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Cadmium, mercury and PCB residues in blue crab

(*Callinectes sapidus*)

taken from the Hudson River and New York's marine district

March 2016

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Abstract

Sediments in Foundry Cove, Constitution Marsh and Cold Spring were contaminated with cadmium from a nickel-cadmium battery factory that operated from 1952 to 1979. As a consequence of the contamination, cadmium residues in blue crab hepatopancreas and muscle tissues were elevated and resulted in issuance in 1979 of health advice to consumers of blue crab to avoid consumption of the hepatopancreas and to discard cooking liquids. In 1994-1995, most of the highly contaminated sediments were removed in a major Superfund dredging project. This study examined blue crabs in the Hudson River nine years post-remediation as well as blue crabs in two waters of western Long Island.

In the Hudson River, cadmium in hepatopancreas averaged 2.11 ± 1.77 µg/g (n = 88) with a maximum of 13.0 µg/g. In leg muscle, 44 percent of samples no longer contained detectable cadmium, and the average in samples with detected cadmium was 0.052 ± 0.074 µg/g (n = 49; excluding an outlier of 0.530 ng/g, the mean is 0.042 ± 0.026 µg/g). Compared to cadmium concentrations in blue crabs from the initial sampling events in 1979-1981 (n = 55), in 2004, cadmium concentrations in blue crab from the Hudson River had declined by at least 73 percent in the hepatopancreas and leg muscle. Similar cadmium declines have occurred in blue crab from Jamaica Bay.

Mercury levels in samples at all locations averaged 0.05 µg/g or less, well below levels of human health concern. Mercury concentrations have declined by over 80 percent and over 60 percent in Hudson River and Jamaica Bay blue crabs, respectively.

A subset of specimens from each location were analyzed for PCB concentrations. PCBs were elevated in the hepatopancreas but infrequently detected in leg or thoracic muscle. Mean PCB concentrations in hepatopancreas were 0.845 ± 0.686 µg/g (n = 29) and 0.235 ± 0.195 µg/g (n = 10) in Hudson River and marine waters, respectively. This reflects the well known long term PCB contamination of the Hudson River. PCB concentrations in Jamaica Bay blue crabs have declined by at least 78 percent since 1993.

The improvements in residue levels have been acknowledged by health authorities. However, due to the continued presence of elevated levels of cadmium and PCBs, the health risks of consumption of the hepatopancreas continue to be greater than is considered acceptable for unrestricted consumption. No changes in health advice to consumers of blue crabs resulted from the chemical residue assessment in this study. Periodic surveillance of chemical residues in blue crabs is recommended.

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Introduction

In 1979, blue crab were found to contain elevated concentrations of cadmium in their hepatopancreas (Kneip and Hazen 1979; Sloan and Karcher 1984). The levels were judged to be unacceptable to human health and, as a consequence, the New York State Department of Health issued health advice to consumers of Hudson River blue crabs to consume no more than six crabs per week, not to eat the hepatopancreas, and to discard cooking liquids (referenced in NYSDOH 1981). This health advice was extended to blue crabs in the entire portion of New York's marine district, i.e., the tidal portion of the Hudson River and coastal waters of the New York metropolitan area and Long Island (NYSDOH 1981). In addition, the New Jersey Department of Environmental Protection issued similar health advice for blue crabs in their coastal waters adjacent to New York and throughout their state. These health advisories remain in effect today (NYSDOH 2015; NJDEP/NJDOH 2013).

One of the primary sources of cadmium to the Hudson River was the former Marathon Battery Company at Cold Spring, NY. The facility, which produced nickel-cadmium batteries primarily for the U.S. Department of Defense but also for commercial industries, operated between 1952 and 1979. The legacy of usage and discharge of cadmium and other metals resulted in the contamination of a wetlands complex known as Foundry Cove and Constitution Marsh which are immediately adjacent to the Hudson River. In addition, prior to 1965, the company's wastewater treatment system discharged to the Hudson River through the Cold Spring municipal sewer system (Kneip and Hazen 1979, USEPA 1989). Sediment cadmium concentrations of several hundred ppm dry weight were widely distributed and hot spots, particularly near the Marathon Battery outfall, exceeded 10,000 ppm cadmium (Occhiogrosso et al. 1979; Bower et al. 1978; Kneip and Hazen 1979; Knutson et al. 1987). Efforts to remove the most highly contaminated sediments were conducted in 1972-73 and again in the mid-1980s but were unsuccessful in significantly reducing cadmium exposures to biota. The areas were declared an inactive hazardous waste site and added to the National Priorities List (NPL) by the U.S. Environmental Protection Agency (USEPA) in 1983. USEPA issued three Records of Decision (ROD) to address various aspects of the contaminated site. The first ROD (USEPA 1986) required removal of highly contaminated sediments from east Foundry Cove and restoration of affected areas plus diversion of storm sewers entering Foundry Cove. The second ROD (USEPA 1988) required decontamination of the building and removal of contaminated soils from surrounding grounds and neighborhood yards; ultimately, the building was removed in 1995. The last ROD (USEPA 1989) required removal of sediments from other portions of East Foundry Cove and from the Cold Spring pier area. However, contaminated sediments in Constitution Marsh, an Audubon nature sanctuary, and in western Foundry Cove were deemed, at the time, too difficult to remove. Further, removal was expected to have a disproportionate and unacceptable ecological impact to the marsh ecosystem. Post-remedial monitoring was required but did not include blue crabs.

USEPA, as the lead agency for remedial activities, completed removal and restoration actions at Foundry Cove and Cold Spring in 1994 and 1995. The site was deleted from the NPL in 1996 (USEPA 1996; USEPA 2012b).

Since blue crab are a migratory species, the area of impact of cadmium accumulation in the crabs affects the entirety of the tidal Hudson River (Sloan and Karcher 1984), and contributes to cadmium levels observed in blue crabs in New York Harbor (Skinner *et al*. 1997a) and possibly other marine waters of New York and New Jersey.

Polychlorinated biphenyls (PCBs) were principally discharged to the upper Hudson River in the vicinity of two capacitor manufacturing facilities located at Hudson Falls (approximate river mile 196) and Fort Edward (approximate river mile 195), NY. Direct discharges from these General Electric Company owned plants began in 1947 and continued until ordered to be terminated in 1977. Since the two facilities are perched on shale outcroppings above the river, indirect discharges via penetration of and transport through the underlying fractured shale and along discharge lines embedded in the shale continued at both facilities although remedial actions have reduced inputs over time until nearly eliminated in 2003. PCBs contaminate sediments of both the river and floodplain from near their sources all the way to New York Harbor (Horn et al. 1979; Bopp et al. 1981, 1998; USEPA 2002, 2010, 2012a), a distance of nearly 200 miles. Pursuant to a Superfund Record of Decision (USEPA 2002), dredging began in 2009 and targeted the most contaminated sediment between the PCB sources downstream to Waterford, a distance of about 40 miles. The PCB sediment removal actions were projected to be completed in 2015. PCBs from the sediment and water column have contaminated fish and aquatic invertebrates (Nadeau and Davis 1976; Spagnoli and Skinner 1977; Horn et al. 1979; Sloan et al. 2002 and 2005; Bush et al. 1985; HRNRT 2009), frogs and snapping turtles (HRNRT 2005, 2013; Kelley et al. 2008; Eisenreich et al. 2009), local birds (Foley 1992; Secord and McCarty 1997; Secord et al. 1999; McCarty and Secord 1999; HRNRT 2011, 2013), and fish-eating and other small mammals (Foley et al. 1988; HRNRT 20013). The presence of excessive PCBs in edible flesh of fish, waterfowl and turtles led to issuance of restrictive consumption advisories which began in 1975 and continues to the present time (NYSDOH 1976; NYSDEC 1976; NYSDOH 2015). Recreational fisheries from the PCB sources to the Federal Dam at Troy (approximate river mile 153) were closed from 1975 through 1995, and thereafter were available on a catch-and-release basis only (USDOI, NOAA, NYSDEC 2001; 6 NYCRR Section 11.2). Commercial fisheries, primarily for striped bass, in the tidal river were closed in 1976 (NYSDEC 1976) and remain closed (6 NYCRR Section 11.3). Blue crabs are among those species affected by excessive PCB concentrations (Sloan et al. 2005).

