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Young of the year bluefish (*Pomatomus saltatrix*) as a bioindicator of estuarine health: Establishing a new baseline for persistent organic pollutants after Hurricane Sandy for selected estuaries in New Jersey and New York

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ABSTRACT

Atlantic coastal bays of the US are essential habitat for young of year bluefish (*Pomatomus saltatrix*). Their residence in these estuaries during critical life stages, high lipid content, and piscivory make bluefish an ideal bioindicator species for evaluating estuarine health. Individual whole fish from four estuaries impacted by Hurricane Sandy were collected in August 2013, analyzed for a suite of persistent organic pollutants (POPs) including polychlorinated biphenyls, polybrominated diphenyl ethers and organochlorine pesticides and evaluated using health metrics. Concentrations in whole bluefish differed by estuary; however, concentrations for many POPs decreased or were similar to those observed prior to the hurricane. Prevalence of the ectoparasitic gill isopod (*Lironeca ovalis*) varied by estuary and no relationships between contaminants and lesions were observed. Bluefish should be considered for monitoring programs and, if sampled frequently, could be an effective bioindicator of incremental and episodic changes in contaminants within aquatic food webs.

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1. Introduction

Bluefish (*Pomatomus saltatrix*) are migratory species with worldwide distribution (Juanes and Conover, 1994) and considered an important commercial and recreational species along the Atlantic coast of the US (O'Bannon, 1988). The Atlantic bluefish population spawns offshore during two major events: one in the spring in the South Atlantic Bight and one in the summer in the Mid-Atlantic Bight near the edge of the continental shelf (Wuenschel et al., 2012; Kendall and Walford, 1979). Spring-spawned cohorts recruit north to the Mid-Atlantic Bight estuaries in late-May to mid-June at about 60 mm length, while summer-spawned cohorts either remain in the coastal ocean or recruit to the estuaries at about 46 mm length (Able et al., 2003; Chiarella and Conover, 1990). As bluefish recruit into the estuaries, their diet shifts from planktivory to piscivory and their growth rates increase dramatically (Marks and Conover, 1993). Because young of year (YOY) bluefish feed voraciously in the estuaries, they have unusually high growth rates (0.9–2.1 mm/day) compared to morphologically similar species in the area (Juanes and Conover, 1994).

Persistent organic pollutants (POPs) such as polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs) and organochlorine pesticides (OCPs) associated with densely urbanized areas, are common in estuaries and coastal marine environments and tend to biomagnify through the food web (Fisk et al., 1998, 2001; Wu et al., 2009; Khairy et al., 2014). Much of the habitat occupied by YOY bluefish along the northeastern Atlantic coast is considered contaminated with organic compounds such as PCBs, PBDEs and legacy OCPs (Candelmo et al., 2010). Their residence in these contaminated estuaries during critical periods of growth, their high lipid content, and piscivory increase the likelihood that bluefish will accumulate high concentrations of contaminants (Williams, 2006; Deshpande et al., 2013, 2015). Several studies have reported significant bioaccumulation of PCBs in bluefish despite their relatively short summer residence in two urbanized estuaries along the northeastern US (Williams, 2006; Deshpande et al., 2013, 2015). Because YOY bluefish displayed reduced feeding and growth following laboratory exposures to PCBs, it has been hypothesized that they are more vulnerable to contaminants than other resident fish species, despite their short residence times in coastal estuaries (Candelmo et al.,

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2010). These characteristics suggest that YOY bluefish may be a useful bioindicator species for evaluating the impacts of regional-scale disturbances on ecosystem health in vital estuarine nursery grounds of the northeastern Atlantic Coast.

The impacts of Hurricane Sandy on coastal communities and habitats in New Jersey and New York were severe (Manuel, 2013). Although a number of studies have assessed the water-quality impacts of hurricanes (Greening et al., 2006), few studies have addressed the ecological impacts of hurricane-driven contaminant re-mobilization and subsequent uptake and bioaccumulation in coastal estuarine species (Johnson et al., 2009).

The objective of the study was to assess the distribution and ecological effects of contaminants in selected estuaries following Hurricane Sandy using YOY bluefish as an indicator species. The specific objectives were to measure the concentrations of POPs in whole bluefish to compare post-Sandy concentrations to available pre-Sandy data and to assess potential effects using histology. YOY bluefish were selected because they reside in the impacted estuaries, have some associated historical chemical data from previous local and regional monitoring programs and are a valuable recreational aquatic resource that are consumed by humans and other piscivorous wildlife. New Jersey and New York coastal bays are considered "essential fish habitat" for YOY bluefish (Able et al., 2003). Concentrations of POPs in YOY bluefish collected after the storm are presented and compared to the limited regional data that existed prior to the storm (Deshpande et al., 2013, 2015). Understanding the persistence and accumulation of contaminants in fish tissue will help scientists and resource managers to further assess the impacts to ecosystem health and establish a new baseline for tissue-bound contaminants in the aftermath of a major coastal storm.

2. Methods

2.1. Study area and sample collection

The study area consisted of bays and estuaries adjacent to lands in New Jersey and New York that were inundated by Hurricane Sandy (Fig. 1). Sampling locations were selected to coincide with those of a previous, pre-Hurricane Sandy study on bluefish within the storm

Fig. 1. Location of young of year bluefish (*Pomatomus saltatrix*) sampling sites in estuaries impacted by Hurricane Sandy. Nine sites in four bays were sampled in the summer of 2013 during YOY bluefish recruitment. The estuaries sampled included Barnegat Bay, NJ, Sandy Hook Bay, NJ, Jamaica Bay, NY and Great South Bay, NY.

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impacted area (Deshpande and Dockum, 2013; Deshpande et al., 2015). Spring spawned YOY bluefish were collected by hook and line from 9 sites in 4 estuaries (Barnegat Bay, Sandy Hook Bay, Jamaica Bay and Great South Bay) between August and September, 2013 (Fig. 1). At each site crews randomly selected approximately 40 fish between 110 and 250 mm total length (100–215 mm fork length) for analysis. Ten individuals were randomly selected and kept alive in aerated 5 gal buckets for histopathology. The remaining 30 fish collected for tissue analysis were placed in whirl pack bags on ice and transported back to the laboratory where they were stored frozen at −80 °C. Prior to analysis the length and weight were recorded for all fish and 12–15 randomly selected individual fish were analyzed for PCBs, PBDEs and OCPs (Deshpande et al., 2013). Fulton's Condition Factor (K), an index of relative fish robustness, for each bluefish was also calculated as: $(K = W^* 100{,}000)/L^3$, where L is bluefish length in millimeters and W is bluefish weight in grams (Ricker, 1975) and the information was compared to previous studies (Deshpande and Dockum, 2013; Deshpande et al., 2013; Deshpande et al., 2015).

