Multidisciplinary Assessment of Pollution at Three Sites in Long Island Sound

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ABSTRACT: Winter flounder (Pseudopleuronectes americanus) were sampled from three sites located near Norwalk, New Haven, and Niantic, Connecticut, in Long Island Sound during February 1987, to evaluate the degree of chemical contamination and to determine possible effects of contaminant exposure. At each site, sediment and infaunal invertebrates were also collected and analyzed for trace metals and organic chemicals. Specimens of liver and kidney from winter flounder were examined for histopathological conditions, including the presence of macrophage aggregates in liver tissue. Liver samples were also analyzed for DNA damage (i.e., the formation of adducts between DNA and chemical contaminants). Blood samples were collected and analyzed for erythrocyte micronuclei. The sampling site near New Haven was determined to be the most affected site, from the standpoints of greater chemical contamination and possible effects on winter flounder. Concentrations of aromatic hydrocarbons (AHs) and polychlorinated biphenyls (PCBs) were highest in sediment from this site, and the highest prevalences of the histopathological changes and DNA alterations were also found in the livers of winter flounder from this site. No differences in the concentrations of contaminants in fish or in frequencies of erythrocyte micronuclei in fish blood were found between sites. None of the sites sampled had contaminant levels or prevalences of lesions as high as previously found at other East Coast locations (e.g., Boston Harbor, Massachusetts, Raritan Bay, New York). Overall, our results indicate moderate levels of pollution at two of the urban sites in Long Island Sound and provide a framework for expanded studies to better define the extent and impact of chemical pollution in Long Island Sound.

Introduction

Long Island Sound, located within the states of New York and Connecticut, is a major shipping route and is heavily used seasonally for pleasure boating. In addition, the area supports a large recreational fishery (Poole 1966; Mohr 1976). Earlier reports on contaminant concentrations and associated effects in Long Island Sound (Greig et al. 1977; Hunt 1979; Reid 1983) emphasized primarily trace metal contamination and effects inferred from laboratory bioassays. More recent reports (Zdanowicz et al. 1986; Turgeon and O'Connor 1991) have included more information on organic chemical contaminants in sediments and biota and potential effects on fish. In this paper we present results of analyses of a broad range of organic and inorganic chemical contaminants in sediments, selected infaunal invertebrates, and tissue and stomach contents of winter flounder (Pseudopleuronectes americanus) and of measurements of biological effects in winter flounder sampled from three sites in Long Island Sound.

Sediments serve as a repository for a large number of environmental contaminants, particularly those that are relatively water insoluble (Malins et al. 1984; O’Connor and Huggett 1988). Fish can accumulate chemical contaminants from multiple sources, including sediments (Eadie et al. 1982; Gossett et al. 1983; Varanasi et al. 1985). The presence of selected chemical contaminants, along with certain histopathological conditions in fish liver, such as neoplasms and macrophage aggregates, serve as useful indicators of environmental degradation (Murchelano and Wolke 1985; Wolke et al. 1985; Blazer et al. 1987; Myers et al. 1987).

In addition to histopathology, other approaches have been suggested as indicators of possible effects of environmental degradation by toxic chemicals: measurement of DNA damage (adducts) in marine fish (Varanasi et al. 1989b, c), and the quan-
titiation of micronuclei in fish erythrocytes (Hose et al. 1987).

Accordingly, in this study, we have measured all these parameters to evaluate their significance in assessing levels and impact of contamination.

Methods

Samples were collected aboard the NOAA ship Ferrel in February 1987 at three sites in Long Island Sound (Fig. 1). The sites, which were thought to represent a range of chemical contamination, from west to east were located at the mouth of the Norwalk River, near Norwalk, Connecticut; at Morris Cove, south of New Haven, Connecticut; and at Niantic Bay, south of Niantic, Connecticut. Additional samples of winter flounder were collected from the Niantic site in winter 1988 and spring 1989. Similarly collected samples were obtained from a site near Deer Island in Boston Harbor in winter 1988 and some results were included here for comparative purposes.