Mercury analyses are included as part of the state's routine chemical residue surveillance program for fish which was initiated in 1969. Excessive mercury concentrations in fish are the most common cause of restrictive consumption advisories for fish in waters of New York State (NYSDOH 2015) and the United States (USEPA 2013a). Elevated

mercury levels in fish and the adverse impact of mercury on human health are major factors influencing national efforts to control mercury sources, including emissions from fossil fuel combustion sources (e.g., power plants) and waste incineration. In New York, most advisories are for waters that have a pH less than 6.5, have limited acid neutralizing capacity, low calcium and low conductivity, although other factors (e.g., impoundments, extent of fringing wetlands) may be factors in some cases (Simonin et al. 2008). These are characteristics most often associated with waters in the Adirondack and Catskill Mountains and other waters at higher elevations. There are some waters (e.g., Onondaga Lake) (Sloan et al. 1987) which did experience direct discharges of mercury causing excessive mercury concentrations in fish. Mercury is present at elevated levels in smallmouth bass from the upper Hudson River, but it is not known to be an issue in fish from the tidal Hudson River. Low concentrations of mercury have been reported in blue crabs (Sloan and Karcher 1984).

This study re-examines the status of cadmium levels in blue crab nine years following completion of the cadmium removal action. Mercury analyses were included for all samples. Due to the spatially extensive and known long-term PCB contamination of Hudson River fish and other aquatic biota (Horn et al. 1979; Sloan *et al*. 2002, 2005; HRNRT 2009), and the extensive injury to human consumers of the fisheries resource (USDOI, NOAA, NYSDEC 2001), PCB analyses of edible tissues of blue crab were included for a subset of samples. Temporal changes in chemical residue concentrations are assessed, where possible, for the 23 year interval following the original blue crab collections.

Methods

Blue crabs were collected by NYSDEC's marine resources professionals from six locations on the Hudson River in 2004 and two locations around Long Island in 2005 (Figure 1) by use of crab pots or traps. The original project design requested sampling of 10 male and 10 female blue crabs although all desired samples were not available. The locations sampled and the characteristics of samples taken, by sex, are given in Table 1.

Larger blue crab, those having a carapace width greater than 127 mm, were chosen to correspond with sizes of blue crabs normally taken by commercial and recreational fishers. Minimum legal size is 115 mm carapace width (6 NYCRR Section 44.2). Total weight and carapace width (the distance between the tips of the horns of the carapace) were measured and recorded, a unique sample label was assigned and attached, samples were placed in individual food grade plastic bags, iced in coolers, and the specimens were frozen on the day of collection. At the laboratory, separate samples of leg muscle and hepatopancreas were excised from each crab using teflon coated stainless steel instruments and submitted for chemical analysis. In addition, thoracic muscle was removed from blue crabs collected from the three locations around the cadmium source and care was taken to minimize hepatopancreas tissue being included.

All samples were analyzed for cadmium and mercury. Cadmium analysis of each tissue followed Method 7131A (USEPA 1994a). Mercury concentrations were determined by Method 7471A (USEPA 1994b), a cold vapor analytical technique. Polychlorinated biphenyl (PCB) concentrations were determined in subsamples of the blue crabs, selected randomly, from each sampling location. Aroclors 1016 (or 1242), 1248, 1254 and 1260 were determined by Method 8082 (USEPA 1996). Lipid content was determined gravimetrically.

Quality assurance samples included blanks, spiked recovery samples, and duplicate analyses of randomly selected samples where sufficient sample mass was present. One of each type of quality assurance sample was analyzed for every 17 unknown samples. For cadmium and mercury analyses, detection limits were low and acceptable, no blank contamination was detected, standard reference material and lab control spike recoveries were good and all duplicate samples, but one, were within acceptance limits (USEPA 1995). The one duplicate exception, for cadmium, had a high relative percent difference (|RPD|) but was a sample approximating the detection limit for which a high |RPD| is not unexpected. For PCBs, all detection limits were less than 0.012 µg/g, no blank PCB contamination was detected, recoveries of matrix spikes with PCBs, duplicate sample results, and lab control spike recoveries were acceptable. Surrogate spike recoveries were acceptable in all samples except one blank which had very low recovery of both surrogate compounds. However, all other quality control measures associated with the sample were acceptable. Duplicate determinations of lipids were acceptable.

This report provides the chemical residue findings for the blue crab samples taken in 2004 and 2005. In addition, temporal assessments used original data provided in other studies.

Results

Cadmium

Cadmium concentrations differed in the blue crabs based on the tissue analyzed. The hepatopancreas consistently contained concentrations that were one to two orders of magnitude greater than levels in leg muscle or thoracic muscle (Table 2). Sex was not a significant determinant of cadmium concentrations. Spatial differences for cadmium in the hepatopancreas were apparent ($p<0.001$) with samples from Jamaica Bay and Little Neck Bay having 0.38 ± 0.21 µg/g ($n = 24$) while samples from the Hudson River contained 2.11 ± 1.77 µg/g cadmium ($n = 88$). Among Hudson River samples, the numerically greatest cadmium concentrations were found at Cold Spring and Foundry Cove but spatially there were no significant differences in cadmium concentrations. The maximum cadmium concentration in the hepatopancreas was 13 µg/g.

In leg muscle, cadmium levels were below detection limits in all marine blue crab and in 34.8 percent of all Hudson River blue crab. For Hudson River blue crab, the cadmium concentration was estimated at 0.034 ± 0.059 µg/g if non-detects were assumed to be one half the detection limit. Leg muscle of blue crab from around the cadmium source did not have detectable cadmium in 36.6 percent of the 30 samples while all thoracic muscle samples contained detectable cadmium.

Mercury

Mercury was detected in all samples but the concentrations were less than 0.1 µg/g in most cases. In the 112 specimens only 1 sample of hepatopancreas and 5 leg muscle samples contained mercury equal to or exceeding 0.1 ug/g; the maximum concentration was 0.15 µg/g. Mean mercury concentrations at each location were approximately 0.05 µg/g or less (Table 2).

Mercury concentrations were greater in males than females within both the hepatopancreas and leg muscle (each $p<0.05$). There were no spatial differences for mercury concentrations within females or when all samples were considered. However, mercury concentrations in hepatopancreas and leg muscle of males from Cornwall, Cold Spring and the Tappan Zee Bridge were significantly ($p<0.01$) greater than at other locations. When sexes are combined, mercury concentrations in muscle of blue crab did not differ ($p>0.05$) between the Hudson River (0.043 ± 0.026 µg/g) and marine waters (0.036 ± 0.018 µg/g). Similarly, there were no differences between the two areas for mercury in the hepatopancreas, i.e., 0.026 ± 0.020 µg/g and 0.022 ± 0.012 µg/g in Hudson River and marine specimens, respectively. Any spatial differences for the combined samples would be spurious and dependent on the proportion of males to females within each sample location.

