A Comparison of Congeneric PCB Patterns in American Eels and Striped Bass from the Hudson and Delaware River Estuaries

Jeffrey T.F. Ashley[1,2], Richard Horwitz[2], Joe Steinbacher[3], and Bruce Ruppel[4]

[1]Philadelphia University, School of Science and Health, School House Lane and Henry Avenue, Philadelphia, Pennsylvania 19144

[2]Patrick Center for Environmental Research, Academy of Natural Sciences, 1900 Benjamin Franklin Parkway, Philadelphia, Pennsylvania 19103

[3]National Oceanographic and Atmospheric Administration, Silver Spring, Maryland

[4]New Jersey Department of Environmental Protection, Division of Science and Research, 401 East State Street, Trenton, New Jersey 08625

Abstract

The Hudson River estuary has enormous spatial variation in polychlorinated biphenyl (PCB) contamination due in large part to historical point source discharges above the Troy Dam. Unlike the Hudson River, the Delaware River estuary was not inundated by a single large point source of PCBs. However, through decades of industrial, municipal, and non-point source inputs, the Delaware Estuary has accumulated significant levels of PCBs. The overall goal of this research was to use existing data sets to compare and contrast the patterns of accumulated PCB congeners in sub-populations of American eels and striped bass inhabiting the these two estuaries and surrounding coastal waters. Data derived from the three separate research projects, each using identical preparatory and analytical procedures, were amalgamated, resulting in one data set containing congeneric PCB concentrations for 100 American eels and 125 striped bass. Collection sites extended from above the fall line of the Delaware River at the confluence of the

Lehigh River, PA to the upper portions of the Hudson River estuary at Troy, NY. Using principal component analysis (PCA), some inter- and intra-estuarine differences in accumulated congeneric patterns were denoted for both species. For striped bass, three distinct patterns were observed: 1) one dominated by more lightly chlorinated congeners from resident bass around Troy; 2) a mix of light and heavy chlorinated congeners from a contingent collected between New York Harbor and Catskill; and, 3) one dominated by more heavily chlorinated congeners from a group comprised of all those collected sites in New Jersey/Delaware coastal zones and the Delaware River estuary. Results from this study support the idea that migration behavior of striped bass hampers the use of accumulated congener specific PCB patterns in providing information on localized contamination. However, because of their limited home range, further evidence through this study supports the potential use of the American eel as a biomonitoring tool. Data from the amalgamated data set may ultimately be used in existing or future mathematical models which predict bioaccumulation patterns in upper trophic level biota in heterogeneously-contaminated estuaries.

Introduction

Of the thousands of anthropogenic substances produced and emitted into the environment, the suite of compounds collectively known as polychlorinated biphenyls (PCBs) have fallen under appreciable scientific scrutiny. Concern over these globally ubiquitous contaminants arises because of their bioaccumulative nature and, for some congeners, their well-documented toxicity to higher trophic level organisms such as fish (Monosson, 1999/2000) and potential carcinogenicity to humans. Over the past several decades, North Americans have witnessed the effects of PCB contamination on recreational and commercial fisheries (*e.g.*, Bush *et al*., 1989; Madenjian *et al.*, 1998). Consumption advisories, promulgated by the U.S. Food and Drug Administration (US FDA) and at times by individual States, have been instituted to protect fish consumers against the possible detrimental effects of ingesting PCB-contaminated fish (*e.g.*, Hansler and Fisklin, 1998; Stow *et al.*, 1994). Driven by human health concerns and protection of wildlife, a significant focus of PCB research has been elucidating the factors determining accumulation in fish.

Bioaccumulation of PCBs and other lipophilic contaminants may be controlled by such factors as age, weight and lipid content of the organism. However, additional factors may be important. For example, proximity to source has been suggested to be the dominant factor in determining total body burdens of PCBs in eels (*e.g.*, van der Oost *et al.*, 1996; Steinbacker, 2001). However, metabolic degradation/elimination of certain congeners (*e.g*., Brown, 1992; Stapleton, 2001) may alter both the magnitude and pattern of accumulated PCBs. Another important factor that has been recently identified in migratory fishes is habitat use. Research has shown that the recent habitat use by Hudson River striped bass was a large determinant of PCB concentrations, both magnitude and pattern wise (Zlokovitz and Secor, 1999; Ashley *et al.*, 2000). One or several of these factors (or others) may be acting solely or in combination to determine the degree to which each congener is retained in the tissue of that organism.

The task of elucidating these factors is often daunting. Some researchers have turned towards specific PCB congeneric patterns in hopes of providing further information. By quantifying the similarities and differences in accumulated patterns between and among species from various locations, insight into the inter- and intra-estuarine and inter- and intra-specific factors controlling bioaccumulation may be gained. The objectives of this study were (1) to amalgamate data sets quantifying congener-specific PCB concentrations in American eels (*Anguilla rostrata*) and striped bass (*Morone saxatilis*) from two U.S. east coast estuaries, the Hudson and Delaware Rivers, (2) to compare and contrast the patterns of accumulated PCB congeners among and between the two species throughout the study area, and (3) if possible, to provide information regarding the factors contributing to the observed congeneric patterns.

Given the different contaminant sources, inventories, and geomorphologies of the two estuaries, coupled with the possibility of different abundances and species of prey items existing between them, it was hypothesized that different accumulated PCB patterns would be discernable among and between species utilizing these two distinct estuaries. If this hypothesis proved true, characteristic accumulation patterns in species, particularly those having limited home ranges (*e.g.*, American eels), could possibly be used as indicators of localized contamination. Moreover, by relating accumulated patterns in both species with available data on biological and physical factors such as lipid content, location caught, and size (length and weight), factors driving those patterns may be discerned.

Methods

Site Description and Data Set Amalgamation

The Hudson River estuary extends over 200 km from the fresh/oligohaline waters below the Troy Dam, NY to the polyhaline waters of New York Harbor, NY. Over this distance, the estuary has enormous spatial variation in PCB contamination (Bush *et al.*, 1986; Bush *et al.*, 1989; Bush *et al.*, 1994). From the mid-1940s to the mid-1970s, the Hudson River estuary received over 250 tonnes of PCBs, largely as a result of industrial discharges above the Troy Dam at Ft. Edward and Hudson Falls (Bush *et al.*, 1989). Largely as a consequence of the decades of PCB release in the upper estuary, the commercial eel and striped bass fisheries in the entire Hudson River were closed and consumption advisories for recreational anglers were issued in 1976.

Steinbacher (2001) recently evaluated PCB concentrations in 30 eels collected from six sites along the salinity gradient of the estuary from Albany, NY to the George Washington Bridge (Fig. 1). Using a sub-set of samples collected from the New York Department of Environmental Conservation's (NYDEC) 1994-5 collections, Ashley *et al.* (2000) evaluated the congener-specific PCB concentrations in 74 striped bass collected from Troy, NY to New York Harbor (and included 6 from Long Island Sound). Together, these studies have generated a spatially-extensive data set that includes congener-specific PCB patterns for American eels and striped bass within the Hudson River estuary.

Similar to the Hudson River, the Delaware River estuary stretches approximately 200 km, from the fall line of the Delaware River just above Trenton, NJ to the mouth of the Delaware Bay between Cape May, DE and Cape Henlopen, DE. However, unlike the scenario in the upper Hudson River, the Delaware River estuary was not inundated by a single large point source of PCBs. Rather, through decades of industrial, municipal, and non-point source inputs, the Delaware Estuary has accumulated significant levels of PCBs (Sheldon and Hites, 1978; Ashley, unpublished data; DRBC, 1998). Although consumption guidelines exist for certain regions of concern within the estuary (NJDEP, 1999), striped bass and American eel landings from this area constitute a large portion of the multi-million dollar fisheries in Delaware, New Jersey and Pennsylvania (NOAA, 1996). For example, in Delaware waters alone, recreational harvests in 1999 were estimated at 11,000 and 110,000 individuals for American eel and striped bass, respectively (NMFS, 2001)

Since 1975, the New Jersey Department of Environmental Protection (NJDEP) has conducted comprehensive contaminant monitoring surveys of fish species inhabiting estuarine and coastal marine waters of New Jersey due to concern about concentrations of persistent, bioaccumulative contaminants such as PCBs, mercury and organochlorine pesticides including chlordanes, DDT, and DDT metabolites (NJDEP, 1998; Kennish and Ruppel, 1996). As part of this effort, congener-specific PCB concentrations in 70 American eels and 51 striped bass collected from the Delaware Estuary and its tributaries (Fig. 2) have been evaluated (Ashley and Horwitz, 2001). Fish were collected from areas ranging in contaminant inventories (either suspected or known) from above the fall line at the confluence of the Lehigh and the Delaware Rivers to the mouth of Delaware Bay at Cape May, DE. As part of this data set, eels and striped bass were collected from coastal waters (extending from Cape May, DE to Raritan Bay, NJ) and several of the tributaries along the Atlantic coast (Shark River and Toms River, NJ).

Data derived from these three research projects (Ashley and Horwitz, 2001; Steinbacher, 2001; Ashley *et al.*, 2000) were merged, resulting in one containing congeneric PCB concentrations for 100 American eels and 125 striped bass. Amassed, collection sites extended from above the fall line of the Delaware River at the confluence of the Lehigh River, PA to the upper portions of the Hudson River estuary at Troy, NY.

PCB Congener Analysis

Though each of these three data sets making up the amalgamated data set were generated as part of separate projects, the method of analysis (both preparatory and analytical) were identical. This ensured that comparability of PCB patterns in the amalgamated data set was not complicated by inter-laboratory differences in PCB quantification. Congeneric PCB analysis followed previously published methods (Ashley, 1998; Kucklick *et al.*, 1996). Briefly, homogenized fish samples were stored frozen until extraction. Samples were thawed and 2-5 g of the homogenate was sub-sampled and dried with pre-cleaned Na_2SO_4. The dried sample was placed in a Soxhlet extractor with approximately 200 mL dichloromethane (DCM) for a minimum of 18 hours. The extracts were sub-sampled for gravimetric lipid determination. For this, a known volume of extract was transferred to a pre-weighed aluminum pan. The solvent was evaporated at 110 ° C for at least 24 hours. The residue remaining (lipid) was weighed and percent lipid was calculated. Lipids were removed from sample extracts by gel permeation chromatography (GPC) using DCM as the mobile phase. The collected fraction containing PCB congeners was concentrated by roto-evaporation with a N_2 stream. Solid-liquid chromatography using florisil was performed as an additional clean-up step.

