Analysis of edible tissue from white shrimp collected in coastal waters of the Gulf of Mexico potentially affected by Hurricane Katrina to determine recent exposure to persistent organic pollutants (POPs) and polycyclic aromatic compounds (PACs)

Margaret M. Krahn, Gina M. Ylitalo, Donald W. Brown and Tracy K. Collier
Environmental Conservation Division
Northwest Fisheries Science Center
NOAA Fisheries Service

Summary
Analyses for persistent organic pollutants (POPs; e.g., PCBs and DDTs) and polycyclic aromatic compounds (PACs; e.g., naphthalene, phenanthrene) have been completed for white shrimp collected during two cruises of the *F/V Patricia Jean* (13-19 September 2005 and 2-6 October 2005) and also for "pre-Katrina" reference shrimp from the commercial fishery.

The results showed that the shrimp collected after Hurricane Katrina, as well as the "pre-Katrina" shrimp, contained concentrations of POPs that were well below the FDA regulatory limits for seafood, and these concentrations were generally lower than the levels found in Atlantic croaker muscle sampled at the same time (Krahn *et al.*, 2005). Furthermore, the levels of POPs found in shrimp from the study area were similar to those reported for seafood from nonurban areas of the world. Polybrominated diphenyl ether (PBDE) flame retardants—thought to be associated with urban runoff—were detected at very low levels in a single sample, which suggested that the POPs detected in the shrimp samples were likely not a result of contamination released due to Hurricane Katrina.

The sum of PACs measured in the shrimp composites (both "pre-Katrina" and from the *F/V Patricia Jean* cruises) were low (below 25 ng/g). However, the Food and Drug Administration (FDA) provides no regulatory limits for PACs in seafood. For comparison, the PAC levels in the shrimp were similar to those measured in clams and mussels from nonurban areas. Additionally, the levels reported here are far lower than levels found in other crustacean species following major oil spills.

To look at temporal trends in POPs and PACs among samples collected before Hurricane Katrina, as well as in mid-September and early October, the mean concentrations of summed POPs and PACs in composite samples of shrimp collected from the three regions (Mobile Bay, Mississippi Sound and Lake Borgne) were statistically compared. Although the statistically significant increases in PCBs and chlordanes found for Lake Borgne shrimp in early October might be indicative of contamination released by Hurricane Katrina, concentrations of all POPs were still very low (<5 ng/g). Furthermore, shrimp from the three regions are showing no consistent increases in PACs that would be attributable to contamination released following Hurricane Katrina.

Introduction

Major concerns following Hurricane Katrina included risks to human health through consumption of contaminated seafood, as well as effects of contaminants on the health of living marine resources. During the cruises of the *F/V Patricia Jean* in coastal waters of the Gulf of Mexico (13-19 September 2005 and 2-6 October 2005), seafood species (i.e., shrimp, crab and fish) were sampled in order to measure chemical contaminant levels for determining suitability for consumption. The analyses for POPs and PACs in white shrimp from those samplings, as well as "pre-Katrina" samples from the commercial fishery, have now been completed.

POPs include several classes of pesticides and industrial chemicals (e.g., PCBs, chlordanes, DDTs) that can bioaccumulate to relatively high concentrations in top-level predators (e.g., fish and marine mammals) of the marine food web through trophic transfer. POPs enter the marine environment via several sources (e.g., atmospheric transport, terrestrial runoff) and are found in environmental samples from all over the world (de Wit *et al.*, 2004). A large body of evidence links POP exposure to a wide range of deleterious biological effects (e.g., immunosuppression, endocrine disruption) in marine animals (de Wit *et al.*, 2004; Meador *et al.*, 2002; O'Hara and O'Shea, 2001). Many of these POPs are toxic to wildlife and humans, thus a number of these compounds have been banned in the U.S. (e.g., DDTs 1972; PCBs for new uses 1970; lindane 1983; chlordanes 1988) (AMAP, 1998).

PBDEs are a class of "emerging" environmental contaminants that are quickly gaining the attention of regulatory agencies (de Wit, 2002). These compounds are added to plastics, textiles, clothing, electronic circuit boards and other materials as flame retardants. PBDEs are known to enter the environment through urban runoff and sewage outfalls and have been shown to bioaccumulate in marine animals (de Wit, 2002). A number of studies have shown that some PBDE congeners may induce toxicological effects in laboratory animals, including immune dysfunction, liver toxicity and thyroid disruption (de Wit, 2002).

PACs (e.g., phenanthrene, benzo[*a*]pyrene) are a class of chemical contaminants primarily derived from oil products or combustion of oil products. These compounds are frequently found in urban embayments and can alter physiological functions in marine biota (Johnson *et al.*, 2002). Concerns have been raised over the effects of exposure to PACs, alone or in combination with other toxic contaminants, on marine organisms because of the worldwide use of fossil fuels (Geraci and Aubin, 1990) and the occurrence of oil spills in areas that support populations of marine fish and invertebrates. Marine animals can be exposed to oil via various routes (e.g., consumption of contaminated prey, uptake via gills, direct contact with sediments) and rapidly take up PACs present in the environment. Fish efficiently metabolize PACs, and thus rarely contain substantial amounts of PACs in their edible muscle (Varanasi *et al.*, 1989). In contrast, invertebrate species have limited ability to metabolize PACs, so these compounds, if present in the environment, are comparatively more likely to accumulate in edible tissues of invertebrate species.