Mercury concentrations in the hepatopancreas were significantly ($p<0.001$) lower than in the leg muscle or thoracic muscle. Thoracic muscle mercury levels were greater than in leg muscle ($p=0.025$) in the smaller subset of samples ($n = 30$) tested. In samples from the vicinity of the cadmium source, concentrations of mercury were 0.025 ± 0.014 µg/g in hepatopancreas, 0.043 ± 0.025 µg/g in leg muscle and 0.054 ± 0.029 µg/g in thoracic muscle.

PCBs

PCBs reside primarily in the hepatopancreas, indeed, all samples of hepatopancreas had detectable PCBs (Table 3). PCBs were not detected in 77% of leg muscle and 80% thoracic muscle samples. Further, in those muscle samples where PCBs were detected, the concentrations reported were generally no greater than twice the detection limit.

In the hepatopancreas, PCB concentrations in males were greater ($p=0.002$) than in females. Spatial differences were determined for males only ($n = 30$) since the number of females (9) tested was insufficient for conducting spatial analysis. Samples from Cornwall (1.53 ± 0.50 µg/g) and the Tappan Zee Bridge (1.66 ± 0.91 µg/g) had significantly ($p<0.05$) greater PCB concentrations than all other locations and contained 8 of the 9 samples with 1.0 µg/g or more PCB. The two greatest PCB concentrations were 2.2 and 3.1 µg/g. Samples from Jamaica Bay and Little Neck Bay had the lowest PCB concentrations (i.e., 0.104 and 0.175 µg/g, respectively) (Table 3).

All PCBs detected were quantitated as Aroclor 1260. None of the samples were determined as having PCB mixtures with lower levels of chlorination.

Discussion

Blue crab are migratory. They migrate into and reside in the Hudson River and other tributaries and bays of the Atlantic Ocean during spring through early fall before returning to the Atlantic Ocean or burrowing in mud in deeper waters for winter residence. In the Hudson River, they have been found as far north as the Federal Dam at Troy (river mile 153) which impedes more upstream migration. The migrations cause mixing of the population which affects the distribution of chemical residues.

Differences by tissue type

Several investigators have shown the muscle of blue crab contain low levels of chemical residues (e.g., cadmium, PCBs, PCDD/Fs) and that the hepatopancreas is the organ that concentrates these residues (Sloan and Karcher 1984; Belton *et al*. 1985; Hauge *et al*. 1994; NOAA/NMFS 1996; Skinner *et al*. 1996, 1997a, 1997b; McReynolds et al. 2004a, 2004b, 2005). The accumulation in the hepatopancreas is likely part of the process for chemical detoxification and eventual removal from the body. The repeated absence or limited presence of chemical resides in the muscle of blue crabs in sufficient concentrations to warrant concern by health authorities is suggestive that the hepatopancreas can be used as the primary indicator of the status of chemical residues in blue crab. Muscle or other tissues may be examined where specific needs or issues warrant their inclusion.

As in this study, Sloan and Karcher (1984) noted that thoracic muscle contains somewhat greater concentrations of cadmium than leg muscle. They could not attribute a cause for the difference in cadmium levels in the two muscle types, nor can this study. They suggested three possible causes: 1) differing protein characteristics which have differing affinity for cadmium; 2) freezer storage conditions that may cause mobilization of some cadmium from the hepatopancreas to the thoracic muscle; and 3) dissection techniques which may have incorporated cadmium in the thoracic muscle samples despite

the care in dissection that was conducted. None of these potential causes can be ruled out in this study, nor can it be suggested that the difference in cadmium levels in muscle tissues is not real.

Uptake and storage mechanisms for the analytes differ. Mercury in fish is present primarily as methylmercury (Bloom 1992). While uptake and assimilation of methylmercury occurs in all tissues upon original exposure, eventually most of the mercury is redistributed to muscle where it is bound to sulfhydryl groups in protein (McKim et al. 1976; Olson et al. 1978; Boudou and Ribeyre 1983; Harrison et al. 1990). Cadmium is transported to the hepatopancreas where it is bound in metallothionein complexes and will eventually be excreted (Wiedow et al. 1982; Roesijadi 1992, 1994; Viarengo and Nott 1993; Ahearn et al. 2004). PCBs preferentially bind to lipids (Eisler 1986; Eisler and Belisle 1996) whose concentrations are greatest in the hepatopancreas (Table 3).

Differences by sex

Only three locations (Kingston, Cornwall and the Tappan Zee Bridge) produced sufficient numbers of specimens of each sex to make good comparisons of cadmium and mercury concentrations by sex. Concentrations of cadmium in the hepatopancreas and leg muscle could not be differentiated by sex ($p>0.05$ in 5 of 6 comparisons). Indeed, cadmium concentrations in leg muscle were below detection in many of the samples from Kingston and Cornwall, negating comparisons. In contrast, mercury concentrations were greater in males than in females in both hepatopancreas and leg muscle (five of six comparisons); mercury in leg muscle of blue crabs from Kingston was equivalent by sex.

Relationship to cadmium sources

This study was conducted nine years after the cadmium removal action was completed in 1995, albeit an incomplete removal by design. Sediments were removed in east Foundry Cove, and at the Cold Spring Pier. Sediments in Constitution Marsh containing excessive cadmium were not removed because removal operations would destroy a valuable wetland ecosystem (USEPA 1986, 1989, 2012). In this study, cadmium in Hudson River blue crabs from three locations associated with the Marathon Battery Site (i.e., East Foundry Cove, Constitution Marsh and Cold Spring) were not significantly different from blue crabs at three more distant riverine sites. This observation is consistent with Sloan and Karcher (1984) who stated that for the Hudson River there was "no relationship between cadmium sources and cadmium in blue crab." Therefore, the impacted area for blue crab may encompass the entire estuarine portion of the Hudson River. As a consequence, assessing temporal changes is not limited to just sites for which sampling has been conducted on two or more occasions but can be assessed using samples from all sampling sites within the river within a given year. Therefore, a more robust assessment of temporal changes can be obtained.

The Marathon Battery Site is not the only significant source of cadmium to the river. For example, cadmium was discharged to the river by the former Hercules Inc. (now the CIBA-Geigy Site) at Glens Falls, NY and was the subject of sediment removal actions completed in 2000 (NYSDEC 2001). Further, there are other significant cadmium uses in the New York metropolitan area, primarily for electroplating and in pigments and stabilizers, and also in batteries for consumer electronics which has increased substantially (Aucott 2006). These uses may contribute to cadmium in sediments and waters of New York Harbor, an area in which blue crab reside and/or migrate through for ingress to and egress from the Hudson River. Each of these sources may have an impact on cadmium residues found in blue crab.

Temporal changes

Sampling of blue crab in the Hudson River and the marine district has been inconsistent both spatially and temporally. At least five studies (Sloan and Karcher 1984; Skinner et al. 1996; Sloan et al. 2002; McReynolds et al. 2004a, 2005; this study) have examined chemical residues in blue crab from portions of the Hudson River and several marine waters. Some duplication of locations has occurred and they are the basis for individual site comparisons. In the current study, if the impact of sex is ignored, there was a lack of spatial differentiation in cadmium and mercury concentrations within the Hudson River, and as observed by Sloan and Karcher (1984).

