	30.1865	87.2463	23.5	Hook and Line
4/7/2006	Tug Silvia AR Site	30.1849	87.2367	22.9	Hook and Line
4/7/2006	Tug Deliverance AR Site	30.1818	87.2437	23.5	Hook and Line
4/7/2006	Russian Freighter AR Site	30.1887	87.2178	25.6	Hook and Line
4/20/2006	Inshore 1	30.1878	87.2775	18.8	Trawling
4/20/2006	Inshore 2	30.1923	87.2775	20.7	Trawling
4/20/2006	Offshore 1A	29.9835	87.0838	54.6	Trawling
4/20/2006	Offshore 1B	29.9607	87.1097	56.4	Trawling
4/20/2006	Offshore 2A	30.0475	86.9932	67.1	Trawling
4/20/2006	Offshore 2B	30.0442	86.9911	84.4	Trawling
5/16/2006	Natural Hardbottom	29.9833	87.2837	30.5	Hook and Line
5/16/2006	Natural Hardbottom	29.8472	87.3042	57.9	Hook and Line
5/16/2006	Natural Hardbottom	30.0522	87.3058	25.9	Hook and Line

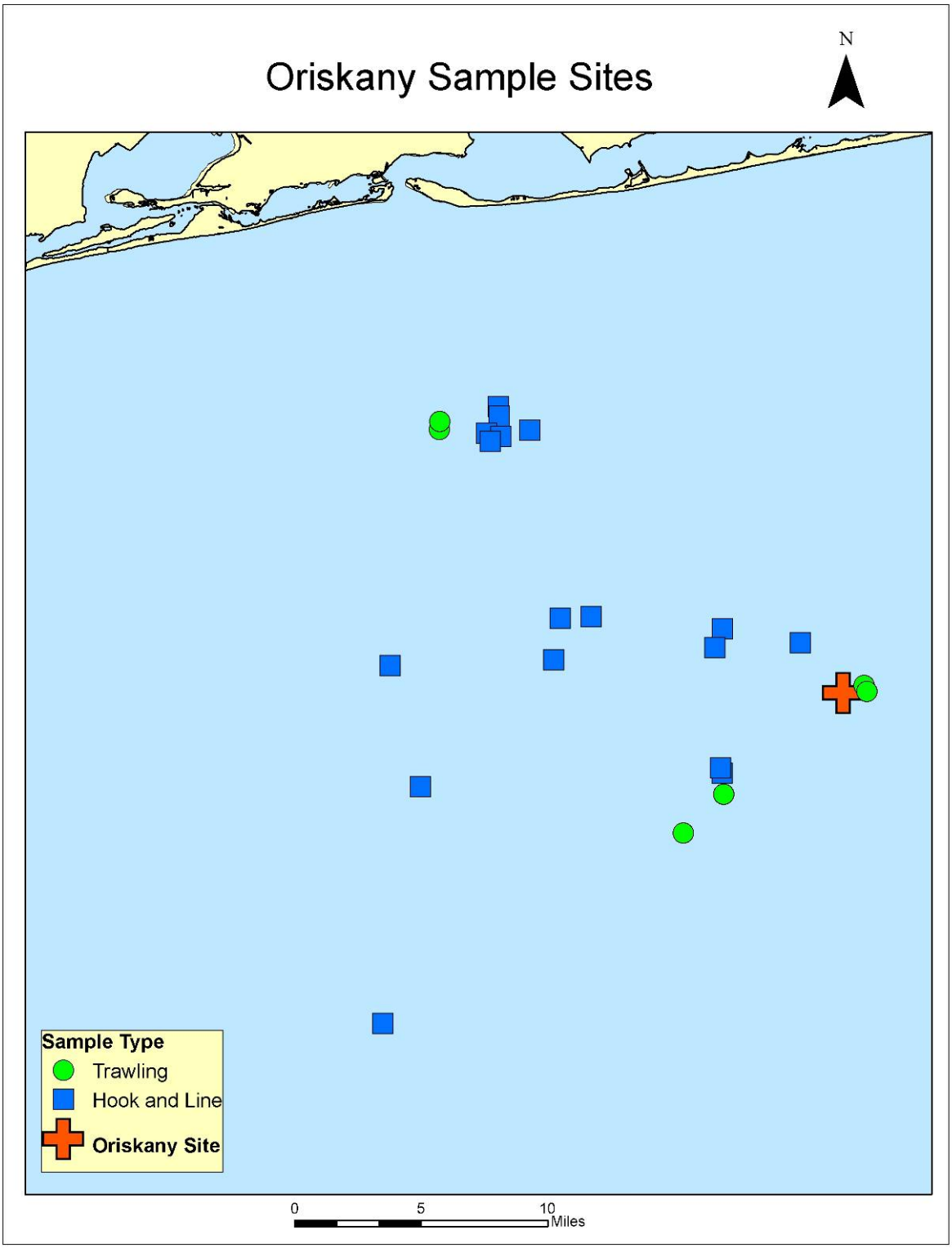

Figure 4. Locations of fish and invertebrate sample collections relative to the ex-Oriskany reefing site.

Fish Age Estimation

Sagittae were prepared for age estimation by first embedding them sulcus side down in epoxy resin. Once the epoxy hardened, samples were mounted on microscope slides with Cryastalbond thermal setting epoxy and sectioned with a Buehler Isomet low-speed diamond-bladed saw (Figure 5). Resultant thin sections (~0.5 mm thick) were polished with 3200 grit wet dry sand paper and an alumina powder (0.3 μm) slurry on a felt polishing cloth. Opaque zones in otolith thin sections were counted independently by two readers using an image analysis system that consisted of an Olympus DP70 digital camera mounted on an Olympus SZX12 dissecting microscope and integrated with a personal computer running Image Pro image analysis software. Between reader precision was estimated by computing average percent error (APE) and coefficient of variation (CV) (Campana 2001).

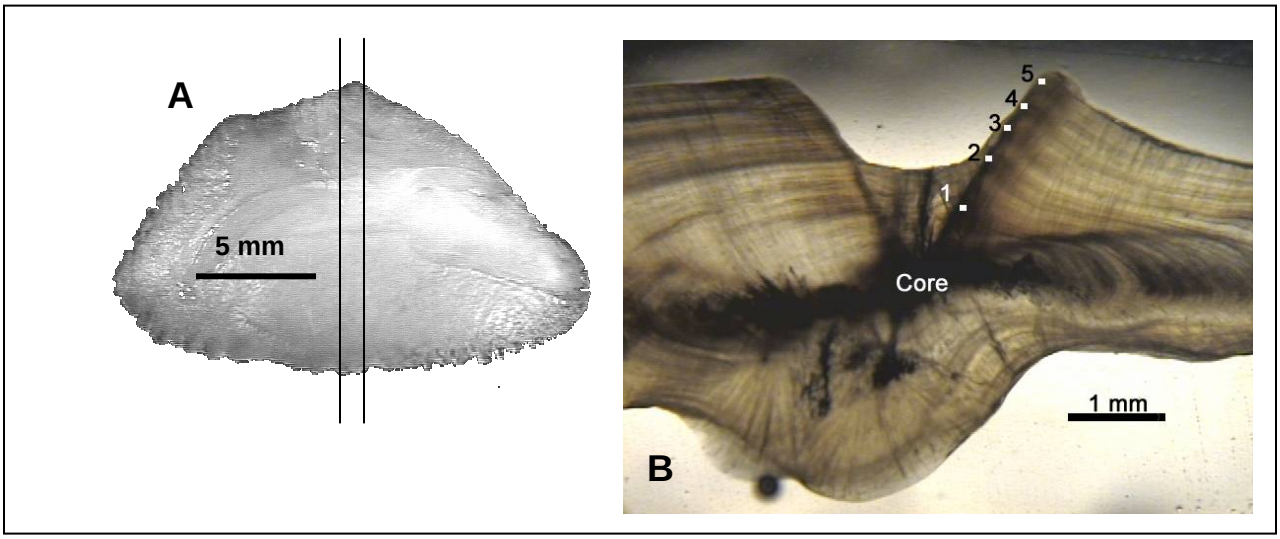

Figure 5. Otolith age estimation. A. Region of transverse section made through the core of a 683 mm TL red snapper sagitta analyzed in a previous study and B. the resulting thin section. Five opaque zones (i.e., annuli) are apparent in the thin section.

Opaque zone formation has been validated in previous studies as forming on an annual basis for adults of most species we analyzed. For other species, annual opaque zone formation has been validated for closely related species. We assumed opaque zone formation occurred on an annual time step for all species in our study, which is supported by recent reviews (Campana, 1999, 2005; Morales-Nin and Panfili, 2005). Therefore, annual age was equal to opaque zone counts (Figure 5). Fish age was determined for all individuals but was averaged among individuals in composites to compute a mean composite age.

Fish Gut Content Analysis

Gut contents of sampled fish were identified to the lowest taxon possible. Small prey items were identified with the image analysis system described above. Large prey items were identified without magnification. Individual prey items were counted, dried in an oven at 60º C for 24 hr, and then weighed. Percent by mass of predominant prey items was computed.

Elemental and Stable Isotope Analysis

Stable isotope analysis was conducted to estimate trophic position of samples based on C and N stable isotope ratios, and to assess if fishes and invertebrates fed predominantly on pelagic or benthic prey based on S stable isotope values. Phytoplankton in the northern Gulf typically has $\delta^{13}C$, $\delta^{15}N$, and $\delta^{34}S$ stables isotope delta values between –21 and –20‰, 5 and 9‰, and 18 and 19‰, respectively (Fry 2006). Due to trophic fractionation, there is approximately a 0.5 to 1‰ enrichment in $\delta^{13}C$ for each trophic level above phytoplankton and a 1 to 3‰ enrichment in $\delta^{15}N$ (Fry 1988, 2006). Therefore, trophic level can be inferred from apparent enrichment of $\delta^{13}C$ and $\delta^{15}N$ relative to phytoplankton values. Sulfur isotope ratios do not experience trophic fractionation but they can be used to infer pelagic versus benthic production because S biogeochemical cycling in the benthos yields S isotope values (~14-15‰) depleted approximately 4 to 5‰ relative to phytoplankton (~18-19‰). Depleted S values in benthic organisms result from bacterial reduction of sulfate in sediments, which can yield greatly depleted sediment $\delta^{34}S$ values (e.g., < -20‰; Yamanaka et al., 2003).

Carbon, nitrogen and sulfur content was determined with an elemental analyzer; total phosphorous was determined using EPA method 365.4. Stable isotope ratios (C, N, S) were measured with elemental analysis coupled to a Europa Scientific GSL/Geo 20-20 isotope ratio-mass spectrometer (IR-MS). First, frozen homogenized samples were thawed and dried in an oven at 60° C for 48 hours. Dried samples were weighed and stored in glass vials. Analytes included $\delta^{13}C_{V\text{-}PBD}$ ($\delta^{13}C$), $\delta^{15}N_{Air}$ ($\delta^{15}N$), and $\delta^{34}S_{V\text{-}CDT}$ ($\delta^{34}S$). International Atomic Energy Agency (IAEA) standard reference materials (SRMs) were run periodically to assess machine performance. Analytical precision was estimated from duplicate analysis of randomly selected samples. Results of stable isotope analysis are reported here in the standard delta notation, with delta values computed as:

$$\delta X = [(R_{sample}/R_{standard}) - 1] \times 1{,}000 \qquad \text{equation (1)}$$

Where: $X = {}^{13}C$, ${}^{15}N$, or ${}^{34}S$
$R = {}^{13}C{:}{}^{12}C$, ${}^{15}N{:}{}^{14}N$, or ${}^{34}S{:}{}^{35}S$
standards = Pee Dee Belemnite (PDB) for C, Air for N, and Canyon Diablo Triolite for S.

PCB Analysis

Procedures for analysis of tissues followed guidelines established by the US EPA (US EPA 2000) for assessing the necessity for seafood consumption advisories due to toxins. Polychlorinated biphenyls (PCBs) were analyzed in all samples with high resolution gas chromatography coupled with high resolution mass spectrometry (HRGC-HRMS) using USEPA Method 1668A. Following lipid extraction, a portion of the extract was dried and weighed to estimate the mass of lipid per volume of extract, which in turn was used to estimate percent lipid of the sample. During HRGC-HRMS analysis, ^{13}C labeled internal standards were recovered with extraction efficiencies ranging from 50-149%. Quantification of native congeners was based on isotope dilution of ^{13}C labeled internal standards. Method blanks, duplicate samples (intra-lab and inter-lab), matrix spikes, and laboratory control samples were used for quality control. Raw data ≤ 5 times method blank values were considered non-detects (ND) and substituted with 0.5 times the reporting limits to account for the possibility of a particular congener being present but not detectable. Values for individual congeners were summed to obtain total PCBs for each sample. Toxic Equivalency Quotients for the Dioxin-like PCBs

(TEQ_P; congeners 77, 81, 105, 114, 118, 123, 126, 156/157, 167, 169, 189) were calculated using the toxic equivalency factors for humans established by the World Health Organization (Van den Berg et al., 1998).

Results and Discussion

Sediments

Sediments along the transect from the reefing site to the Tenneco Reef were dominated by coarse biogenic calcareous material. Calcium carbonate content of the sediments was high, ranging from 55 to 90% as expected (Table 5), with higher values closer to the reefing site. Large shell fragments shifted the particle size distribution to the larger size classes in the samples from the offshore transect (Table 6). Phosphorous content was low and consistent for all samples in the offshore transect (Table 5). Sediment particles at the reefing site were coated with dark material in contrast to the sediments south of the Tenneco reef (Figure 6). Sediments from the reefing site contained viable benthic diatoms and benthic foraminifera (Figure 7). The presence of live diatoms indicates light penetration to the benthos supporting primary production, suggesting autotrophic production may occur extensively over the *ex-Oriskany* reef. The two stations closer to Pensacola Pass, EZAR8 and PCOB had comparatively finer sediments (Table 6) with more quartz sand grains and lower carbonate content (Table 5).

Table 5. Mean and standard deviations (SD) of carbonate and percent phosphorous content of sediment samples (n=3 replicates per sample).

Sample ID	Carbonate %	SD	Phosphorous %	SD
ORISKE	89.44	0.33	0.3213	0.0192
ORISK1	88.85	1.30	0.3746	0.0155
ORISK2	90.38	0.71	0.3710	0.0117
ORISK3	90.30	0.92	0.3940	0.0109
ORISK4	89.53	0.39	0.4302	0.0456
ORISK5	87.59	1.43	0.4029	0.0331
ORISK6	65.14	3.33	0.3628	0.0159
ORISK7	55.20	3.42	0.3911	0.0132
EZAR8	15.58	1.63		
PCOB	8.91	3.27		

Table 6. Particle size analysis of sediment samples. All figures are means and standard deviations (SD) of three replicates.

	Particle size (mm)							
Sample ID	**1.00-1.40 %**	**SD**	**0.500-0.850 %**	**SD**	**0.300-.0425 %**	**SD**	**<0.300 %**	**SD**
ORISKE	51.659	3.860	36.560	3.085	10.060	1.482	2.657	0.578
ORISK1	48.342	8.102	41.194	4.450	9.730	2.602	1.566	0.429
ORISK2	52.607	2.659	37.656	2.240	8.610	1.252	1.525	0.686
ORISK3	47.873	4.653	40.888	3.152	10.106	1.478	1.860	0.639
ORISK4	42.456	5.945	43.154	3.409	12.735	2.349	2.137	0.271
ORISK5	46.338	3.161	41.330	0.600	10.875	3.765	1.821	0.648
ORISK6	35.137	0.629	46.727	1.179	15.676	0.581	2.828	0.374
ORISK7	37.285	4.407	42.111	2.284	18.417	1.612	3.338	0.374
EZAR8	5.953	0.564	32.513	4.238	44.192	0.214	17.164	3.898
PCOB	0.642	0.367	10.013	4.886	30.880	6.074	59.495	10.547

Figure 6. Sediment samples from the vicinity of the reefing site (ORISKE1-1; right) and south of the Tenneco reef at the end of the sampling transect (ORISK7-3; left).

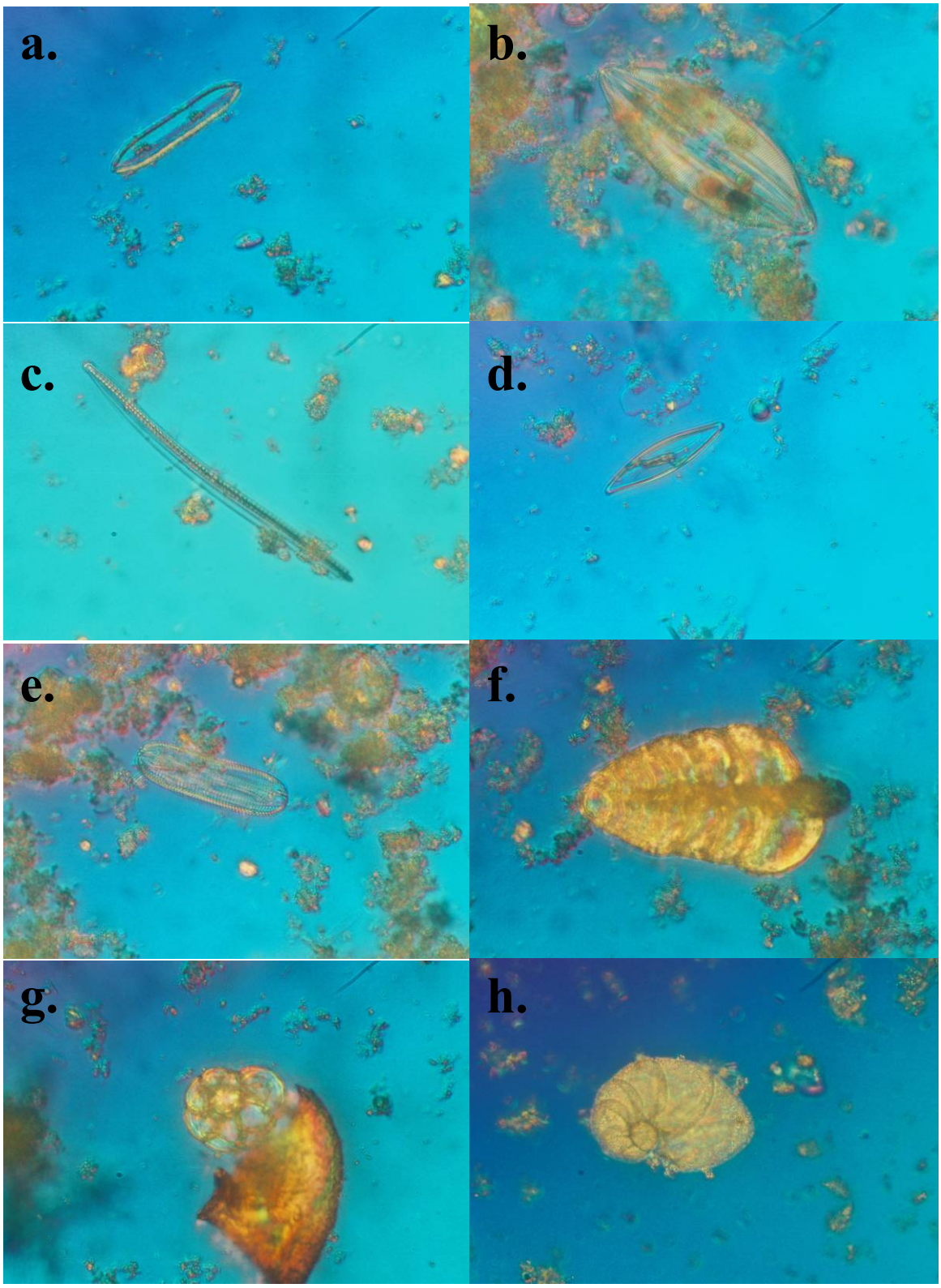

Figure 7. Micrographs of benthic microflora and microfauna in sediments from the reefing site. Benthic diatoms (a-e) and benthic foraminifera (f-h) were well represented.