Congener-specific PCBs were analyzed using a Hewlett Packard 5890 gas chromatograph equipped with a ^{63}Ni electron capture detector and a 5% phenylmethyl silicon capillary column. The identification and quantification of PCB congeners followed the ‘610

Method' (Mullin, 1985). This method uses a mixed Aroclor standard (25:18:18 mixture of Aroclors 1232, 1248 and 1262) in which the identities and concentrations of each congener were determined by calibration with individual PCB congener standards. Congener identities in the sample extracts were based on their chromatographic retention times relative to the internal standards added. In cases where two or more congeners could not be chromatographically resolved, the combined concentrations were reported. In total, eighty-four congeners were quantified, either singly or as coeluting congeners.

Data Analysis

To mathematically aid in discrimination of congeneric pattern differences/similarities, principal component analysis (PCA) was be performed on the mean congeneric PCB concentrations of American eels and striped bass grouped according to collection site. To remove the effect of absolute concentration on the first principal component, individual PCB congener concentrations were normalized to total PCBs (*t*-PCBs), the sum of all quantified congeners (Schwartz *et al.*, 1991; Wenning *et al.*, 1992). For those congener concentrations falling below the instrumental detection limit, the detection limit was substituted such that those congeners could still be used in the PCA (Meglan, 1992). The first two principal component scores of a PCA were used to denote differences or similarities among congeneric patterns both among and between each species from the two estuaries. The resulting eigenvectors in the principal component equation (eigenvalues) were used to identify those specific congeners, or groups of congeners, which contributed the most to the observed pattern differences. Using that information, additional uni-variate statistical treatments (*e.g.*, regressions) were performed to test if observed differences in PCB congener patterns could be related to factors such as lipid content, length, and weight.

Results

Total PCB Concentrations

Individual American eels and striped bass were grouped according to collection site and mean values for length, weight, lipid content and total PCBs (*t*-PCBs) were calculated with associated standard deviations (Table 1 and 2). The number of American eels caught at each site ranged from 3 to 8; at one site (Pennsauken River, NJ), only one eel was caught (Table 1). Mean lengths of individual American eels were relatively uniform (overall mean of 51 cm) though corresponding mean weights ranged from 130 ± 60 g near Kingston, NY to 560 ± 400 g in Shark River, NJ. American eel mean lipid contents ranged from 3 to 14 %. Within the Delaware River estuary and its tributaries, mean concentration of *t*-PCBs in eels ranged from 80 ± 20 ng/g in Cohansey River, NJ to 1600 ± 1000 ng/g in the Delaware River at Ft. Mifflin, PA. Within the Hudson River, mean *t*-PCB concentrations ranged from 1800 ± 1100 ng/g at Athens, NY to 7700 ± 2000 ng/g at Newburgh, NY.

The number of individual striped bass caught at each location ranged from 5 to 18 with the exception of Raccoon Creek, NJ and Delaware Bay at Bowers Beach, NJ were only one and two fish were caught, respectively (Table 2). Similar to eels, lengths of individual striped bass were relatively uniform (overall mean of 72 cm) though corresponding mean weights ranged from 2400 ± 700 cm in the Delaware River Below Trenton to 10100 ± 6100 cm from the Atlantic Ocean near Cape May, DE. Striped bass mean lipid contents ranged from 2 to 7 %. Within the

Delaware River estuary and its tributaries, the mean concentration of *t*-PCBs was 590 ± 350 ng/g. From the Atlantic coast collections, mean *t*-PCB concentrations ranged from 290 ± 230 ng/g near Island Beach State Park, NJ to 400 ± 300 ng/g near Cape May, DE. Within the Hudson River, mean *t*-PCB concentrations ranged from 650 ± 500 ng/g at Catskill, NY to 3400 ± 1600 ng/g at Troy, NY.

Accumulation Patterns in American Eels

The average normalized congeneric patterns for American eels collected from various regions within the Delaware River and NJ coastal waters, shown with congeners in order of chromatographic elution order (Fig. 3a-c), revealed remarkable similarity. Patterns were dominated by a large contribution from coeluting congener groups 153+132+105 and 163+138, and to a lesser degree 77+110, 180 and 170+190. Visually, there were no striking differences in the accumulated patterns even in eels from highly industrialized and urbanized portion of the Delaware River adjacent to Ft. Mifflin (Fig. 3c) compared to those captured at the confluence of the Delaware and Lehigh Rivers, PA (Fig. 3a).

This overall invariant pattern in accumulated congeners by American eels utilizing the Delaware River estuary was not observed in collections from in the Hudson River estuary (Fig. 4 a-c). Rather, as Steinbacker (2001) reported, with increasing up-estuary collections, PCB congeneric patterns shifted from those dominated by more heavily chlorinated congeners to those having a greater proportion of lighter chlorinated congeners (di-, tri- and tetrachlorbiphenyls). Noteworthy was the greater contribution of the coeluting congener group 31+28 with up-estuary collections.

Accumulation Patterns in Striped Bass

As with American eels, the average normalized congeneric patterns for striped bass collected from various regions within the Delaware River and NJ coastal waters showed remarkable similarity (Fig. 5a-c). For example, striped bass collected from various locations within Delaware River revealed very similar normalized patterns, all of which had the coeluting congener groups 153+132+105 and 163+138 as the dominant conformations (*e.g.*, Fig. 5 a and b). Moreover, striped bass collected from coastal and oceanic waters in southern, eastern and northern NJ displayed visually similar patterns (*e.g.*, Fig. 5c).

This invariant PCB pattern was not observed in those striped bass collected along the salinity gradient within the Hudson River estuary where, as reported by Ashley *et al.* (2000), a shift in striped bass congeneric patterns within the Hudson River was statistically discernable. Congeneric patterns with higher proportions of di-, tri- and tetrachlorbiphenyls were found in those striped bass residing in the upper reaches of the estuary around Troy (Fig. 6a), while the converse was true for those fish spending more time in saline waters or those undergoing annual migrations throughout the salinity gradient (Fig. 6 b and c). However, even these fish collected from sites down-estuary had a comparatively ‘lighter’ pattern than the Delaware River estuary fish (Fig. 5a-c). The dominance of coeluting congeners 31+28 and other less chlorinated congeners is clearly distinguishable by visual comparison.

Principal Component Analysis of Congeneric PCB Patterns

Though visual inspection of congeneric PCB patterns provides cursory insight into the spatial and species differences in accumulation, PCA is helpful in reducing the data set and further identifying differences in relative contribution of each congener. The first two principal components (PC1 and PC2) described 37% and 14% of the variability among the PCB congener patterns of all fish, respectively. That is, considering only the first and second principal components, over half of the variance in congeneric patterns was captured. Distinct clustering of the sampled populations of American eels and striped bass into groups was not observed from the PCA crossplot (Fig. 7). However, in general, American eels did cluster in one mass (left portion of the crossplot) and striped bass in another (right portion of the crossplot) denoting that the two species had different accumulated PCB patterns. Within these two groups, a further trend was observed in which species from the Hudson River estuary were separated (both in the PC1 and PC2 direction) from those from the Delaware River estuary.

For PC1, coefficient weightings (eigenvectors) revealed that instead of a few congeners driving the differences in PCB patterns, as was observed in Hudson River striped bass (Ashley and Baker, 2000), there were many that contributed (Fig. 8). Except for one, all those congeners chromatographically eluting before congener 118 had positive PC1 coefficients; those eluting after and including 118, except for five congeners, had negative coefficients. The sum of the all congeners from 4+10 to 149 (termed "light") were divided by the sum of all congeners 118 to 206 (termed "heavy") to yield a ratio. As expected, PC1 and the "light PCBs/heavy PCBs" ratio (Fig. 9) were highly correlated for both striped bass and American eel ($r=0.98$ and $r=0.92$, respectively; $p<0.001$).

Discussion

Inter- and Intra-Estuarine Differences in *t*-PCBs

The Hudson River estuary is undoubtedly the most widely characterized estuary with respect to the sources, transport and fate of PCBs. Observing elevated PCB concentrations in its sediment (*e.g.*, Bush *et al.*, 1994), water column (*e.g.*, Achman *et al.*, 1996) and biota (*e.g.*, Armstrong and Sloan, 1988; Ashley *et al.*, 2000; Sloan *et al.*, 1995; Steinbacher, 2001) has not been difficult. Moreover, upon comparison of these biotic or abiotic PCB concentrations to those found in other estuaries (*e.g.*, Chespeake Bay, Delaware Bay), the Hudson River estuary often remains unrivaled. By amalgamating the three data sets summarizing *t*-PCBs for American eels, this was again evident. American eels collected from the Hudson River estuary had significantly higher concentrations of *t*-PCBs than those collected from the Delaware River (Table 1). However, variations in striped bass PCB concentrations were considerably less between the two estuaries (Table 2) with the exception of those captured at Troy. The differences may be attributed to their contrasting migration (home-range) behaviors. Striped bass are “facultatively anadromous” (Secor, pers. comm.), meaning most (but not all) undergo annual migrations to fresh waters as adults, returning to coastal systems to spawn in spring. Unlike their relative the white perch (*Morone americanus*), most adult striped bass do not utilize estuaries for the duration of the year. Because of this behavior, striped bass would not be expected to reflect the contaminant conditions where they are captured. More likely, they are integrators of the contaminated habitats which they have recently utilized.

In comparison to striped bass, American eels have strong site fidelity; in narrow estuaries and rivers, the yellow eels’ home range is thought to be less than one mile (Dave Secor, pers. comm.; Parker, 1995), possibly more in larger rivers and estuaries (Morrison, 2001). Shifts to deeper waters may occur in winter (Secor, pers. comm.). Unlike striped bass which tend to feed largely on pelagic and occasionally epi-benthic organisms (Secor, pers. comm), eels have a strong interaction with sediment and their diets reflect this (*e.g.*, small benthivores, insects, amphipods, crustaceans, molluscs, and annelids) though other items may be ingested (*e.g.*, phytoplankton, mice). These properties, as well as owing to their high lipid contents, have prompted some to propose that eels could act as "sentinel species" of persistent, bioaccumulative contaminant pollution and habitat quality (*e.g.*, van der Oost *et al.*, 1996; Steinbacher, 2001; Weatherley *et al.*, 1997). For example, the American eels from the Hudson River evaluated by Steinbacher (2001) had *t*-PCB body burdens that were well-correlated to surficial sediment PCB concentrations, lending support to their potential utilization as a biomonitoring tool.