Overall, in 2004, cadmium concentrations in blue crabs from the Hudson River had declined by at least 70 percent, while mercury concentrations had declined by 80 percent or more since 1979-81. In Jamaica Bay, cadmium levels experienced a similar decline. However, declines in mercury levels were somewhat less robust at 60 to 70 percent. Further, PCB concentrations in Jamaica Bay blue crabs had declined more than 50 percent and as much as 78 percent or more (Tables 4 and 5 for hepatopancreas and leg muscle, respectively).

Mackie et al. (2007) documented greater than 300 fold reduction in cadmium concentrations in sediments of Foundry Cove following sediment removal actions completed in 1995. Cadmium in sediments declined from a range of 109 to 1500 mg/kg dry weight in 1983 to 2.4 to 230 mg/kg dry weight in 2005. From the perspective of sediment contamination and mass transfer from Foundry Cove, Mackie et al. (2007) stated "dredging was successful in reducing a major source of cadmium to the Hudson River." Upon examination of the impact on blue crabs, using data from this study, Levinton et al. (2006) showed cadmium levels in blue crabs following removal from the sediments had declined by a factor of 4 to 5, which is less than that observed for the sediments. Both Levinton et al. (2006) and this study demonstrate the efficacy of removal of a major cadmium source on cadmium levels in biota on both local and regional Hudson River scales.

Total Aroclor PCBs vs total congener PCBs

PCB Aroclor analytical methods have been available since the 1970s. The earlier methods used packed glass columns for general characterization of chemical mixtures but frequently lacked the ability to separate individual compounds of similar chemical structure. The ability to separate individual PCB congeners and detect lower concentrations became possible as capillary columns became available for use in gas chromatography in the 1980s. Today, capillary columns are used for either PCB Aroclor or PCB congener analyses resulting in greater certainty of proper identification of compounds or chemical mixtures. With capillary columns, various PCB congener methods were developed to analyze selected PCB congeners and were used primarily for specific research purposes (e.g., Bush et al. 1989; Jones et al. 1989). Standard methods to analyze all 209 PCB congeners in tissue were not available until 1999 (USEPA 1999) but their use was very expensive. Consequently, routine use of PCB congener methods was avoided, and quantification of PCBs as Aroclors continued to be a common practice. However, there is increasing use of PCB congener methods, and the costs of conducting those analyses are declining and are no longer cost prohibitive. The ability to provide more accurate estimates of individual and total PCB concentrations and improved ability to assess the toxicological significance of individual compounds favors the use of PCB congener methods.

In this study, PCB concentrations were quantified as Aroclor mixtures by capillary column methods and all comparisons for temporal trend assessment were conducted using total Aroclor concentrations. However, McReynolds et al. (2005) quantified PCBs on both Aroclor and congener bases in a variety of aquatic species from New York Harbor and the lower reaches of the tidal Hudson River. For blue crabs, total Aroclor PCB concentrations were greater than total congener PCB concentrations. Among seven locations with 87 comparisons, total Aroclor concentrations exceeded total congener PCB concentrations by an average of 73.8 percent (minimum 39.3%, maximum 99.3%). In this instance, it is evident that Aroclor methods significantly overestimated total PCB congener concentrations. In four peregrine falcon eggs from along the Hudson River, PCB congeners did not present recognizable patterns consistent with PCB Aroclors. Aroclor concentrations were estimated using quantification factors applied to specific PCB congeners associated with Aroclor mixtures. In that case, total Aroclor PCB concentrations averaged 59 percent (range 20 to 79 percent) greater than total PCB congener concentrations (HRNRT 2004), but the difference could be solely due to selecting quantification factors that were too liberal. In aquatic insects from the Hudson River, total PCB Aroclor concentrations were noted as being greater than total PCB homolog concentrations (HRNRT 2009). Since the same laboratory was used in the assessment of PCBs in aquatic insects, again, liberal quantification factors may have been the cause of the differences.

In contrast, for 15 smallmouth bass and 12 striped bass taken from the Hudson River in 2003 (PCB congener data were reported by Skinner 2011), total PCB congener

concentrations determined by one contract laboratory were generally greater than total PCB Aroclor values (the data are a portion of the data set included in Sloan et al. 2005) determined by a second contract laboratory. The differences in total PCB concentrations were generally not as great as noted previously, and were determined by use of differing analytical methods.

Whether total Aroclor data reported in this study underestimates or overestimates true total PCB concentrations is not known. The Aroclor data as used for temporal changes does indicate that real declines in PCB concentrations in blue crab are occurring. However, as Valoppi et al. (2000) noted, although Aroclor values were and are commonly determined, PCB congeners would provide a more useful and accurate assessment of total PCB concentrations and associated environmental health risks.

Edible portions

The intent of sample preparation was to include as much of the edible tissues (either hepatopancreas, leg muscles or thoracic muscles) that could be extracted to ensure adequate sample mass for chemical analyses. It is presumed that the mass of samples extracted are representative of, and would approximate the mass of material that could be extracted for human consumption. Based on this presumption, the proportions of the blue crab that could be consumed (assuming the crabs are not eaten as soft shell crabs) are presented in Table 6. In this context, about 4.2% of the total weight of the crab would be hepatopancreas, 14% is leg muscle, and, similarly, 15% is thoracic muscle. These proportions add perspective to potential exposure of people that eat tissues of the hard shelled blue crab.

Blue crabs periodically molt their shell to allow expansion and growth of the exoskeleton and body. During this period of three to five days, the exoskeleton is soft and specimens in this stage are frequently eaten as "soft shell crabs". Consequently, the edible portion of a blue crab is greater. Chemical analyses of soft shell blue crabs, as they would be prepared for human consumption, were not conducted and the chemical residue concentrations that may be experienced upon their consumption are unknown.

Health advisory issues

Mercury concentrations were uniformly well below the Food and Drug Administration's (FDA) tolerance of 1.0 µg/g methylmercury (USFDA 1984a). Indeed, levels were generally only 5 percent or less of the tolerance. Mercury in edible tissues of blue crabs from New York waters is not a cause for human health concern.

The NYS Department of Health acknowledged that cadmium levels had declined in blue crabs from the Hudson River and the marine district. However, in their professional opinion, the improvements in cadmium concentrations were not sufficient to cause removal or other modification of health advice for consumers of blue crabs.

PCB concentrations in blue crab were elevated, although mean concentrations do not exceed the FDA tolerance of 2.0 µg/g in edible tissues (USFDA 1984b) in most samples; only two of 39 samples (5.1%) exceeded 2.0 µg/g. The presence of PCBs above 1.0 µg/g in 23% of the samples was a sufficient cause, in addition to cadmium, to continue restrictive health advisory recommendations. However, as noted previously, the concentrations of PCBs and associated health impacts may be more accurately assessed if PCB congener analyses were conducted.