Fish selected for histopathology were processed within 1 h of collection. Fish were euthanized with Finquel (MS222; Argent Laboratories, Redmond, Washington), measured to the nearest mm and bled from the caudal vein using heparinized 3-cm^3 syringes with 23-gauge needles. Fish were inspected for visible abnormalities and then dissected. Small pieces of the liver were removed and placed in RNAlater® for future molecular analyses. The remaining portions of liver, as well as kidney, gonad, gills and heart were removed and preserved in Z-fix™ (Anatech LTD, Battle Creek, Michigan) for histopathological analyses. Blood was placed in heparinized Vacutainer® tubes containing sodium heparin and placed on wet ice for overnight shipment to the laboratory. Upon arrival, blood was centrifuged at 1000 ×*g* for 10 min, plasma was removed and frozen at −80 °C for future analyses. Tissues collected for histopathology were trimmed into cassettes, dehydrated through a series of alcohols, routinely processed for light microscopy, and embedded into paraffin. Tissues were cut at 5 μm, placed on glass slides, and stained with hematoxylin and eosin (H&E) (Luna, 1992). Slides were examined for microscopic tissue abnormalities.

2.2. Bluefish tissue extraction and analysis

Individual bluefish tissue samples were analyzed at the NOAA Fisheries James J. Howard Marine Sciences Laboratory (Sandy Hook, NJ) for 3 classes of selected persistent organic contaminants using previously published methods (Deshpande et al., 2000; Deshpande et al., 2013; Deshpande and Dockum, 2013). Briefly, individual whole freeze-dried tissues were pulverized in a blender with diatomaceous earth, extracted with dichloromethane (DCM) using either a Dionex 300 Accelerated Solvent Extractor (2 times at 12 °C and 1500 psi) or a Soxhlet (18 h) and reduced under nitrogen gas. Prior to extraction, recovery surrogates DBOFB, Ronnel, PCB 198 and 6-F-PBDE 47 were added to each tissue sample. Bulk polar interfering compounds of biological origin were removed from the target analytes using florisil/silica/alumina glass column chromatography. Following initial clean-up, twenty percent by volume of the extract, was used for the gravimetric lipid determination. Lipids and other interferences were removed using high performance liquid chromatography (HPLC) size-exclusion column (Phenogel 10, 600-mm × 21.20-mm, 100 pore size, 10-μm particle size; Phenomenex, Torrance, California). Prior to lipid removal by HPLC, 1,2,3-trichlorbenzene (TBC) and PCB 192 were added to the samples. HPLC fractions containing the target analytes were collected, exchanged to hexane, concentrated to less than 1 ml, GC internal standards were added, and the volume was adjusted to 1 ml. Each final extract was split into three separate vials for analysis of PCBs, OCPs and PBDEs.

Target analytes were quantified using an Agilent 6890 GC coupled to an Agilent 5973 mass spectrometer (MS) operating in selective ion monitoring (SIM) mode. PCB congeners and OCPs were analyzed using a DB-5 0.25 mm ID × 60-m capillary column. PBDE congeners were analyzed by using a Restek 1614 0.25 mm × 15-m PBDE column. Analyte concentrations in each sample are expressed as μg/kg on a weight wet basis. Reporting limits (RLs) for PCBs, OCPs and PBDEs ranged from 0.5 to 3.2 μg/kg wet weight and are summarized in Smalling et al. (2015).

2.3. Quality assurance/quality control

A comprehensive set of quality assurance/quality control parameters were analyzed in conjunction with the environmental samples; these included laboratory blanks and standard reference materials. If compounds were detected in the laboratory blanks above the RLs, the environmental samples were censored based on the following criteria: if the environmental concentration was less than 3 times the blank value then that value was deemed to be a non-detect and not reported, if the environmental concentration was greater than 3 times the blank value then the reported concentration was considered an estimate and coded with an 'E' and if the environmental concentration was greater than 10 times the blank value than the actual concentration is reported without censoring (Smalling et al., 2015). No PCBs or OCPs were detected in the laboratory blanks above the RL analyzed with the respective environmental samples. PBDE 47 was detected in 5 of the 7 blanks above the RL, PBDE 49 + 71 and 99 were detected in 4 of the 7 blanks above the RL and PBDE 100 was detected in 1 of the 7 blanks above the RL.

Recovery surrogates were added to each sample to measure method performance. For PCBs and OCPs, mean recoveries with standard deviations of 1,2,3-TCB, DBOFB, Ronnel, PCB 192 and PCB198 were 85 ± 31%, 70 ± 17%, 71 ± 25%, 95 ± 17% and 89 ± 19%, respectively. For PBDEs, mean recovery with standard deviation of 6-F-PBDE47 was 100 ± 34%. The percent recoveries based on NIST certified values for PCBs and OCPs in SRM 1946 (Lake Superior Fish Tissue) ranged from 68 to 121% with a median of 95% and from 45 to 121% with a median of 95%, respectively. All reported PCB and OCP concentrations above the RL were acceptable based on the 95% confidence intervals of the true value. In SRM 1946, 7 compounds (6 PCBs and 1 OCP) had NIST certified values that were at or below the laboratory RLs and were either not detected or were detected at extremely low (estimated) concentrations. The standard reference material utilized for the tissue analysis did not include PBDE congeners.