Fish were collected with otter trawl and sediment was collected with either a 0.1 m² box corer or a modified Van Veen grab. At each site the first 30 adult fish collected were dissected. Three sets of three sediment grabs were used at each fishing site for collection of sediment for chemical analysis. Procedures for collecting sediments and winter flounder for analytical chemistry and for histopathological evaluations followed protocols developed for the National Benthic Surveillance Project (NBSP) of NOAA's National Status and Trends Program (Krahn et al. 1988; Varanasi et al. 1989a).

Bile florescent aromatic compounds (FACs) were determined by high pressure liquid chromatography (Krahn et al. 1986). Otoliths were examined to determine the age of each fish. Assessment of liver macrophage aggregates was done by estimating cellular density and calculating a relative index (Wolke et al. 1985). The levels of DNA-xenobiotic adducts in liver were assessed using $^{32}$P labelling and autoradiography (Varanasi et al., 1989c). Invertebrates sieved from sediment were used for organic chemical analysis.

Sheffes F-test (Zar 1984) was used to compare differences in mean levels of DNA adducts in winter flounder livers. Fisher's Exact test (Zar 1984) was used to test for significance of differences in prevalences of lesions in tissue specimens of winter flounder. The relative macrophage aggregate indices of the liver of individual winter flounder were compared with the Kruskal-Wallis test (Zar 1984). Comparison intervals were calculated for graphical comparisons of significant differences in levels of organic chemicals and trace metals in sediments and liver (Gabriel 1978; Sokal and Rohlf 1981). When examining comparison intervals, overlapping intervals indicate means that are not significantly different. For all statistical analyses performed, probabilities less than or equal to 0.05 were considered significant.

Results

The evidence suggests that winter flounder from the New Haven site showed the greatest changes in certain biochemical and pathological character-
significant correlation with exposure to chemical contaminants (Malins et al. 1984) and is interpreted to be the result of chronic exposure to toxic agents (Myers et al. 1987).

Similarly, the prevalence of severe hydropic degeneration (SHD) in the hepatic parenchyma of winter flounder from the Niantic site was significantly lower than the prevalences of this condition at the other sites (Fig. 2). This lesion type has been reported to co-occur with degenerative, neoplastic, and other proliferative lesions in winter flounder from polluted sites such as Boston Harbor (Murchelano and Wolke 1985), and appears to be indicative of an increased rate of cell death and turnover of hepatocytes and biliary epithelial cells, probably as a result of exposure to toxic agents.

The liver macrophage aggregate (MA) index was consistently and significantly lower for all age groups of winter flounder examined at the Niantic site in 1987 (Fig. 3). In succeeding years, additional samples from the Niantic site confirmed the low frequency of this condition. The MA index in fish from the New Haven site was nearly identical with that for fish sampled at the site near Deer Island in Boston Harbor in 1988. The presence of liver MA in winter flounder from nonurban sites, even though the index values are low, suggests that this condition is not strictly a pathological change, but rather a normal feature of winter flounder liver. It appears, therefore, that high liver MA index values are a response to exposure to "stressful" environmental stimuli including chemical contamination (Wolke et al. 1985).

Although many pathological conditions do have a tendency to increase in frequency in older fish, age differences between sites did not appear to be a factor in the differences in prevalences, because the average age of fish (4 yr) at each site was nearly identical.

Potentially contaminant-associated lesions in the kidney (necrosis or mesangiolysis) were found only in fish from the New Haven site, at a prevalence of 3%. No other pathological conditions of the kidney were detected in any of the fish examined.
Levels of Hepatic DNA Adducts

![Graph showing levels of hepatic DNA adducts with data points for Boston Harbor, New Haven, Norwalk, and Niantic.](image)

*Significantly different (p<0.05) from Niantic by Sheffe's F Test

Fig. 4. Levels of hepatic DNA adducts in winter flounder from three sites in Long Island Sound and a contaminated site in Boston Harbor. (Circles indicate means, n denotes sample size, and vertical bars indicate standard deviation.)

DNA Adducts

The levels of hepatic DNA-xenobiotic adducts in winter flounder from the New Haven site were significantly higher than the levels in flounder from the other sites. The level of adducts in fish from the Norwalk site was similar to those in fish from the Niantic site (Fig. 4). As was found with hepatic MA, the levels of hepatic DNA-xenobiotic adducts in fish from the New Haven site were almost identical to those found in winter flounder from the contaminated site in Boston Harbor.