The current health advice for consumption of blue crab is "Do not eat" the hepatopancreas due to the presence of cadmium, PCBs, and chlorinated dioxins and furans (PCDD/Fs). PCDD/Fs were not addressed by this study. In New York, this health advice applies to blue crabs taken from the Hudson River downstream of the Rip Van Winkle Bridge at Catskill and includes all marine waters within the New York-New Jersey Harbor estuary and waters surrounding Long Island. Further, in some areas of New York Harbor, there are recommendations to limit consumption of the meat of blue crabs (NYSDOH 2015). New Jersey prohibits harvest, sale and eating blue crabs taken from the Newark Bay Complex (which includes some shared waters in New York Harbor) and advises people not to eat the hepatopancreas from blue crab taken from the remainder of waters shared with New York. In the latter waters, certain consumption recommendations for the meat of blue crabs apply (NJDEP/NJDOH 2013).

Recommendations

Since cadmium and PCB concentrations in blue crab hepatopancreas in 2004 and 2005 remained at levels unacceptable for human consumption, and since an additional 10 years have elapsed since conduct of the study, resumption of periodic surveillance of cadmium and PCB residues in blue crab from the Hudson River and other marine waters of New York is warranted. However, future studies can incorporate findings of this study to obtain a more effective assessment and expand the scope of the assessment. Some recommendations and their rationale for future studies are noted hereafter.

1. As a minimum, adopt the same locations used in the 2004-2005 study.

    The 2004-2005 study provided an association with the cadmium and PCB sources and examined the spatial extent of their effects on blue crabs in the Hudson River. Further, reference sites were included against which the extent of contamination could be ascertained.

2. Include additional locations in the New York Harbor estuary for examining chemical residues in blue crabs. Recommended locations include Upper and Lower Bays, East River, The Kills (Arthur Kill and Kill Van Kull), and New York Bight Apex.

Blue crab migrate through these waters to and from the Hudson River. Cadmium, PCBs, and PCDD/Fs all have local sources in the harbor estuary and in adjacent New Jersey waters. These compounds have accumulated in blue crab to unacceptable levels in the harbor estuary (Skinner et al. 1996, 1997a, 1997b, McReynolds et al. 2004a, 2004b, Rappe et al. 1991; Belton et al. 1985, Hauge et al. 1994) and may be contributing to residues observed in Hudson River blue crabs. Efforts have been made to remove or control sources of these compounds (e.g., the phaseout of PCBs required by the Toxic Substances Control Act of 1978, and the removal of PCDD/Fs from the Passaic River and Newark Bay (USEPA 2013b and 2014)) throughout the harbor estuary but the effectiveness of controls with respect to blue crabs has not been assessed since 1999-2000.

The health advice to avoid consumption of the hepatopancreas applies to blue crabs from all marine waters. The recommended distribution of sampling sites would be inadequate to assess the status of chemical residues in blue crabs taken elsewhere from Long Island waters east of Jamaica Bay and Little Neck Bay, and, therefore, it may be insufficient for the Department of Health to make an assessment of chemical residues for health advisory purposes for those other waters. However, the sampling program recommended does address the New York waters from which the greatest issues with chemical residues in blue crab have been found. The Department should consider whether blue crab from additional marine waters should be collected and determine if there are sources of funding for an expanded project.

3. Discontinue analysis of muscle tissues. Analyze only the hepatopancreas.

All the compounds of interest, described later, preferentially accumulate in the hepatopancreas. It is the hepatopancreas which is the target of health advice for consumers of blue crab. If funding is limited or finite, elimination of analysis of muscle tissues provides flexibility to expand the locations sampled, and/or the analyte groups that can be assessed.

4. Discontinue mercury analyses.

Mercury concentrations are well below levels of concern for protection of human health and for protection of environmental health. This recommendation adds further flexibility to study design.

5. As a minimum, cadmium, PCBs and PCDD/Fs are recommended for analysis.

> All these compounds contribute to the health advice to avoid consumption of the hepatopancreas of blue crabs. In the absence of data that demonstrates these compounds are below levels which are of human health concern, the Department of Health will not entertain changes to the health advice.
>
> PCBs in blue crab in earlier studies identified in this paper had been analyzed as Aroclor mixtures. Over time, Aroclor mixtures become environmentally degraded thus affecting the quantitation of the mixture. As Aroclors, total PCB concentrations may be overstated, as observed by McReynolds et al. (2005) and others. It is recommended that quantitation of PCBs be conducted as individual congeners to provide a more accurate description of PCB concentrations. The need for improved accuracy of PCB concentrations increases as the levels decline. However, this will result in added cost so this recommendation must be evaluated in the context of potential funding and may need to be considered in an exploratory element of project design.

6. Analysis of polybrominated diphenyl ethers (PBDEs) should be considered and included if possible.

> PBDEs have been identified in fish, blue crab, aquatic insects and bullfrogs from the Hudson River (Xia et al. 2008; Skinner 2011) although the concentrations were at levels below those which NYSDOH believes would trigger inclusion in the health advisory. PBDEs are present in greater quantities in fish associated with population centers due to human use of products containing PBDEs as a flame retardant (Skinner 2011). Since blue crabs must migrate through waters adjacent to the very large population center in the New York metropolitan area, there is a likelihood of elevated PBDEs in blue crabs and that likelihood should receive at least a limited assessment.

7. The recommended number of specimens to be collected from each sample site is 10 females and 10 males, each greater than 127 mm in carapace width. However, not all samples collected need to be analyzed for all chemical compounds. All samples should be analyzed for cadmium and PCBs. For PCDD/Fs, a sample size of 3 females and 3 males per site, or if one sex is not available in sufficient numbers, a total of 5 samples per site would be acceptable. Similarly, if PBDEs are included, a sample construct like that for PCDD/Fs is proposed.

> The recommended sample sizes for cadmium and PCB analyses provide a good statistical basis for assessing the status of the chemical residues. Due to the expense of PCDD/F and PBDE analyses, and the need for additional tissue mass for these analyses (especially of a tissue - the hepatopancreas - which comprises

about 4 percent of the total mass of the specimen), the smaller numbers of PCDD/F and PBDE analyses would provide a representative, albeit limited, assessment of the status of those residues. If funding is restricted, priority of analysis of should be placed on cadmium, PCBs and PCDD/Fs.

Due to the need for additional mass for analysis of PCDD/Fs and PBDEs, it may be advisable to collect additional specimens beyond the minimum numbers recommended.

8. The maximum recommended sampling interval for this project is once every 5 years and the project would be terminated one sampling event following elimination of health advice. The minimum sampling interval is once every 10 years and the project would be terminated one sampling event following elimination of health advice. Sampling should commence in 2016, if possible.

Ten years have elapsed since the last sampling event. The recommendation is a melding of concerns for practicality, workload management, the likelihood of significant changes in residue levels as chemical controls are implemented and natural processes reduce the availability of the chemical residues, the need for timely information and assurance of success, and the ability to obtain funding.

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Table 1: Carapace width and total weight of blue crab samples collected for chemical analyses in 2004-2005.