Methods

Station names and identification numbers for locations where white shrimp were captured during the *F/V Patricia Jean* cruises (13-19 September 2005 and 2-6 October 2005) are shown in Figure 1. In addition, "pre-Katrina" samples from the commercial fishery (collected from the Gulf of Mexico before the hurricane and frozen) were analyzed for comparison. Prior to analysis, the shrimp heads and shells were removed and the remaining edible portion (tail muscle) of 2-36 individual shrimp were composited. Then, the shrimp composite samples were extracted and analyzed for POPs and PACs using the method of Sloan *et al.* (2005).

This method involves: (1) extraction of tissue using methylene chloride in an accelerated solvent extraction procedure, (2) clean-up of the methylene chloride extract on a single stacked silica gel/alumina column, (3) separation of POPs and PACs from the bulk lipid and other biogenic material by high-performance size exclusion liquid chromatography, and (4) analysis on a low resolution quadrupole GC/MS system equipped with a 60-meter DB-5 GC capillary column. The instrument was calibrated using sets of up to ten multi-level calibration standards of known concentrations. Following this procedure, a total of 40 PCB and 10 PBDE congeners and 24 chlorinated pesticides were determined in these samples. Total lipid in the shrimp samples was measured by a thin-layer chromatography flame ionization method (Ylitalo *et al.*, 2005).

All contaminant concentrations in this document are reported in ng/g (parts per billion), wet weight. Sum PCBs is the sum of congeners 17, 18, 28, 31, 33, 44, 49, 52, 66, 70, 74, 82, 87, 95, 99, 101/90, 105, 110, 118, 128, 138/163/164, 149, 151, 153/132, 156, 158, 170, 171, 177, 180, 183, 187/159/182, 191, 194, 195, 199, 205, 206, 208, 209. Sum DDTs is the sum of *o,p*'-DDD, *p,p'*-DDD, *o,p*'-DDE, *p,p*'-DDE, *o,p*'-DDT and *p,p*'-DDT. Sum Chlordanes is the sum of oxychlordane, *gamma*-chlordane, nona-III-chlordane, *alpha*-chlordane, *trans*-nonachlor and *cis*-nonachlor. Sum hexachlorocyclohexanes (HCHs) is the sum of *alpha*-, *beta*-, and *gamma*-HCH isomers, and sum PBDEs is the sum of congeners 28, 47, 49, 66, 85, 99, 100, 153, 154, 183. Sum "low molecular weight PACs" (LMWACs) includes naphthalene, C1- through C4-naphthalenes, biphenyl, acenaphthylene, acenaphthene, fluorene, C1- through C3-fluorenes, phenanthrene, C1- through C4-phenanthrenes, dibenzothiophene, C1- through C3-dibenzothiophenes and anthracene. Sum "high molecular weight PACs" (HMWACs) includes fluoranthene, pyrene, C1-fluoranthenes/pyrenes, benz[a]anthracene, chrysene/ triphenylene, C1- through C4-chrysenes/ benz[*a*]anthracenes, benzo[*b*]fluoranthene, benzo[*j*]fluoranthenes/benzo[*k*]fluoranthene, benzo[*e*]pyrene, benzo[*a*]pyrene, perylene, idenopyrene, dibenz[*a,h*+*a,c*]anthracene, benzo[*ghi*]perylene. Total PACs is the sum of LMWACs and HMWACs.

All multivariate and univariate statistical analyses were conducted using JMP Statistical Discovery Software (Macintosh profession edition, version 5.01). Univariate comparisons between 2 group means were significance tested ($\alpha = 0.05$) using a 2-sample Student's *t*-test. Significant differences among multiple groups were evaluated using a Tukey HSD test ($\alpha = 0.05$). All values that were less than the limit of quantitation (<LOQ) were set to zero.

As part of performance-based laboratory quality assurance, quality control samples [a method blank, replicate and Standard Reference Materials (SRMs, e.g., NIST 1974a and 1946)] were analyzed with each sample set (Krahn *et al.*, 1988). Results for SRMs and other quality control samples met established laboratory criteria.

Results and Discussion

Persistent organic pollutants

A summary of the results obtained from analyzing for POPs in white shrimp (from the two *F/V Patricia Jean* cruises and the "pre-Katrina" samples) is presented in Table 1; results for each of the samples and individual analytes, as well as Quality Assurance tables, are available in Appendix 1. In all the shrimp composites, summed concentrations of POPs (i.e., the sums of PCBs, DDTs, chlordanes, HCHs and PBDEs) were below 5 ng/g (Table 1). The highest concentrations for sum PCBs (4.5 ng/g) and sum DDTs (1.8 ng/g) were found in the shrimp composite (9/13/2005) from station number 101 in Mobile Bay. Sum chlordanes was highest in the shrimp composite (9/14/2005) from station number 109 in Mississippi Sound (about 0.5 ng/g); sum HCHs and sum PBDEs were below limits of quantitation (< LOQ) in nearly all samples.