Organic content, as measured by sediment carbon, nitrogen, and sulfur content, decreased from the reefing site to the end of the transect near the Tenneco reef, and was lower for the sediments nearer the pass than the for the offshore stations (Table 7; Figure 8). Organic matter in offshore sediments was enriched in ^{13}C relative to the nearer shore stations, indicating a greater impact of near-coastal phytoplankton production on sediment organic matter. Nitrogen isotope ratios were similar for all stations. Sulfur ratios were more variable within and among offshore stations. Organic sulfur content of inshore sediments was too low to provide reliable results.

Table 7. Results of elemental and stable isotope analysis of sediment organic matter. Figures are means and standard deviations (SD) of three replicates.

Sample ID	Elemental Carbon %	SD	$\delta^{13}C$ ‰	SD
ORISKE	1.5370	0.1024	-19.4632	0.3384
ORISK1	1.0448	0.1446	-19.4084	0.1059
ORISK2	1.1208	0.0692	-19.1999	0.0420
ORISK3	1.0227	0.1117	-19.5558	0.1298
ORISK4	0.8088	0.1955	-19.6161	0.3288
ORISK5	0.8447	0.0779	-19.4996	0.2448
ORISK6	0.2192	0.0206	-19.9604	0.3076
ORISK7	0.1284	0.0203	-20.5067	0.0957
EZAR8	0.0388	0.0077	-21.6801	0.2282
PCOB	0.0369	0.0037	-21.3743	0.1919

Sample ID	Elemental Nitrogen %	SD	$\delta^{15}N$ ‰	SD	C:N ratio
ORISKE	0.1964	0.0100	5.9706	0.5112	7.8240
ORISK1	0.1334	0.0264	5.4010	0.4135	7.8307
ORISK2	0.1535	0.0103	5.4487	0.1845	7.3005
ORISK3	0.1294	0.0119	5.1515	0.0762	7.9057
ORISK4	0.1083	0.0294	5.2433	0.1171	7.4676
ORISK5	0.1092	0.0064	5.5412	0.5861	7.7354
ORISK6	0.0269	0.0033	5.4389	0.3905	8.1552
ORISK7	0.0141	0.0039	5.9820	0.8068	9.1069
EZAR8	0.0042	0.0002	N content too low		9.2020
PCOB	0.0044	0.0004	N content too low		8.4295

Sample ID	Elemental Sulphur %	SD	$\delta^{34}S$ ‰	SD	C:S ratio
ORISKE	0.1679	0.0453	-27.0090	3.4083	9.1542
ORISK1	0.1306	0.0151	-28.1697	1.7575	8.0025
ORISK2	0.1190	0.0070	-25.9029	0.4245	9.4148
ORISK3	0.1256	0.0305	-24.0246	0.8989	8.1418
ORISK4	0.1504	0.0408	-27.6411	1.0604	5.3777
ORISK5	0.1255	0.0272	-23.4541	3.5690	6.7295
ORISK6	0.0234	0.0027	S content low		9.3573
ORISK7	0.0122	0.0043	S content too low		10.5681
EZAR8	0.0178	0.0024	-22.9413	2.1748	
PCOB	0.0052	0.0001	S content too low		7.1243

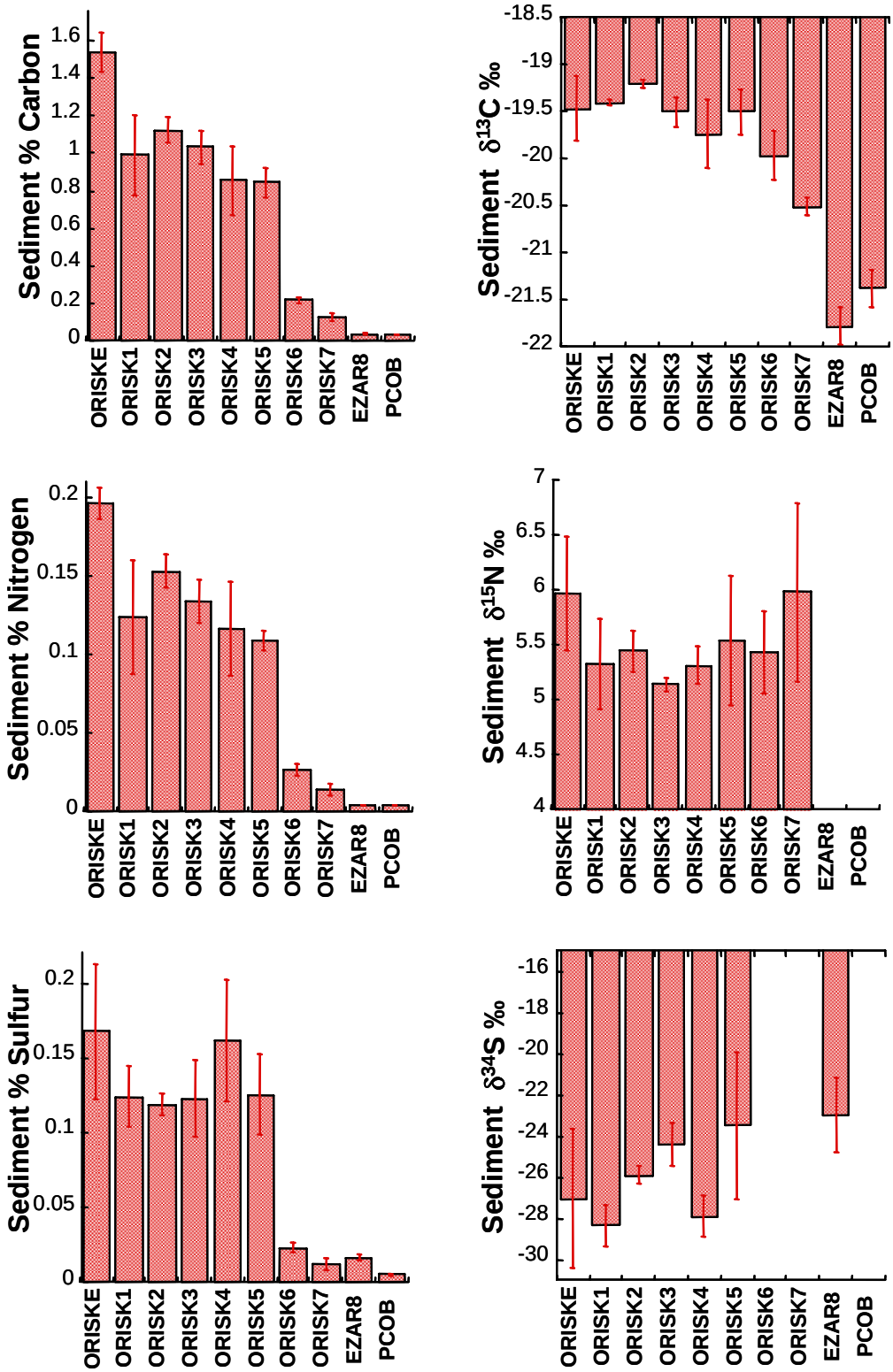

Figure 8. Organic Carbon (top row), organic Nitrogen (middle row), and organic Sulfur (bottom row) content (left column) and stable isotope ratios (right column) of sediments samples.

Polychlorinated biphenyl content of offshore sediments was consistently low and below reporting limits (RL) and blank results for most congeners (Table 8; Figure 9). Thus, ΣPCB values computed by substituting ½ RL values for non-detects showed very little difference among stations. Differences among stations are more apparent when we did not substitute ½ RL values for non-detects (Table 8; Figure 9). Precision estimates for both within lab analysis and between lab analyses were within acceptable limits (Table 9).

Table 8. TEQ for coplanar dioxin-like PCBs, the sum of all PCBs computed with and without substituting ½ reporting limit values for non-detects, and the percent lipids in sediment samples. All figures are averages and standard deviations (SD) of three replicates.

Sample ID	TEQ_P	SD	ΣPCBs µg/kg ND=1/2 RL	SD	ΣPCBs µg/kg ND=0	SD	% Lipids	SD
ORISKE	0.0468	0.0004	0.4202	0.04250	0.0231	0.0209	0.1203	0.1558
ORISK1	0.0477	0.0020	0.4289	0.1370	0.0213	0.0164	0.0470	0.0207
ORISK2	0.0498	0.0038	0.4350	0.0928	0.0088	0.0046	0.0495	0.0205
ORISK3	0.0501	0.0034	0.5712	0.1186	0.0187	0.0143	0.0340	0.0419
ORISK4	0.0788	0.0478	0.3962	0.1100	0.0274	0.0100	0.1967	0.3061
ORISK5	0.0483	0.0046	0.3653	0.0388	0.0173	0.0017	0.0540	0.0227
ORISK6	0.0496	0.0014	0.5144	0.1293	0.0143	0.0086	0.2150	0.2988
ORISK7	0.0476	0.0022	0.4437	0.0632	0.0093	0.0061	0.0367	0.0121
EZAR8	0.0441	0.0071	0.3881	0.1415	0.0043	0.0028		
PCOB	0.0442	0.0057	0.4177	0.1260	0.0079	0.0061	0.0605	0.0134

Table 9. Precision estimates for sediment PCB analysis

Sample ID	Duplicate Match	ΣPCBs µg/kg	Mean	SD	RPD
Within Lab Blind Duplicates					
ORISK2-2	ORISKZ-1	0.1034			
ORISKZ-1	ORISK2-2	0.1048	0.1041	0.00103	1.39%
ORISKZ-2	ORISKE-3	0.0955			
ORISKE-3	ORISKZ-2	0.1284	0.1119	0.02330	29.44%
Cross-Lab Duplicates					
ORISKE-1	ORISKE-1-A	0.0936			
ORISKE-1-A	ORISKE-1	0.1290	0.1113	0.02504	31.82%
ORISK3-3	ORISK3-3-A	0.1020			
ORISK3-3-A	ORISK3-3	0.1107	0.1064	0.00619	8.23%

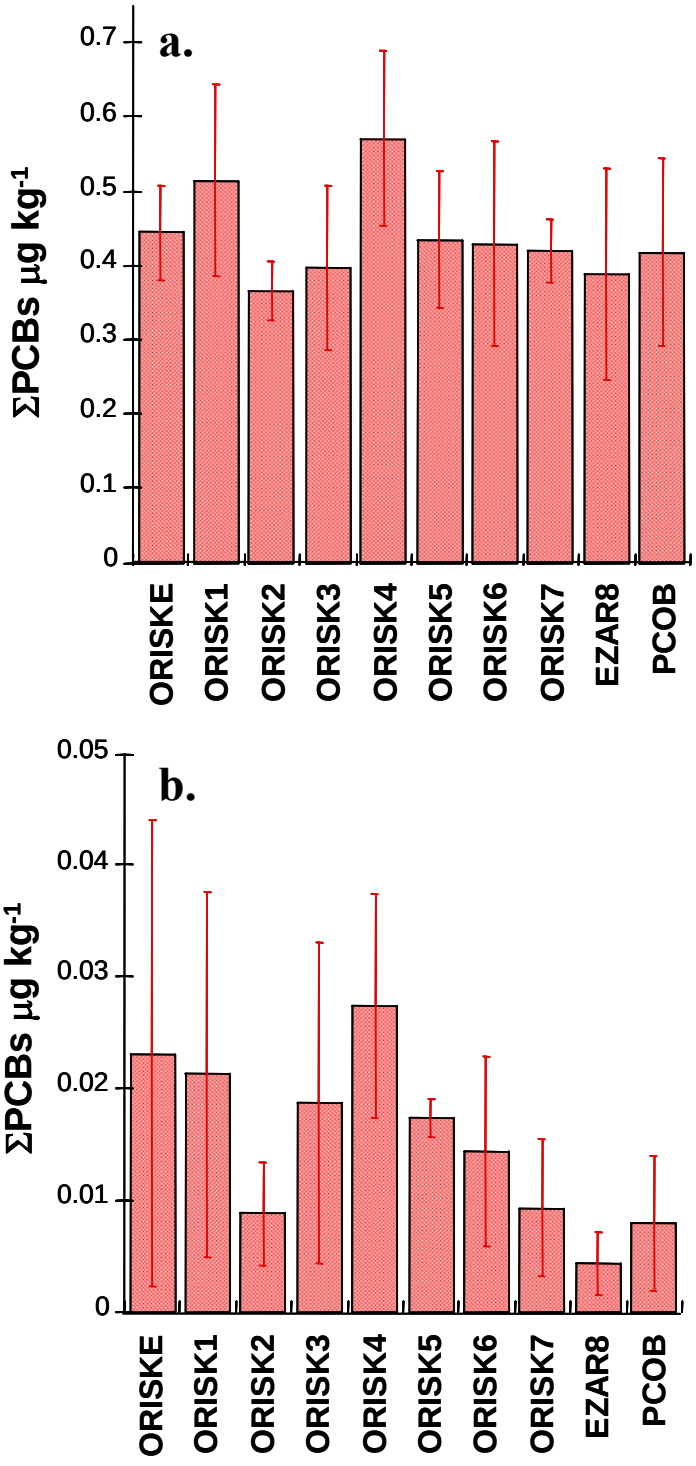

Figure 9. Polychlorinated biphenyl (PCB) content of sediment samples. One half the reporting limit substituted for non-detected congeners (a) and zeros substituted for non-detected congeners (b).

Water Column Particulates

The material collected from the water column included all organisms and floating detritus larger than 0.7 μm, but excluded large particulates such as ctenophores and other gelatinous zooplankton larger than ~ 1 cm. Values of C and N in this material was highly variable, but with a tendency towards higher concentrations inshore (EZAR8) and near the Tenneco Reef (ORISKT) (Table 10; Figure 10). It remains unknown if the vicinity of the large Tenneco reef structure had any role in particle production and export to the water column, but the values clearly show an enrichment relative to the *ex-Oriskany* sinking site. The suspended material at the Tenneco site also was enriched in N relative to the other sites, as indicated by C:N ratios (Table 10). Stable isotope values for carbon reveal a stronger similarity for the Tenneco Reef particulates and the EZAR8 samples than the particulates recovered from the sinking site. This trend is offset by the nitrogen isotope values for the particulates collected closer to shore being depleted (but variable) for the inshore station relative to the Tenneco reef site, perhaps reflecting nitrogen sources from the mainland at the EZAR8 site and more regenerated nitrogen at the Tenneco Reef site (Table 10 and Figure 10). The quantity of N in the samples from the *ex-Oriskany* reefing site were not sufficient to obtain a N isotope signal. It will be interesting to see if the *ex-Oriskany* as reef structure will have the same effect on water column particulates as the Tenneco Reef structure.

Table 10. Results of elemental and stable isotope analysis of water column particulates

Sample ID	C content μg l^{-1}	δ ^{13}C ‰	N content μg l^{-1}	δ ^{15}N ‰	C:N
EZAR8-1A	100.2803	-25.5908	9.0831	2.2312	11.0403
EZAR8-1B	199.5496	-23.8427	26.0372	3.6009	7.6640
EZAR8-1C	102.3020	-25.3060	9.9510	6.3291	10.2806
ORISK0-A	100.7520	-22.5372	12.2455	-	8.2277
ORISK0-B	69.4144	-23.8079	6.7213	-	10.3275
ORISK0-C	62.8998	-22.4292	6.1934	-	10.1559
ORISKT-A	215.6565	-24.4241	28.9302	7.6511	7.4544
ORISKT-B	167.4707	-26.5522	20.6751	7.1087	8.1001
ORISKT-C	245.6462	-23.3176	32.1724	5.9035	7.6353

The PCB content per weight of material (non-detects = 0) was highest at the Tenneco site, although samples at the reefing site had high variability, and was lowest at the inshore site (Table 11). PCB content by volume of seawater (non-detects = 0) also showed the highest content at the Tenneco site, with similar values for the inshore and reefing sites.

Table 11. PCB content in water column particulates.