Because of the lack of quality congener-specific data for surficial sediments collected from locations in the Delaware River where American eels were caught in this study, a similar comparison is not possible. However, some evidence supporting a relationship between body burdens and surficial sediment contamination exists from this study. For American eels collected from the Delaware River estuary, highest PCB concentrations were observed in those captured adjacent to Ft. Mifflin, PA, a site less than 1 km downstream of confluence of the Schuylkill and Delaware Rivers. Previous data have shown elevated levels of trace metals and organic contaminants (PAHs and PCBs) in the sediments of the lower tidal portion of the Schuylkill River (Boyd *et al.*, 1998). More recently, *t*-PCB concentrations were found to range from 50 to 650 ng/g dry weight (Ashley; unpublished data). However, it is not known whether the sources of these contaminants are from historical or current inputs, whether they originated from local or upstream sources, or whether the relative contributions from industrial point sources, urban runoff, or combined sewer overflows are more important (Boettner *et al.*, 2001). In the Philadelphia/Camden region of the Delaware River, elevated concentrations of PCBs have been found in surficial sediments although the data are limited (DRBC, 2001). This region of elevated sedimentary contamination also harbors American eels with the highest *t*-PCB concentrations of all those evaluated in the Delaware River estuary. Though not statistically proven, this does suggest that eels are likely mirroring the magnitude of contamination within their habitat and may be effectively used as tools for assessing localized contamination. Plans to conduct a spatially intensive mapping of congener specific PCB concentrations in surficial sediments collected from sites between the Delaware Memorial Bridge, DE and the fall-line just above Trenton, NJ are slated for Fall 2001. These data will allow a more extensive and statistically-based evaluation of corresponding sediment and eel data.

The standard deviation of each mean *t*-PCB concentration value within a particular collection zone attests to the enormous variability in individual concentrations within a collected sub-population (Table 1 and 2). Often, this variability may be explained by the equally large variance in fish characteristics such as length and lipid content (Larsson *et al.*, 1991). When considering one species collected from all sites within each estuary, fishes’characteristics (*e.g.*, length, weight, and lipid content) were all poorly correlated to *t*-PCB concentrations. For example, American eels collected from the entire Delaware River estuary and it tributaries had lipid contents that were not highly correlated to t-PCB concentrations ($r<0.2$). However, within one specific collection zone for one species, fish characteristics were sometimes highly correlated to *t*-PCB concentrations such as those collected adjacent to Ft. Mifflin, PA (r=0.95; p<0.001). This suggests that proximity to source, as well as fish characteristics such as lipid content, play a role in determining *t*-PCB body burdens in American eels within some sub-regions of both the Delaware and Hudson River estuaries.

Using a sub-sample of striped bass collected along the Hudson River estuary and Long Island Sound, previous researchers (Zlokovitz and Secor, 1999) found that such factors as age, lipid content, length, sex, and weight were all poorly correlated to *t*-PCB concentrations. However, by evaluating lifetime salinity histories using the otolith analysis, an inverse correlation (r=-0.75, p<0.001) with recent habitat use (within 1 year) was found, suggesting habitat use, or extent of migration, was a major determinant of the magnitude of *t*-PCB accumulation. However, this correlation was largely driven by a sub-set of striped bass whose otolith analyses revealed no annual migrations. That is, those striped bass residing in the upper portions of the estuary (below the Troy Dam) had elevated *t*-PCBs concentrations. Those striped bass which utilized down-estuary portions of the Hudson River, had lower body-burdens.

Inter- and Intra-Estuarine Differences in Congeneric Patterns

The analysis of PCBs on a congener specific basis facilitates comparison of accumulated patterns among fish of the same species but collected from different regions. In the Hudson River estuary, American eel patterns shifted to those that were more chlorinated with down-estuary collection sites (Figure 4) while within the Delaware River estuary, no differences in patterns were observed (Figure 3). However, by using the light/heavy ratios resulting from PCA, differences within and between estuaries were noted (Figure 9b). On average, Hudson River

American eels had higher ratios denoting their patterns were dominated by more lighter chlorinated congeners than those from the Delaware River. However, there were notable exceptions (*e.g.*, those eels collected from Toms, Navesink, Shrewsbury, and Lehigh Rivers and also Raritan Bay). The most striking of these exceptions was seen in eels from Toms River, NJ, a coastal tributary. The six eels collected there, having a mean PCB concentration of 200 ± 170 ng/g, had a pattern that closely resembled that found in eels from the upper Hudson River at Albany. Though not as 'light' in pattern as Albany eels, those captured from Raritan Bay had a relatively high 'light/heavy' ratio similar to that found in eels from Athens. Due to their limited home range, these eels may be reflective of specific, and possible unique, congeneric patterns within their home range habitat. Though Tom's River eels had relatively low t-PCBs, the source and therefore inventory of specific PCB congeners in that river is likely unique to that particular area, imparting an upper Hudson-like light congeneric pattern to them. However, other factors may be contributing to the observed pattern. It is possible that the Toms River pattern resulted from different diets of those eels compared to those in other tributaries and estuaries. Also, congeneric patterns may be altered as a result of active metabolic elimination or transformation of particular PCB congeners (Brown, 1992). This could be coupled to the fact that for some highly chlorinated congeners, depuration is extremely slow or not significant (de Boer *et al.*, 1994).

However, there may be other explanations those eels that had "lighter" patterns but were not collected in the Hudson River estuary. Those eels from Toms and Navesink River, and also Raritan Bay, had a large degree of variation in their mean light/heavy ratios. For example, percent relative standard deviations of the mean for Toms River and Raritan Bay eels was 64% and 45% whereas it was much lower at most other sites (average of 30%). This indicates that the patterns of collected eels from these sites were highly variable suggesting movement or mixing of stocks. If eels have more wide home ranges than thought, these collected eels from Raritan Bay and Toms River may be representative of several different habitats ranging from coastal NJ rivers as well as Hudson River estuary.

For striped bass, its anadromous behavior may preclude the usefulness of using this species to gain any information based accumulated congeneric patterns. In addition, striped bass have pulsed growth dependent on season (Secor, pers. comm.). This could have an effect on not only the magnitude of PCBs within individuals due to growth dilution effects but could also change the observed PCB pattern. During periods of growth, depuration of more lightly chlorinated congeners may occur. As well, striped bass migrating from known contaminated areas may have time to depurate lighter congeners, shifting the accumulated pattern that is seen upon capture and analysis. From the light/heavy ratios resulting from the PCA (Figure 9a), striped bass grouped into three distinct clusters: those caught at Troy, those caught at all other sites within the Hudson River estuary, and those caught in the Delaware River estuary and NJ/DE coastal areas. From earlier otolith analysis, all those captured at Troy were deemed resident, undergoing no annual migrations down-estuary. This contingent had the lightest PCB patterns, reflective of the lighter source in the upper estuary (Ashley *et al.*, 2000). The other Hudson River striped bass sub-population underwent varying migrations throughout the estuary prior to capture (Zlokovitz and Secor, 1999) but likely are reflective of their recent habitat use within the estuary. Their patterns, which were somewhat heavier than the "resident" contingent, were likely derived from a combination of selective loss of lighter congeners and retention of heavier ones, or may be reflective of other source patterns along the Hudson River having a heavier pattern (Durrell and Lizotte, 1998). The heaviest accumulated pattern came from all striped bass caught at sites along the NJ/DE coast and Delaware River estuary. Though habitat use (extent of estuarine migration) information gathered through otolith analysis does not exist on these fish, it is likely that NJ coastal collections at Raritan Bay, Sandy Hook and Island Beach Park contained striped bass that utilized the Hudson River estuary. Those collected from southern coastal stations such as Cape May, Reeds Beach and Bowers Beach likely utilized the Delaware River Estuary. The fact that all observed patterns were so similar again suggests that these fish may have the ability to quickly depurate lighter chlorinated congeners while retaining those higher chlorinated congeners or may be indicate a more heavily chlorinated signature pattern within the Delaware River estuary. However, with the data available, it is not known which of these factors are important in determining the accumulated congener-specific PCB patterns observed in this study.

Conclusions

By amalgamating the results of three separate research projects, each using identical preparatory and analytical techniques, a final data set containing analytically comparable congener-specific PCB concentrations of 225 American eels and striped bass was created. Using this data set, the first comprehensive comparison of the bioaccumulated congeneric patterns in American eels and striped bass utilizing two important east-coast habitats (the Delaware and Hudson Estuaries) was made. This study also provided additional insight into the important factors controlling PCB accumulation in these ecologically and financially important species. Though more data is needed, this research lends further support to the notion that the American eel may be used as a reliable biomonitoring tool because proximity to source and fish characteristics such as lipid content appear to be important factors in determining contaminant body burdens. For striped bass, its migratory behavior precludes its usefulness for indicating local contamination. However, accumulated patterns in addition to habitat use information gained from otolith analysis or tagging studies, may provide information on the important factors driving accumulated patterns. The resulting amalgamated data set may ultimately be used in existing (*e.g.*, Farley *et al.*, 1999*)* or future mathematical models which predict bioaccumulation patterns in upper trophic level biota in heterogeneously-contaminated estuaries.

Acknowledgments

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Literature Cited

Ashley, J.T.F. 1998. Habitat use and trophic status as determinants of hydrophobic organic contaminant bioaccumulation within shallow systems. Ph.D. Dissertation, University of Maryland, College Park, MD.

Ashley, J.T.F., and R. Horwitz. Assessment of PCBs, Selected Organic Pesticides and Mercury in Fishes from New Jersey: 1998-1999. Academy of Natural Sciences. Draft report submitted to New Jersey Department of Environmental Protection. 2001.

Ashley, J.T.F., J.E. Baker, D.H. Secor, E. Zlokovitz, and S. Wales. 2000. Linking habitat use of Hudson River striped bass to accumulation of PCB congeners. *Environ. Sci. Technol.* **34**:1023-1029.

Achman, D.R., B.J. Brownawell, and L. Zhang. 1996. Exchange of polychlorinated biphenyls between sediment and water in the Hudson River estuary. *Estuaries.* **19:** 950-965.

Armstrong, R.W., and R.J. Sloan. 1988. PCB patterns in Hudson River fish. In: Smith, C.L. (Ed.). Fisheries Research in the Hudson River, Hudson River Environmental Society. State University of New York Press.