The concentrations found in the shrimp composites were also generally lower than the levels found in Atlantic croaker muscle sampled from Mississippi Sound at about the same time (Krahn *et al.*, 2005). Furthermore, the levels of POPs found in shrimp from the study area were similar to those reported for seafood from nonurban areas of the world, e.g., for pollock from remote areas of Alaska (Heintz *et al.*, 2004) and invertebrates (i.e., lobster tail muscle, blue mussel) from Johns Bay, Maine (Ylitalo *et al.*, 1999). PDBE flame retardants—thought to be associated with urban runoff—were only detected at very low levels in a single sample, suggesting that the POPs detected in the shrimp samples were not likely a result of contamination released as a result of Hurricane Katrina.

To look at temporal trends in POPs among samples (those collected before Hurricane Katrina, in mid-September and in early October), the mean concentrations of summed POPs (i.e., the sums of PCBs, DDTs, chlordanes, HCHs and PBDEs) in composite samples of shrimp collected from the three regions (Mobile Bay, Mississippi Sound and Lake Borgne) were statistically evaluated. Concentrations of POPs in shrimp from Mobile Bay and Mississippi Sound in October were not significantly different from those collected in September or pre-Katrina ($p<0.05$). However, for shrimp collected from Lake Borgne, mean sum PCBs were significantly higher in October compared to those collected pre-Katrina or in September and mean sum chlordanes were significantly higher in October compared to September, but were not different from those sampled before Katrina. Although the slight increases in concentrations of certain POPs in Lake Borgne might be suggestive of contamination released by Hurricane Katrina, the early October concentrations were still very low (<5 ng/g for sum PCBs and <0.25 ng/g for chlordanes).

The FDA has published regulatory guidelines for seafood safety as follows (wet weight): PCBs, 2,000 ng/g; DDTs, 5,000 ng/g; chlordanes, 300 ng/g (National Academy of

Sciences, 1991). There are no FDA guidelines available for HCHs or PBDEs. All the shrimp analyzed in the current study had concentrations of POPs (< 5 ng/g) well below the FDA regulatory guidelines.

Polycyclic aromatic compounds

A summary of the results from analyzing for PACs in white shrimp (from the two *F/V Patricia Jean* cruises and "pre-Katrina"), based on collection site and region, are presented in Table 2. Results for each of the samples and individual analytes, as well as Quality Assurance tables, are available in Appendix 2. From Table 2, it is apparent that sum PACs (sum LMWACs + sum HMWACs) were low (< 15 ng/g) in the white shrimp. LMWACs (petroleum-related PACs) were found in all shrimp samples and contributed more than 90% to the sum PACs. In contrast, a number of the shrimp composites contained concentrations of HMWACs (urban run-off related PACs) that were below the limits of quantitation for all compounds included in the sum (Table 2). Comparisons of PAC levels in white shrimp by collection region showed that the three regions (Mississippi Sound/Gulf of Mexico, Lake Borgne and Mobile Bay), as well as the "pre-Katrina" reference shrimp, all had mean sum PACs that were less than 15 ng/g.

PAC concentrations found in individual white shrimp composites were low (all less than 25 ng/g) compared to levels measured in other marine seafood species (e.g., blue crab, blue mussels, American lobster) collected near urban or semi-urban areas of the U.S. (Mercaldo-Allen *et al.*, 1994; Mothershead *et al.*, 1991). For example, the highest sum PAC levels in white shrimp was 21 ng/g, wet weight (from North of Dauphin Island; Table 2) and this was much lower than the range (7,200 – 10,900 ng/g, wet wt.) reported in grass shrimp from Bayou Trepagnier near Lake Pontchartrain, Louisiana (Oberdorster *et al.*, 1999). In addition, the highest PAC sum was about two orders of magnitude lower than the mean values in muscle of live-caught and moribund lobsters captured in oiled areas following the 1996 *North Cape* oil spill (1,200 ng/g and 9,500 ng/g, respectively; Table 3) and was similar to concentrations (12 ng/g) measured in tail muscle of lobster captured from unoiled areas (Table 3).

To investigate temporal trends in PACs among samples (those collected before Hurricane Katrina, and also in mid-September and early October), the mean summed concentrations of LMWACs and HMWACs in shrimp composites collected from the three regions (Mobile Bay, Mississippi Sound and Lake Borgne) were statistically evaluated. Mean sums of LMWACs in shrimp from Mississippi Sound and Mobile Bay collected in October were significantly higher than those collected in September, but not different from those collected pre-Katrina ($p<0.05$). In contrast, mean sum LMWAC concentrations were significantly higher in shrimp collected from Lake Borgne before Katrina compared to those collected in September or October. Sum HMWAC concentrations were not statistically different during any time period for any of the regions. Therefore, shrimp from the three regions showed no consistent increases in PACs that would be attributable to contamination released following Hurricane Katrina.