Erythrocyte Micronuclear Abnormalities

No differences were found among the sites in frequencies of erythrocyte micronuclei or other nuclear characteristics in the blood of winter flounder. These observations agree with those of Carrasco et al. (1990) for other species of fish exposed to chemical contamination.

Chemical Contamination

Aromatic Hydrocarbons (AHs)

Sediment concentrations of AHs were significantly different among all sites, with the highest mean concentration in sediments from the New Haven site and the lowest mean concentration in samples from the Niantic site (Fig. 5). The concentrations of AHs in infaunal invertebrates (polychaetes) and fish stomach contents (various proportions of polychaetes, molluscs, and crustaceans) were also highest at the New Haven site. However, these analyses were done on pooled samples which precluded statistical analysis of differences between sites. These concentrations were considerably lower than the sediment concentrations of AHs at each site, suggesting that infaunal invertebrates were not bioconcentrating AHs.

Since aromatic hydrocarbons are rapidly metabolized in fish (Varanasi et al. 1985) and are generally at levels below detection limits in liver tissue, analysis of bile for fluorescent aromatic compounds was used (Krahn et al. 1986) as an indicator of recent exposure to aromatic hydrocarbon compounds. These measurements had high variability (Fig. 6), and no significant differences between sites were observed. The apparent anomaly indicated

Fig. 5. Concentrations (ng g⁻¹ dry wt) of aromatic hydrocarbons (AHs) in sediment, infaunal invertebrates, and stomach contents of winter flounder. Clear squares indicate means ± comparison intervals. Solid square indicates results of analysis of composites. Lower case letters denote results of statistical testing.

Bile FACs

![Graph showing average concentrations (± standard deviation) of fluorescent aromatic compounds determined at naphthalene (FACs NPH) and at benzo[a]pyrene wavelengths (FACs BaP) in bile of winter flounder.](image)
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Fig. 7. Concentrations (ng g\(^{-1}\) dry wt) of PCBs in sediment, infaunal invertebrates, and stomach contents and liver of winter flounder. Open squares indicate means ± comparison intervals. Solid squares indicate results of analysis of composites. The numbers associated with the mean sediment concentrations are the actual levels. Lower case letters denote results of statistical analysis.

by the low levels of FACs in bile of fish from New Haven (compared to sediment concentrations of AHs) may have been related to the late spawning stage of fish from this site compared to the fish from the other sites.

Chlorinated Hydrocarbons

The mean concentration of polychlorinated biphenyls (PCBs) in sediment was significantly higher at the New Haven site than the two other sites (Fig. 7). The mean concentrations of PCBs in livers of winter flounder increased in the same order as concentrations in sediments; however, no significant differences were found between the levels of PCBs in the livers of winter flounder between sites. At each site, concentrations of PCBs in fish livers and stomach contents and in infaunal polychaetes tended to be several-fold higher than those in sediments and may indicate bioaccumulation of these chemicals.

Sediment concentrations of chlorinated pesticides (CPs) were low (3-8 ng g\(^{-1}\) dry wt) at all sites, and there were no significant differences among any of the sites. Similarly, concentrations in both stomach contents, infaunal invertebrates (50-90 ng g\(^{-1}\) dry wt), and fish livers (300-900 ng g\(^{-1}\) dry wt) showed no between-site significant differences. As with PCBs these data suggest bioaccumulation of CPs.

 Trace Metals

Mean concentrations of several trace metals (zinc, lead, copper, chromium, mercury, silver, and antimony) in sediments were lower in samples from the Niantic site than those in sediments from the other sites (Figs. 8 and 9). However, no differences were found in the mean concentrations of tin and nickel in sediment from the Niantic site compared to the other sites. Although mean concentrations of most metals were highest at the New Haven site, only one metal, silver, was significantly higher at this site compared to the other sites. The concentrations of trace metals in stomach contents and in liver of winter flounder varied considerably among the sites and appeared unrelated to sediment concentrations. These findings agree with those in other studies (Zdanowicz et al. 1986; Varanasi et al. 1988) where concentrations of trace metals in sediment and fish tissue were not correlated.
Sediment Characteristics