Location	RM[1]	Sex	No.	Carapace width (mm) Mean ± SD	Carapace width (mm) Min. - Max.	Total weight (g) Mean ± SD	Total weight (g) Min. - Max.
Hudson River							
- Kingston	91	F	10	134 ± 19.6	115 - 174	90.0 ± 31.0	66 - 164
		M	10	143 ± 9.3	129 - 158	138 ± 28.9	84 - 170
- Cornwall	56	F	9	123 ± 17.6	104 - 158	78.9 ± 29.0	50 - 128
		M	10	144 ± 12.5	120 - 162	145 ± 24.1	116 - 182
- Cold Spring Pier	54	F	2	149	128 - 170	111	76 - 146
		M	10	145 ± 12.9	125 - 165	130 ± 32.8	86 - 180
- East Foundry Cove	54	F	1	125		60	
		M	5	126 ± 13.9	112 - 148	86.8 ± 19.1	64 - 112
- Constitution Marsh, South Cove	52	F	2	119	114 - 123	66	56 - 76
		M	10	129 ± 18.4	92 - 156	95.0 ± 36.5	38 - 168
- Tappan Zee Bridge	27	F	9	147 ± 12.4	122 - 166	145 ± 18.8	120 - 174
		M	10	147 ± 12.7	127 - 166	187 ± 49.4	134 - 308
Marine waters							
- Jamaica Bay		F	5	138 ± 15.1	122 - 158	127 ± 25.9	105 - 163
		M	10	143 ± 10.1	130 - 158	172 ± 45.1	100 - 260
- Little Neck Bay		F	4	136 ± 15.8	122 - 155	108 ± 20.1	94 - 138
		M	5	157 ± 14.5	138 - 170	214 ± 36.6	167 - 264

[1] Approximate river mile.

Table 2: Cadmium and mercury concentrations (µg/g wet weight) in edible tissues of blue crab taken in 2004-2005.

				Cadmium		Mercury	
Location	Tissue[1]	Sex	No.	Mean ± SD	Min. - Max.	Mean ± SD	Min - Max.
Hudson River							
- Kingston	HEP	F	10	1.45 ± 0.58	0.55 - 2.2	0.014 ± 0.0055	0.0058 - 0.027
		M	10	1.67 ± 0.67	0.41 - 2.6	0.019 ± 0.0054	0.011 - 0.028
	LM	F	10	80% <DL[2]	<0.018 - 0.026	0.029 ± 0.0056	0.020 - 0.040
		M	10	60% <DL[2]	<0.019 - 0.031	0.034 ± 0.011	0.014 - 0.13
- Cornwall	HEP	F	9	1.43 ± 0.71	0.47 - 2.5	0.019 ± 0.013	0.0043 - 0.049
		M	10	2.90 ± 1.85	1.1 - 7.1	0.033 ± 0.014	0.014 - 0.058
	LM	F	9	67% <DL[2]	<0.018 - 0.031	0.030 ± 0.0088	0.016 - 0.047
		M	10	50% <DL[2]	<0.019 - 0.075	0.060 ± 0.031	0.025 - 0.11
- Cold Spring Pier	HEP	F	2	1.25	1.0 - 1.5	0.029	0.015 - 0.043
		M	10	2.17 ± 0.58	1.5 - 2.9	0.037 ± 0.014	0.0091 - 0.054
	LM	F	2	0.040	0.022 - 0.058	0.042	0.038 - 0.045
		M	10	60% <DL[2]	<0.019 - 0.050	0.052 ± 0.016	0.033 - 0.087
	TM	F	2	0.063	0.036 - 0.090	0.056	0.049 - 0.063
		M	10	0.079 ± 0.043	0.034 - 0.19	0.070 ± 0.025	0.045 - 0.13
- East Foundry Cove	HEP	F	1	5.1		0.012	
		M	5	4.34 ± 4.85 (2.18 ± 0.32)[3]	1.9 - 13.0	0.019 ±0.013	0.0066 - 0.037
	LM	F	1	0.14		0.026	
		M	5	0.16 ± 0.21	0.024 - 0.53	0.057 ± 0.048	0.020 - 0.12
	TM	F	1	0.24		0.036	
		M	5	0.36 ± 0.42	0.12 - 1.1	0.064 ± 0.051	0.025 - 0.13

Table 2 continued:

Location	Tissue[1]	Sex	No.	Cadmium Mean ± SD	Cadmium Min. - Max.	Mercury Mean ± SD	Mercury Min. - Max.
- Constitution Marsh, South Cove	HEP	F	2	1.80	1.4 - 2.2	0.017	0.015 - 0.019
		M	10	1.50 ± 0.82	0.80 - 3.4	0.019 ± 0.0098	0.010 - 0.044
	LM	F	2	0.027	0.019 - 0.034	0.029	0.028 - 0.029
		M	10	50% <DL[2]	<0.020 - 0.067	0.032 ± 0.015	0.017 - 0.070
	TM	F	2	0.074	0.047 - 0.10	0.035	0.029 - 0.041
		M	10	0.091 ± 0.094	0.023 - 0.30	0.040 ± 0.016	0.022 - 0.081
- Tappan Zee Bridge	HEP	F	9	1.56 ± 0.996	0.60 - 3.7	0.017 ± 0.0035	0.011 - 0.022
		M	10	2.85 ± 2.42	0.94 - 8.5	0.054 ± 0.038	0.023 - 0.14
	LM	F	9	0.053 ± 0.030	0.022 - 0.12	0.024 ± 0.0037	0.020 - 0.032
		M	10	30% < DL[2, 4]	<0.019 - 0.067	0.079 ± 0.030	0.048 - 0.15
Marine waters							
- Jamaica Bay	HEP	F	5	0.41 ± 0.15	0.30 - 0.63	0.029 ± 0.013	0.016 - 0.048
		M	10	0.36 ± 0.21	0.013 - 0.72	0.024 ± 0.013	0.0099 - 0.044
	LM	F	5	<0.028	<0.028 - <0.028	0.026 ± 0.0099	0.015 - 0.041
		M	10	<0.028	<0.028 - <0.028	0.041 ± 0.019	0.014 - 0.070
- Little Neck Bay	HEP	F	4	0.32 ± 0.10	0.23 - 0.42	0.011 ± 0.0064	0.0071 - 0.021
		M	5	0.44 ± 0.33	0.12 - 0.95	0.020 ± 0.0052	0.015 - 0.028
	LM	F	4	<0.028	<0.028 - <0.028	0.028 ± 0.014	0.014 - 0.046
		M	5	<0.028	<0.028 - <0.028	0.041 ± 0.025	0.019 - 0.083

[1] HEP = hepatopancreas; LM = leg muscle; TM = thoracic muscle.
[2] Detection limits range from 0.018 to 0.021 µg/g; the smallest detection limit is given as the minimum.
[3] Mean and standard deviation excluding outlier value.
[4] Mean ± standard deviation of values above detection limits is 0.042 ± 0.016 ng/g (n = 7) which overestimates the true value for all 10 samples.

Table 3: Lipids (percent) and total polychlorinated biphenyl (PCB) concentrations (ng/g wet weight) in edible tissues of blue crabs taken in 2004-2005.