Sum PAC levels measured in all the shrimp composites (both "pre-Katrina" and from the study areas) were low (below 15 ng/g), However, the FDA provides no regulatory limits

for PACs in seafood. For comparison, the PAC levels measured in the shrimp were similar to those measured in clams and mussels from nonurban areas of the U.S. [e.g., from remote areas of Alaska (Varanasi *et al.*, 1993)]. Additionally, the levels reported here are far lower than levels found in other crustacean species following oil spills.

References

AMAP. 1998. Persistent organic pollutants. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. xii+859pp.

de Wit, C., Fisk, A., Hobbs, K., Muir, D., Gabrielsen, G., Kallenborn, R., Krahn, M.M., Norstrom, R. and Skaare, J. 2004. AMAP Assessment 2002: Persistent Organic Pollutants in the Arctic. Arctic Monitoring and Assessment Program, Oslo, Norway. xvi + 310pp.

de Wit, C.A. 2002. An overview of brominated flame retardants in the environment. Chemosphere 46(5):583-624.

Geraci, J.R. and Aubin, D.J.S. 1990. Sea Mammals and Oil: Confronting the Risks. Academic Press, San Diego.

Heintz, R., Krahn, M.M., Ylitalo, G.M. and Morado, F. 2004. Organochlorines in walleye pollock from the Aleutian Islands and Southeastern Alaska. In proceedings of: Lowell Wakefield Symposium on the Sea Lions of the World, Anchorage, Alaska, USA.

Johnson, L.L., Collier, T.K. and Stein, J.E. 2002. An analysis in support of sediment quality thresholds for polycyclic aromatic hydrocarbons (PAHs) to protect estuarine fish. Aquat. Cons.: Mar. Freshwater Ecosyst. 12:517-38.

Krahn, M.M., Moore, L.K., Bogar, R.G., Wigren, C.A., Chan, S.-L. and Brown, D.W. 1988. High-performance liquid chromatographic method for isolating organic contaminants from tissue and sediment extracts. J. Chromatogr. 437:161-75.

Krahn, M.M., Brown, D.W., Ylitalo, G.M. and Collier, T.K. 2005. Analysis of edible tissue from fish collected in coastal waters of the Gulf of Mexico potentially affected by Hurricane Katrina to determine recent exposure to persistent organic pollutants (POPs). NOAA Fisheries, Northwest Fisheries Science Center, Seattle, WA. Report submitted to Steven Murawski of NOAA Fisheries.

Meador, J.P., Collier, T.K. and Stein, J.E. 2002. Use of tissue and sediment-based threshold concentrations of polychlorinated biphenyls (PCBs) to protect juvenile salmonids listed under the US Endangered Species Act. Aquat. Cons.: Mar. Freshwater Ecosyst. 12:493-516.

Mercaldo-Allen, R., Kuropat, C.A., Greig, R.A. and Sennefelder, G. 1994. PCB and metal concentrations in American lobsters from the Acushnet River Estuary and Long-Island Sound. Bull. Environ. Contam. Toxicol. 53(6):820-7.

Mothershead, R.F., Hale, R.C. and Greaves, J. 1991. Xenobiotic compounds in blue crabs from a highly contaminated urban subestuary. Environ. Toxicol. Chem. 10(10):1341-9.

National Academy of Sciences. 1991. Seafood Safety. National Academy Press, Washington, D.C. 432pp.

Oberdorster, E., Martin, M., Ide, C.F. and McLachlan, J.A. 1999. Benthic community structure and biomarker induction in grass shrimp in an estuarine system. Arch. Environ. Contam. Toxicol. 37(4):512-8.

O'Hara, T.M. and O'Shea, T.J. 2001. Toxicology. p. 471-520. In: L.A. Dierauf and F.M.D. Gulland (eds.) CRC handbook of marine mammal medicine (Second edition). CRC Press, Boca Raton, FL.

Sloan, C.A., Brown, D.W., Pearce, R.W., Boyer, R.H., Bolton, J.L., Burrows, D.G., Herman, D.P. and Krahn, M.M. 2005. Determining aromatic hydrocarbons and chlorinated hydrocarbons in sediments and tissues using accelerated solvent extraction and gas chromatography/mass spectrometry. p. 631-51. In: G.K. Ostrander (eds.) Techniques in Aquatic Toxicology. 2. CRC Press, Boca Raton, FL, USA.

Varanasi, U., Stein, J.E. and Nishimoto, M. 1989. Biotransformation and disposition of polycyclic aromatic hydrocarbons in fish. p. 93-149. In: U. Varanasi (eds.) Metabolism of Polycyclic Aromatic Hydrocarbons in the Aquatic Environmen. CRC Press, Boca Raton, FL.

Varanasi, U., Brown, D.W., Hom, T., Burrows, D.G., Sloan, C.A., Field, L.J., Stein, J.E., Tilbury, K.L., McCain, B.B. and Chan, S.-L. 1993. Survey of Alaskan Subsistence fish, marine mammal, and invertebrate samples collected 1989-91 for exposure to oil spilled from the Exxon Valdez. U.S. Dept. of Commerce, NOAA Tech. Memo., NMFS-NWFSC-12, Seattle, WA. 110pp.