Two of the factors which influence concentration of chemicals in sediments are particle size and total organic carbon (TOC). For Norwalk, New Haven, and Niantic, respectively, the percentages of clay/silt were 64, 62, and 82, with the percentage from Niantic being significantly different from the other sites. Low concentrations of certain chemicals are often associated with low clay/silt percentages (Means et al. 1980). However, in these studies, sediments from Niantic had the lowest concentrations of most chemicals, they also had the highest proportion of clay/silt. TOC percentages of 2, 3.5, and 0.6 were found for sediments from the Norwalk, New Haven, and Niantic sites, respectively. These values were significantly different between sites, and the low value for Niantic sediments may have had some influence on concentrations of contaminants.

Discussion

Although significantly higher concentrations of several of the organic chemical contaminants in sediment appeared to be associated with significantly higher frequencies of several biological effects observed in winter flounder, the cause-and-effect relationships between these effects and contaminants are poorly understood. Nevertheless, extensive studies in Puget Sound (Malins et al. 1984) on the relationships between chemical contaminants in sediment and pathological conditions in liver of English sole (Parophrys vetulus) have shown significant relationships between concentrations of AHs and these conditions. In addition, laboratory studies on English sole have demonstrated that exposure to extracts of sediment from a contaminated site with high levels of AHs resulted in development of liver pathology similar to that seen in fish living in association with contaminated sediments (Varanasi 1987). The formation of hepatic DNA adducts has also been demonstrated for both English sole (Varanasi et al. 1989b) and winter flounder (Varanasi et al. 1989c) exposed to extracts of contaminated sediments, specific AHs, and for those collected from contaminated sites in Puget Sound and Boston Harbor.

The concentration of sediment AHs (4,000 ng g⁻¹ dry wt) found at New Haven which appear associated with elevated hepatic disorders and DNA adducts in winter flounder are similar to those reported for both Raritan Bay and a site in western Long Island Sound (Zdanowicz et al. 1986). Very similar sediment concentrations of AHs (ca. 5,000 ng g⁻¹ dry wt) were associated with elevated frequencies of liver pathology in English sole from Elliott Bay, near Seattle, WA (Varanasi et al. 1989a).

Although the concentration gradients for many contaminants generally decrease from west to east (Turgeon and O’Connor 1991), inputs from urban sites within Long Island Sound such as New Haven and Norwalk should not be dismissed. These urban sites have contributed moderately high concentrations of sediment contamination even in areas several miles from sources. Additionally, populations of winter flounder which use areas such as New Haven and Norwalk for seasonal feeding and reproductive activities (represented by those used in these studies) appear to have been deleteriously affected by contaminants.

Conclusions

This study has shown that the New Haven site generally had the highest levels of organic chemical contamination of sediment of the three sites sampled in Long Island Sound. The evidence also demonstrated that winter flounder at the New Haven site had the highest frequencies of biochemical and pathological anomalies among the sites. Both DNA adducts and macrophage aggregates appear to be promising measures of effects of contaminant exposure in winter flounder.

None of the sites sampled had contaminant levels as high as the worst conditions previously found as part of the NBSP at other East Coast sites (Zdanowicz et al. 1986). However, sediment concentrations (AHs) at New Haven should be considered moderately high (Turgeon and O’Connor 1991). It should be recognized that the moderately high levels of chemical contaminants (particularly levels of AHs) at the New Haven site were apparently sufficient to have exceeded thresholds for effects, such as hepatic DNA xenobiotic adducts and liver pathology in winter flounder.

Acknowledgments

Sincere thanks to all of the present and former NMFS Environmental Conservation Division staff members who contributed to this study. Especially T. Emry and L. Rhodes for dedicated service and high quality work during field collections; K. Carrasco for micronucleus evaluations; P. D. Plesha for invertebrate collections; Dr. W. L. Reichert for DNA adduct analyses; S. Perry for typing; S. Pierce for comparison interval calculations and all of the other National Analytical Facility staff for timely and complete chemical analysis. Thanks also to the officers and crew of the NOAA Ship Ferrel especially Cmdr. R. Hunt and Chief Boatswain R. Brinnon for outstanding leadership and advice in field operations.

Literature Cited