	Non-detects = one half reporting limit				Non-detects = zero			
Sample ID	Mean ΣPCBs μg/kg	SD	Mean ΣPCBs pg l^{-1}	SD	Mean ΣPCBs μg/kg	SD	Mean ΣPCBs pg l^{-1}	SD
EZAR8	0.00162	0.0001	0.1224	0.0864	0.000710	0.000023	0.0537	0.0986
ORISK0	0.00512	0.0054	0.0772	0.1063	0.00434	0.005536	0.0654	0.1090
ORISKT	0.00707	0.0019	0.2136	0.0726	0.00633	0.001908	0.1912	0.0729

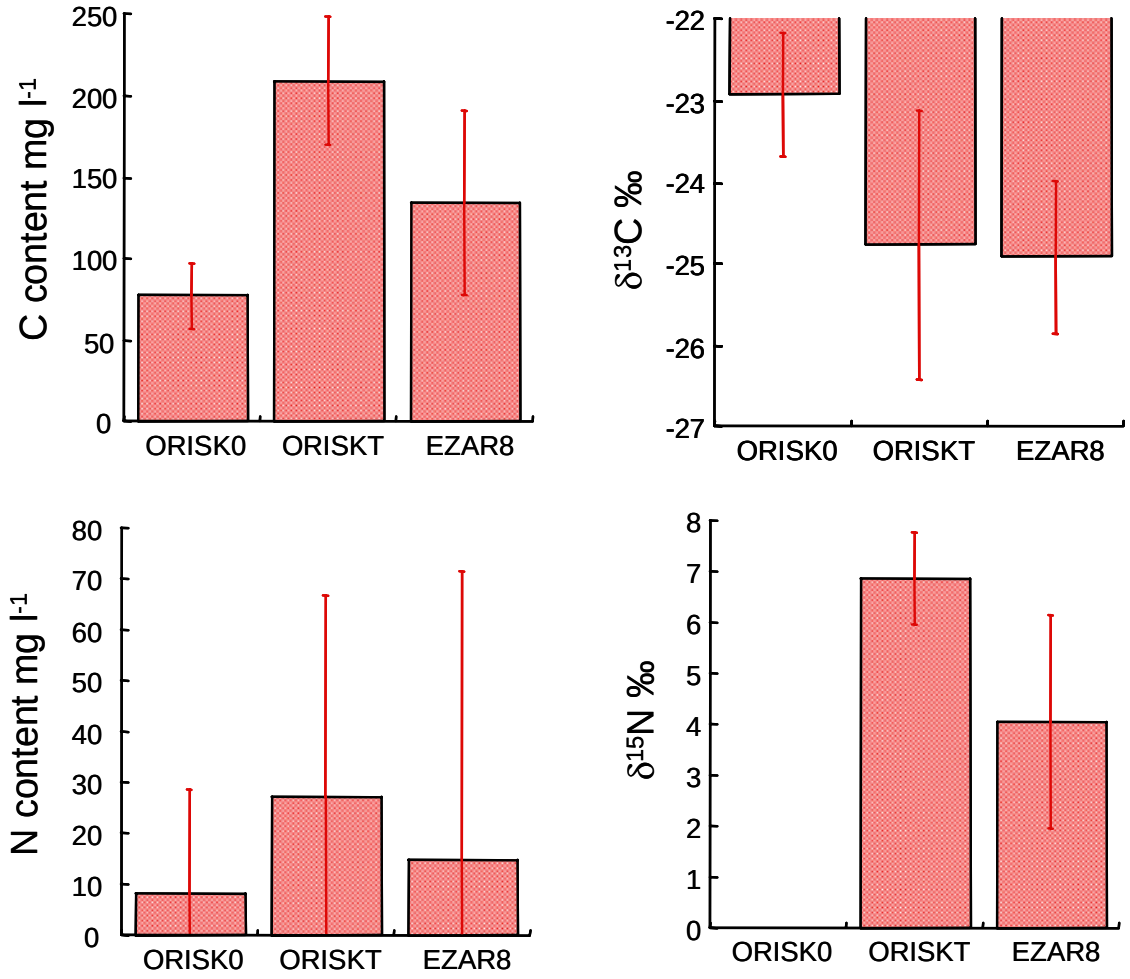

Figure 10. Results of elemental and stable isotope analysis of water column particulates.

Fish and Invertebrate Samples

A total of 24 taxa were analyzed for PCB tissue concentrations. Fish species accounted for 21 taxa, while invertebrates accounted for the remaining 3 (Table 12; Figure 11). Of the 286 individuals in those samples, 201 were obtained by trawling and 85 by hook and line sampling. Red Snapper represented the largest sample size at 17 individuals and had the greatest geographic coverage (Table 13; Figure 11m).

Fish Gut Content Analysis

Gut content analysis was performed for 214 of 232 fishes sampled (Table 13). Those fishes not analyzed had poorly preserved stomachs. Overall, 48% of the prey items were not identifiable among all stomach contents. Fish constituted the largest identifiable prey category among samples (22%), while decapods (i.e., crabs and shrimps) constituted 16%.

Elemental and Stable Isotope Analysis

Analytical accuracy and precision were high for stable isotope analysis of fish and invertebrate tissues. Concurrent analysis of SRMs indicated high accuracy of analysis (Table 14). Duplicate analysis was performed for 19 of 57 study samples. Results indicated high analytical precision of the IR-MS (Table 15). Stable isotope values of C and N were used as variables in correlation analysis as proxies for trophic position (Table 16).

Fish Age Estimation

Age was estimated for 232 individual fish sampled in the study (Table 18). Average percent error between the two readers was 6.77% and the coefficient of variation between readers was 9.57%. Typically, production aging facilities aim for APEs and CVs of 5 to 10%, depending on the species examined. Both measures of between reader agreement estimated in this study are within that range. That instills confidence in our aging techniques, especially given the diversity of species examined and the mostly young ages of individuals, for which disagreement of just one year can inflate APE and CV significantly. Ages of composite samples were averaged (Table 18). Composites consisted of similar sized fish within a given species. Comparison of mean age to age mode confirms the central tendency in the data and the similarity of ages among individuals in a given composite. Fish age was used as a variable in correlation analysis to assess bioaccumulation patterns.

Table 12. Synopsis of fish and invertebrate samples collected for PCB analysis.

Species	Common Name	Sample ID	Analytical ID	# in Sample	Sample Date	Lat °N	Long °W	Gear
Argopecten gibbus	Calico Scallop	Scallop-1	060420AD1	23	4/20/06	29.98350	87.08383	Trawl
Balistes capriscus	Gray Triggerfish	GrayTrig-1	060406I1	1	4/6/06	30.06720	87.09217	HnL
Balistes capriscus	Gray Triggerfish	GrayTrig-2	060406L1	1	4/6/06	30.05775	87.19817	HnL
Balistes capriscus	Gray Triggerfish	GrayTrig-3	060406T1	1	4/6/06	30.08303	87.17423	HnL
Balistes capriscus	Gray Triggerfish	GrayTrig-4	060516A1	3	5/16/06	29.98333	87.28367	HnL
Balistes capriscus	Gray Triggerfish	GrayTrig-5	060516E1	1	5/16/06	29.84717	87.30417	HnL
Calamus leucosteus	Whitebone Porgy	WhBPorgy-1	060406A2	1	4/6/06	29.99843	87.08638	HnL
Centropristes ocyurus	Bank Seabass	BankSeaBass-1	060420B1	18	4/20/06	30.04422	86.99112	Trawl
Centropristes ocyurus	Bank Seabass	BankSeaBass-2	060420Y1	13	4/20/06	29.98350	87.08383	Trawl
Cynoscion arenarius	Sand Seatrout	SandSeatrout-1	060420G1	6	4/20/06	30.04422	86.99112	Trawl
Diplectrum formosum	Sandperch	Sandperch-1	060420AH1	6	4/20/06	30.19233	87.27750	Trawl

Table 12 (concluded). Synopsis of fish and invertebrate samples collected for PCB analysis.

Species	Common Name	Sample ID	Analytical ID	# in Sample	Sample Date	Lat °N	Long °W	Gear
Encope aberrans	Sand Dollar	SandDollar-1	060420AX1	25	4/20/06	30.19233	87.27750	Trawl
Epinephelus morio	Red Grouper	RedGrouper-1	060516D1	1	5/16/06	29.84717	87.30417	HnL
Epinephelus morio	Red Grouper	RedGrouper-2	060516D2	1	5/16/06	29.84717	87.30417	HnL
Epinephelus morio	Red Grouper	RedGrouper-3	060516D3	1	5/16/06	29.84717	87.30417	HnL
Haemulon aurolineatum	Tomtate	Tomtate-1	060406N1	10	4/6/06	30.08168	87.19457	HnL
Haemulon aurolineatum	Tomtate	Tomtate-2	060407N1	11	4/7/06	30.18868	87.21780	HnL
Lagodon rhomboides	Pinfish	Pinfish-1	060420H1	15	4/20/06	30.04422	86.99112	Trawl
Leiostomus xanthurus	Spot	Spot-1	060420I1	15	4/20/06	30.04422	86.99112	Trawl
Loligo sp.	Squid	Squid-1	060420AR1	4	4/20/06	29.98350	87.08383	Trawl
Loligo sp.	Squid	Squid-2	060420AT	2	4/20/06	30.18783	87.27750	Trawl
Lutjanus campechanus	Red Snapper	RedSnapper-1	060406C1	1	4/6/06	29.99843	87.08638	HnL
Lutjanus campechanus	Red Snapper	RedSnapper-2	060406C2	1	4/6/06	29.99843	87.08638	HnL
Lutjanus campechanus	Red Snapper	RedSnapper-3	060406C3	1	4/6/06	29.99843	87.08638	HnL
Lutjanus campechanus	Red Snapper	RedSnapper-4	060406C4	1	4/6/06	29.99843	87.08638	HnL
Lutjanus campechanus	Red Snapper	RedSnapper-5	060406C5	1	4/6/06	29.99843	87.08638	HnL
Lutjanus campechanus	Red Snapper	RedSnapper-6	060406H1	1	4/6/06	30.07803	87.08740	HnL
Lutjanus campechanus	Red Snapper	RedSnapper-7	060406K3	1	4/6/06	30.05775	87.19817	HnL
Lutjanus campechanus	Red Snapper	RedSnapper-8	060406S2	1	4/6/06	30.08303	87.17423	HnL
Lutjanus campechanus	Red Snapper	RedSnapper-9	060406S3	1	4/6/06	30.08303	87.17423	HnL
Lutjanus campechanus	Red Snapper	RedSnapper-10	060407A1	1	4/7/06	30.20170	87.23920	HnL
Lutjanus campechanus	Red Snapper	RedSnapper-11	060407A5	1	4/7/06	30.20170	87.23920	HnL
Lutjanus campechanus	Red Snapper	RedSnapper-12	060407A7	1	4/7/06	30.20170	87.23920	HnL
Lutjanus campechanus	Red Snapper	RedSnapper-13	060407O1	2	4/7/06	30.18868	87.21780	HnL
Lutjanus campechanus	Red Snapper	RedSnapper-14	060407O4	2	4/7/06	30.18868	87.21780	HnL
Lutjanus campechanus	Red Snapper	RedSnapper-15	060420AF1	6	4/20/06	29.98350	87.08383	Trawl
Lutjanus campechanus	Red Snapper	RedSnapper-16	060420W1	4	4/20/06	29.96067	87.10967	Trawl
Lutjanus campechanus	Red Snapper	RedSnapper-17	060516I1	1	5/16/06	29.84717	87.30417	HnL
Lutjanus griseus	Gray Snapper	GraySnapper-1	060516B1	1	5/16/06	29.98333	87.28367	HnL
Lutjanus griseus	Gray Snapper	GraySnapper-2	060516J1	1	5/16/06	30.05217	87.30583	HnL
Micropogonias undulatus	Atlantic Croaker	AtlCroaker-1	060420A1	13	4/20/06	30.04422	86.99112	Trawl
Mycteroperca microlepis	Gag	Gag-1	060406J1	1	4/6/06	30.06720	87.09217	HnL
Mycteroperca microlepis	Gag	Gag-2	060407C1	1	4/7/06	30.19628	87.23845	HnL
Mycteroperca microlepis	Gag	Gag-3	060407H1	1	4/7/06	30.18487	87.23667	HnL
Mycteroperca microlepis	Scamp	Gag-4	060516F1	1	5/16/06	29.84717	87.30417	HnL
Mycteroperca phenax	Scamp	Scamp-1	060516C1	1	5/16/06	29.84717	87.30417	HnL
Mycteroperca phenax	Scamp	Scamp-2	060516C2	1	5/16/06	29.84717	87.30417	HnL
Mycteroperca phenax	Scamp	Scamp-3	060516C3	1	5/16/06	29.84717	87.30417	HnL
Pagrus pagrus	Red Porgy	RedPorgy-1	060406G1	5	4/6/06	30.07803	87.08740	HnL
Pagrus pagrus	Red Porgy	RedPorgy-2	060406U1	1	4/6/06	30.08303	87.17423	HnL
Pagrus pagrus	Red Porgy	RedPorgy-3	060420AA1	3	4/20/06	29.96067	87.10967	Trawl
Rhomoplites aurorubens	Vermilion Snapper	VerSnapper-1	060406B1	1	4/6/06	29.99843	87.08638	HnL
Rhomoplites aurorubens	Vermilion Snapper	VerSnapper-2	060406B2	1	4/6/06	29.99843	87.08638	HnL
Rhomoplites aurorubens	Vermilion Snapper	VerSnapper-3	060406O1	11	4/6/06	30.08168	87.19457	HnL
Rhomoplites aurorubens	Vermilion Snapper	VerSnapper-4	060407M1	3	4/7/06	30.18868	87.21780	HnL
Sciaenops ocelatus	Red Drum	Redfish-1	060406F1	1	4/6/06	30.07118	87.03577	HnL
Scomberomorus cavalla	King Mackerel	KingMack-1	060516H1	1	5/16/06	29.84717	87.30417	HnL
Seriola dumerilli	Amberjack	Amberjack-1	060516G1	1	5/16/06	29.84717	87.30417	HnL
Seriola dumerilli	Amberjack	Amberjack-2	060516G2	1	5/16/06	29.84717	87.30417	HnL
Synodus foetens	Inshore Lizardfish	Lizardfish-1	060420AB1	1	4/20/06	29.96067	87.10967	Trawl
Synodus foetens	Inshore Lizardfish	Lizardfish-2	060420K1	6	4/20/06	30.04422	86.99112	Trawl
Trachurus lathami	Round Scad	RoundScad-1	060420AC1	41	4/20/06	29.96067	87.10967	Trawl

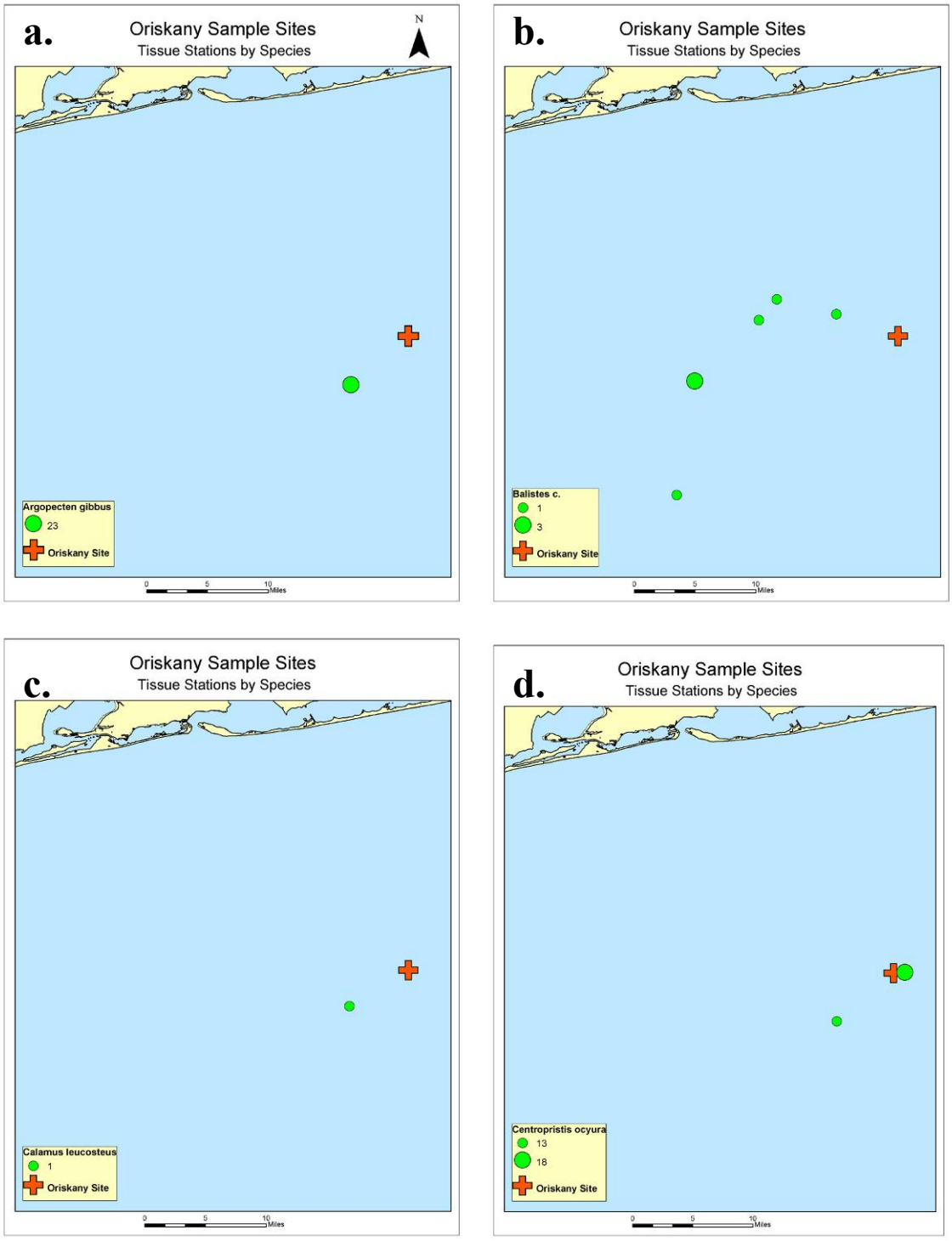

Figure 11. Sampling locations and number of individuals (in legend) for species analyzed for PCB tissue concentrations. a. Atlantic calico scallop *Argopectin gibbus*. b. gray triggerfish, *Ballistes capricsus*. c. whitebone porgy, *Calamus leucosteus*. d. bank seabass, *Centropristes ocyurus*.