Boettner, A., D.V. Velinsky, T. Fisklin, P. Kiry, J. DeAlteris, A.M. Compton, and A. Wilson-Finelli. 2001. Water Quality Assessment fo the Tidal Schuylkill River, Philadelphia, PA: Understanding Sources and Fate of Nutrient and Trace Metals in an Urban Stream. Poster presentation at 2001 American Geophysical Union conference.

Bopp, R.F., H.J. Simpson, C.R. Olsen, and N. Kostyk. 1982. Polychlorinated biphenyls in sediments of the tidal Hudson River, *New York. Environ. Sci. Technol*. **15**:210-216.

Boyd. J.J., M.J. Montegomery, R.J. Spargo, R.B. Coffin, J.K. Steele, J.W. Phohlman, D.J. Velinsky. 1998. Characterization of Intrinsic Bioremediation within the Philadelphia Naval Yard Complex Research Basin. Naval Research Lab. Final Report to Philadelphia Naval Complex.

Brown, J.F., Jr. 1992. Metabolic alterations of PCB residues in aquatic fauna: Distribution of cytochrome P4501A- and P4502B-like activities. *Marine Environ. Res*. **34**:261-266.

Bush, B., R.W. Streeter, and R.J. Sloan. 1989. Polychlorinated biphenyl congeners is striped bass (*Morone saxatilis*) from marine and estuarine waters of New York state determined by capillary gas chromatography. *Arch. Environ. Contam. Toxicol*. **19**:49-61.

Bush, B., L.A. Shane, and M. Wablen. 1986. Sedimentation of 74 PCB congeners in the upper Hudson River. *Chemosphere*. **16**:733-744.

Bush, B., S. Dzurica, L. Wood, and E.C. Madrigal. 1994 Sampling the Hudson River estuary for PCBs using multiplate artificial substrate samplers and congener-specific gas chromatography in 1991. *Environ. Toxicol. Chem.* **13**:1259-1272.

de Boer, J., F. van der Valk, M.A. Kerkhoff, and P. Hagel. 1994. 8-Year study on the elimination of PCBs and other organochlorine compounds from eel (*Anguilla anguilla*) under natural conditions. *Environ. Sci. Technol*. **28**:2242-2248.

DRBC- Delaware River Basin Commission. 1998. Study of the loadings of PCBs from tributaries and point sources discharging to the tidal Delaware River. Estuary Toxics Management Program. West Trenton, NJ.

Durrell, G.S., and R.D. Lizotte, Jr. 1998. PCB levels at 26 New York City and New Jersey WPCPs that discharge to the New York/New Jersey Harbor estuary. *Environ. Sci. Technol*. **32**:1022-1031.

Farley, K. J.; R.V. Thomann, T.F. Cooney, D.R. Damiani, and J.R. Wands. An Integrated Model of Organic Chemical Fate and Bioaccumulation in the Hudson River Estuary. Hudson River Foundation. New York, NY. 1999

Hansler, G.M., and T.J. Fikslin. 1998. Study of the loadings of polychlorinated biphenyls from tributaries and point sources discharging to the tidal Delaware River. A report by the Estuary Toxics Management Program, Delaware River Basin Commission, West Trenton, NJ.

Kennish, M.J., and B.E. Ruppel. 1996. Polychlorinated biphenyl contamination in selected estuarine and coastal marine finfish and shellfish of New Jersey. *Estuaries.* **19**:288-295.

Kucklick, J.R., H.R. Harvey, P.H. Ostrom, N.E. Ostrom, and J.E. Baker. 1996. Organochlorine dynamics in the pelagic food web of Lake Baikal. *Environ. Tox. Chem.* **15**:1388-1400.

Larsson, P., S. Hamrin, and L. Okla. 1991. Factors determining the uptake of persistent pollutants in an eel population (*Anguilla anguilla*). *Environ. Pollut.* **69**:39-58.

Madenjian, C.P., S.R. Carpenter, G.W. Eck, and M.A. Miller 1993. Accumulation of PCBs by Lake Trout (Salvelinus namaycush): An individual-based model approach. *Can. J. Fish. Aquat. Sci.* **50**:97-109.

Meglan, R.R. 1992. Examining large databases: A chemometric approach using principal component analysis. *Mar. Chem.* **39**:217-237.

Monosson, E. 1999/2000. Reproductive and developmental effects of PCBs in fish: A synthesis of laboratory and field studies. *Reviews in Toxicology*. **3**: 25-75.

Morrison, W. 2001. American Eel: Biology, Mystery, Mangement. In Marine Notes, Maryland Sea Grant, Volume 19: Number 3.

Mullin, M.D. 1985 Workshop, U.S. Environmental Protection Agency Large Lakes Research Station, U.S. EPA, Grosse Ile., MI, USA.

NOAA-National Oceanic and Atmospheric Administration. 1996. Commercial Fisheries Revenues for Northeast Coastal States Hit $980 Million in 1995. Northeast Region News. September 17, 1996:5.

NMFS - National Marine Fisheries Service web site (www.st.nmfs.gov/st1/recreational/index)

NJDEP-New Jersey Department of Environmental Protection. New Jersey Fish and Wildlife Digest-A Summary of Rules and Management Information. January, 1999.

NJDEP-New Jersey Department of Environmental Protection. Mercury and organic contaminant concentrations in NJ fishes: Evaluating potential for human health impacts. 1998.

Parker, S.J. 1995. Homing ability and home range of yellow-phase American in a tidally dominated estuary. *J. Mar. Biol. Ass. U.K.* **75**:127-140.

Sheldon, L.S., and R.A. Hites. 1978. Organic contaminants in the Delaware River. *Environ. Sci. Technol*. **12**:1188-1194.

Sloan, R., B. Young, and K. Hattala. 1995. PCB paradigms for striped bass in New York state. New York State Department of Environmental Conservation, Division of Fish and Wildlife, Division of Marine Resources. Technical Report 95-1.

Schwartz, T.R., and D.L. Stalling. 1991. Chemometric comparison of polychlorinated biphenyl residues and toxicologically active polychlorinated biphenyl congeners in the eggs of Foster’s Terns (*Sterna fosteri*) *Arch Environ Contam Toxicol* 20:183-199.

Stapleton, H.M., R.J. Letcher, and J.E. Baker. 2001. PCB metabolism in a freshwater fish. *Science*. Submitted.

Steinbacher, J.C. The American eel, Anguilla rostrata, as a sentinel species of PCB contamination in the Hudson River. MS Thesis. University of Maryland at College Park. 2001

Stow, C.A., S.R. Carpenter, and J.F. Amrhein. 1994. PCB concentration trends in Lake Michigan Coho (*Oncorhynchus kisutch*) and Chinook Salmon (*O. Tshawytscha*). *Can. J. Fish. Aquat. Sci*. **51**:1384-1390.

van der Oost, R., A. Opperhuizen, K. Satumalay, H. Heida, and N. Vermeulen. 1996. Biomonitoring aquatic pollution with feral eel (*Anguilla anguilla*). *Aquat. Toxicol.* **35**:221-46.

Weatherley, N.S., G.L. Davies, and S. Ellery. 1997. Polychlorinated biphenyls and organochlorine pesticides in eels (*Anguilla anguilla*) from Welsh rivers. *Environ. Poll*. **95**:127-134.

Wenning, R.J., M.A. Harris, M.J. Ungs, D.J. Paustenbach, and H. Bedbury. 1992. Chemometric comparisons of polychlorinated dibenzo-p-dioxin and dibenzofuran residues in surficial sediments from Newark Bay, New Jersey and other industrialized waterways. *Arch. Environ. Contam. Toxicol.* **22**:397-413.

Zlokovitz, E.R., and D.H. Secor. 1999. Effect of habitat use on PCB body burden in Hudson River striped bass (*Morone saxatilus*). *Can. J. Fish. Aquat. Sci*. **56**:86-93.

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Fig. 8. Resulting PC1 and PC2 eigenvectors from the PCA of American eels and striped bass from the Hudson and Delaware River Estuaries.

Fig. 9. The ratio of the sum of “light” congeners (4+10 to 149) to the sum of “heavy” congeners (118 to 206).

Table 1

Location caught	Location Code	Number of Fish	Length (cm)	Weight (g)	Lipid Content (%)	Concentration of Total PCBs (ng/g wet wgt)
Cohansey River, NJ	COHR	5	56 ± 4	330 ± 83	8 ± 6	80 ± 20
Delaware River Below Trenton, NJ	DRBT	6	56 ± 3	360 ± 54	7 ± 5	580 ± 470
Delaware River at Lehigh River, PA	DRLR	5	60 ± 13	400 ± 190	14 ± 6	280 ± 200
Delaware River near Ft. Mifflin, PA	DRFM	5	60 ± 15	455 ± 366	8 ± 7	1600 ± 1000
Maurice River, NJ	MAUR	5	46 ± 9	200 ± 120	6 ± 6	130 ± 130
Mullica River, NJ	MULR	6	45 ± 13	240 ± 190	4 ± 5	120 ± 60
Navesink River, NJ	NAVR	3	40 ±6	140 ± 47	4 ± 2	200 ± 85
Passaic River, NJ	PASR	4	50 ± 9	280 ± 160	5 ± 4	500 ± 220
Pennsauken River, NJ	PENR	1	43	130	3	330
Raccoon Creek, NJ	RCCK	8	52 ± 10	330 ± 230	3 ± 3	900 ± 700
Raritan Bay, NJ	RARB	4	43 ± 9	190 ± 100	11 ± 7	1100± 590
Shark River, NJ	SHKR	5	60 ± 15	560 ± 400	11 ± 7	510 ± 420
Shrewsbury River, NJ	SHWR	7	54 ± 9	315 ± 155	7 ± 5	230 ± 140
Toms River, NJ	TOMR	6	53 ± 13	430 ± 310	11 ± 9	200 ± 170
Hudson River at Albany, NY	ALBY	5	47 ± 3	160 ± 15	13 ± 3	6500 ± 820
Hudson River at Athens, NY	ATHS	5	50 ± 6	170 ± 33	5 ± 4	1800 ± 1140
Hudson River at Kingston, NY	KING	5	44 ± 6	130 ± 60	7 ±4	4000 ± 150
Hudson River at Newburgh, NY	NEWB	5	60 ± 6	430 ± 150	12 ± 4	7730 ± 2000
Hudson River at Haverstraw, NY	HAVS	5	52 ± 5	240 ± 70	9 ± 3	2820 ± 600
Hudson River at GW Bridge	GWBR	5	55 ± 3	300 ± 74	8 ± 3	4000 ± 830