2.4. Historical data retrieval and literature search

Information from previous studies of tissue contaminant data in the study area prior to Hurricane Sandy was reviewed to examine the ecological impacts of the storm in historical context (Smalling et al., 2015). Federal, State, local, and academic sources of data were consulted, an extensive literature search was conducted, and data were retrieved from various on-line databases. Historic tissue data was retrieved from several EPA and NOAA databases including EPA's Regional Environmental Monitoring and Assessment Program (REMAP), and EPA's National Coastal Assessment (NCA) Program and included over 20,000 individual data results from over 8 different species (Smalling et al., 2015). All individual historic site information was mapped with the 9 post-Sandy sites and all information outside the 4 bays sampled was disregarded. Historic PCB, PBDE and OCP data available for interpretation included bluefish from Great Bay (southern portion of Barnegat Bay, Fig. 1), Sandy Hook Bay, and Great South Bay (Deshpande and Dockum, 2013; Deshpande et al., 2015). The historic PCB and OCP data available for the comparison to other species included 3 sites in Barnegat Bay sampled 2000–2002, 5 sites in Jamaica Bay sampled 2004–2005 and 36 sites in Great South Bay sampled 2000–2005. The available species included whole summer flounder (*Paralichthys dentatus*), winter flounder (*Pseudopleuronectes americanus*), weakfish (*Cynoscion regalis*), porgy (*Sparidae*), and scup (*Stenotomus chrysops*).

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2.5. Statistical analysis

Nonparametric methods were used to compare characteristics of bluefish specimens, contaminant concentrations, and other variables among sampling sites and estuaries. Total concentrations of classes of contaminants (PCBs, PBDEs and OCPs) were compared among YOY bluefish from specific sites and estuaries by applying analysis of variance (ANOVA) of ranked data. Where the null hypothesis of no difference among locations was rejected, the Tukey Multiple Comparison test was applied to obtain pairwise comparisons between sites or estuaries. S-Plus (TIBCO Software Inc., Palo Alto, CA) was used for all statistical analysis. Discriminant Function Analysis (DFA) test was performed to examine the possibility of segregating subpopulations of YOY bluefish from different estuaries based on characteristic fingerprints of PCB congeners similar to Deshpande et al. (2015) using Statistica 8.0 (Statsoft: Tulsa, Oklahoma, USA). In this test, each PCB congener concentration was normalized to the sum of the concentrations of all detected PCB congeners in an attempt to remove the effects of absolute concentrations on the first principal component (Schwartz and Stalling, 1991; Monosson et al., 2003; Wenning et al., 1992).

3. Results and discussion

3.1. Contaminant profiles and estuary differences

Persistent organic pollutants including PCBs, PBDEs and OCPs have been documented extensively in fish and other important commercial and recreational species in the northeast (Deshpande et al., 2015; Deshpande and Dockum, 2013; Deshpande et al., 2013; Horwitz et al., 2006; Kennish and Ruppel, 1996, 1998). These compounds tend to biomagnify, potentially impacting ecological and human health. OCPs, such as DDT, as well as PCBs have been banned in the US for decades but are still detected frequently in the environment because of their persistence. Flame retardants containing PBDEs can cause adverse effects to wildlife and humans and are still used today despite their increasing worldwide distribution and persistence in coastal sediments and biota (Wurl and Obbard, 2005; Hites, 2004; Kimbrough et al., 2009).

The life history, energetics and migratory behavior of bluefish within a nursery ground or estuary make them a unique and effective indicator species to understand and compare contaminant distributions between estuaries in the hurricane impacted area. YOY bluefish reside in coastal estuaries for up to 60 days (Manderson et al., 2014) where they feed on a broad variety of prey taxa, over a wide spatial scale and grow exponentially to attain the size and condition necessary for the successful autumn emigration, overwinter survival, and predator avoidance (Juanes and Conover, 1994; Able et al., 2003). In the current study, contaminant body burdens were similar between individuals residing in and collected from a single estuary and no capture location differences were observed (Table 1). The contaminant residue concentrations in the bluefish reflected a broad-scale, integrated portrayal of the nursery ground, rather than localized snapshot of the given capture location, which is often the case with resident species.

Significant differences in contaminant concentrations in bluefish were observed between the estuaries (Fig. 2). Based on existing land-cover information, (Jin et al., 2013; Fischer et al., 2015), the amount of developed land was 11% in Great Bay, NJ, 31% in Barnegat Bay, NJ, 55% in Sandy Hook Bay, NJ, 75% in Jamaica Bay, NY, and 57% Great South Bay, NY (Fischer et al., 2015). To examine estuary differences, a total PCB concentration (sum of all 33 congeners detected) in each fish was calculated for statistical analysis (Table 1). The co-eluting PCB congeners 153/132 as well as PCB 138 were detected frequently throughout the study area and at some of the highest concentrations compared to the other congeners (Table A1). Total PCBs were the lowest in Barnegat Bay and Great South Bay compared to Jamaica Bay and Sandy Hook Bay where no differences were observed (Fig. 2A). Although, estimated developed land in Sandy Hook Bay and Great South Bay were similar, bluefish collected from Sandy Hook Bay have the potential to accumulate contaminants from the highly urbanized lower New York Harbor/Raritan Bay. A food web approach to PCBs in Florida yielded similar results to the current study where fish tissue was dominated by PCB 153 and 138 (Johnson-Restrepo et al., 2005), however, studies have noted that PCB profiles in aquatic organisms can differ regionally based on the Aroclor mixture used in the study area (Deshpande et al., 2015, 2013).

Similar to Deshpande et al. (2015), discriminant function analysis was conducted to assess differences in PCB congener profiles normalized to the sum of the 33 PCB congeners detected. This type of analysis is useful in assessing site fidelity of YOY bluefish throughout the Hurricane Sandy affected region. In the current study, total PCB normalized fingerprints of individual congeners were statistically different between estuaries as well as capture locations (Fig. 3). For example, YOY bluefish collected from Jamaica Bay North had dissimilar PCB profiles compare to fish from Jamaica Bay South approximately 10 km apart (Fig. 1). YOY bluefish site fidelity to a nursery estuary has been noted previously where PCB fingerprints were used to differentiate subpopulations on a fine geographic scale (Deshpande et al., 2015). Although, total PCB concentrations were not significantly different between capture locations in a given estuary, PCB fingerprinting indicates high site fidelity and an extended residence time in a sub-estuary.

PBDE profiles were not different between sites and congeners 47, 99, 100 and 154 were detected frequently and at the highest concentrations compared to the other congeners (Table A2). To compare to Deshpande and Dockum (2013), concentrations of the 4 congeners listed above were summed and a total PBDE concentration was used for all statistical analyses (Table 1). PBDE concentrations were the highest in Jamaica Bay

Table 1
Summary statistics for young of year bluefish including length, weight, condition factor and concentrations of total PCBs, PBDEs and OCPs by site. Concentrations of persistent organic pollutants are in ng/g wet weight. Median values are reported with ranges in parentheses.