Ylitalo, G.M., Buzitis, J. and Krahn, M.M. 1999. Analyses of tissues of eight marine species from Atlantic and Pacific coasts for dioxin-like chlorobiphenyls (CBs) and total CBs. Arch. Environ. Contam. Toxicol. 37(2):205-19.

Ylitalo, G.M., Yanagida, G.K., Hufnagle Jr, L. and Krahn, M.M. 2005. Determination of lipid classes and lipid content in tissues of aquatic organisms using a thin layer chromatography/flame ionization detection (TLC/FID) microlipid method. p. 227-37. In: G.K. Ostrander (eds.) Techniques in Aquatic Toxicology. 2. CRC Press, Boca Raton, FL, USA.

Table 1. Concentrations of persistent organic pollutants (POPs) measured in white shrimp collected in coastal waters of the Gulf of Mexico affected by Hurricane Katrina during two *F/V Patricia Jean* cruises (13-19 September 2005 and 2-6 October 2005) and in a commercial fishery before the hurricane.

Station number	Collection site[1]	Date sampled	ng/g wet weight				
			Sum PCBs[2]	Sum DDTs[2]	Sum CHLDs[2]	Sum HCHs[2]	Sum PBDEs[2]
Mobile Bay							
Patricia Jean Cruise #1							
101	Little Point Clear	9/13/2005	4.5	1.8	0.23	< LOQ	< LOQ
102	Middle Ground, Mobile Bay	9/13/2005	1.0	1.1	0.20	< LOQ	< LOQ
103	Stump Beacon	9/14/2005	0.30	0.53	< LOQ	< LOQ	< LOQ
			1.9 ± 2.3	***1.1 ± 0.64***	***0.14 ± 0.13***	***< LOQ***	***< LOQ***
Patricia Jean Cruise #3							
101	Little Point Clear	10/6/2005	1.1	0.68	< LOQ	< LOQ	< LOQ
102	Middle Ground, Mobile Bay	10/6/2005	0.076	0.53	< LOQ	< LOQ	< LOQ
103	Stump Beacon	10/5/2005	0.48	0.39	< LOQ	< LOQ	< LOQ
			0.55 ± 0.52	***0.53 ± 0.15***	***< LOQ***	***< LOQ***	***< LOQ***
Mississippi Sound/Gulf of Mexico							
Patricia Jean Cruise #1							
104	North of Dauphin Island	9/14/2005	1.0	0.54	< LOQ	< LOQ	< LOQ
106	North of Petit Bois Island	9/14/2005	0.80	0.40	< LOQ	< LOQ	< LOQ
107	Pascagoula Ship Channel	9/14/2005	2.4	0.40	< LOQ	< LOQ	< LOQ
108	North of Horn Island	9/14/2005	4.0	1.2	0.34	< LOQ	< LOQ
109	Middle Ground, Horn Island	9/14/2005	1.1	0.25	0.52	< LOQ	< LOQ
110	South of Horn Island	9/15/2005	2.0	0.43	< LOQ	< LOQ	< LOQ
111	Cat Island	9/15/2005	0.96	< LOQ	< LOQ	< LOQ	< LOQ
112	Pass Marianne	9/15/2005	0.15	< LOQ	< LOQ	< LOQ	< LOQ
113	Grand Island Channel	9/16/2005	0.97	< LOQ	< LOQ	< LOQ	< LOQ
124	Cabbage Reef	9/17/2005	0.76	< LOQ	< LOQ	< LOQ	< LOQ
125	Cat Island Shoal	9/17/2005	1.2	< LOQ	< LOQ	< LOQ	< LOQ
126	North of Ship Island	9/17/2005	2.0	0.9	1.0	< LOQ	< LOQ
127	Biloxi Ship Channel	9/18/2005	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ
			1.3 ± 1.1	***0.31 ± 0.38***	***0.14 ± 0.31***	***< LOQ***	***< LOQ***
Patricia Jean Cruise #3							
104	North of Dauphin Island	10/5/2005	1.8	1.00	< LOQ	< LOQ	< LOQ
108	North of Horn Island	10/5/2005	2.8	0.35	< LOQ	0.23	< LOQ
109	Middle Ground, Horn Island	10/5/2005	0.78	0.22	0.31	< LOQ	< LOQ
111	Cat Island	10/4/2005	0.064	< LOQ	< LOQ	< LOQ	< LOQ
112	Pass Marianne	10/2/2005	1.75	< LOQ	< LOQ	0.060	< LOQ
113	Grand Island Channel	10/2/2005	0.32	< LOQ	< LOQ	< LOQ	< LOQ
125	Cat Island Shoal	10/4/2005	0.37	< LOQ	< LOQ	< LOQ	< LOQ
126	North of Ship Island	10/4/2005	0.082	< LOQ	0.42	< LOQ	< LOQ
128	East of Biloxi Ship Channel	10/5/2005	0.11	< LOQ	< LOQ	< LOQ	< LOQ
			0.90 ± 0.99	***0.17 ± 0.33***	***0.08 ± 0.16***	***0.03 ± 0.08***	***< LOQ***

Table 1, continued. Concentrations of persistent organic pollutants (POPs) measured in white shrimp collected in coastal waters of the Gulf of Mexico affected by Hurricane Katrina during two *F/V Patricia Jean* cruises (13-19 September 2005 and 2-6 October 2005) and in a commercial fishery before the hurricane.