Table 2

Location caught	Location Code	Number of Fish	Length (cm)	Weight (g)	Lipid Content (%)	Concentration of Total PCBs (ng/g wet wgt)
Atlantic Ocean at Island Beach Park, NJ	AOIB	7	75± 8	4300 ± 1200	2 ± 1	290 ± 230
Atlantic Ocean near Cape May Rips, DE	AOCM	6	100 ± 15	10100 ± 6100	4 ± 2	400 ± 300
Atlantic Ocean at Sandy Hook, NJ	AOSH	10	80 ± 7	5300 ± 1700	4 ± 3	400 ± 180
Delaware Bay at Bowers Beach, DE	DBBB	2	80	4300	4	430
Delaware Bay at Reeds Beach	DBRB	8	80 ± 9	6100 ± 2400	4 ± 0.5	680 ± 380
Delaware River at Paulsboro, NJ	DRBT	6	60 ± 6	2400 ± 700	2 ± 1	500 ± 240
Delaware River and Lehigh River, PA	DRLR	6	70 ± 20	4200 ± 2600	3 ± 2	600 ± 500
Raccoon Creek, NJ	RCCK	1	67	3100	2	770
Raritan Bay at Perth Amboy, NJ	RBPA	5	70 ± 7	3300 ± 1100	2 ± 3	380 ± 200
Hudson River at Catskill, NY	CATS	13	700 ± 100	4800 ± 2300	5 ± 2	650 ± 500
Hudson River at Haverstraw, NY	HAVS	18	700 ± 100	3500 ± 2400	5 ± 2	750 ± 750
Long Island Sound, NY	LGIS	6	600 ± 150	3800 ± 2300	5 ± 3	420 ± 340
Hudson River at NY Harbor, NY	NYHB	17	650 ± 200	3300 ± 2500	6 ± 3	1000 ± 960
Hudson River at Poughkeepsie, NY	POGH	8	640 ± 60	3000 ± 730	7 ± 3	800 ± 400
Hudson River at Troy, NY	TROY	12	670 ± 140	3600 ± 3000	4 ± 2	3400 ± 1600

Fig. 1

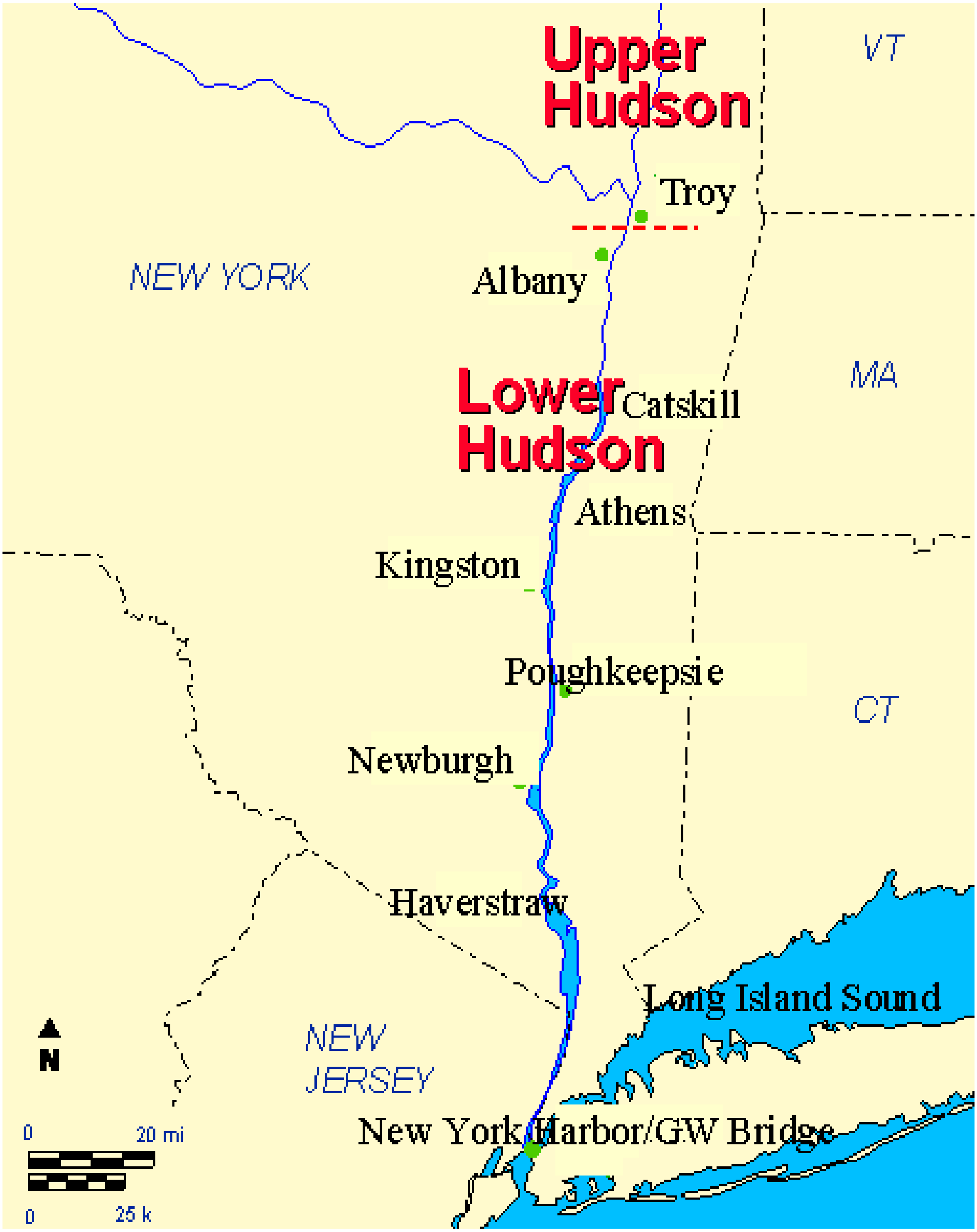
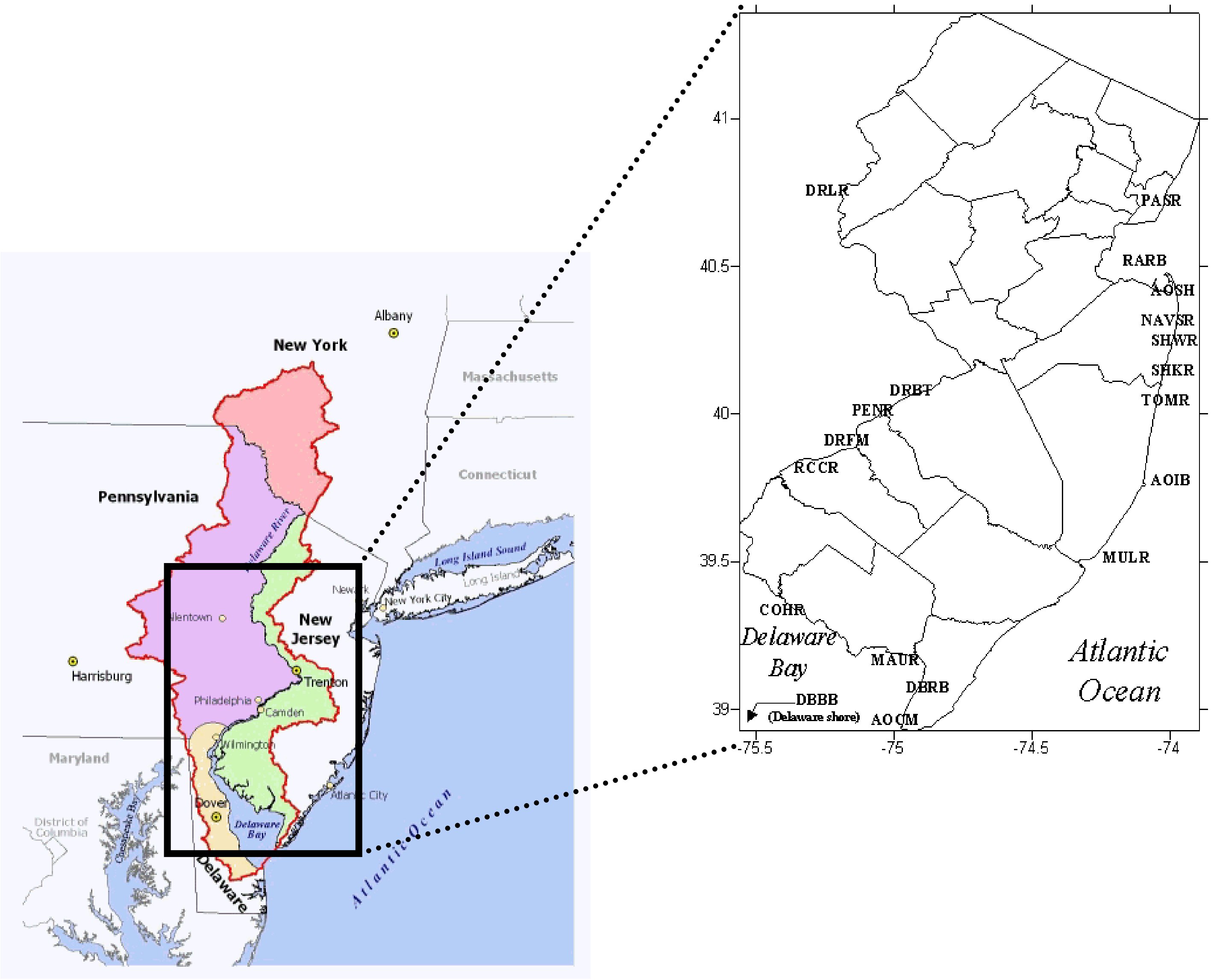

Upper Hudson
VT
Troy
NEW YORK
Albany
MA
Lower Hudson
Catskill
Athens
Kingston
Poughkeepsie
CT
Newburgh
Haverstraw
Long Island Sound
N
NEW JERSEY
New York Harbor/GW Bridge
0
20 mi
0
25 k

Fig. 2



New York
Albany
Massachusetts
Connecticut
Pennsylvania
Delaware River
Long Island Sound
Long Island
Newark
New York City
New Jersey
Allentown
Harrisburg
Trenton
Philadelphia
Camden
Wilmington
Maryland
District of Columbia
Chesapeake Bay
Dover
Delaware Bay
Delaware
Atlantic City
Atlantic Ocean
41
40.5
40
39.5
39
-75.5
-75
-74.5
-74
DRLR
PASR
RARB
AOSH
NAVSR
SHWR
SHKR
TOMR
DRBT
PENR
DRFM
RCCR
AOIB
MULR
COHR
Delaware Bay
MAUR
DBRB
DBBB
(Delaware shore)
AOCM
Atlantic Ocean