Site code	Sample size	Wet weight (g)	Length (mm)	Condition factor (K)	ΣPCBs	ΣPBDEs	ΣOCPs
Barnegat Bay							
Great Bay (GB)	12	43.1 (18.6–53.1)	164 (111–175)	0.989 (0.750–1.38)	48.8 (27.9–168)	6.9 (2.8–19.0)	41.6 (20.5–52.7)
Tom's River (TR)	15	32.2 (13.0–104)	149 (112–223)	0.887 (0.806–1.22)	28.8 (8.1–96.7)	3.1 (nd −30.3)	21.0 (2.53–270)
Upper Barnegat Bay (UBB)	15	33.5 (18.5–106)	153 (127–225)	0.984 (0.8063–1.16)	34.9 (14.5–232)	6.5 (nd-33.6)	49.2 (4.48–299)
Sandy Hook Bay							
Navesink River (NR)	15	23.5 (12.8–71.1)	137 (114–186)	0.897 (0.801–1.10)	57.0 (26.4–118)	9.0 (nd-41.1)	52.9 (27.7–90.8)
Sandy Hook Bay (SaH)	15	28.9 (16.1–62.3)	142 (120–185)	0.987 (0.852–1.14)	69.4 (35.8–89.5)	0.82 (0.23–6.5)	39.9 (23.4–69.1)
Jamaica Bay							
Jamaica Bay North (JBN)	15	32.2 (17.6–51.1)	152 (122–180)	0.959 (0.854–1.01)	84.1 (nd-159)	16.6 (nd-79.7)	37.9 (20.7–56.5)
Jamaica Bay South (JBS)	15	42.7 (19.4–104)	170 (131–214)	0.918 (0.733–1.06)	60.5 (15.2–1703)	7.7 (0.68–178)	27.5 (9.6–523)
Great South Bay							
Great South Bay A (GSBA)	15	62.4 (26.3–123)	183 (142–231)	0.966 (0.688–1.19)	41.6 (17.0–173)	1.8 (0.20–6.7)	21.5 (13.3–76.3)
Great South Bay B (GSB)	15	62.3 (31.1–143)	186 (147–239)	0.923 (0.851–1.06)	26.5 (8.4–110)	7.6 (0.17–12.9)	18.4 (5.66–54.8)

PCB, polychlorinated biphenyl; PBDE, polybrominated diphenyl ether; OCP, organochlorine pesticide.

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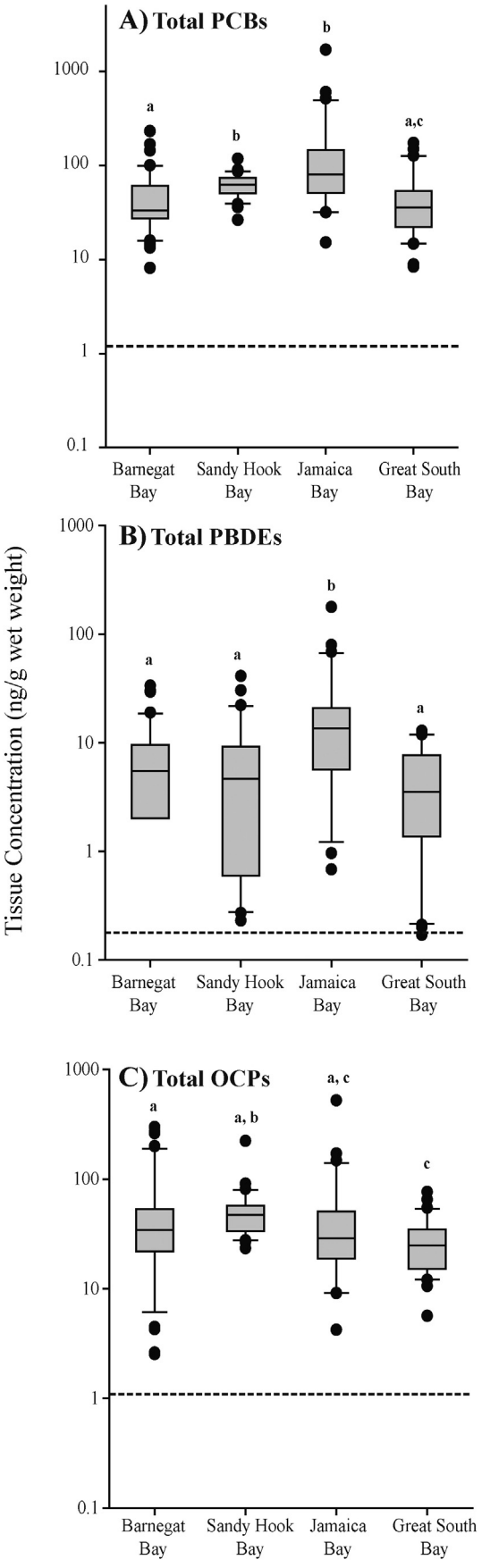

but no differences in the other bays were observed (Fig. 2B). With the exception of DDE, OCP concentrations were low (5–10 ng/g wet weight) and profiles varied slightly by estuary for many of the compounds (Table A3). This was expected based on the differences in land-uses and potential sources of OCPs throughout the study area. However, because most of the compounds were detected infrequently and at low concentrations, total OCPs were calculated for estuarine comparisons and analysis. Total OCP concentrations were the highest in Sandy Hook Bay compared to Jamaica Bay and Great South Bay (Fig. 2C). Unlike PCBs and PBDE, OCP concentrations in Barnegat Bay were similar to the more urbanized estuaries of Sandy Hook Bay and Jamaica Bay (Fig. 2C). The northern portion of Barnegat Bay is more densely populated (31% developed land) than the southern portion (11% developed land) which could be driving the OCP differences (Fischer et al., 2015). Concentrations of total DDTs (*p,p′*-DDD, *o,p′*-DDE, *p,p′*-DDE, *o,p′*-DDE, *p,p′*-DDT, *o,p′*-DDT) were compared and no significant differences between estuaries were observed. Although banned in the US for over 30 years, DDT and its degradates persist in the environment, are biologically available for uptake and trophic magnification and are typically the most frequently detected legacy pesticide in marine fish species throughout the study area (Kennish and Ruppel, 1996; Kennish and Ruppel, 1998). The site fidelity of YOY bluefish along with their life history and migratory behavior further highlights the benefits of this unique species as an indicator to monitor estuarine change.