Station number	Collection site[1]	Date sampled	ng/g wet weight				
			Sum PCBs[2]	Sum DDTs[2]	Sum CHLDs[2]	Sum HCHs[2]	Sum PBDEs[2]
Lake Borgne							
Patricia Jean Cruise #1							
114	Malheureux Point	9/16/2005	0.34	0.22	< LOQ	< LOQ	< LOQ
114	Malheureux Point	9/17/2005	0.07	< LOQ	< LOQ	< LOQ	< LOQ
115	Alligator Point	9/16/2005	1.3	< LOQ	< LOQ	< LOQ	< LOQ
116	Proctor Point	9/16/2005	1.4	< LOQ	< LOQ	< LOQ	< LOQ
117	Blind Bayou	9/16/2005	0.63	< LOQ	< LOQ	< LOQ	< LOQ
118	Pointe aux Marchettes	9/16/2005	0.5	< LOQ	< LOQ	< LOQ	< LOQ
118	Pointe aux Marchettes	9/17/2005	1.2	< LOQ	< LOQ	< LOQ	< LOQ
119	St. Joe Pass	9/17/2005	0.46	< LOQ	< LOQ	< LOQ	< LOQ
120	Gamblers Bend	9/17/2005	0.39	< LOQ	< LOQ	< LOQ	< LOQ
123	Turkey Bayou	9/17/2005	0.91	< LOQ	< LOQ	< LOQ	< LOQ
			0.72 ± 0.46	***0.02 ± 0.07***	***< LOQ***	***< LOQ***	***< LOQ***
Patricia Jean Cruise #3							
114/115	Malheureux Point/Alligator Point	10/3/2005	3.7	0.89	0.2	< LOQ	< LOQ
116	Proctor Point	10/3/2005	1.9	< LOQ	< LOQ	< LOQ	< LOQ
117	Blind Bayou	10/3/2005	1.1	< LOQ	< LOQ	< LOQ	0.35
118	Pointe aux Marchettes	10/3/2005	2.5	< LOQ	0.16	< LOQ	< LOQ
119	St. Joe Pass	10/3/2005	1.6	0.12	0.16	< LOQ	< LOQ
119	St. Joe Pass	10/3/2005	1.5	0.11	0.11	< LOQ	< LOQ
120	Gamblers Bend	10/2/2005	1.4	< LOQ	< LOQ	< LOQ	< LOQ
			2.0 ± 0.89	***0.16 ± 0.33***	***0.09 ± 0.09***	< LOQ	***0.05 ± 0.13***
Pre-Katrina[3]							
	Composite #1		0.92	0.65	< LOQ	< LOQ	< LOQ
	Composite #2		0.27	< LOQ	< LOQ	< LOQ	< LOQ
	Composite #3		0.31	< LOQ	< LOQ	< LOQ	< LOQ
			0.50 ± 0.36	***0.22 ± 0.38***	***< LOQ***	***< LOQ***	***< LOQ***

[1] Collection stations are shown on the map in Figure 1.

[2] Individual compounds summed are given in the Methods section.

[3] "Reference" shrimp that were collected and frozen prior to hurricane

< LOQ for the sum indicates concentrations of all compounds included in the sum were below their individual limits of quantitation. For each < LOQ, a value of zero was used to calculate the mean and standard deviation of the mean.

Table 2. Concentrations of sum polycyclic aromatic compounds (PACs) measured in white shrimp collected in coastal waters of the Gulf of Mexico affected by Hurricane Katrina during two *F/V Patricia Jean* cruises (13-19 September 2005 and 2-6 October 2005) and in a commercial fishery before the hurricane.