Fig. 3

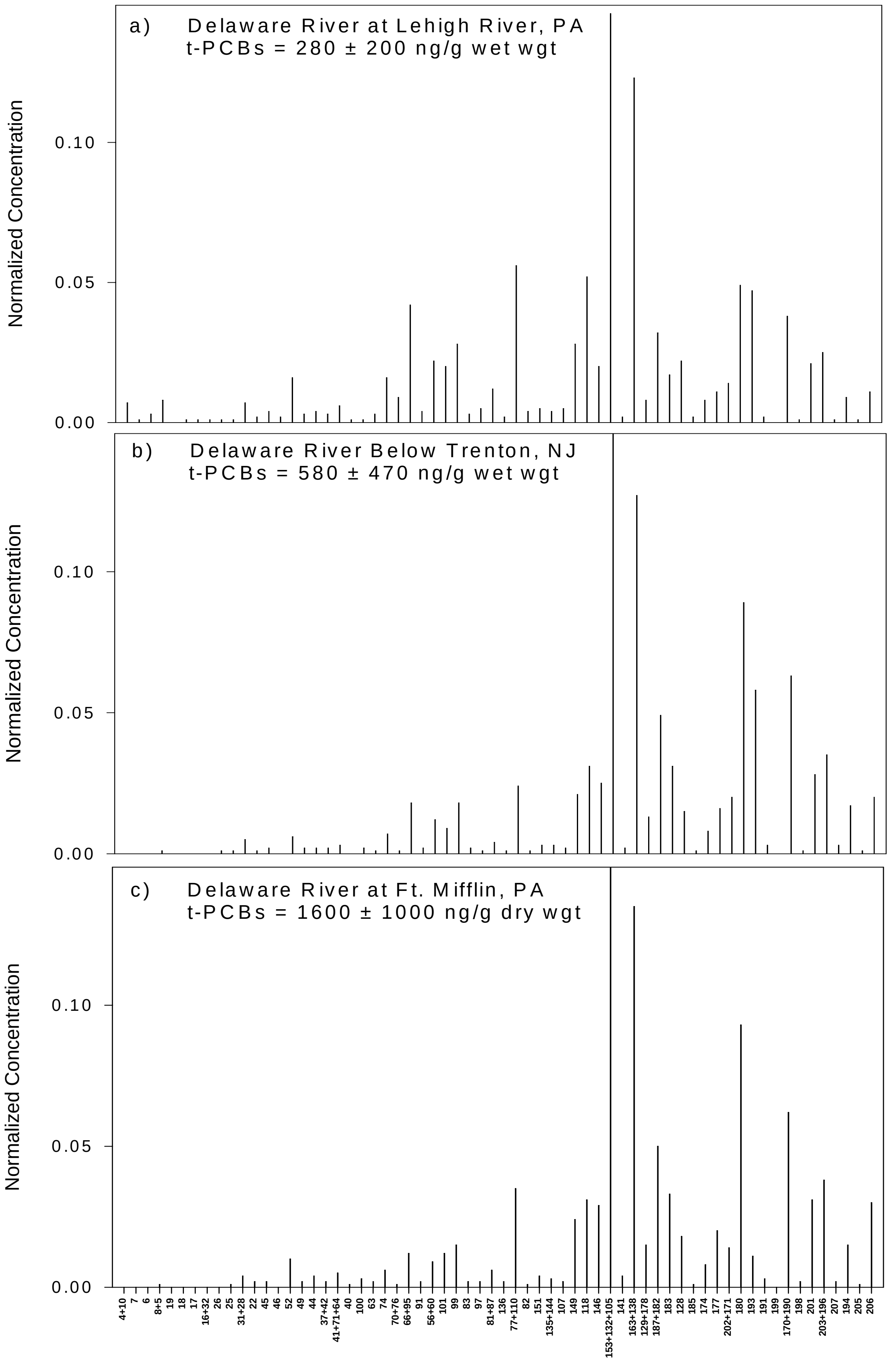

a) Delaware River at Lehigh River, PA
t-PCBs = 280 ± 200 ng/g wet wgt
b) Delaware River Below Trenton, NJ
t-PCBs = 580 ± 470 ng/g wet wgt
c) Delaware River at Ft. Mifflin, PA
t-PCBs = 1600 ± 1000 ng/g dry wgt
Normalized Concentration
0.00
0.05
0.10
4+10
7
6
8+5
19
18
17
16+32
26
25
31+28
22
45
46
52
49
44
37+42
41+71+64
40
100
63
74
70+76
66+95
91
56+60
101
99
83
97
81+87
136
77+110
82
151
135+144
107
149
118
146
153+132+105
141
163+138
129+178
187+182
183
128
185
174
177
202+171
180
193
191
199
170+190
198
201
203+196
207
194
205
206

Fig. 4

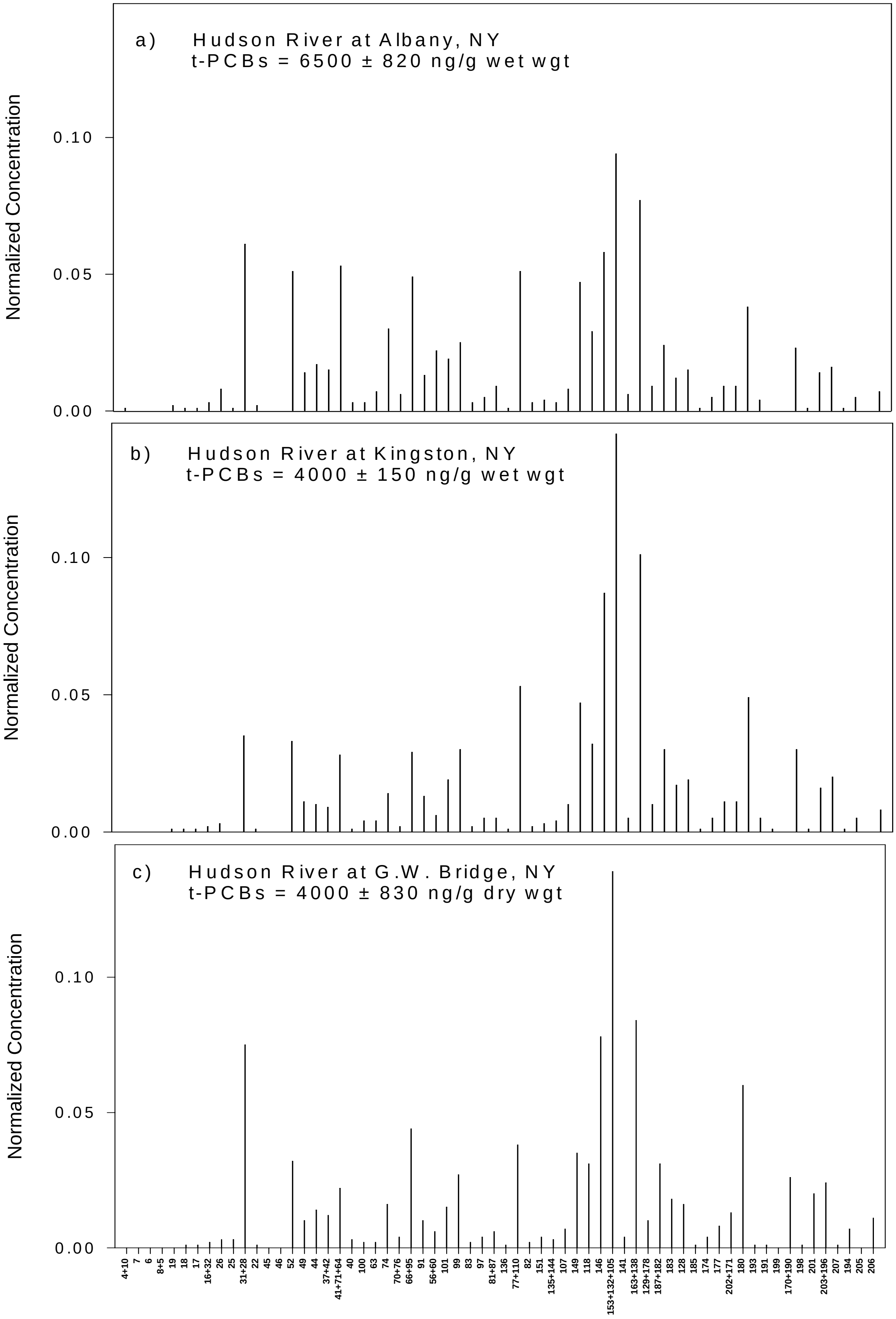
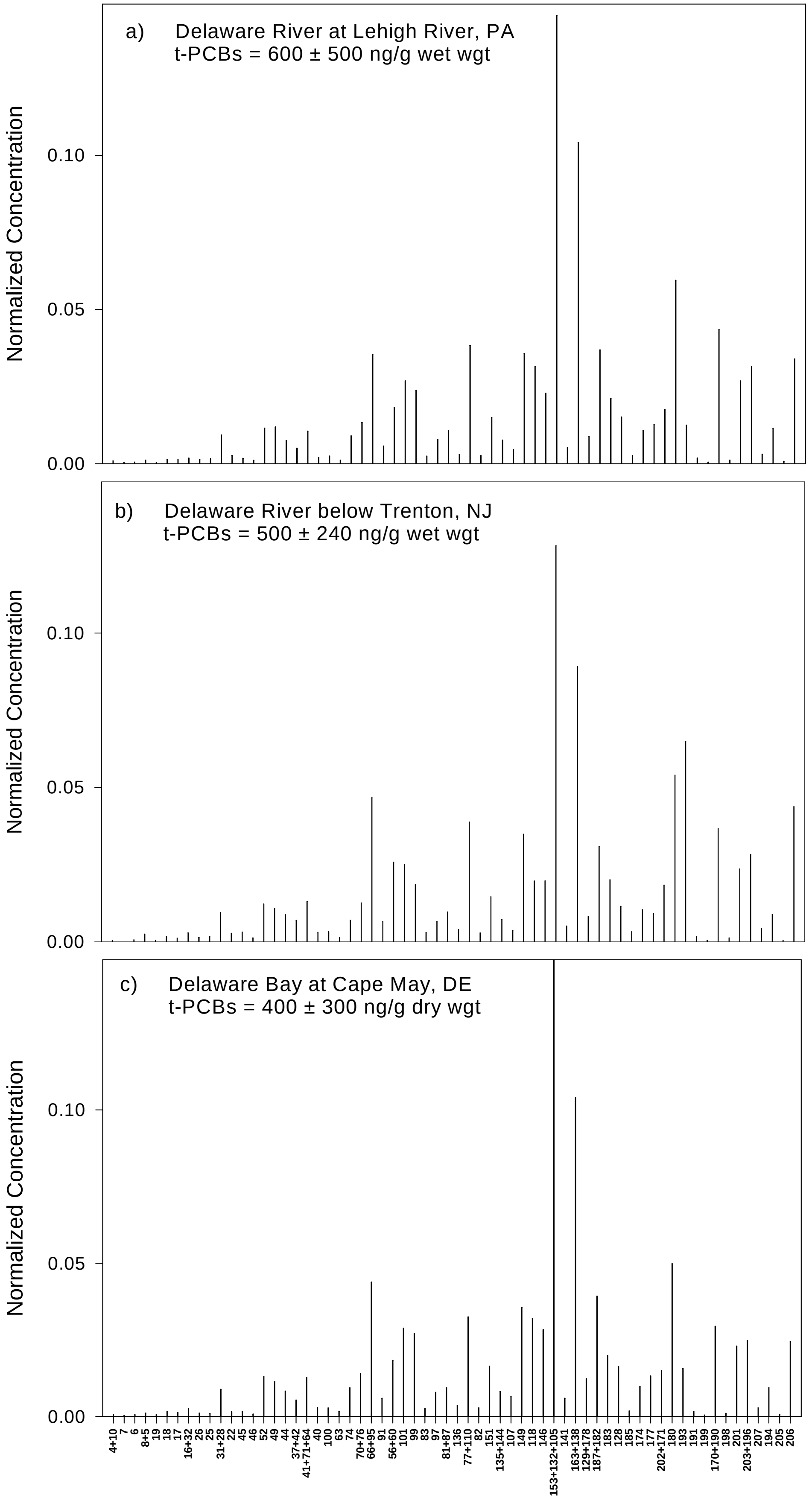