3.2. Comparison to historic data

A historic contaminant tissue dataset was fairly limited in the hurricane impacted area; however, post-Sandy sites were selected based on previous information on PCB, PBDE and OCP concentrations in YOY bluefish collected between 2002 and 2003 (Deshpande et al., 2015; Deshpande and Dockum, 2013). To consistently compare the current study to historic data, concentrations of the 4 major PBDE congeners 47, 99, 100 and 154 were totaled for all comparisons. No information on PBDEs was available for Jamaica Bay; therefore, comparisons were possible only for Barnegat Bay, Sandy Hook Bay and Great South Bay. Concentrations in bluefish collected prior to Hurricane Sandy (2000–2003) were significantly higher in both Sandy Hook Bay and Great South Bay compared to bluefish collected in the summer following the hurricane (Fig. 4). In Barnegat Bay, samples prior to Hurricane Sandy were collected from Great Bay and Little Egg Harbor but no samples were collected in the northern part of the Bay. No differences in concentrations were observed in Barnegat Bay when comparing total PBDEs using all three locations in 2013 and the 2 locations from Deshpande and Dockum (2013). However, when comparing fish collected from Great Bay only, higher concentrations of PBDEs were observed in 2013 compared to the previous study (Fig. 4). This increase in concentration is more likely influenced by incremental changes in land-use and/or urbanization over the last 10 years rather than hurricane-induced alterations. Concentrations of the major PBDEs in Great Bay even following Hurricane Sandy were low compared to other more urbanized estuaries along the Atlantic coast (Deshpande and Dockum, 2013).

Where possible, post-Sandy PCB concentrations in bluefish were compared to the previous data reported in Deshpande et al. (2015). It is assumed in these comparisons that there would be some unquantifiable bias in the two data sets due to the methodological differences

Fig. 2. Individual young of year bluefish tissue concentrations (ng/g wet weight) of A) total polychlorinated biphenyl (PCB) congeners (sum of 33 congeners measured), B) total polybrominated diphenyl ether (PBDE) congeners (sum of congeners 47, 99, 100 and 154) and C) total organochlorine pesticides (OCPs) from Barnegat Bay (N = 41), Sandy Hook Bay (N = 30), Jamaica Bay (N = 30) and Great South Bay (N = 30) sampled in the summer following Hurricane Sandy. The top and bottom of each box represent the interquartile range (25th and 75th percentile), the black lines represent the maximum and minimum values and the solid circles are considered outliers. Only reported values are shown. Letters above the box plot represent statistical significance, and areas with no letters in common are significantly different from one another ($p < 0.05$). Dashed line represents the median reporting limit for individual analytes by compound class.

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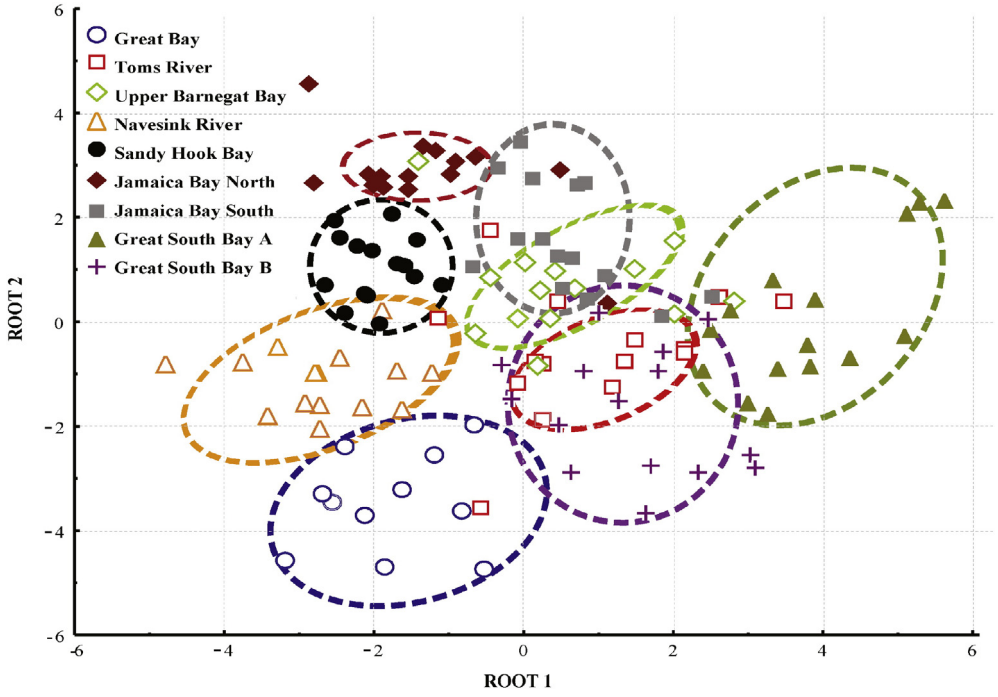

Fig. 3. Polychlorinated biphenyl (PCB) congener profile groupings in individual young of year bluefish (*Pomatomus saltatrix*) tissue based on discriminate function analysis (DFA). Congener profiles used in the DFA are represented as a relative abundance (calculated as individual congener concentrations divided by the sum of all 33 congeners) in each individual fish from the 9 capture locations.

(GC–MS versus GC-ECD). Post-Sandy total PCB concentrations were lower than pre-Sandy concentrations in bluefish from Sandy Hook Bay and Great South Bay while concentrations were similar before and after the storm in Great Bay (Table 2). Average total OCP concentrations in YOY bluefish collected in 2002 and 2003 (Deshpande et al., 2015) where similar to concentrations observed in 2013 after Hurricane Sandy from the three estuaries (Table 2).