Station number	Collection site[1]	Date sampled	ng/g wet weight		
			Sum LMWACs[1]	Sum HMWACs[2]	Sum PACs[3]
Mobile Bay					
Patricia Jean Cruise #1					
101	Little Point Clear	9/13/2005	6.0	0.16	6.2
102	Middle Ground, Mobile Bay	9/13/2005	5.9	0.40	6.3
103	Stump Beacon	9/14/2005	9.0	< LOQ	9.0
			7.0 ± 1.8	***0.19 ± 0.20***	***7.2 ± 1.6***
Patricia Jean Cruise #3					
101	Little Point Clear	10/6/2005	11	0.40	11
102	Middle Ground, Mobile Bay	10/6/2005	12	< LOQ	12
103	Stump Beacon	10/5/2005	11	< LOQ	11
			11 ± 0.6	***0.13 ± 0.23***	***11 ± 0.6***
Mississippi Sound/Gulf of Mexico					
Patricia Jean Cruise #1					
104	North of Dauphin Island	9/14/2005	6.9	0.38	7.3
106	North of Petit Bois Island	9/14/2005	5.9	0.37	6.3
107	Pascagoula Ship Channel	9/14/2005	7.2	0.74	7.9
108	North of Horn Island	9/14/2005	11	0.52	12
109	Middle Ground, Horn Island	9/14/2005	13	0.88	14
110	South of Horn Island	9/15/2005	8.3	0.33	8.6
111	Cat Island	9/15/2005	3.6	< LOQ	3.6
112	Pass Marianne	9/15/2005	3.9	< LOQ	3.9
113	Grand Island Channel	9/16/2005	3.5	< LOQ	3.5
124	Cabbage Reef	9/17/2005	4.1	< LOQ	4.1
125	Cat Island Shoal	9/17/2005	3.8	< LOQ	3.8
126	North of Ship Island	9/17/2005	8.6	< LOQ	8.6
127	Biloxi Ship Channel	9/18/2005	9.0	0.48	9.5
			6.8 ± 3.1	***0.28 ± 0.31***	***7.2 ± 3.4***
Patricia Jean Cruise #3					
104	North of Dauphin Island	10/5/2005	20	0.44	21
108	North of Horn Island	10/5/2005	8.8	0.49	9.3
109	Middle Ground, Horn Island	10/5/2005	12	< LOQ	12
111	Cat Island	10/4/2005	11	< LOQ	11
112	Pass Marianne	10/2/2005	6.6	0.33	6.9
113	Grand Island Channel	10/2/2005	8.5	0.24	8.8
125	Cat Island Shoal	10/4/2005	10	< LOQ	10
126	North of Ship Island	10/4/2005	11	< LOQ	11
128	East of Biloxi Ship Channel	10/5/2005	11	< LOQ	11
			11.0 ± 3.8	***0.17 ± 0.21***	***11.2 ± 4.0***

Table 2. Concentrations of sum polycyclic aromatic compounds (PACs) measured in white shrimp collected in coastal waters of the Gulf of Mexico affected by Hurricane Katrina during two F/V Patricia Jean cruises (13-19 September 2005 and 2-6 October 2005) and in a commercial fishery before the hurricane.

Station number	Collection site[1]	Date sampled	ng/g wet weight		
			Sum LMWACs[1]	Sum HMWACs[2]	Sum PACs[3]
Lake Borgne					
Patricia Jean Cruise #1					
114	Malheureux Point	9/16/2005	6.6	0.46	7.1
114	Malheureux Point	9/17/2005	6.6	< LOQ	6.6
115	Alligator Point	9/16/2005	4.5	< LOQ	4.5
116	Proctor Point	9/16/2005	3.6	< LOQ	3.6
117	Blind Bayou	9/16/2005	4.6	< LOQ	4.6
118	Pointe aux Marchettes	9/16/2005	8.0	0.34	8.3
118	Pointe aux Marchettes	9/17/2005	7.9	< LOQ	7.9
119	St. Joe Pass	9/17/2005	7.5	0.44	7.9
120	Gamblers Bend	9/17/2005	6.3	0.49	6.8
123	Turkey Bayou	9/17/2005	3.5	< LOQ	3.5
			5.9 ± 1.7	***0.17 ± 0.23***	***6.1 ± 1.9***
Patricia Jean Cruise #3					
114/115	Malheureux Point/Alligator Point	10/3/2005	5.9	< LOQ	5.9
116	Proctor Point	10/3/2005	6.3	0.32	6.6
117	Blind Bayou	10/3/2005	6.5	< LOQ	6.5
118	Pointe aux Marchettes	10/3/2005	8.2	< LOQ	8.2
119	St. Joe Pass	10/3/2005	6.6	0.40	7.0
119	St. Joe Pass	10/3/2005	7.9	1.0	8.9
120	Gamblers Bend	10/2/2005	6.9	0.24	7.1
			6.9 ± 0.8	***0.28 ± 0.36***	***7.2 ± 1.0***
Pre-Katrina[3]					
	Composite #1		10	< LOQ	10
	Composite #2		10	0.14	10
	Composite #3		9.7	< LOQ	9.7
			9.9 ±0.2	***0.05 ±0.08***	***9.9 ±0.2***

[1] Sum concentrations of low molecular weight aromatic compounds that include 2 and 3-ring ACs, from naphthalene through C4-phenanthrenes.

[2] Sum concentrations of high molecular weight aromatic compounds that include 4 through 6-ring ACs, from fluoranthene through benzo[ghi]perylene.

[3] Sum PACs includes sum LWMACs and sum HMWACs.

[4] "Reference" shrimp that were collected and frozen prior to hurricane

< LOQ for the sum indicates concentrations of all compounds included in the sum were below their individual limits of quantitation. For each <LOQ, a value of zero was used to calculate the mean and standard deviation of the mean.

Table 3. Concentrations of sum polycyclic aromatic compounds (PACs) measured in tail muscle of American lobster collected in January 1996 after the *North Cape* Oil Spill.