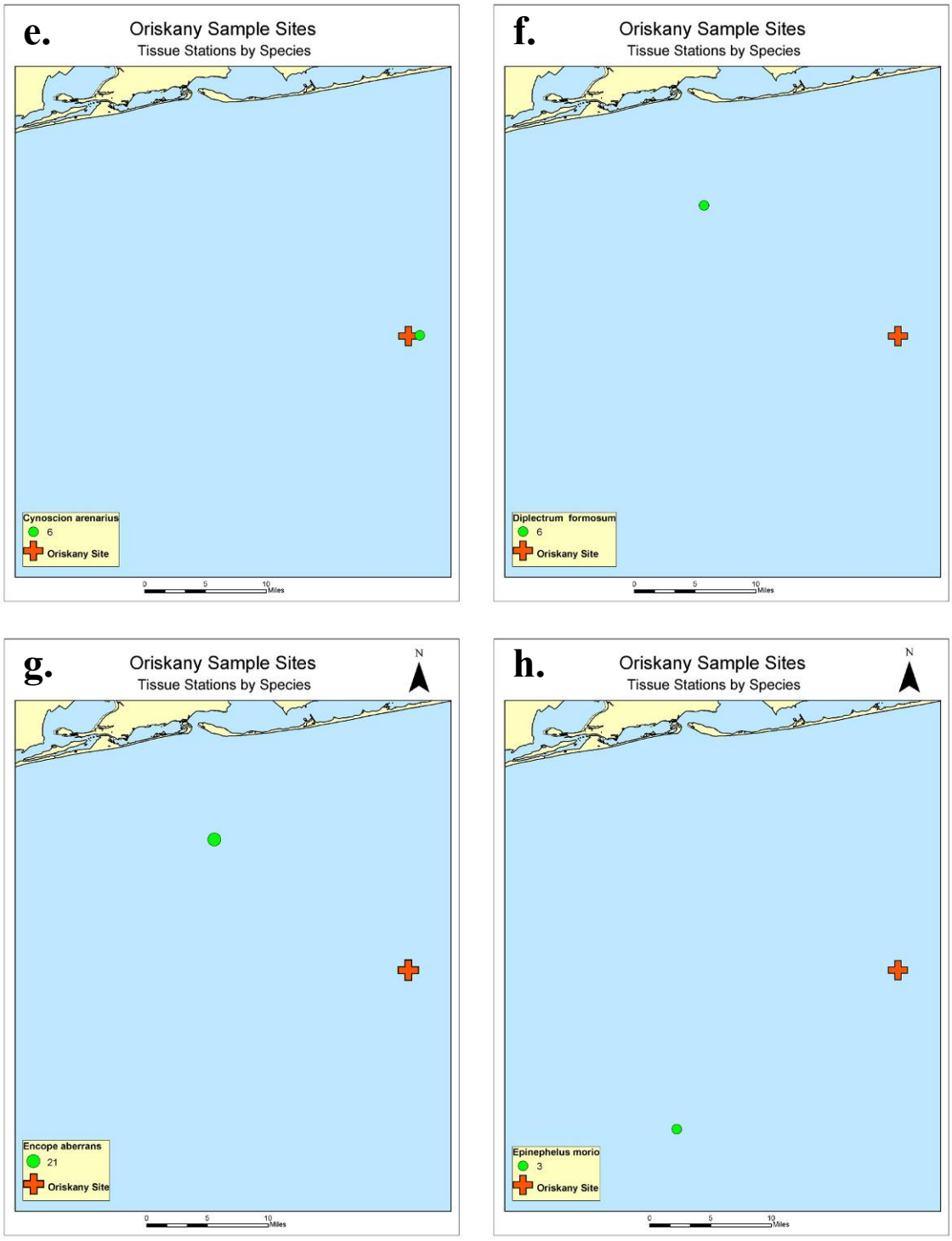

Figure 11 (continued). Sampling locations and number of individuals (in legend) for species analyzed for PCB tissue concentrations. e. sand seatrout, *Cynoscion arenarius*. f. sand perch, *Diplectrum formosum*. g. sand dollar, *Encope aberrans*. h. red grouper, *Epinephelus morio*.

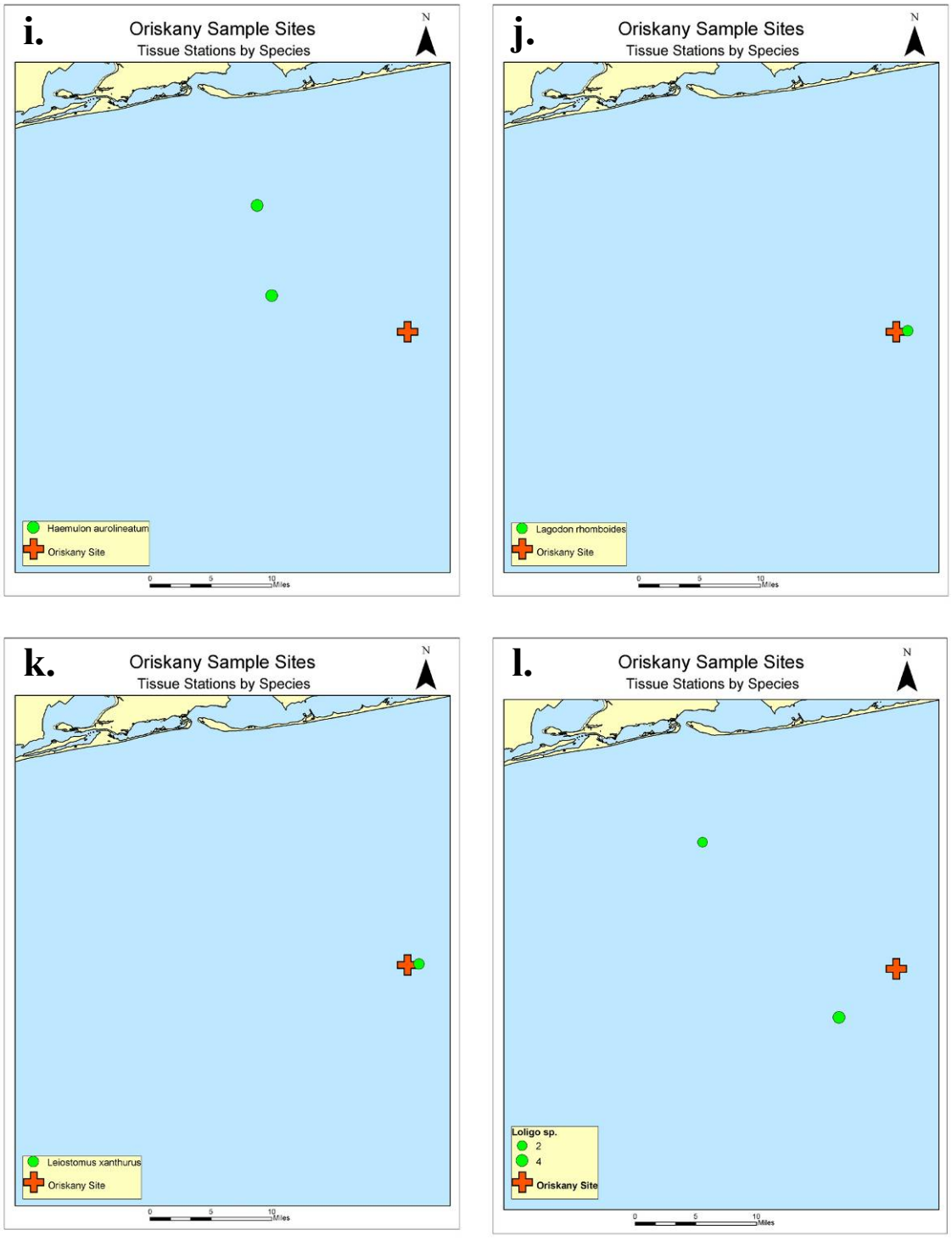

Figure 11 (continued). Sampling locations and number of individuals (in legend) for species analyzed for PCB tissue concentrations. i. tomtate, *Haemulon aurolineatum*. j. pinfish, *Lagodon rhomboides*. k. spot, *Leiostomus xanthurus*, l. squid, *Loglio* sp.

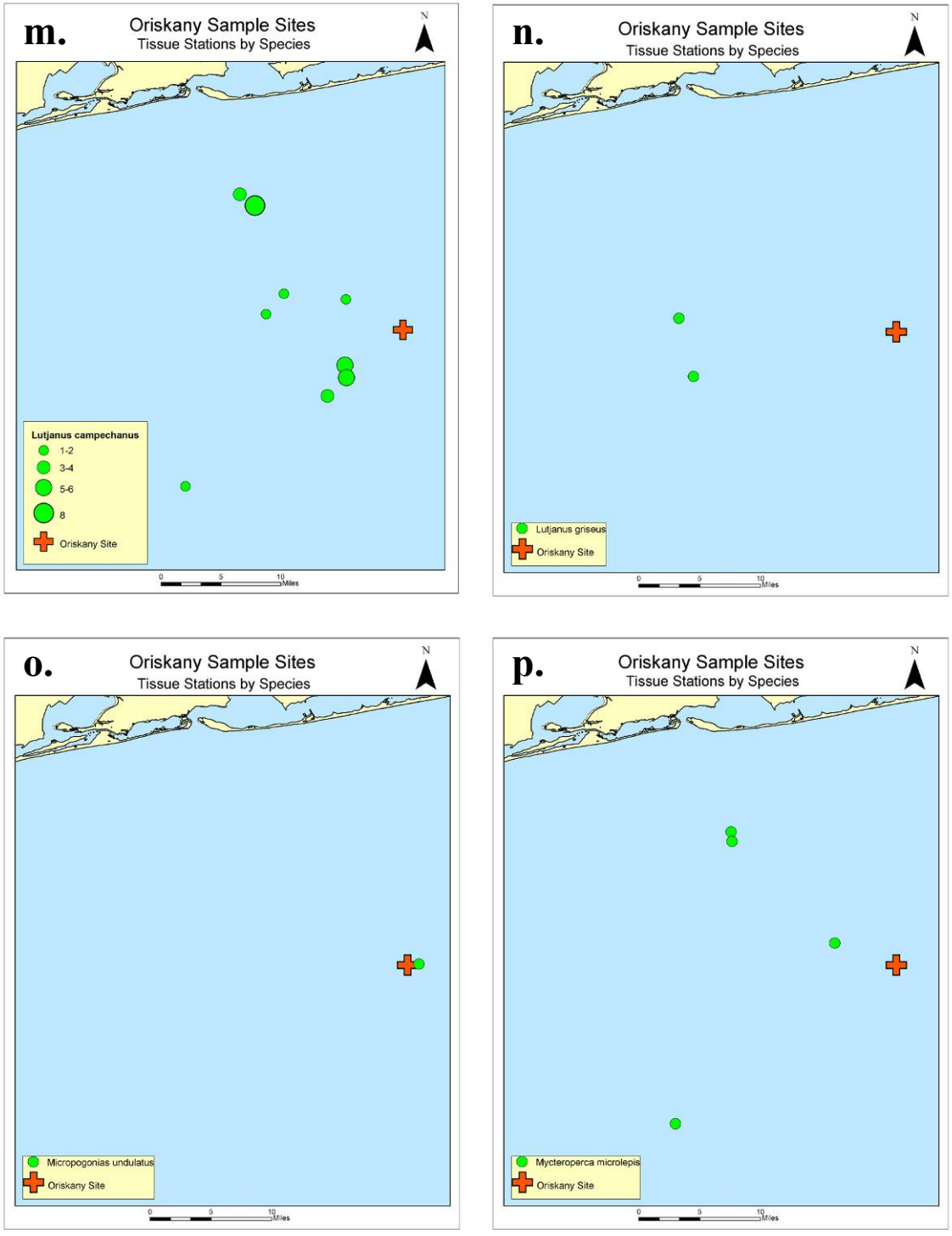

Figure 11 (continued). Sampling locations and number of individuals (in legend) for species analyzed for PCB tissue concentrations. m. red snapper, *Lutjanus campechanus*. n. gray snapper, *Lutjanus griseus*. o. Atlantic croaker, *Micropogonias undulatus*. p. gag grouper, *Mycteroperca microlepis*.

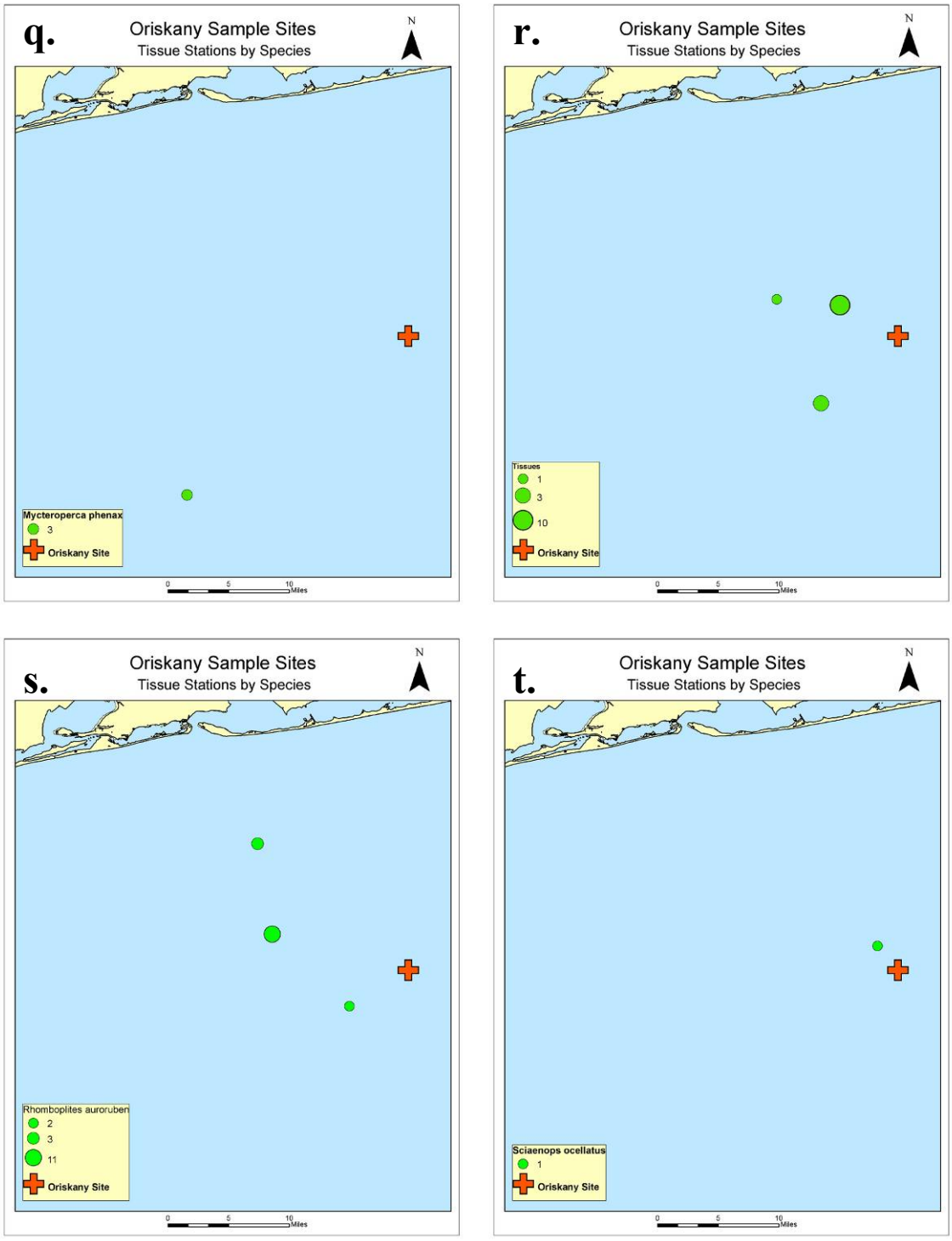

Figure 11 (continued). Sampling locations and number of individuals (in legend) for species analyzed for PCB tissue concentrations. q. scamp grouper, *Mycteroperca phenax*. r. red porgy, *Pagrus pagrus*. s. vermilion snapper, *Rhombolites aurorubens*. t. red drum, *Sciaenops ocelatus*.

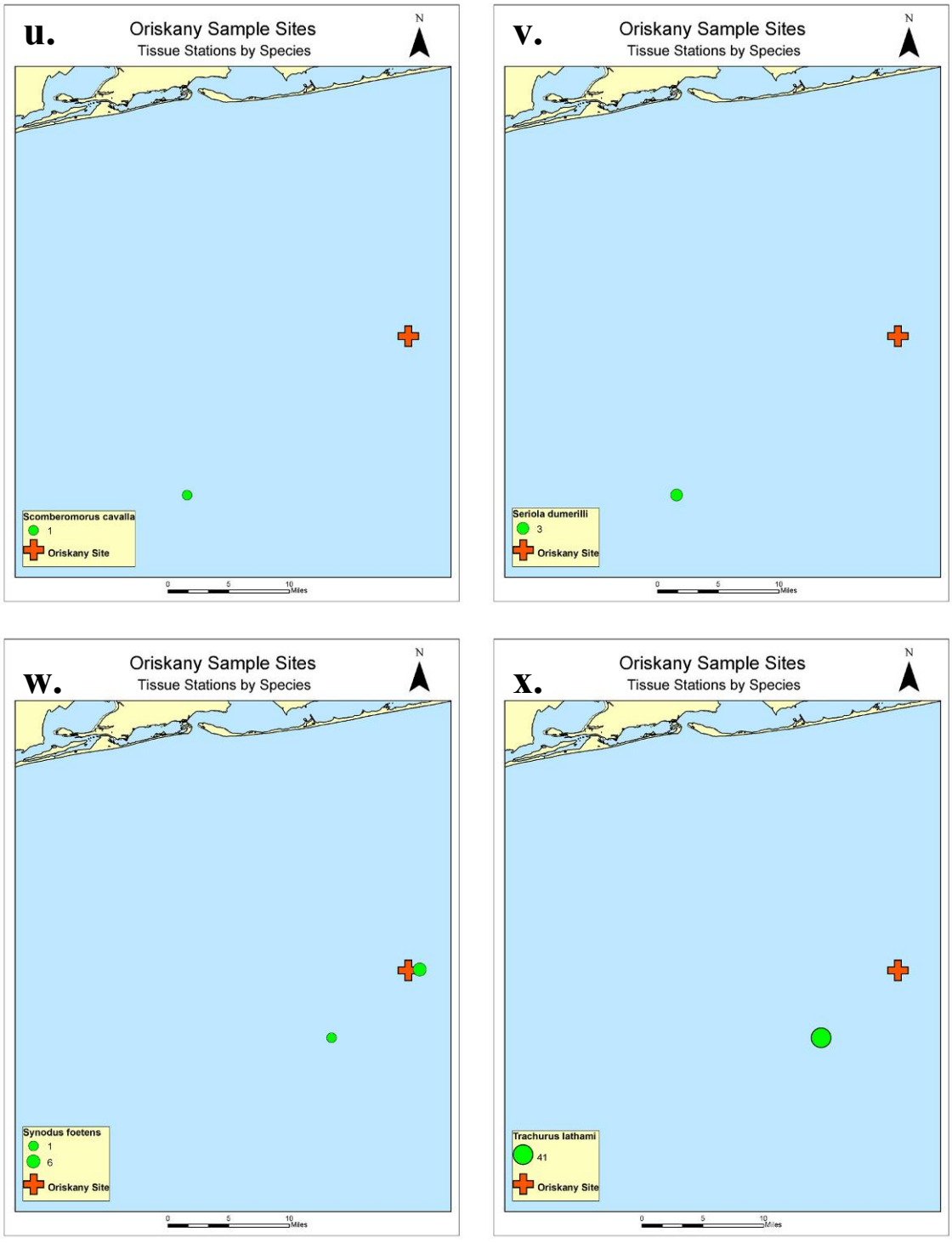

Figure 11 (concluded). Sampling locations and number of individuals (in legend) for species analyzed for PCB tissue concentrations. u. king mackerel, *Scomberomorus cavalla*. v. amberjack, *Seriola dumerilli*. w. inshore lizardfish, *Synodus foetens*. x. round scad, *Trachurus lathami*.