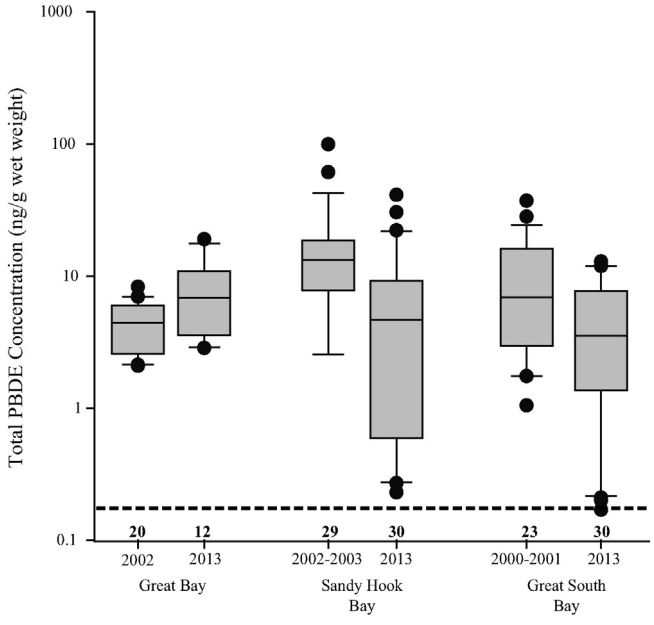

Fig. 4. A comparison of total PBDE (sum of congeners 47, 99, 100 and 154) concentrations in individual young of year bluefish collected in the early 2000's (Deshpande and Dockum, 2013) and 2013 (this study). The top and bottom of each box represent the interquartile range (25th and 75th percentile), the black lines represent the maximum and minimum values, the solid circles are considered outliers and the number at the bottom represents the sample size. PBDE concentrations were significantly higher in 2013 compared to the previous study in Great Bay, NJ but significantly lower in Sandy Hook Bay, NJ and Great South Bay, NY. Dashed line represents the reporting limit for individual PBDE congeners. All differences were statistically significant ($p < 0.05$).

Post-Sandy bluefish data were also compared to available PCB and OCP information from fish (summer and winter flounder, porgy, scup, weakfish and white perch) collected by EPA during routine ecological monitoring. Historic PCB and OCP data in individual fish were available from locations near post-Sandy sampling sites in Barnegat Bay (N = 3), Jamaica Bay (N = 6) and Great South Bay (N = 29) collected between 2000 and 2005 (Table 2). However, there were not sufficient historic data available to statistically compare data from bluefish collected from post-Sandy locations other than Great South Bay. PCB and OCP concentrations in bluefish post Sandy were significantly higher than concentrations observed in fish species collected prior to 2005. However, this difference is more likely due to life history than storm induced impacts. YOY bluefish have among the highest consumption (20–30% body weight/day) and growth rates (1–2 mm/day) reported for any temperate fish species (Juanes and Conover, 1994) and have a higher percent lipid compared to fish sampled during these national assessments. This high lipid content, consumption of a variety of prey species and their exponential growth yield higher body burdens of hydrophobic organic contaminants compared to species with lower lipids and a less variable diet (Deshpande et al., 2013). Total PCB concentrations in adult bluefish (40–100 cm in length) caught along the NJ/NY coast in the Atlantic Ocean ranged from 500 to 2000 ng/g wet weight and concentrations increased with length and lipid content (Horwitz et al., 2006). Similar trends were also observed with total DDTs, where DDT concentrations in adult bluefish increased linearly with size and lipid content (Kennish and Ruppel, 1996, 1998). Bluefish are migratory and as adults spend much of their time offshore from Florida to Maine, therefore the contaminant profiles in adult bluefish are not considered representative of the coastal estuaries where they are caught. Unfortunately, historical data needed to relate contaminant body burdens to storm induced effects were not available.

Coastal monitoring programs (NCA, REMAP) are designed to survey the condition of coastal resources, not to assess the impacts of incremental and episodic events at the ecosystem level. YOY bluefish reside in coastal estuaries for up to 60 days (Manderson et al., 2014) and

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Table 2
Comparison of the average total PCB and OCP concentrations (ng/g wet weight) in young of year bluefish tissue collected in 2013 to the historic data available for the study area. N represents the number of fish in each study.

Bay	Common name	Latin name	Year	N	ΣPCBs	ΣOCPs
Barnegat Bay	White perch[a]	*Morone americana*	2000, 2002	2	49.3–58.2	25.4–39.1
	Porgy[a]	*Sparidae*	2002	1	16.6	2.3
	Bluefish[b]	*Pomatomus saltatrix*	2002–2003	20	32.8–81.7	10.2–43.2
	Bluefish	*Pomatomus saltatrix*	2013	15	8.1–232	2.5–299
Sandy Hook Bay	Bluefish[b]	*Pomatomus saltatrix*	2002–2003	24	71.2–301	11.5–126
	Bluefish	*Pomatomus saltatrix*	2013	15	26.4–118	23.4–223
Jamaica Bay	Summer flounder[a]	*Paralichthys dentatus*	2004–2005	4	55.8–86.8	27.4–64.9
	Winter flounder[a]	*Pseudopleuronectes americanus*	2004	1	64.8	35.9
	Scup[a]	*Stenotomus chrysops*	2005	1	40.3	100
	Bluefish	*Pomatomus saltatrix*	2013	15	15.2–1703	9.6–523
Great South Bay	Summer flounder[a]	*Paralichthys dentatus*	200–2005	9	7.9–40.1	2.0–34.0
	Winter flounder[a]	*Pseudopleuronectes americanus*	2000–2005	17	2.0–20.5	nd-32.1
	Scup[a]	*Stenotomus chrysops*	2003, 2005	2	22.4–23.6	7–19.8
	Weakfish[a]	*Cynoscion regalis*	2002	1	27.7	9.2
	Bluefish[b]	*Pomatomus saltatrix*	2002–2003	21	46.0–309	10.1–77.5
	Bluefish	*Pomatomus saltatrix*	2013	15	8.4–173	5.7–76.3

PCB, polychlorinated biphenyl; OCP, organochlorine pesticide.
[a] EPA REMAPand NCA Programs; http://www.epa.gov/emap/nca/html/data/index.html
[b] Deshpande et al. (2013).

accumulate organic contaminants quickly from their food due to their rapid growth and high lipid content indicating that concentrations observed in 2013 whether higher or lower than previous data represent a new baseline for the compounds measured in the study area. This new baseline could reflect changes in the estuary, including redistribution of bed sediments or changes in contaminant bioavailability in the aquatic environment. Based on their life histories, YOY bluefish are a unique species that are effective indicators of environmental health at the regional scale which, if monitored frequently and before/after events, would address this need for event-specific impact analysis. Information provided from the current study, represents a new baseline in contaminant data following a major coastal disturbance along the northeastern coastline. It also establishes a model to assess the impacts of future storms from a contaminant perspective within the study area.