Sample Information	# individuals	Collection Year	Sum LMWACs[1] ng/g, wet wt.	Sum HMWACs[2] ng/g, wet wt.	Sum PACs[3] ng/g, wet wt.
Control - captured from unoiled area	3	1996	8.7 ± 2.3	3.7 ± 0.58	12 ± 2.9
Captured alive from oiled area	7	1996	1,200 ± 1,200	25 ± 27	1,200 ± 1,200
Moribund from oiled area	7	1996	9,400 ± 2,400	110 ± 36	9,500 ± 2,500

[1] Sum concentrations of low molecular weight aromatic compounds that include 2 and 3-ring ACs, from naphthalene through C4-phenanthrenes.

[2] Sum concentrations of high molecular weight aromatic compounds that include 4 through 6-ring ACs, from fluoranthene through benzo[ghi]perylene.

[3] Sum PACs includes sum LWMACs and sum HMWACs.

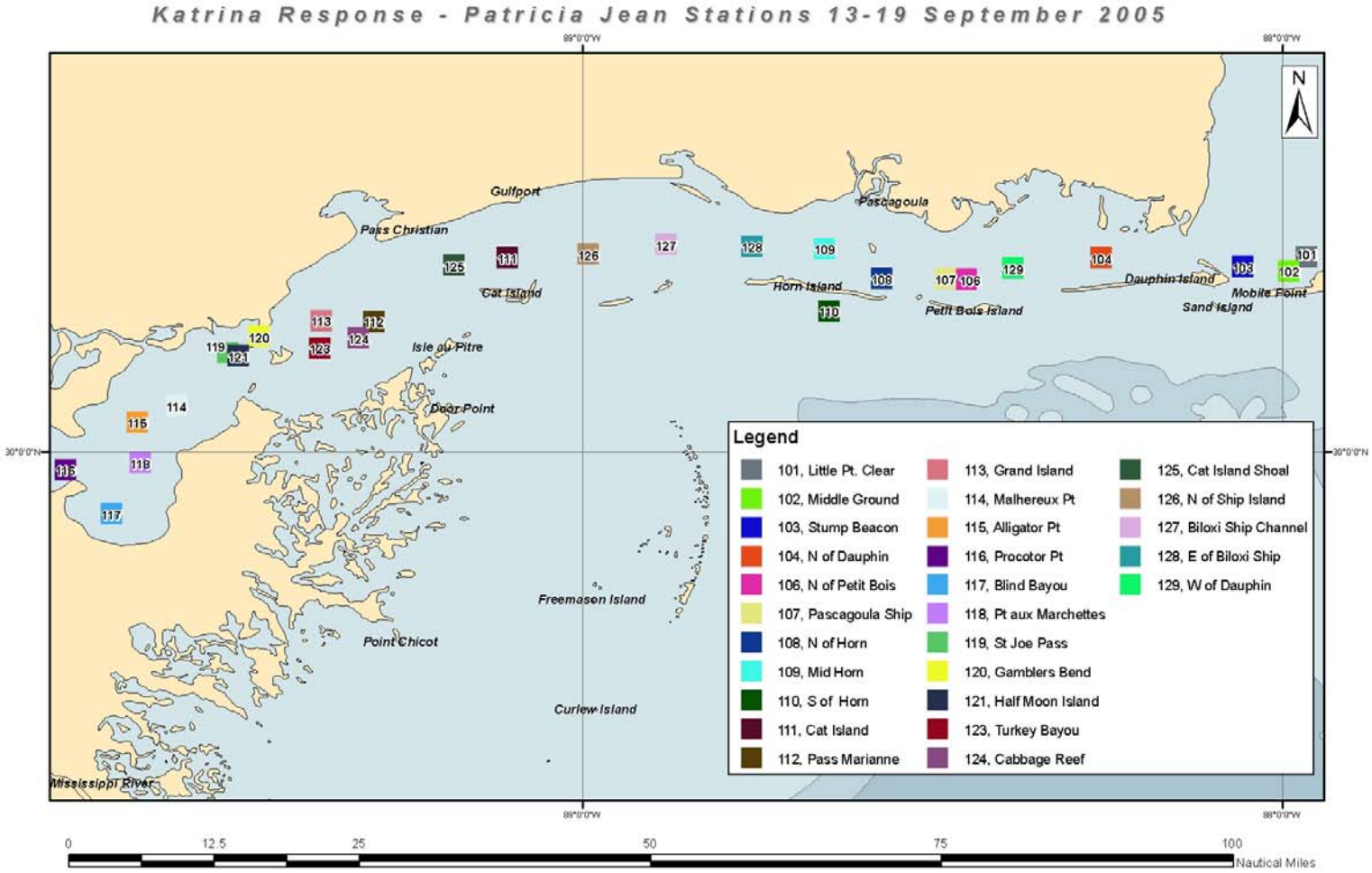

Figure 1. Stations (numbers 101-129) sampled during the *F/V Patricia Jean* cruise of 13-19 September 2005; many of these stations were re-sampled on the *F/V Patricia Jean* cruise of 2-6 October 2005.