Table 13. Results of diet analysis for fish composites. Diet percentages of predominant prey categories are given; Un-ID = unidentified prey and Un-ID = unidentified invertebrate prey. Data are not available for composites denoted NA (poor preservation) or SE (stomach everted).

Sample ID	Common Name	Un-ID	Fish	Decapoda	Cephalopoda	Other Inverts	Un-ID Invert
GrayTrig-1	Gray Triggerfish	0	0.57	0.43	0	0	0
GrayTrig-2	Gray Triggerfish	0.05	0	0	0	0.95	0
GrayTrig-3	Gray Triggerfish	0	0	1	0	0	0
GrayTrig-4	Gray Triggerfish	0.28	0.32	0	0.05	0.35	0
GrayTrig-5	Gray Triggerfish	0	0	0.37	0	0.1	0.53
WhBPorgy-1	Whitebone Porgy	1	0	0	0	0	0
BankSeaBass-1	Bank Seabass	0	0.66	0.34	0	0	0
BankSeaBass-2	Bank Seabass	NA	NA	NA	NA	NA	NA
SandSeatrout-1	Sand Seatrout	0.5	0.5	0	0	0	0
Sandperch-1	Sandperch	0	0.86	0.14	0	0	0
RedGrouper-1	Red Grouper	0	0	1	0	0	0
RedGrouper-2	Red Grouper	0	0.88	0.12	0	0	0
RedGrouper-3	Red Grouper	1	0	0	0	0	0
Tomtate-1	Tomtate	0.61	0.17	0	0.22	0	0
Tomtate-2	Tomtate	0.42	0.58	0	0	0	0
Pinfish-1	Pinfish	0.16	0.81	0.02	0	0.01	0
Spot-1	Spot	0.61	0	0.3	0	0.09	0
RedSnapper-1	Red Snapper	SE	SE	SE	SE	SE	SE
RedSnapper-2	Red Snapper	0	0.88	0.12	0	0	0
RedSnapper-3	Red Snapper	0	0	0	1	0	0
RedSnapper-4	Red Snapper	1	0	0	0	0	0
RedSnapper-5	Red Snapper	1	0	0	0	0	0
RedSnapper-6	Red Snapper	1	0	0	0	0	0
RedSnapper-7	Red Snapper	0	0	1	0	0	0
RedSnapper-8	Red Snapper	0	0	1	0	0	0
RedSnapper-9	Red Snapper	1	0	0	0	0	0
RedSnapper-10	Red Snapper	0	0.46	0	0.54	0	0
RedSnapper-11	Red Snapper	0	0	1	0	0	0
RedSnapper-12	Red Snapper	0	1	0	0	0	0
RedSnapper-13	Red Snapper	0	1	0	0	0	0
RedSnapper-14	Red Snapper	1	0	0	0	0	0
RedSnapper-15	Red Snapper	0.8	0	0.2	0	0	0
RedSnapper-16	Red Snapper	0	0	1	0	0	0
RedSnapper-17	Red Snapper	1	0	0	0	0	0
GraySnapper-1	Gray Snapper	1	0	0	0	0	0
GraySnapper-2	Gray Snapper	1	0	0	0	0	0
AtlCroaker-1	Atlantic Croaker	0.92	0	0.08	0	0	0
Gag-1	Gag	0	1	0	0	0	0
Gag-2	Gag	1	0	0	0	0	0
Gag-3	Gag	0	1	0	0	0	0
Gag-4	Scamp	0	0	0	0	1	0
Scamp-1	Scamp	1	0	0	0	0	0
Scamp-2	Scamp	1	0	0	0	0	0
Scamp-3	Scamp	1	0	0	0	0	0
RedPorgy-1	Red Porgy	0.5	0	0.25	0.25	0	0
RedPorgy-2	Red Porgy	1	0	0	0	0	0
RedPorgy-3	Red Porgy	NA	NA	NA	NA	NA	NA
VerSnapper-1	Vermilion Snapper	0	0	0	0	0.69	0.31
VerSnapper-2	Vermilion Snapper	1	0	0	0	0	0
VerSnapper-3	Vermilion Snapper	0.78	0.11	0	0.11	0	0
VerSnapper-4	Vermilion Snapper	0.33	0.67	0	0	0	0
Redfish-1	Redfish	1	0	0	0	0	0
KingMack-1	King Mackerel	1	0	0	0	0	0
Amberjack-1	Greater Amberjack	1	0	0	0	0	0
Amberjack-2	Greater Amberjack	0	1	0	0	0	0
Lizardfish-1	Inshore Lizardfish	NA	NA	NA	NA	NA	NA
Lizardfish-2	Inshore Lizardfish	0.33	0.02	0	0.65	0	0
RoundScad-1	Round Scad	0.49	0.05	0	0	0.07	0.4

Table 14. Results of IR-MS analysis of International Atomic Energy Agency standard reference material samples run concurrently with study samples.

Analyte	IAEA SRM	Accepted Value ‰	n	Mean Analysis Value ‰ (± SD)
$\delta^{15}N_{Air}$	NBS-1577b, Bovine Liver	7.65	17	7.64 ± (0.11)
$\delta^{15}N_{Air}$	IAEA-R007, Ammonium Sulfate N1	0.40	6	0.47 ± (0.09)
$\delta^{15}N_{Air}$	IAEA-R007, Ammonium Sulfate N2	20.30	5	20.50 ± (0.05)
$\delta^{13}C_{V\text{-}PBD}$	NBS-1577b, Bovine Liver	-21.60	17	-21.60 ± (0.06)
$\delta^{13}C_{V\text{-}PBD}$	IAEA-CH-6, Cane Sugar	-10.43	8	-10.42 ‰ (± 0.03)
$\delta^{13}C_{V\text{-}PBD}$	IA-R005, IA-Beet Sugar	-26.03	8	-26.00 ‰ (± 0.05)
$\delta^{34}S_{V\text{-}CDT}$	IA-R027, Whale Baleen	16.30	16	16.59 ‰ (± 0.22)
$\delta^{34}S_{V\text{-}CDT}$	IA-R036, Barium Sulfate	20.74	15	20.76 ‰ (± 0.14)

Table 15. Results of duplicate IR-MS analysis of fish and invertebrate tissue samples.

Duplicate Samples	Mean Difference in $\delta^{13}C$‰	SD ‰	Mean Difference in $\delta^{15}N$ ‰	SD ‰	Mean Difference in $\delta^{34}S$‰	SD ‰
19	0.00	0.105	-0.01	0.054	-0.01	0.134

Stable isotope analysis of fish and invertebrate tissue samples revealed information about their trophic ecology not available from stomach content analysis, which suffered from small sample size and identification issues related to digestion. Reef fishes showed a trend in trophic position from planktivorous vermilion snapper to piscivorous gag and amberjack, as the latter two species were approximately two trophic levels above vermilion snapper (Figure 12A). Trophic position tended to increase with fish size (Figure 12B), but vermilion snapper trophic position was relatively low regardless of size. Vermilion snapper, as planktivores, clearly had pelagic $\delta^{34}S$ signatures (Figure 12C). Red snapper prey resources were intermediate between pelagic and benthic, while amberjack and large groupers consumed mostly benthic prey. There was a less clear trend in pelagic versus benthic prey resources with increasing fish size (Figure 12D).

Stable isotope signatures of non-reef fishes and invertebrates also were informative relative to their trophic position. The one sand dollar sample had C and N signatures consistent with an algal diet (Figure 13A). However, the sample was insufficient to analyze for S (Figure 13C), thus no information is available to infer a pelagic phytoplankton versus a benthic microphytobenthos carbon source. All other invertebrate samples had pelagic S signatures, as did the single king mackerel sample. The king mackerel had an intermediate $\delta^{13}C$ value, which, combined with its gut contents and S signature, indicated a pelagic prey base likely consisting of planktivorous fishes.

Table 16. Results of IR-MS analysis of fish and invertebrate tissue samples. NA = Not Analyzed.

Sample ID	Species	Taxa	$\delta^{15}N$ ‰	$\delta^{13}C$‰	$\delta^{34}S$‰
Scallop-1	*Argopectin gibbus*	Invert	10.81	-18.3	19.51
GrayTrig-1	*Balistes capriscus*	Fish	12.67	-17.44	19.06
GrayTrig-2	*Balistes capriscus*	Fish	12.64	-17.21	19.48
GrayTrig-3	*Balistes capriscus*	Fish	NA	NA	NA
GrayTrig-4	*Balistes capriscus*	Fish	12.71	-17.88	19.39
GrayTrig-5	*Balistes capriscus*	Fish	11.46	-17.21	18.28
WhBPorgy-1	*Calamus lecosteus*	Fish	12.54	-16.38	18.92
BankSeaBass-1	*Centropristis ocyura*	Fish	10.8	-17.94	19.98
BankSeaBass-2	*Centropristis ocyura*	Fish	9.26	-17.82	18.92
SandSeatrout-1	*Cynoscion arenarius*	Fish	NA	NA	NA
Sandperch-1	*Diplectrum formosum*	Fish	11.54	-17.25	17.78
SandDollar-1	*Encope aberrans*	Invert	6.37	-20.12	NA
RedGrouper-1	*Epinephelus morio*	Fish	12.84	-17.24	18.12
RedGrouper-2	*Epinephelus morio*	Fish	12.33	-16.36	17.65
RedGrouper-3	*Epinephelus morio*	Fish	12.99	-16.69	18.63
Tomtate-1	*Haemulon aurolineatum*	Fish	11.81	-16.93	17.22
Tomtate-2	*Haemulon aurolineatum*	Fish	12.62	-17.13	-17.11
Pinfish-1	*Lagadon rhomboides*	Fish	10.57	-17.64	16.9
Spot-1	*Leiostomus xanthurus*	Fish	12.71	-18.22	15.02
Squid-1	*Loglio sp.*	Invert	10.25	-19.3	20.44
Squid-2	*Loglio sp.*	Invert	10.58	-18.81	19.43
RedSnapper-1	*Lutjanus campechanus*	Fish	12.67	-17.69	19.89
RedSnapper-2	*Lutjanus campechanus*	Fish	NA	NA	NA
RedSnapper-3	*Lutjanus campechanus*	Fish	12.7	-17.63	20.08
RedSnapper-4	*Lutjanus campechanus*	Fish	NA	NA	NA
RedSnapper-5	*Lutjanus campechanus*	Fish	12.57	-17.37	19.12
RedSnapper-6	*Lutjanus campechanus*	Fish	13.56	-16.6	19.46
RedSnapper-7	*Lutjanus campechanus*	Fish	13.23	-16.62	17.98
RedSnapper-8	*Lutjanus campechanus*	Fish	12.53	-17.23	18.95
RedSnapper-9	*Lutjanus campechanus*	Fish	12.54	-17.04	18.47
RedSnapper-10	*Lutjanus campechanus*	Fish	13.05	-17.8	18.61
RedSnapper-11	*Lutjanus campechanus*	Fish	13.7	-16.91	18.67
RedSnapper-12	*Lutjanus campechanus*	Fish	13.65	-17.1	18.79
RedSnapper-13	*Lutjanus campechanus*	Fish	NA	NA	NA
RedSnapper-14	*Lutjanus campechanus*	Fish	NA	NA	NA
RedSnapper-15	*Lutjanus campechanus*	Fish	NA	NA	NA
RedSnapper-16	*Lutjanus campechanus*	Fish	11.8	-17.48	19
RedSnapper-17	*Lutjanus campechanus*	Fish	13.21	-16.76	17.36
GraySnapper-1	*Lutjanus griseus*	Fish	12.73	-17.26	14.28
GraySnapper-2	*Lutjanus griseus*	Fish	13.86	-16.87	17.36
AtlCroaker-1	*Micropongonias undulatus*	Fish	12.42	-18.28	17.04
Gag-1	*Mycteroperca microlepis*	Fish	13.08	-16.36	16.96
Gag-2	*Mycteroperca microlepis*	Fish	14.09	-16.46	14.83
Gag-3	*Mycteroperca microlepis*	Fish	12.62	-16.73	17.86
Gag-4	*Mycteroperca microlepis*	Fish	13.17	-16.67	16.5
Scamp-1	*Mycteroperca phenax*	Fish	13.44	-16.93	18.77
Scamp-2	*Mycteroperca phenax*	Fish	12.8	-17.47	19.92
Scamp-3	*Mycteroperca phenax*	Fish	12.59	-17.48	19.07
RedPorgy-1	*Pagrus pagrus*	Fish	11.82	-17.58	18.46
RedPorgy-2	*Pagrus pagrus*	Fish	12.84	-16.94	17.34
RedPorgy-3	*Pagrus pagrus*	Fish	12.12	-17.42	18.64
VerSnapper-1	*Rhomboplites aurorubens*	Fish	11.87	-18.3	19.72
VerSnapper-2	*Rhomboplites aurorubens*	Fish	11.54	-18.25	19.92
VerSnapper-3	*Rhomboplites aurorubens*	Fish	NA	NA	NA
VerSnapper-4	*Rhomboplites aurorubens*	Fish	12.64	-18.03	19.65
Redfish-1	*Sciaenops ocelatus*	Fish	11.38	-17.51	14.17
KingMack-1	*Scoberomorus cavalla*	Fish	12.63	-18.88	19.67
Amberjack-1	*Seriola dumerilli*	Fish	13.99	-16.37	17.05
Amberjack-2	*Seriola dumerilli*	Fish	13.31	-16.94	17.62
Lizardfish-1	*Synodus foetens*	Fish	13.06	-16.6	16.16
Lizardfish-2	*Synodus foetens*	Fish	NA	NA	NA
RoundScad-1	*Trachurus lathami*	Fish	9.66	-20.02	19.16

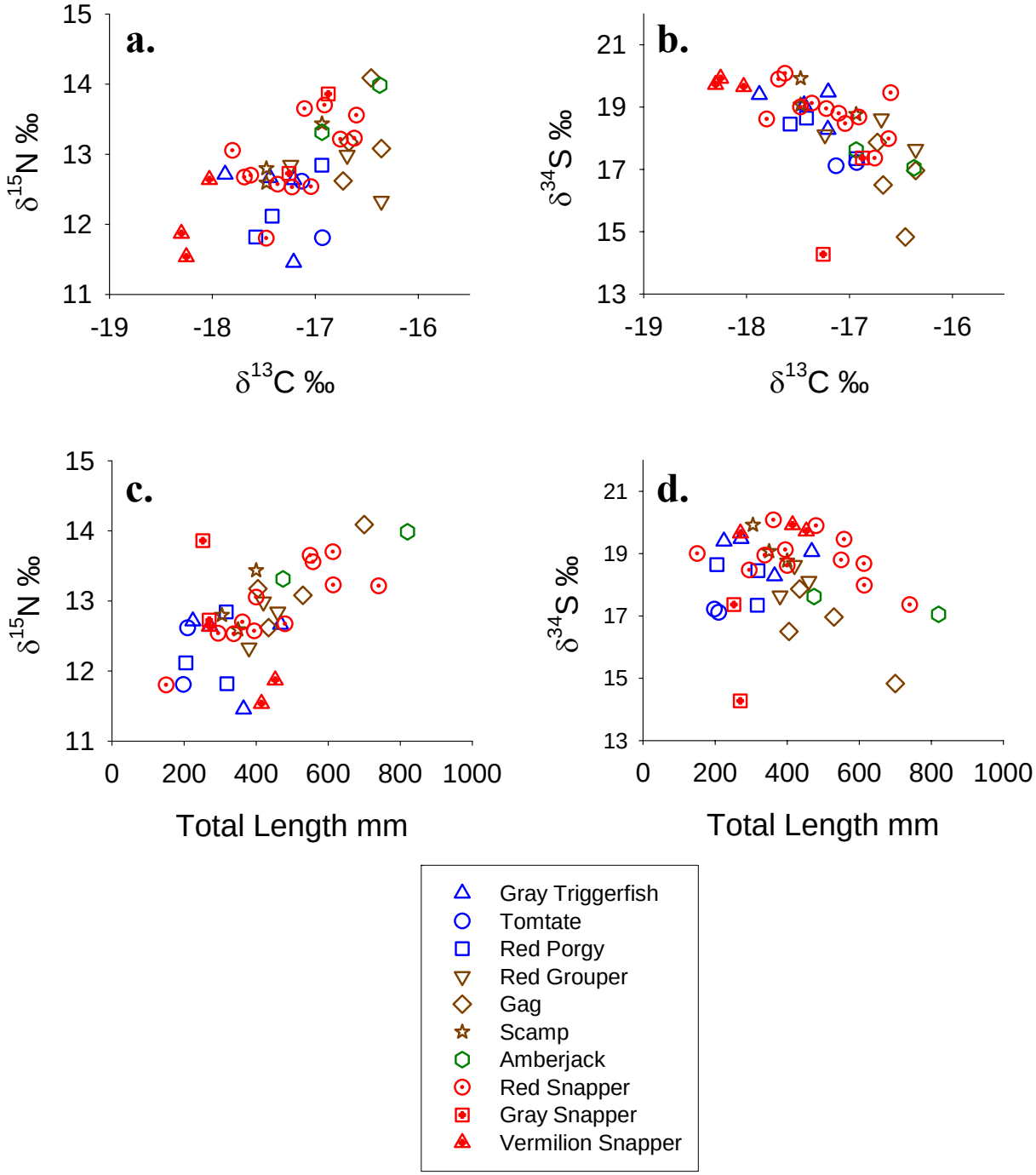

Figure 12. Plots of stable isotope ratio data for reef fishes.