3.3. YOY bluefish health and isopod prevalence

YOY bluefish size (length and weight) varied by estuary and fish from Great South Bay were significantly larger ($p < 0.05$) compared to the other bays while fish from Sandy Hook Bay were the smallest. The observed differences in size between estuaries could merely be a result of the collection of both spring and summer spawned cohorts throughout the study area. However, despite bay differences in contaminants, the Fulton's condition index (K) was similar between sites and estuaries (Table 1). In previous studies a high condition index was also reported in contaminated estuaries along the Atlantic coast (Deshpande et al., 2015, 2013). Although, these more contaminated estuaries potentially support a lower biodiversity of taxa, they tend to have a higher prey density and are still capable of providing services to resident and migratory species (Candelmo et al., 2010). Similar to other studies, the condition index was not correlated to contaminant concentrations (Deshpande et al., 2013; Deshpande and Dockum, 2013) and may not be the most useful metric for an overall health assessment.

To better assess the health of fish in the study area, 20 individual YOY bluefish from each estuary were collected for gross histopathology. Lesions were observed in the heart (parasites and discolored areas), liver and ovaries in fish from the study area (Smalling et al., 2015). Previous studies have suggested that parasitic heart infections are an important source of juvenile bluefish mortality in the Hudson River estuary (Koske and Juanes, 2012). However, the most common lesion observed was the presence of an ectoparasitic gill isopod (*Lironeca ovalis*). These isopod parasites attach to the gills, causing localized erosion of gill tissue. The prevalence of the gill isopod infestation was 30% in Barnegat Bay and Sandy Hook Bay, 35% in Jamaica Bay, and 20% in Great South Bay. The parasite has been previously identified on YOY bluefish (Landau et al., 1995) with a reported prevalence of 7–16% in Great South Bay and 10% in Sandy Hook Bay (Marks et al., 1996), considerably less than those observed in this study. Microscopic examination of the gills demonstrated localized areas of erosion and fusion due to the presence of the isopod but the fish were not considered seriously impacted. In the current study, it is unclear whether the contaminants present in the YOY bluefish impacted their susceptibility to parasitic infections. It also could not be determined if the observed increased frequency of isopod infestation is related to disturbances caused by Hurricane Sandy. Cumulative effects of parasitism and anthropogenic stressors have the potential to cause immunosuppression, mortality and a reduction in overall fitness (Marcogliese and Pietrock, 2011). However, a direct relationship between increased parasitic infections and contaminants has not been fully established (Yen Le et al., 2014).

The gill isopods from bluefish in Jamaica Bay ($N = 6$) were removed prior to fish homogenization, composited and analyzed for PCBs, PBDEs and OCPs. Fewer contaminants were detected in the isopods compared to the fish but, of those detected, the profiles were similar (Fig. 5). Twenty-one PCB congeners, 3 PBDE congeners and 4 OCPs were detected in the composite isopod sample (Table 3). Composite concentrations of individual compounds were higher in the isopod samples compared to their bluefish hosts. Total PCBs were 4 times higher, total PBDEs were 8 times higher and total OCPs were 6 times higher in composite isopods compared to their bluefish hosts. Relative abundances based on individual contaminant concentration divided by the sum of all congeners or compounds was calculated for each class of contaminants to compare the overall profiles between isopods and their bluefish host. Similar to the bluefish, the co-eluting congeners PCB 153/132, PBDE 47 and DDE were notably higher than the other compounds. This is only 1 composite of 6 individual isopods from 1 estuary but it provides the first ever snapshot of contaminant profiles in a parasitic isopod. It is hypothesized that isopods are able to selectively accumulate hydrophobic contaminants from their host and contaminant body burdens may indeed be higher in the isopod compared to the host. Intestinal parasites of certain fish species are able to efficiently accumulate metals at concentrations hundreds of times higher than their hosts (Sures, 2008). Because isopods are ectoparasites that feed on lipid rich blood from their hosts, concentrations of organic contaminants are expected to be higher compared to their hosts (Yen Le et al., 2014), however, the fractionation

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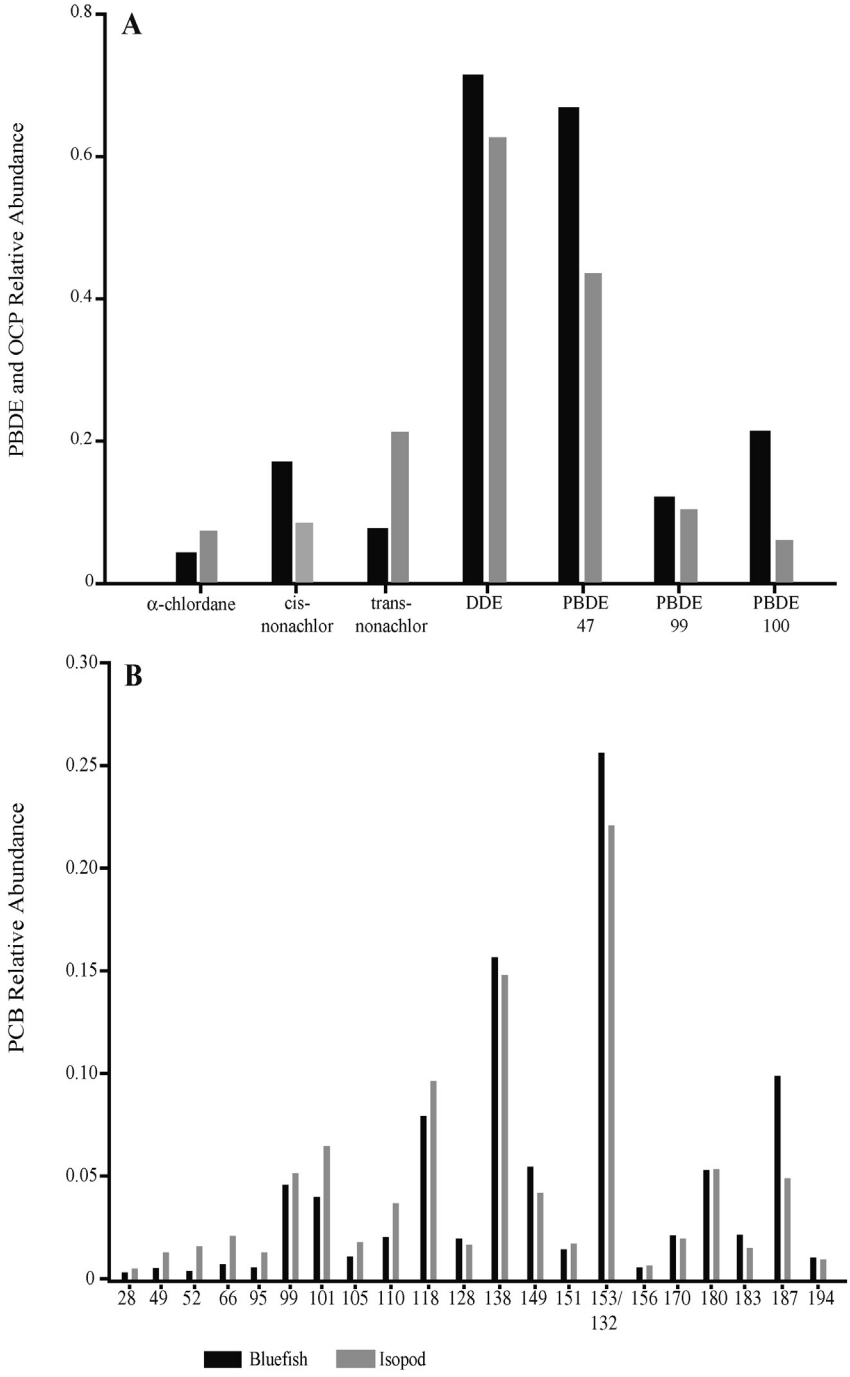