				Lipid		Total PCB	
Location	Tissue[1]	Sex	No.	Mean ± SD	Min. - Max.	Mean ± SD	Min. - Max.
Hudson River							
- Kingston	HEP	F	2	5.40	3.29 - 7.50	305	280 - 330
		M	3	7.86 ± 1.58	6.06 - 8.99	593 ± 297	340 - 920
	LM	F	2	0.42	0.31 - 0.52	<14	<10 - <14
		M	3	0.35 ± 0.040	0.30 - 0.37	<15	<11 - <15
- Cornwall	HEP	F	1	1.41		350	
		M	4	8.00 ± 2.55	5.81 - 10.9	1525 ± 499	1000 - 2200
	LM	F	1	0.21		16	
		M	4	0.44 ± 0.14	0.26 - 0.57	50% <DL[2]	<14 - 28
- Cold Spring Pier	HEP	M	4	9.63 ± 3.78	4.74 - 12.7	475 ± 117	310 - 580
	LM	M	5	0.41 ± 0.17	0.28 - 0.66	<19	<12 - <19
	TM	M	5	0.48 ± 0.12	0.33 - 0.66	80% <DL[2]	<13 - 9.8
- East Foundry Cove	HEP	F	1	3.84		390	
		M	4	5.30 ± 1.77	3.19 - 7.51	770 ± 544	210 - 1500
	LM	F	1	0.71		<14	
		M	4	0.48 ± 0.14	0.31 - 0.66	50% <DL[2]	<16 - 36
	TM	F	1	0.42		<13	
		M	4	0.51 ± 0.022	0.48 - 0.53	50% <DL[2]	<15 - 25

Table 3 continued:

Location	Tissue[1]	Sex	No.	Lipid Mean ± SD	Lipid Min. - Max.	Total PCB Mean ± SD	Total PCB Min. - Max.
- Constitution Marsh, South Cove	HEP	F	1	6.17		330	
		M	4	6.62 ± 3.13	3.02 - 10.5	418 ± 122	250 - 540
	LM	F	1	0.54		<15	
		M	4	0.65 ± 0.18	0.43 - 0.87	<18	<13 - <18
	TM	F	1	0.38		<17	
		M	4	0.54 ± 0.10	0.45 - 0.67	<17	<11 - <17
- Tappan Zee Bridge	HEP	M	5	7.64 ± 1.92	4.59 - 9.35	1662 ± 907	710 -3100
	LM	M	5	0.45 ± 0.055	0.40 - 0.51	17.6 ± 6.99	<12 - 24
Marine waters							
- Jamaica Bay	HEP	F	2	10.31	5.21 - 15.4	104	38 - 170
		M	3	14.23 ± 5.90	9.39 - 20.8	210 ± 72.1	130 - 270
	LM	F	2	0.73	0.33 - 1.12	<19	<14 - <19
		M	3	0.43 ± 0.17	0.24 - 0.57	<16	<12 - <16
- Little Neck Bay	HEP	F	2	15.13	9.35 - 20.9	175	160 - 190
		M	3	10.68 ± 4.90	6.25 - 14.2	387 ± 497	170 - 760
	LM	F	2	0.67	0.56 - 0.78	<15	<13 - <15
		M	3	0.39 ± 0.22	0.21 - 0.64	<16	<12 - <16

[1] HEP = hepatopancreas; LM = leg muscle; TM = thoracic muscle.
[2] Detection limits range from 13 to 19 ng/g; the smallest detection limit is given as the minimum.

Table 4: Change in concentrations of cadmium, mercury and polychlorinated biphenyls in the hepatopancreas of blue crabs taken from the Hudson River and New York's marine waters.

Location	Collection Years[1]	n_1, n_2	Cadmium Conc.[2]	Cadmium %Δ[3]	Mercury Conc.	Mercury %Δ	Total PCBs Conc.	Total PCBs %Δ
Hudson River								
- Cornwall	1981, 2004	5, 19	7.28, 2.21	-69.6				
- Foundry Cove	1979/81, 2004	15, 6	9.67, 4.47	-53.8	0.100, 0.018	-82.0		
- Tappan Zee Bridge/	1979/81, 1999-2000	21, 6	6.05, 2.88	-52.4	0.150, 0.051	-66.0		
Haverstraw Bay	1979/81, 2004	21, 19	6.05, 2.24	-63.0	0.150, 0.037	-75.3		
	1999, 2004	5, 5					3.51, 1.66	-52.7
- All locations	1979/81, 2004	55, 88	7.91, 2.11	-73.3	0.220, 0.026	-88.8		
	1999, 2004	27[4], 29					2.35, 0.845	-64.0
Marine waters								
- Jamaica Bay	1981, 1993	5, 5	0.390, 0.212	-45.6				
	1981, 1999-2000	5, 6	0.390, 1.56	+300				
	1981, 2005	5, 15	0.390, 0.377	-3.33				
	1993, 2005	5, 15	0.212, 0.377	+77.8	0.066, 0.026	-60.6	0.770, 0.168[5]	-78.2
	1999-2000, 2005	6, 15	1.56, 0.377	-75.8	0.077, 0.026	-66.2	1.37, 0.168[5]	-87.7

[1] Data sources: 1979 and 1981 from Sloan and Karcher (1984); 1993 from Skinner et al. (1997); 1999 from Sloan et al. (2002); 1999-2000 from McReynolds et al. (2004) for metals and from McReynolds et al. (2005) for PCBs; 2004-2005 from this study.
[2] Mean concentrations (µg/g wet weight) of analyte in respective years indicated. Data combined for 1979 and 1981 if available for both years.
[3] %Δ means percent change.
[4] Data from Sloan et al. (2002) is for legal sized blue crabs only as obtained from NYSDEC data files.
[5] n = 5 samples for PCB analysis in 2005.

Table 5: Change in concentrations of cadmium, mercury and polychlorinated biphenyls in leg muscle of blue crabs taken from the Hudson River and New York's marine waters.

Location	Collection Years[1]	n_1, n_2	Cadmium Conc.[2]	Cadmium %Δ[3]	Mercury Conc.	Mercury %Δ	Total PCBs Conc.	Total PCBs %Δ
Hudson River								
- Cornwall	1981, 2004	5, 19	0.150, ≈0.018[4]	≈-88[4]				
- Foundry Cove	1979/81, 2004	15, 6	0.356, 0.155	-56.4	0.110, 0.052	-52.7		
- Tappan Zee Bridge/	1979/81, 1999-2000	21, 6	0.105, 0.124	+18.1	0.180, 0.053	-70.6		
Haverstraw Bay	1979/81, 2004	21, 19	0.105, ≈0.042[5]	≈-54[5]	0.180, 0.053	-70.6		
	1999, 2004	5, 5					0.040, 0.0176	-56.0
- All locations	1979/81, 2004	55, 88	0.170, ≈0.034[6]	≈-80[6]	0.260, 0.043	-83.4		
	1999, 2004	27[7], 29					0.036[7], ≈0.012[8]	≈-72[8]
Marine waters								
- Jamaica Bay	1981, 1993	5, 5	0.070, 0.019	-72.8				
	1981, 1999-2000	5, 6	0.070, 0.149	+112				
	1981, 2005	5, 15	0.070, <0.028[9]	>-60				
	1993, 2005	5, 15	0.019, <0.028[9]	nc[9]	0.132, 0.036	-72.7	<0.030, <0.019[10]	nc[9]
	1999-2000, 2005	6, 15	0.149, <0.028[9]	>-81	0.153, 0.036	-76.5	0.041, <0.019[10]	>-53

[1] Data sources: 1979 and 1981 from Sloan and Karcher (1984); 1993 from Skinner et al. (1997); 1999 from Sloan et al. (2002); 1999-2000 from McReynolds et al. (2004) for metals and from McReynolds et al. (2005) for PCBs; 2004-2005 from this study.
[2] Mean concentrations (µg/g wet weight) of analyte in respective years indicated. Data combined for 1979 and 1981 if available for both years.
[3] %Δ means percent change.
[4] 58% nondetects. Mean and %Δ if nondetects = 1/2 detection limit. If nondetects = 0, then %Δ = 92. If nondetects = detection limit, then %Δ = 84.
[5] 16% nondetects. Mean and %Δ if nondetects = 1/2 detection limit. If nondetects = 0, then %Δ = 61. If nondetects = detection limit, then %Δ = 58.
[6] 44% nondetects. Mean and %Δ if nondetects = 1/2 detection limit. If nondetects = 0, then %Δ = 83. If nondetects = detection limit, then %Δ = 78.
[7] Data from Sloan et al. (2002) is for legal sized (≥115 mm) blue crabs as obtained from NYSDEC data files.
[8] 77% nondetects. Mean and %Δ if nondetects = 1/2 detection limit. If nondetects = 0, then %Δ = 83. If nondetects = detection limit, then %Δ = 53.
[9] 100 % nondetects in 2005. nc = not calculated.
[10] n = 5 samples for PCB analyses in 2005; 100% nondetects.