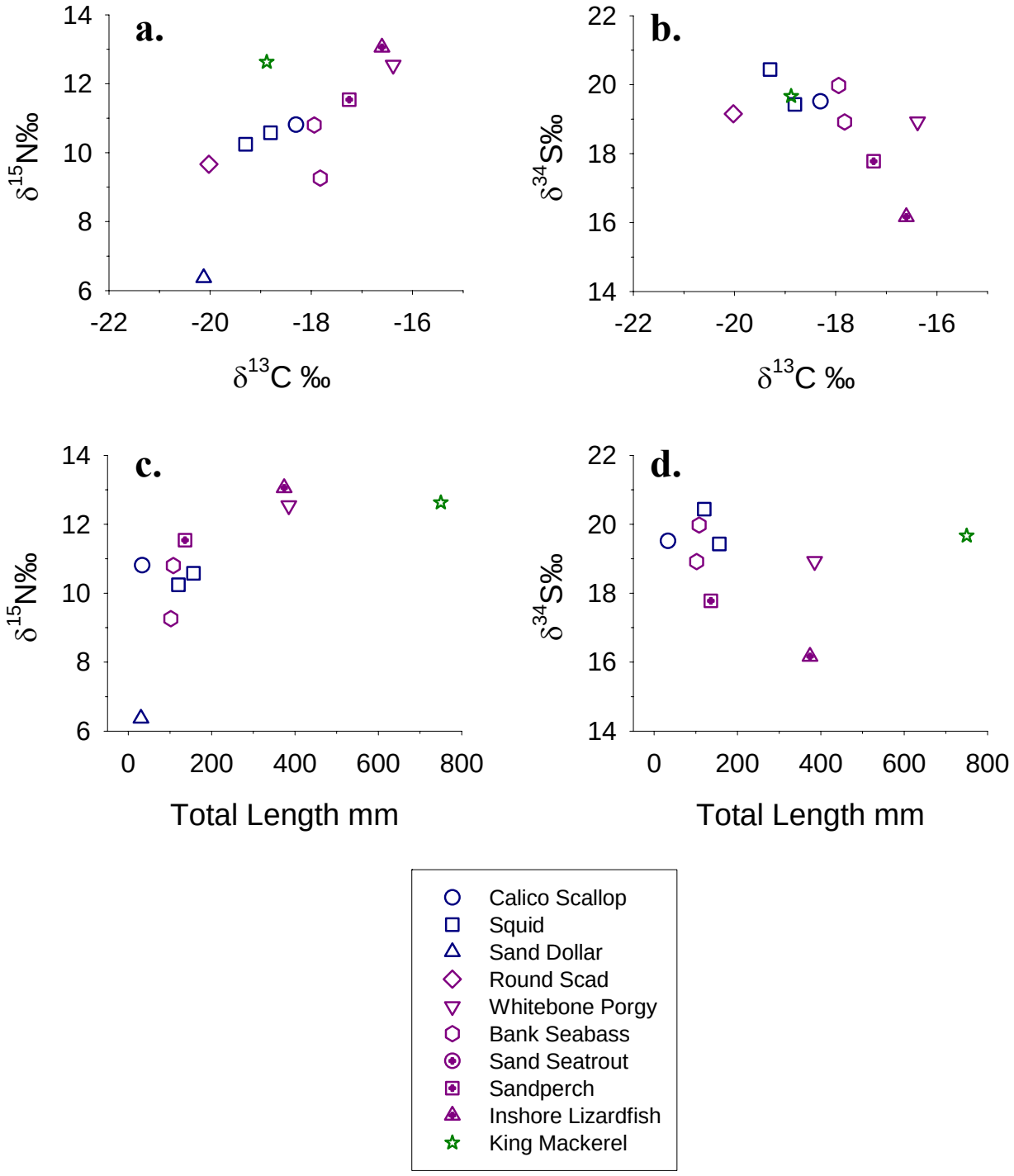

Figure 13. Plots of stable isotope ratio data for non-reef fishes and invertebrates.

Fish and Invertebrate PCB analysis

Precision estimates for PCB analysis were within acceptable limits with the exception of 1 of 4 intra-lab duplicates (060406G1 and 060406ZZ2; RPD 82.6%) and 2 of 7 between lab duplicates (060516D3 and 060516D3-A, 96.7%; 060516E1 and 060516E1-A, 77.12%). Despite the high variance in these samples, the data were accepted. The low levels of PCBs found in the samples makes relatively small differences in measurements seem dramatic when in reality, differences between these samples is not great from a regulatory point of view. For duplicates with high variability, differences between samples for individual congers was proportional for all detected forms, and analytical reporting limits were consistent between samples.

Table 17. Precision estimates for tissue PCB analysis

Sample ID	Duplicate Match	ΣPCBs µg kg^{-1}	Mean	SD	RPD
Blind Duplicates					
060516A1	060516ZZ1	0.2444			
060516ZZ1	060516A1	0.3233	0.2839	0.05574	27.77%
060407O4	060407ZZ3	5.2781			
060407ZZ3	060407O4	4.7858	5.0319	0.34814	9.78%
060516G2	060516ZZ4	9.3039			
060516ZZ4	060516G2	9.7520	9.5280	0.31689	4.70%
060406G1	060406ZZ2	1.2679			
060406ZZ2	060406G1	0.5268	0.8973	0.52408	82.60%
Cross-Lab Duplicates					
060516C1	060516C1-A	2.6166			
060516C1-A	060516C1	3.2104	2.9135	0.41986	20.38%
060406B1	060406B1-A	0.5442			
060406B1-A	060406B1	0.7310	0.6376	0.13207	29.29%
060516E1	060516E1-A	0.1441			
060516E1-A	060516E1	0.3249	0.2345	0.12787	77.12%
060516D3	060516D3-A	0.6326			
060516D3-A	060516D3	1.8160	1.2243	0.83677	96.67%
060407N1	060407N1-A	1.0318			
060407N1-A	060407N1	1.1615	1.0966	0.09173	11.83%
060407A5	060407A5-A	4.8037			
060407A5-A	060407A5	4.2918	4.5478	0.36192	11.25%
060407A7	060407A7-A	4.6464			
060407A7-A	060407A7	6.1121	5.3793	1.03638	27.25%

PCB content of tissue samples is listed in Table 18. The distribution of PCB congers by homologs (degree of chlorination) is presented in Figure 14, along with the homolog composition of commercial Arochlors for comparison. No obvious patterns of similarity are visually apparent, nor are there any similarities by cluster analysis (of individual congeners or homologs) related to species or trophic status. Although some studies have shown pattern matching to sources, several factors contribute to obscuring source patterns in biota. The low levels of PCBs in most of these samples results in many congeners being non-detects, affecting the overall pattern. Biological partitioning can shift proportions of congers in profiles. Multiple sources may blend to confuse patterns in biota. Selective degradation may also shift the proportions of congeners. Many of these factors may be accentuated by the distance from sources of PCBs, resulting in attenuation and mixing by transport and biological activity.

Table 18. Tissue sample characteristics and PCB concentrations by wet mass of invertebrates and skin-off fillets of fish lateral musculature. Sample size (n) indicates tissue from a single individual was analyzed or a composite of tissue from several individuals (n >1) was analyzed.

Sample ID	n	Mean TL mm	Mean Mass g	Mean Age	Age Mode	PCB µg/kg ND = 1/2 RL	TEQ_P µg/kg ND = 1/2 RL	PCB µg/kg ND = 0	TEQ_P µg/kg ND = 0	% Lipid
Amberjack-1	1	820	9330	3	3	9.2656	0.1658	9.2530	0.1658	0.5
Amberjack-2	1	475	2030	1	1	9.3039	0.2857	9.2878	0.2837	0.2
AtlCroaker-1	13	202.38	98.22	1.25	1	1.8246	0.0395	1.8068	0.0177	1
BankSeaBass-1	18	108.17	42.64	0.61	1	0.3529	0.0298	0.3160	0.0022	0
BankSeaBass-2	13	102	35.65	0.5	0	0.4364	0.0546	0.4078	0.0524	0.3
Gag-1	1	530	1890	3	3	2.0362	0.0459	2.0096	0.0187	0.1
Gag-2	1	700	4670	4	4	22.5725	0.4727	22.5604	0.1175	0.7
Gag-3	1	435	840	2	2	2.4448	0.0675	2.4265	0.4707	0.1
Gag-4	1	405	1230	2	2	2.1777	0.0434	2.1583	0.0214	0.2
GraySnapper-1	1	270	510	3	3	1.6499	0.0776	1.6274	0.0756	0.5
GraySnapper-2	1	252	420	2	2	1.2285	0.0397	1.2062	0.0178	0.6
GrayTrig-1	1	468	1800	5	5	0.3430	0.0327	0.3073	0.0078	0.1
GrayTrig-2	1	272	460	3	3	0.3739	0.0300	0.3390	0.0028	0.2
GrayTrig-3	1	353	940	4	4	0.2085	0.0246	0.1778	0.0027	0.2
GrayTrig-4	3	224.67	486.67	2.67	3	0.2444	0.0260	0.2151	0.0041	0.2
GrayTrig-5	1	365	1790	6	6	0.1441	0.0234	0.1127	0.0016	0.3
KingMack-1	1	750	5090	6	6	92.0700	2.3139	92.0626	2.3119	6
Lizardfish-1	1	374	640	6	6	0.2758	0.0228	0.2438	0.0008	0.8
Lizardfish-2	6	208	92.23	4.4	4	0.3743	0.0222	0.3464	0.0005	0.5
Pinfish-1	15	140.07	75.12	2.08	2	2.3580	0.0569	2.3375	0.0370	0.6
Redfish-1	1	796	4630	2	2	1.8908	0.0458	1.8723	0.0239	0.3
RedGrouper-1	1	460	1720	6	6	12.6143	0.2486	12.5981	0.2287	0.2
RedGrouper-2	1	380	2690	6	6	2.7301	0.0490	2.7095	0.0272	0.2
RedGrouper-3	1	420	1780	6	6	0.6326	0.0295	0.6069	0.0078	0.3
RedPorgy-1	5	319	384.72	4.5	3	1.2679	0.0437	1.2443	0.0240	0.5
RedPorgy-2	1	317	435	5	5	2.4261	0.0909	2.4087	0.0908	0.4
RedPorgy-3	3	205	248.77	2.33	2	0.0000	0.0000	0.0000	0.0000	0.1
RedSnapper-1	1	480	1520	5	5	3.6200	0.1238	3.6043	0.1218	1.5
RedSnapper-10	1	400	960	3	3	1.9211	0.0520	1.8962	0.0458	0.1
RedSnapper-11	1	613	3400	4	4	4.8037	0.1007	4.7902	0.0270	0.5
RedSnapper-12	1	550	2300	3	3	4.6464	0.1175	4.6336	0.0987	0.2
RedSnapper-13	2	295	480	2	2	2.0401	0.0718	2.0221	0.0110	0.2
RedSnapper-14	3	336.67	770	3	3	5.2781	0.0674	5.2634	0.0698	1.7
RedSnapper-15	6	153.33	131.29	1	1	0.7828	0.0404	0.7528	0.0129	0.2
RedSnapper-16	4	150.5	122.87	1	1	0.0000	0.0000	0.0000	0.0000	0.6
RedSnapper-17	1	740	5680	5	5	2.8694	0.0662	2.8477	0.0412	0
RedSnapper-2	1	652	3690	4	4	3.0257	0.1181	3.0080	0.1181	0.1
RedSnapper-3	1	362	652.8	3	3	0.9713	0.0314	0.9488	0.0097	0.7
RedSnapper-4	1	401	920	2	2	0.9099	0.0306	0.8898	0.0093	0.1
RedSnapper-5	1	395	780	2	2	1.8036	0.0395	1.7878	0.0180	0.1
RedSnapper-6	1	558	2610	6	6	2.9024	0.0844	2.8861	0.0824	1.7
RedSnapper-7	1	614	316	2	2	2.8451	0.0486	2.8208	0.0212	0.1
RedSnapper-8	1	338	550	3	3	1.4432	0.0405	1.4193	0.0189	0.7
RedSnapper-9	1	295	380	3	3	0.6778	0.0299	0.6537	0.0079	0.4
RoundScad-1	41	NR	NR	0.71	0	1.2568	0.0383	1.2323	0.0106	0.1
SandDollar-1	25	30.15	1.05	NA	NA	0.4071	0.0225	0.3790	0.0005	0.3
Sandperch-1	6	136	75.13	2.17	2	1.3733	0.0808	1.3484	0.0788	0.8
SandSeatrout-1	6	205.5	151.33	2	2	4.3440	0.0665	4.3269	0.0445	1.3
Scallop-1	23	33.28	9.03	NA	NA	0.2726	0.0286	0.2361	0.0013	0.3
Scamp-1	1	400	570	4	4	2.6166	0.0806	2.5989	0.0787	2.2
Scamp-2	1	305	570	4	4	0.3764	0.0255	0.3480	0.0034	0.1
Scamp-3	1	350	90	4	4	0.9334	0.0518	0.9097	0.0497	0.1
Spot-1	15	152.67	91.41	1.47	1	1.0396	0.0347	1.0156	0.0128	0.6
Squid-1	4	120.25	58.91	NA	NA	0.0002	0.0000	0.0000	0.0000	0.3
Squid-2	2	156.5	99.25	NA	NA	2.6134	0.0535	2.5919	0.0320	1.2
Tomtate-1	10	198.1	124.02	2.89	3	1.4012	0.0418	1.3761	0.0145	0
Tomtate-2	11	210.18	139.45	3.27	3	1.0318	0.0383	1.0019	0.0753	0.2
VerSnapper-1	1	453	1180	4	4	0.5442	0.0251	0.5243	0.0055	1
VerSnapper-2	1	415	980	3	3	0.5003	0.0228	0.4737	0.0009	0.8
VerSnapper-3	11	181.27	86.94	3.63	3	1.3265	0.0719	1.3033	0.0699	1.5
VerSnapper-4	3	270.33	333.68	3.33	3	3.1081	0.0773	3.0951	0.0476	1.5
WhBPorgy-1	1	385	970	4	4	1.6436	0.0539	1.6212	0.0340	0.2

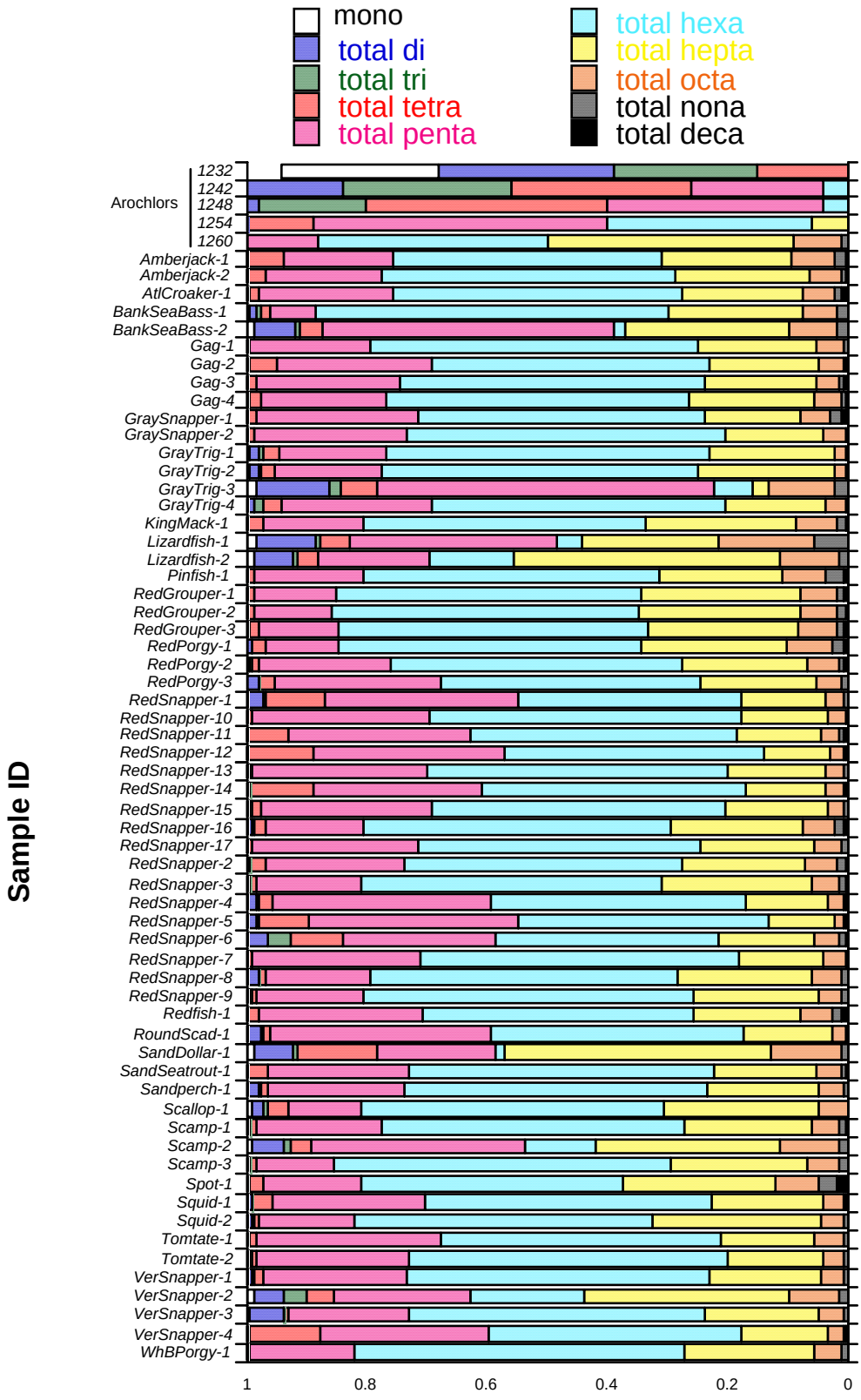

Figure 14. Percent composition of total PCBs (ND=0) by homologs in fish and invertebrate tissues. Arochlor data from DeGrandechamp and Barron (2005).