Fig. 5. Persistent organic pollutant profiles depicted as a relative abundance (calculated as individual pesticide concentration divided by the sum of all compounds/congeners) for (A) polychlorinated biphenyl (PCB) congeners and (B) organochlorine pesticides (OCPs) and polybrominated diphenyl either (PBDE) congeners in young of year bluefish (n = 6) and composite parasitic isopods (n = 1) collected from Jamaica Bay, NY after Hurricane Sandy. Median values for bluefish were used in the relative abundance calculations.

of contaminants from the host to the parasite may vary depending on developmental stage and lifecycle of the parasite (Yen Le et al., 2014). To date, no information on contaminants in gill isopods is available and this is the first study to report the presence of organic contaminants in this common parasite. The co-existence of parasitic infections and contaminant exposure has various impacts on accumulation of hydrophobic contaminants in the host and in some instances the parasites are able to accumulate at a higher rate than their host making them potentially a better bioindicator of exposure than the host. More information on contaminant partitioning into the gill isopod is necessary to understand if it has the potential to be an effective indicator of ecosystem health especially in estuaries where prevalence is quite high.

4. Conclusions

The limited amount of historical data made it difficult to directly identify storm induced impacts within the study area. Concentrations of OCPs following Hurricane Sandy were similar compared to pre-Sandy information while changes in PCB concentrations varied by estuary. PBDE concentrations in bluefish tissue collected from Sandy Hook

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Table 3
Concentrations (ng/g wet weight) of PCBs, PBDEs and OCPs in parasitic isopods (*Lironeca ovalis*) and their young of year bluefish (*Pomatomus saltatrix*) hosts collected from Jamaica Bay, NY. Isopod specific biomagnification factors (BMFs) were calculated as the ratio of the chemical concentration in the isopod to that of the bluefish host. Isopods represent a composite of 6 individuals compared to median host individual bluefish tissue concentration.

	Bluefish host (N = 6)	Isopod composite	BMF
PCB 28	1.6	9.2	5.7
PCB 49	2.1	17.9	8.5
PCB 52	1.8	21.0	11.7
PCB 66	2.6	26.7	10.3
PCB 95	2.2	17.9	8.1
PCB 99	12.3	60.4	4.9
PCB 101	10.8	75.2	7.0
PCB 105	3.5	23.2	6.6
PCB 110	5.9	44.2	7.5
PCB 118	20.7	110	5.3
PCB 128	5.7	21.8	3.8
PCB 138	40.1	167	4.2
PCB 149	14.5	49.8	3.4
PCB 151	4.4	22.5	5.1
PCB 153/132	65.1	248	3.8
PCB 156	2.2	10.8	4.9
PCB 170	6.1	25.1	4.1
PCB 180	14.1	62.7	4.4
PCB 183	6.2	20.2	3.3
PCB 187	25.6	57.6	2.3
PCB 194	3.4	14.1	4.1
ΣPCB (21 congeners)	***251***	***1105***	***4.4***
PBDE 15	nd	40.5	na
PBDE 28	0.4	77.5	194
PBDE 47	24.5	129	5.3
PBDE 99	4.4	30.9	7.0
PBDE 100	7.8	18.1	2.3
ΣPBDE(3 congeners)	***36.7***	***178***	***4.9***
α-Chlordane	1.6	18.0	11.3
cis-Nonachlor	6.5	20.8	3.2
trans-Nonachlor	2.9	52.1	18.0
p,p'-DDE	27.4	153	5.6
ΣOCP (4 compounds)	***38.4***	***244***	***6.4***

nd, not detected; na, not applicable, PCB, polychlorinated biphenyl; PBDE, polybrominated diphenyl ether; OCP, organochlorine pesticide

Bay and Great South Bay following Hurricane Sandy decreased while concentrations in the Great Bay portion of Barnegat Bay increased after the storm. The increase observed in Great Bay compared to previous studies may be a result of land-use change but more data are needed to confirm this observation. The life history, energetics and migratory behavior of bluefish within an estuary make them a unique and effective bioindicator of incremental (land-use change and sea level rise) and episodic (hurricanes) events in an estuary or a food web. However, more frequent monitoring of bluefish on a much finer (minimally annual) timescale is important to generate the data necessary to effectively determine the ecological consequences of a disturbance. Contaminant information gained from bluefish and/or their parasitic isopods represents the entire foodweb and could be an effective way to examine an entire estuary rather than a single point location. Adding YOY bluefish to local and regional monitoring programs would allow for a more comprehensive assessment of contaminants through the food web. The information gained from this study suggests that YOY bluefish might be a viable bioindicator of change within an estuary if sampled more frequently. Fish health assessments should also be expanded and included in regional monitoring programs to determine the potential consequences of residing and feeding in urbanized estuaries even for short periods of time. Limited information on bluefish health was available so more information is necessary to establish any link between contaminants and overall health throughout the study area.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.marpolbul.2016.03.019.

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