Table 6: Proportion of sample weight to total weight of blue crab samples[1].

Location	No.	Tissue	Sample weight (g) Mean ± SD	Sample weight (g) Min. - Max.	Percent of total weight[2] Mean ± SD	Percent of total weight[2] Min. - Max.
Hudson River						
- Kingston	20	HEP	4.51 ± 1.29	2.5 - 6.5	4.38 ± 2.01	1.73 - 9.70
		LM	15.5 ± 6.70	6.5 - 25.9	13.2 ± 2.54	8.63 - 17.7
- Cornwall	19	HEP	4.23 ± 1.34	1.3 - 5.9	4.31 ± 2.28	1.44 - 9.81
		LM	17.6 ± 8.51	6.7 - 30.9	15.0 ± 2.70	7.44 - 18.1
- Cold Spring Pier	12	HEP	5.77 ± 3.24	1.6 - 13.8	4.42 ± 1.81	1.86 - 8.63
		LM	17.8 ± 6.73	7.7 - 31.1	13.8 ± 2.46	8.95 - 17.3
		TM	17.7 ± 3.87	11.7 - 23.3	14.1 ± 0.98	12.3 - 15.9
- East Foundry Cove	6	HEP	3.63 ± 1.64	2.5 - 6.8	4.45 ± 1.61	2.66 - 7.39
		LM	11.3 ± 4.81	5.2 - 16.7	13.9 ± 5.26	5.89 - 18.2
		TM	14.8 ± 4.00	10.1 - 20.4	17.9 ± 1.29	15.8 - 19.5
- Constitution Marsh, South Cove	12	HEP	3.93 ± 1.70	1.0 - 7.8	4.69 ± 2.10	1.19 - 8.55
		LM	13.6 ± 6.49	4.7 - 26.4	14.7 ± 2.19	11.4 - 18.1
		TM	13.4 ± 4.51	6.5 - 23.3	15.2 ± 1.55	13.4 - 18.0
- Tappan Zee Bridge	19	HEP	5.69 ± 3.31	1.5 - 15.0	3.26 ± 1.19	1.12 - 5.21
		LM	25.0 ± 9.86	13.8 - 53.9	14.6 ± 2.51	10.6 - 18.3

Table 6 continued:

Location	No.	Tissue	Sample weight (g) Mean ± SD	Sample weight (g) Min. - Max.	Percent of total weight[2] Mean ± SD	Percent of total weight[2] Min. - Max.
Marine waters						
- Jamaica Bay	15	HEP	6.74 ± 2.30	3.0 - 11.2	4.34 ± 1.29	2.25 - 7.05
		LM	23.6 ± 8.97	14.2 - 43.4	14.8 ± 2.17	11.7 - 17.9
- Little Neck Bay	9	HEP	6.70 ± 2.79	2.9 - 11.4	4.61 ± 2.81	1.44 - 10.4
		LM	27.8 ± 15.1	10.4 - 54.4	15.8 ± 3.37	10.8 - 20.6
Overall	112	HEP	5.16 ± 2.48	1.0 - 15.0	4.23 ± 1.91	1.12 - 10.4
	112	LM	19.4 ± 9.78	4.7 - 54.4	14.4 ± 2.76	5.89 - 20.6
	30	TM	15.4 ± 4.49	6.5 - 23.3	15.3 ± 1.88	12.3 - 19.5

[1]Total weight is summarized in Table 1.
[2] HEP = hepatopancreas; LM = leg muscle; TM = thoracic muscle.

Figure 1: Sampling sites for collection of blue crabs from the Hudson River and New York's marine district in 2004-2005.

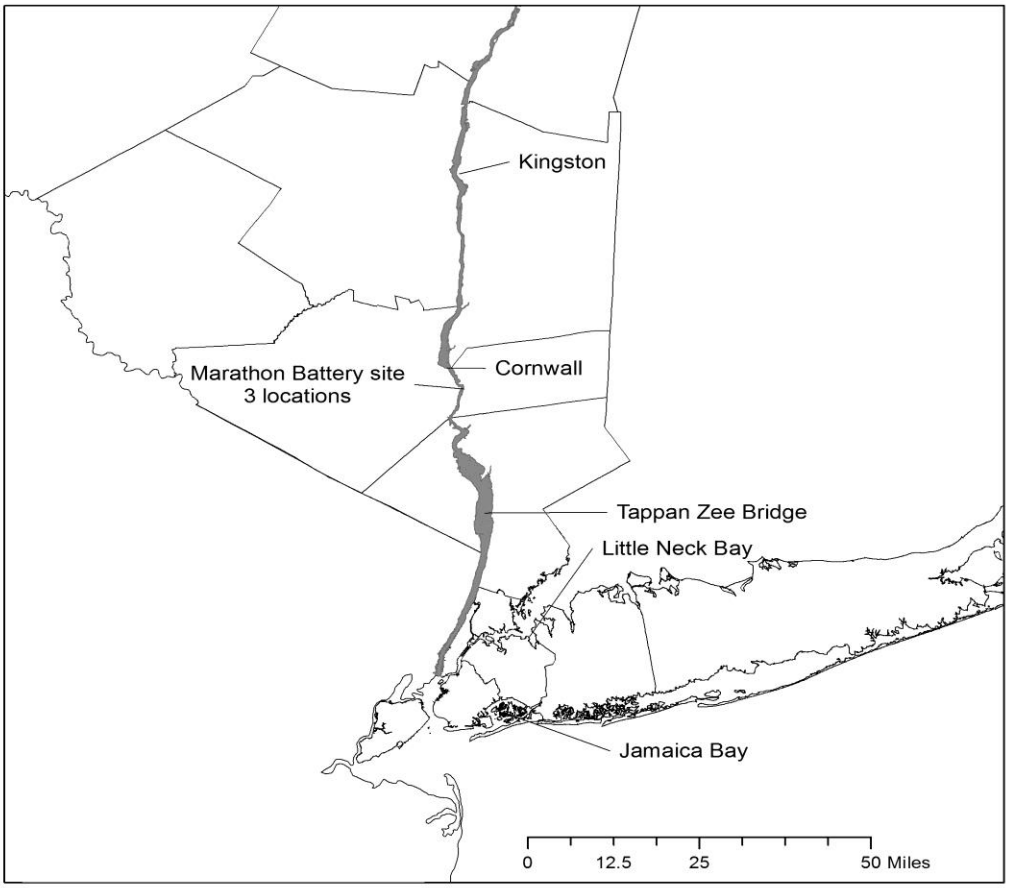

Figure 2: Three blue crab sampling sites in the vicinity of the former Marathon Battery site.