Two samples exceeded the total PCB screening value of 20 μg kg^{-1} (US EPA, 2000), a king mackerel at 92.1 μg kg^{-1} and a gag grouper at 22.6 μg kg^{-1}. The TEQ screening value for Dioxin-like activity (0.26 ng kg^{-1}; US EPA, 2000) was exceeded by four samples, the above two fish at 2.31 and 0.47, respectively, and an amberjack at 0.29, and a red grouper at 0.47. The extremely high levels measured in king mackerel are a cause for concern, and may indicate transport of PCBs from inshore to offshore habitats as that species seasonally enters the southern reaches of Pensacola Bay.

Correlation analysis was used to examine relationships between fish size, trophic position, and percent lipid in muscle tissue and PCB loads (Tables 19-25). Plots of these variables provide visual confirmation of these patterns (Figures 15-19). PCB content and the TEQ_P calculation were highly correlated for all analyses, suggesting the co-planar, Dioxin-like PCB congeners were a constant proportion of the PCB loads, with the exception of some specimens like the Amberjack and Red Grouper noted earlier that exceed the TEQ_P screening value but not the total PCB screening value

For all specimens (Table 19; Figure 15), length, mass, age, $\delta^{15}N$, and $\delta^{13}C$ were significantly correlated will one another, with some variable pairs being highly (i.e., $r > 0.7$) correlated. Lipid content was correlated with age but that correlation was weak ($r = 0.29$). Lipid content was highly correlated with ΣPCB concentration and TEQ_P, but those correlations were driven by high lipid content in muscle of the one king mackerel sampled. Muscle lipid content was not correlated with PCB load when the king mackerel sample was removed form the correlation analysis (Table 20). Interestingly, the strength of correlations between age and mass increased when the king mackerel was omitted, and N and C stable isotope ratios were significantly but weakly correlated with PCB load.

Similar patterns were found for analysis of reef fishes only (Table 21; Figure 16), where fish length and mass were significantly correlated with PCB load. PCB load also was significantly but weakly correlated with $\delta^{15}N$ and $\delta^{13}C$. For non-reef species, however, few significant correlations existed (Table 22; Figure 17). This was most likely due to low levels of PCBs in these organisms. The highest PCB load in this category was for a single pinfish sample, a fish that recruits and matures in estuarine environments before moving offshore with ontogeny.

Sufficient sample sizes existed to examine PCB correlations independently for grouper and snappers. Analysis of correlations for all grouper species indicated several significant correlations existed (Table 23; Figure 18), although single gag and red groupers with elevated PCB loads clearly influenced the analysis relative to the trend of the other samples. Analysis for all snapper species revealed several significant correlations existed among the measured variables (Table 24; Figure 19). Perhaps the most interesting result from correlation analysis on snapper samples is the relatively strong correlation between trophic position ($\delta^{15}N$ value) and PCB concentration. Trophic position increased with size/age which in turn was significantly correlated with PCB concentration, thus indicating bioaccumulation with age. Those trends and significant correlations are present throughout the data, but are most evident in taxa for which higher sample sizes were collected. For example, patterns of bioaccumulation with size and trophic position are clearly apparent in grouper (Figure 18) and snapper data (Figures 19 and 20). It should be stressed, however, that some groupers and snappers sampled can live several decades and most fish we sampled were relatively small, young individuals.

Table 19. Correlation matrix of variables measured in all fish and invertebrate samples (n = 62) analyzed during pre-sinking assessment of PCB distribution and concentration in northern Gulf of Mexico marine fauna. Pearson's *r* and the significance value are provided for each variable pair. Significance probabilities ≤ 0.05 are highlighted.

	Mass	Age	$\delta^{15}N$	$\delta^{13}C$	$\delta^{34}S$	Lipid	ΣPCB	TEQ_P
Length	0.845 <0.001	0.408 0.002	0.602 <0.001	0.468 <0.001	0.047 0.742	0.188 0.146	0.391 0.002	0.369 0.003
Mass		0.327 0.013	0.387 0.005	0.319 0.020	0.014 0.921	0.189 0.145	0.424 <0.001	0.396 0.002
Age			0.380 0.007	0.304 0.037	0.004 0.815	0.290 0.027	0.262 0.047	0.252 0.055
$\delta^{15}N$				0.746 <0.001	-0.106 0.455	0.098 0.486	0.136 0.332	0.116 0.470
$\delta^{13}C$					-0.164 0.244	-0.226 0.103	-0.143 0.309	-0.226 0.103
$\delta^{34}S$						0.107 0.449	0.0426 0.764	0.047 0.739
Lipid							0.799 <0.001	0.805 <0.001
ΣPCB								0.996 <0.001

Table 20. Correlation matrix of variables measured in fish and invertebrate samples (n = 61) analyzed during pre-sinking assessment of PCB distribution and concentration in northern Gulf of Mexico marine fauna. King mackerel were omitted from the analysis. Pearson's *r* and the significance value are provided for each variable pair. Significance probabilities ≤ 0.05 are highlighted.

	Mass	Age	$\delta^{15}N$	$\delta^{13}C$	$\delta^{34}S$	Lipid	ΣPCB	TEQ_P
Length	0.831 <0.001	0.364 0.006	0.618 <0.001	0.587 <0.001	0.032 0.826	-0.062 0.638	0.466 <0.001	0.452 <0.001
Mass		0.276 0.040	0.396 0.004	0.433 <0.001	-0.003 0.981	-0.092 0.483	0.519 <0.001	0.486 <0.001
Age			0.387 0.006	0.417 0.003	0.020 0.895	0.168 0.212	0.105 0.422	0.092 0.482
$\delta^{15}N$				0.776 <0.001	-0.108 0.450	0.126 0.372	0.350 0.011	0.335 0.015
$\delta^{13}C$					-0.158 0.278	-0.055 0.700	0.289 0.038	0.286 0.040
$\delta^{34}S$						0.112 0.435	-0.044 0.757	-0.037 0.798
Lipid							0.105 0.422	0.092 0.482
ΣPCB								0.959 <0.001

Table 21. Correlation matrix of variables measured in all reef fish samples (n = 44) analyzed during pre-sinking assessment of PCB distribution and concentration in northern Gulf of Mexico marine fauna. Pearson's *r* and the significance value are provided for each variable pair. Significance probabilities ≤ 0.05 are highlighted.

	Mass	Age	$\delta^{15}N$	$\delta^{13}C$	$\delta^{34}S$	Lipid	ΣPCB	TEQ_P
Length	0.826 <0.001	0.389 0.010	0.622 <0.001	0.461 <0.004	0.141 0.406	-0.012 0.938	0.481 0.001	0.459 0.002
Mass		0.486 0.001	0.465 0.004	0.443 0.006	0.071 0.678	-0.071 0.651	0.524 <0.001	0.520 <0.001
Age			0.022 0.899	0.149 0.387	0.058 0.737	0.176 0.258	0.198 0.203	0.217 0.162
$\delta^{15}N$				0.599 <0.001	-0.059 0.729	0.151 0.372	0.472 0.003	0.454 0.005
$\delta^{13}C$					-0.161 0.342	-158 0.352	0.324 0.050	0.282 0.091
$\delta^{34}S$						0.141 0.405	-0.039 0.817	-0.031 0.855
Lipid							0.134 0.387	0.150 0.332
ΣPCB								0.976 <0.001

Table 22. Correlation matrix of variables measured in all non-reef fish samples (n = 14) analyzed during pre-sinking assessment of PCB distribution and concentration in northern Gulf of Mexico marine fauna. Pearson's *r* and the significance value are provided for each variable pair. Significance probabilities ≤ 0.05 are highlighted.

	Mass	Age	$\delta^{15}N$	$\delta^{13}C$	$\delta^{34}S$	Lipid	ΣPCB	TEQ_P
Length	0.956 <0.001	0.301 0.318	0.242 0.474	0.322 0.335	-0.022 0.948	-0.100 0.745	-0.004 0.991	0.289 0.338
Mass		0.048 0.877	0.018 0.958	0.125 0.715	-0.026 0.940	-0.170 0.580	0.052 0.865	0.438 0.135
Age			0.695 0.012	0.741 0.006	-0.246 0.441	0.127 0.665	-0.160 0.586	-0.295 0.307
$\delta^{15}N$				0.567 0.055	-0.354 0.260	0.379 0.225	-0.919 0.776	-0.284 0.371
$\delta^{13}C$					-0.198 0.538	0.076 0.814	-0.019 0.953	0.149 0.644
$\delta^{34}S$						0.117 0.716	0.054 0.868	0.127 0.695
Lipid							0.247 0.394	0.141 0.632
ΣPCB								0.562 0.037

Table 23. Correlation matrix of variables measured in grouper samples (n=11) analyzed during pre-sinking assessment of PCB distribution and concentration in northern Gulf of Mexico marine fauna. Pearson's *r* and the significance value are provided for each variable pair. Significance probabilities ≤ 0.05 are highlighted.

	Mass	Age	$\delta^{15}N$	$\delta^{13}C$	$\delta^{34}S$	Lipid	ΣPCB	TEQ_P
Length	0.774 0.005	-0.085 0.815	0.901 <0.001	0.811 0.003	-0.787 0.004	0.110 0.747	0.683 0.021	0.667 0.025
Mass		0.0261 0.467	0.584 0.059	0.0980 0.021	-0.829 0.002	-0.005 0.988	0.793 0.004	0.762 0.006
Age			-0.195 0.589	-0.099 0.785	0.265 0.460	0.031 0.932	0.161 0.657	0.141 0.698
$\delta^{15}N$				0.7064 0.015	-617 0.043	0.351 0.289	0.544 0.084	0.544 0.084
$\delta^{13}C$					-714 0.014	0.067 0.844	0.280 0.404	0.240 0.477
$\delta^{34}S$						0.003 0.993	-0.702 0.016	-0.673 0.023
Lipid							0.133 0.696	0.171 0.616
ΣPCB								0.995 <0.001

Table 24. Correlation matrix of variables measured in snapper samples (n = 21) analyzed during pre-sinking assessment of PCB distribution and concentration in northern Gulf of Mexico marine fauna. Pearson's *r* and the significance value are provided for each variable pair. Significance probabilities ≤ 0.05 are highlighted.

	Mass	Age	$\delta^{15}N$	$\delta^{13}C$	$\delta^{34}S$	Lipid	ΣPCB	TEQ_P
Length	0.837 <0.001	0.619 0.003	0.443 0.097	0.381 0.161	0.099 0.724	-0.232 0.311	0.497 0.022	0.409 0.065
Mass		0.656 0.001	0.412 0.127	0.362 0.184	-0.021 0.940	-0.212 0.356	0.455 0.038	0.481 0.027
Age			0.236 0.398	0.093 0.742	0.225 0.420	0.442 0.045	0.381 0.089	0.445 0.043
$\delta^{15}N$				0.748 0.001	-0.302 0.275	-0.200 0.476	0.654 0.008	0.462 0.083
$\delta^{13}C$					-.0426 0.114	-0.321 0.243	0.387 0.154	0.225 0.420
$\delta^{34}S$						-0.353 0.197	0.491 0.063	0.032 0.909
Lipid							0.178 0.440	0.216 0.347
ΣPCB								0.762 <0.001

Table 25. Correlation matrix of variables measured in red snapper samples (n = 17) anlayzed during pre-sinking assessment of PCB distribution and concentration in northern Gulf of Mexico marine fauna. Pearson's *r* and the significance value are provided for each variable pair. Significance probabilities ≤ 0.05 are highlighted.

	Mass	Age	$\delta^{15}N$	$\delta^{13}C$	$\delta^{34}S$	Lipid	ΣPCB	TEQ_P
Length	0.822 <0.001	0.703 0.004	0.838 0.003	0.595 0.070	-0.412 0.237	-0.100 0.722	0.552 0.033	0.493 0.062
Mass		0.719 0.003	0.591 0.072	0.412 0.236	-0.379 0.280	-0.099 0.725	0.452 0.091	0.515 0.049
Age			0.527 0.117	0.274 0.443	0.206 0.569	0.457 0.086	0.469 0.078	0.525 0.045
$\delta^{15}N$				0.535 0.111	-0.194 0.591	-0.073 0.841	0.760 0.011	0.399 0.252
$\delta^{13}C$					-0.450 0.192	-0.055 0.880	0.225 0.532	-0.119 0.743
$\delta^{34}S$						0.843 0.002	0.094 0.795	0.488 0.152
Lipid							0.274 0.324	0.403 0.137
ΣPCB								0.712 0.003

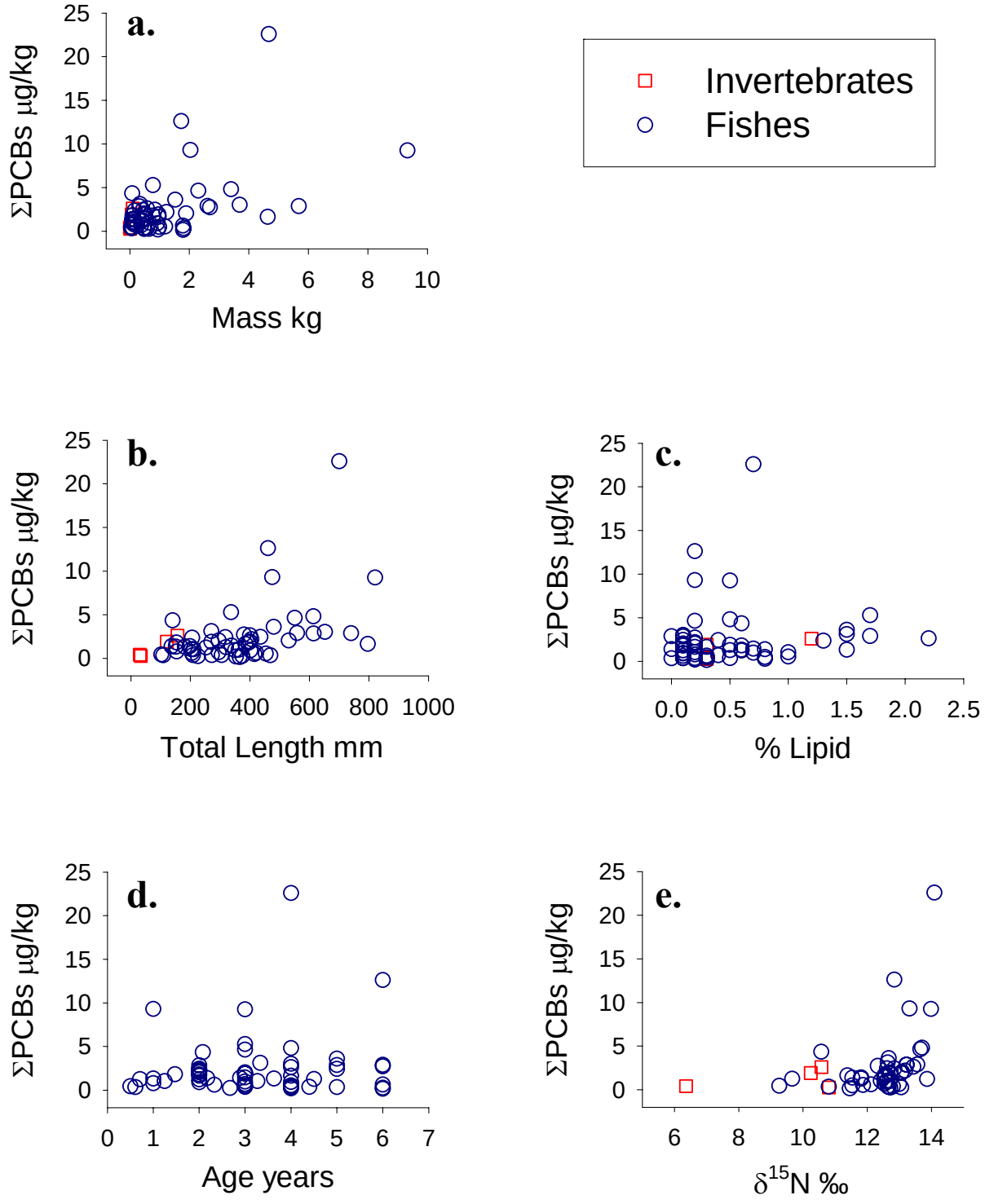

Figure 15. Plots of PCB body burdens in all fish and invertebrate samples as a function of (a) mass, (b) length, (c) %lipid, (d) age, and (e) nitrogen stable isotope ratios. King mackerel is excluded from plots.

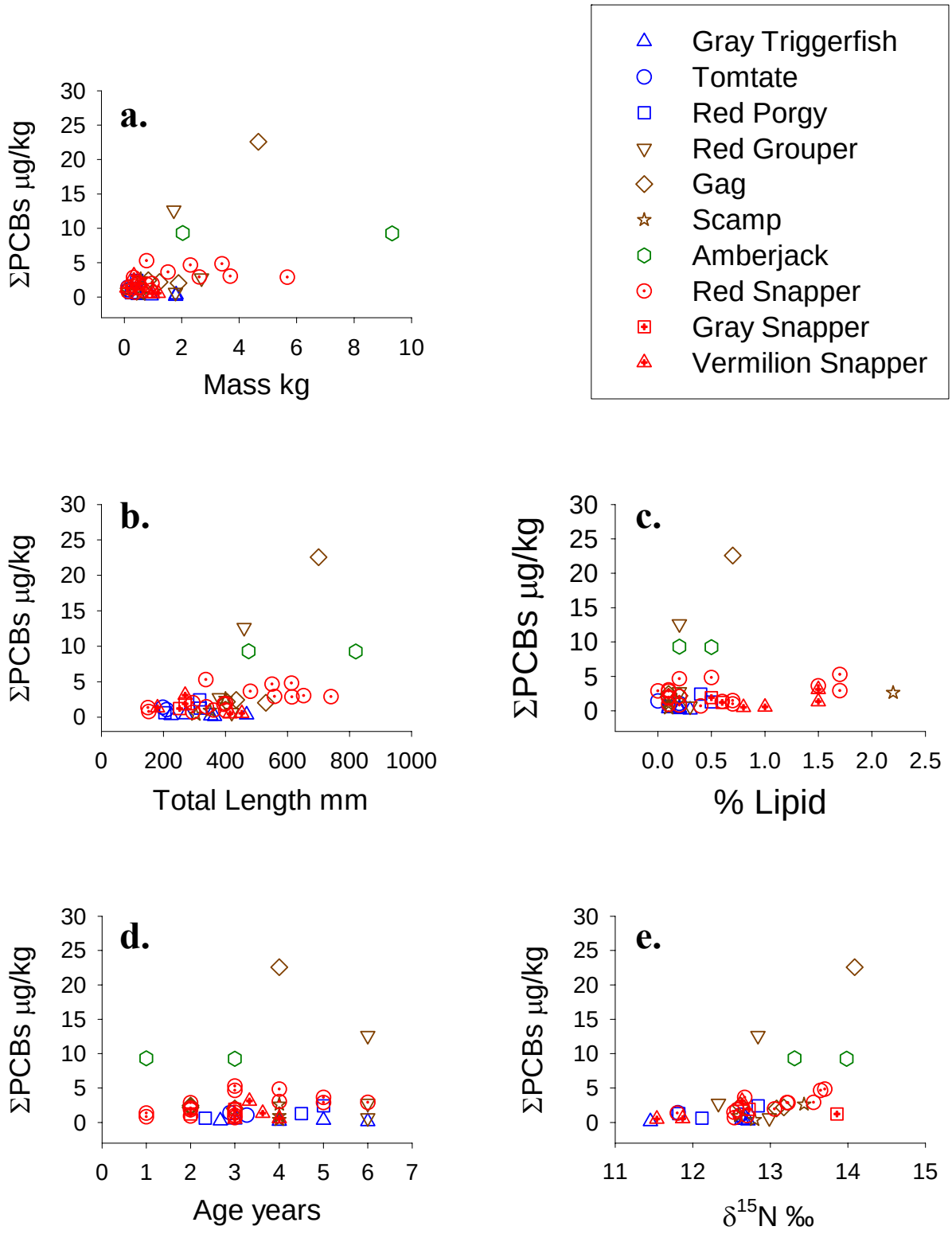

Figure 16. Plots of PCB body burdens in reef fish samples as a function of (a) mass, (b) length, (c) %lipid, (d) age, and (e) nitrogen stable isotope ratios.