a) Hudson River at Albany, NY
t-PCBs = 6500 ± 820 ng/g wet wgt
b) Hudson River at Kingston, NY
t-PCBs = 4000 ± 150 ng/g wet wgt
c) Hudson River at G.W. Bridge, NY
t-PCBs = 4000 ± 830 ng/g dry wgt
Normalized Concentration
0.00
0.05
0.10
4+10
7
6
8+5
19
18
17
16+32
26
25
31+28
22
45
46
52
49
44
37+42
41+71+64
40
100
63
74
70+76
66+95
91
56+60
101
99
83
97
81+87
136
77+110
82
151
135+144
107
149
118
146
153+132+105
141
163+138
129+178
187+182
183
128
185
174
177
202+171
180
193
191
199
170+190
198
201
203+196
207
194
205
206

Fig. 5


a) Delaware River at Lehigh River, PA
t-PCBs = 600 ± 500 ng/g wet wgt
b) Delaware River below Trenton, NJ
t-PCBs = 500 ± 240 ng/g wet wgt
c) Delaware Bay at Cape May, DE
t-PCBs = 400 ± 300 ng/g dry wgt
Normalized Concentration
0.00
0.05
0.10
4+10
7
6
8+5
19
18
17
16+32
26
25
31+28
22
45
46
52
49
44
37+42
41+71+64
40
100
63
74
70+76
66+95
91
56+60
101
99
83
97
81+87
136
77+110
82
151
135+144
107
149
118
146
153+132+105
141
163+138
129+178
187+182
183
128
185
174
177
202+171
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170+190
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203+196
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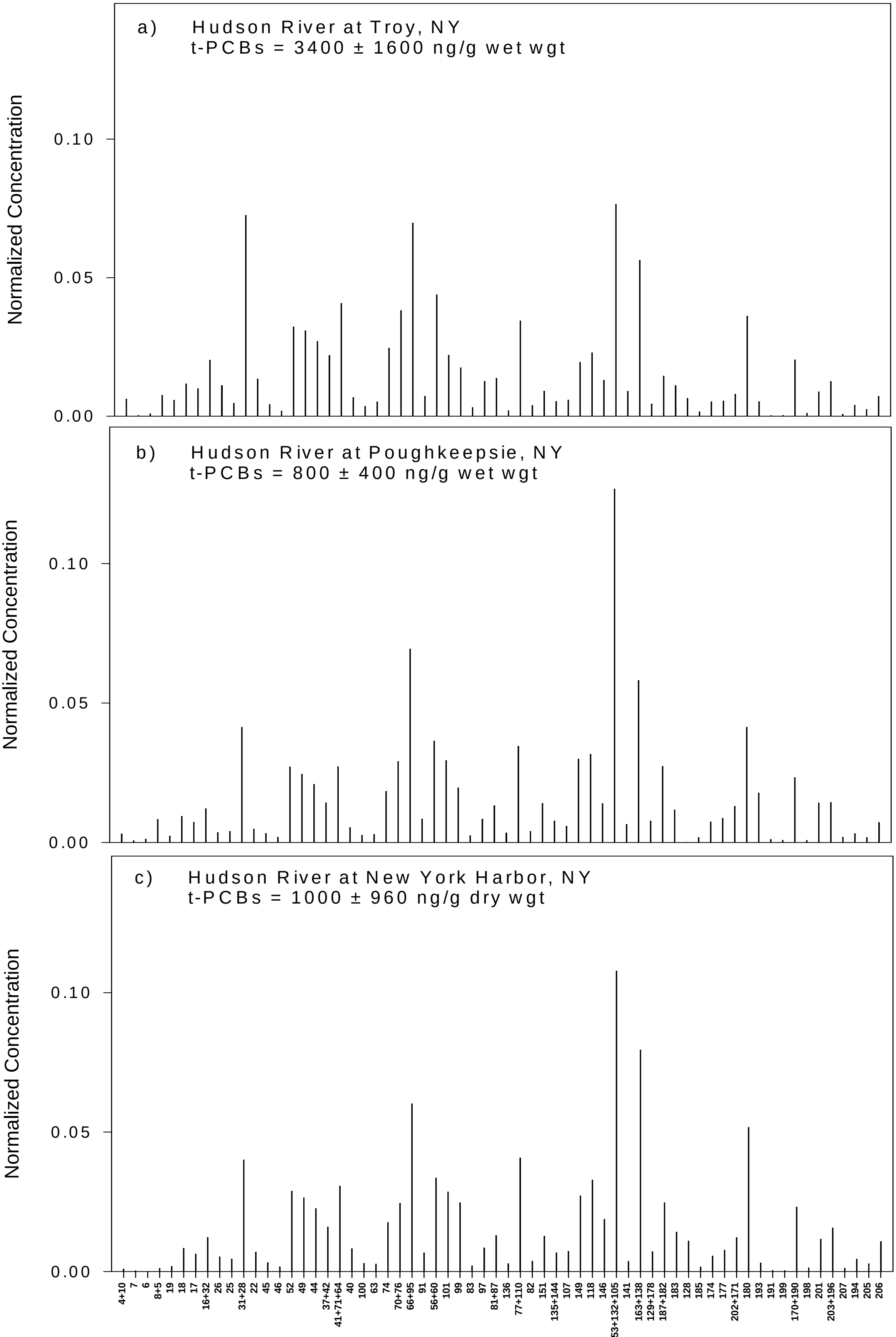
Fig. 6


a) Hudson River at Troy, NY
t-PCBs = 3400 ± 1600 ng/g wet wgt
b) Hudson River at Poughkeepsie, NY
t-PCBs = 800 ± 400 ng/g wet wgt
c) Hudson River at New York Harbor, NY
t-PCBs = 1000 ± 960 ng/g dry wgt
Normalized Concentration
0.00
0.05
0.10
4+10
7
6
8+5
19
18
17
16+32
26
25
31+28
22
45
46
52
49
44
37+42
41+71+64
40
100
63
74
70+76
66+95
91
56+60
101
99
83
97
81+87
136
77+110
82
151
135+144
107
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118
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53+132+105
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163+138
129+178
187+182
183
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202+171
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170+190
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203+196
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Fig. 7