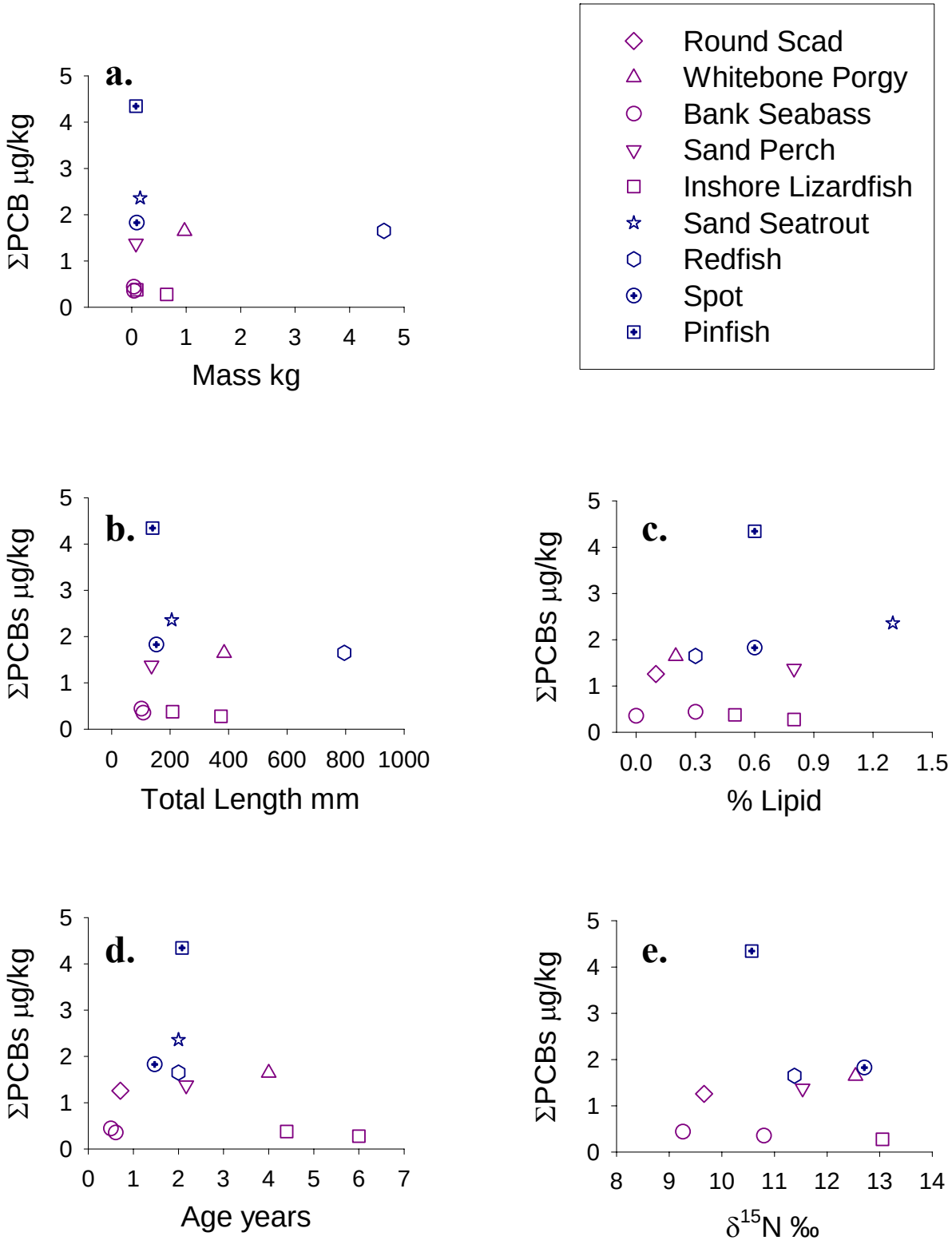

Figure 17. Plots of PCB body burdens in non-reef fish samples as a function of (a) mass, (b) length, (c) %lipid, (d) age, and (e) nitrogen stable isotope ratios King mackerel is excluded from plots.

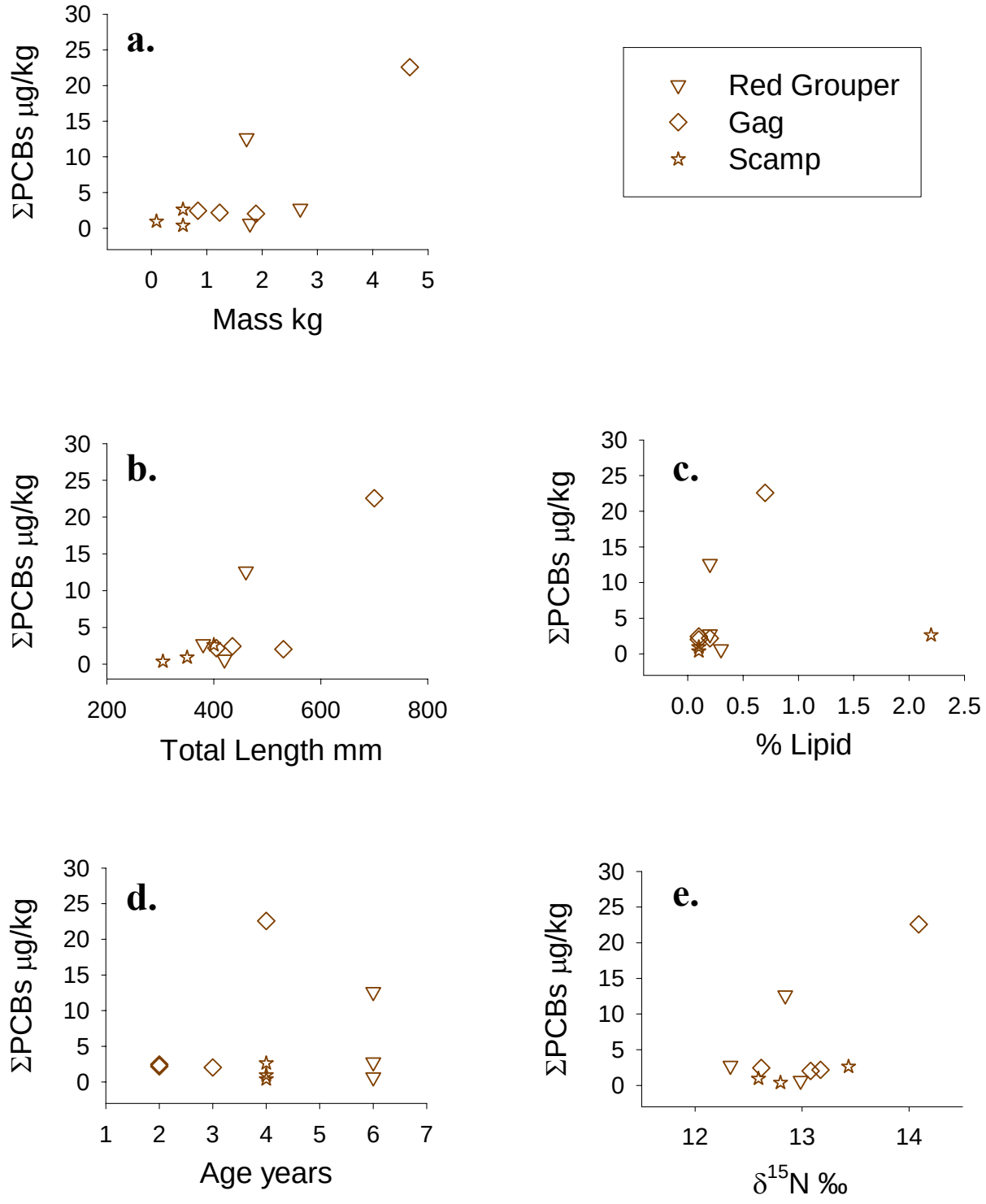

Figure 18. Plots of PCB body burdens in grouper samples as a function of (a) mass, (b) length, (c) %lipid, (d) age, and (e) nitrogen stable isotope ratios.

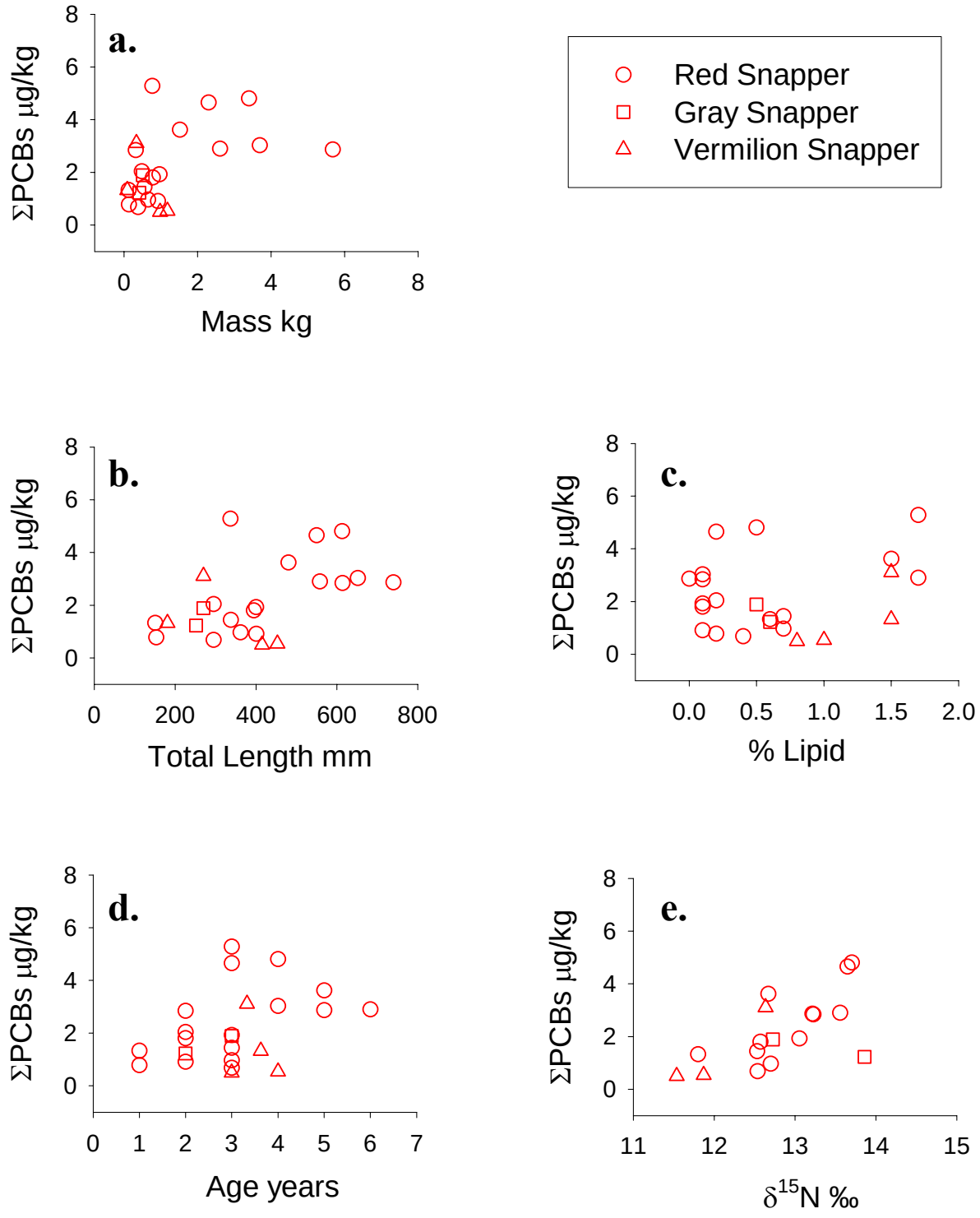

Figure 19. Plots of PCB body burdens in snapper samples as a function of (a) mass, (b) length, (c) %lipid, (d) age, and (e) nitrogen stable isotope ratios.

PCB concentration did not display a strong relationship with latitude which was used as a proxy for distance offshore (Figure 20). The king mackerel that had the highest PCB value among all samples was sampled farthest offshore. Other high PCB loads were measured in top-level predators, which is consistent with correlations between PCB concentration and trophic position. Although PCB concentration generally increased with latitude within taxa (Figure 20), which is especially apparent for red snapper data (Figure 20c), PCB concentration was not significantly correlated to latitude for non-reef species, reef species or even red snapper. King mackerel, whose sole representative had the highest PCB concentration, is a migratory coastal pelagic species which forages in coastal bays where PCB contamination is higher than in the offshore environment. It remains unknown whether reef fishes, like snappers and groupers display high enough site fidelity to individual reefs to impart a gradient of PCB body burdens across the shelf as a function of inshore sources, but the PCB data presented herein suggest that possibility.

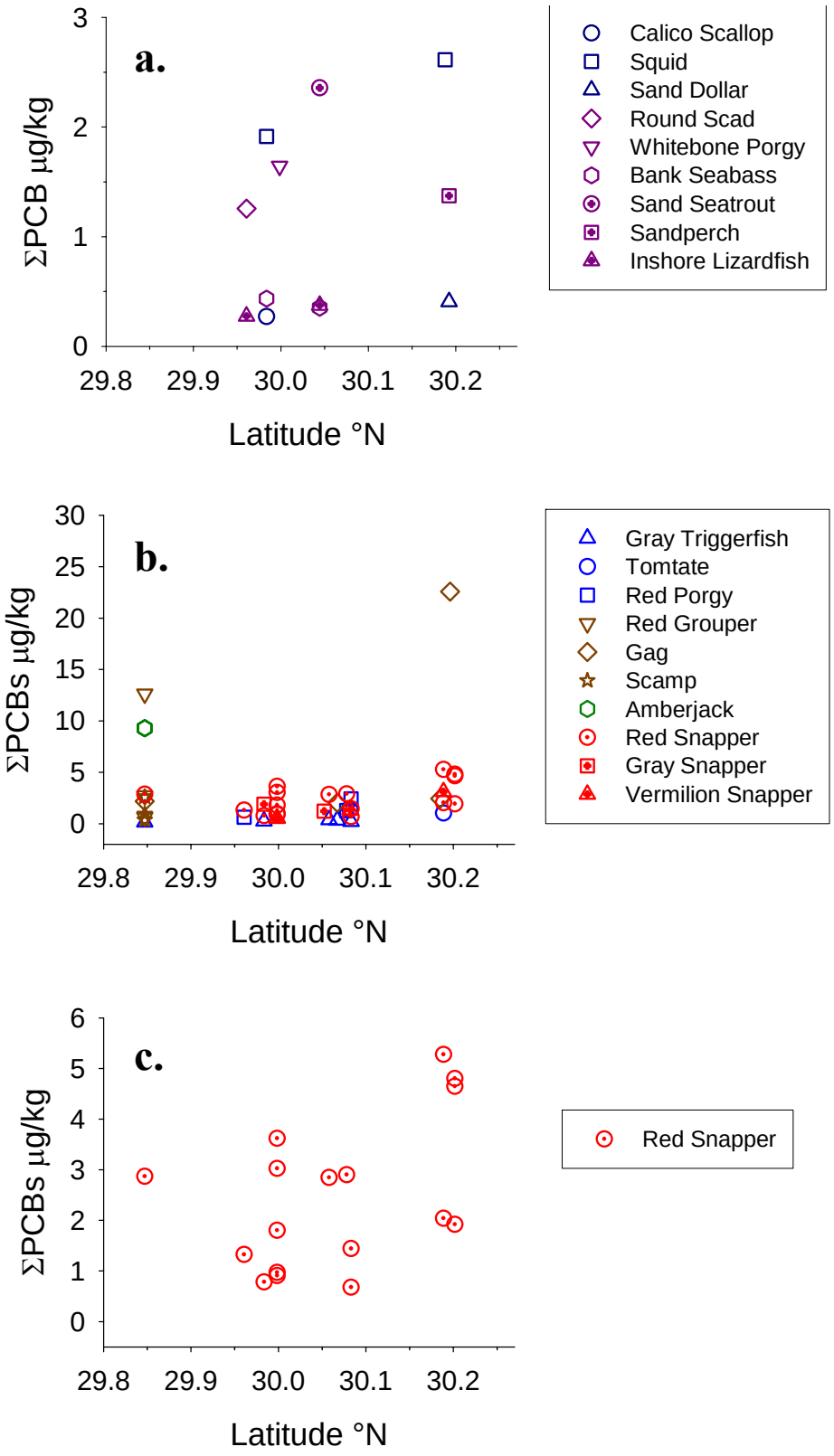

Figure 20. Fish and Invertebrate PCB data plotted by latitude. Data are separated by (a) all non-reef species, (b) reef species, and (c) red snapper only.

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