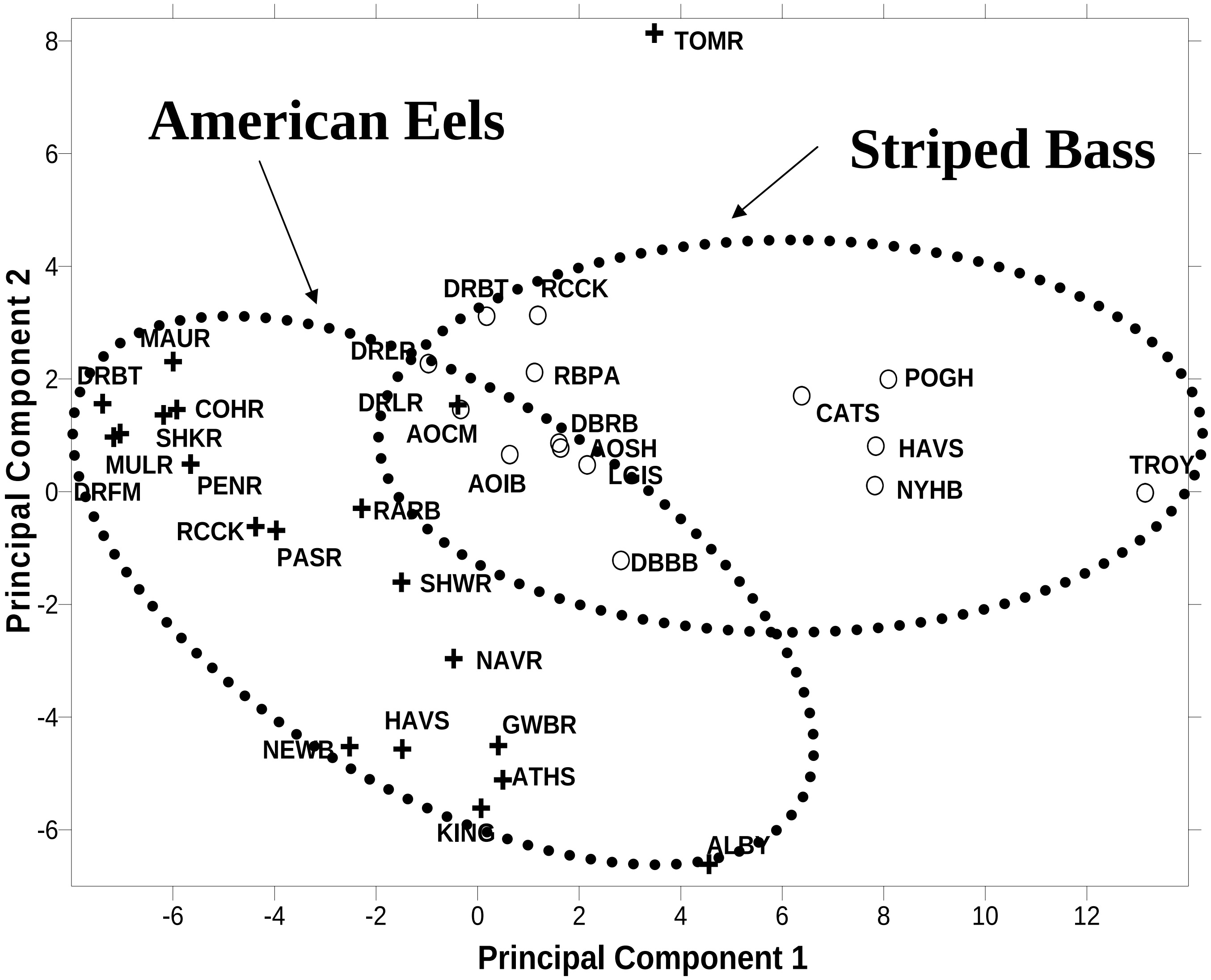
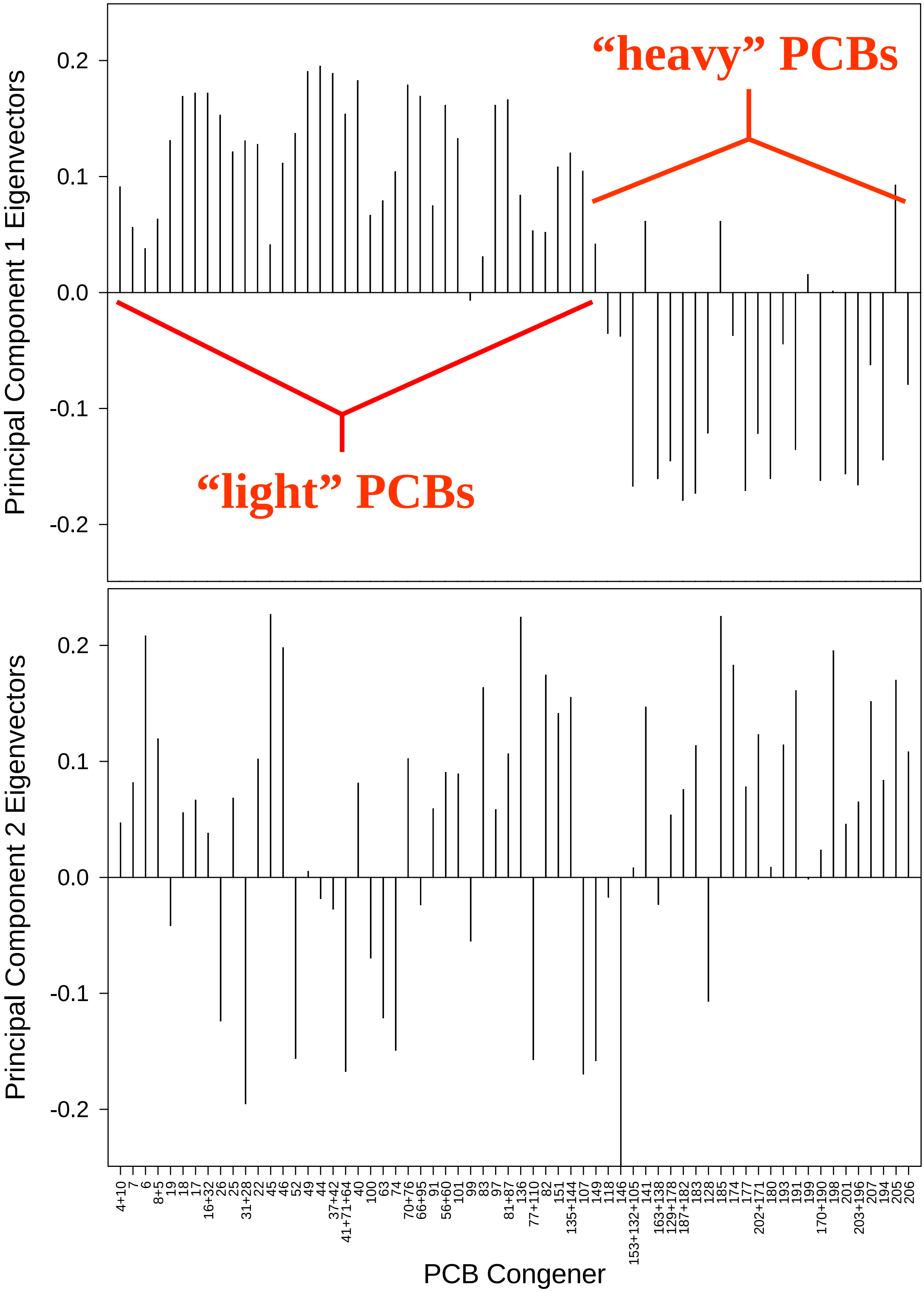

American Eels
Striped Bass
TOMR
DRBT
RCCK
MAUR
DRLR
DRBT
RBPA
POGH
DRLR
COHR
CATS
DBRB
SHKR
AOCM
AOSH
HAVS
MULR
TROY
LCIS
PENR
AOIB
DRFM
NYHB
RARB
RCCK
PASR
DBBB
SHWR
NAVR
HAVS
GWBR
NEWB
ATHS
KING
ALBY
Principal Component 1
Principal Component 2
-6
-4
-2
0
2
4
6
8
10
12
8
6
4
2
0
-2
-4
-6

Fig. 8


“heavy” PCBs
“light” PCBs
Principal Component 1 Eigenvectors
Principal Component 2 Eigenvectors
0.2
0.1
0.0
-0.1
-0.2
PCB Congener
4+10
7
6
8+5
19
18
17
16+32
26
25
31+28
22
45
46
52
49
44
37+42
41+71+64
40
100
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56+60
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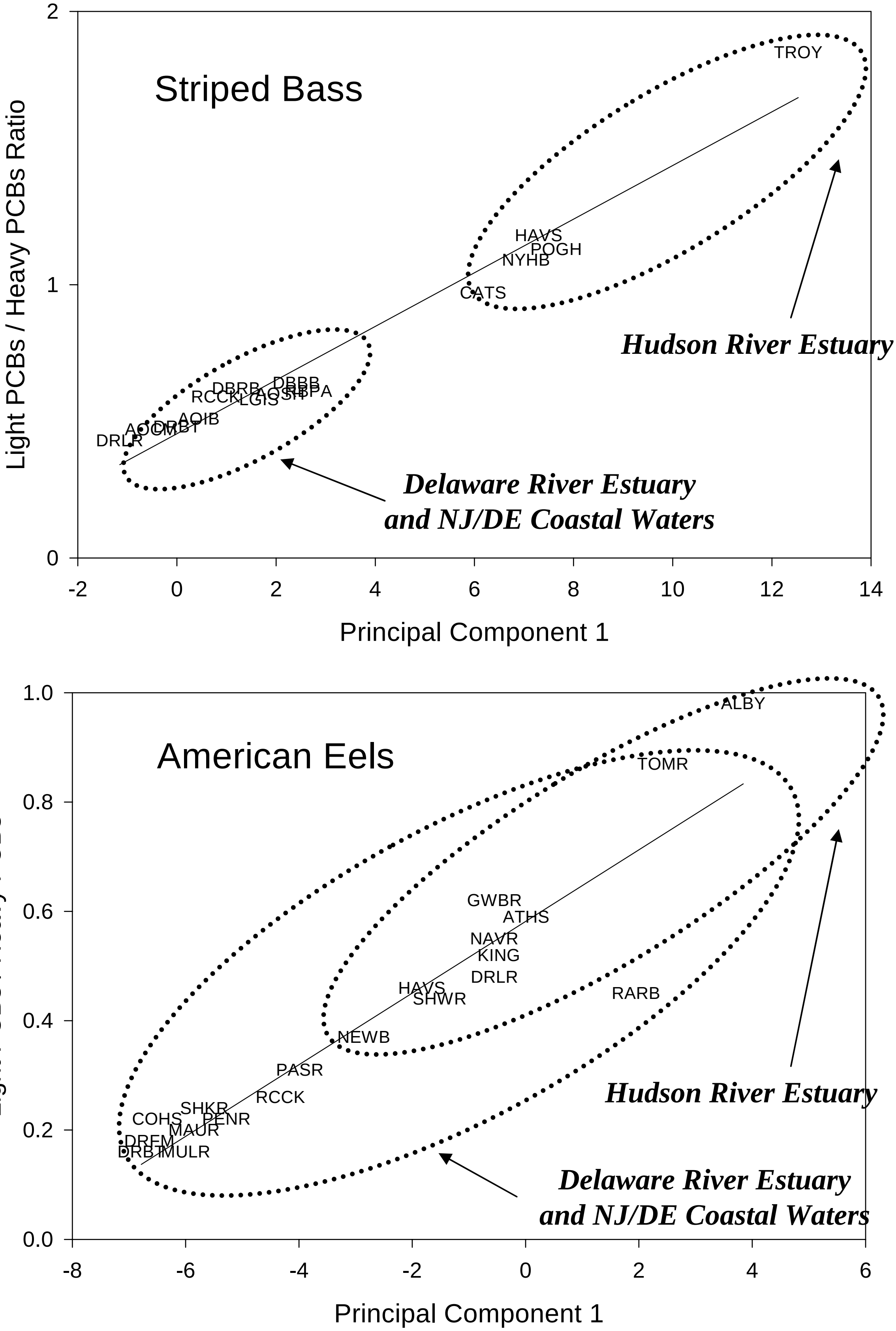
Fig. 9



Striped Bass

Hudson River Estuary

Delaware River Estuary and NJ/DE Coastal Waters

American Eels

Hudson River Estuary

Delaware River Estuary and NJ/DE Coastal Waters