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Food Chain Exposure Assessments: A Multi-Species Approach

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ABSTRACT

Assessment of impacts to aquatic organisms and food chains caused by environmental contaminants is becoming an increasingly important component of remedial investigations, risk/endangerment assessments, feasibility studies and other environmental evaluations aimed at finding environmentally sound solutions to hazardous waste problems. This paper discusses a methodology for food chain exposure assessment and presents a case study for a hazardous waste site.

The proposed methodology goes beyond single species/single toxicant exposure assessments to examine exposures at different trophic levels as well as to individual aquatic organisms within the food chain. The first step is to identify and characterize the aquatic environments near the site of concern, such as rivers, lakes and ponds. The second step is to choose a subset of species based on parameters such as species commonality, food chain function and availability of ecotoxicity data. The third step involves development of two food chains representative of benthic and pelagic communities, which involves compilation of life-cycle and natural history (ecological) data. The purpose of the fourth, or toxicological assessment step, is compilation of ecotoxicity data (species-specific) in order to determine dose or concentration-response relationships. In the final step data generated in the previous steps are combined to characterize the impacts to the individual aquatic organisms and the aquatic food chains at risk.

Using this methodology, it is possible to address the risks associated with exposure to hazardous waste constituents to not only individual organisms but also entire food chains, allowing a semi-quantitative and qualitative assessment of current and future impacts from exposure. This level of detail provides the necessary information upon which to base sound engineering decisions in the development and evaluation of remedial alternatives.

INTRODUCTION

The purpose of an exposure assessment is to identify the receptor species at risk of exposure to contaminants and to determine the major pathways through which they may contact contaminants. For an aquatic environment, identifying receptors and determining the rates of exposure is difficult due to the dynamic interactions between water, sediment and aquatic organisms.

The impact of the physical environment as well as species-specific factors will be considered in evaluating species exposure to PCBs and heavy metals. This food chain exposure assessment will be divided into five sections. The first section provides a brief description of the study area and how the physical/chemical parameters influence species presence and distribution throughout the study area. The second and third steps involve identification and evaluation of a representative subset of species detected at the site and the development of an ecologically sound benthic and pelagic food chain. The purpose of the fourth, or toxicological assessment step, is a compilation of ecotoxicity data (species-specific) in order to determine concentration-response relationships. In the final step, information generated in previous steps will be compared with analytical results for water column concentrations of PCBs and metals to determine potential and/or actual risk to individual organisms and food chains as a whole. To illustrate this exposure methodology, the New Bedford Harbor Superfund Site will be discussed as a case study.

PHYSICAL DESCRIPTION OF NEW BEDFORD HARBOR

The New Bedford, Massachusetts Harbor area contains approximately six mi.^{2} of open water, tidal creeks, salt marshes and wetlands. The major fresh water inflow to this area is the Acushnet River. The introduction of the fresh water river into the salt water harbor creates a unique ecosystem comprised of salinity, depth and temperature gradients. This ecosystem provides habitats for a wide variety of aquatic organisms that utilize this area for spawning, foraging and overwintering. Figure 1 illustrates the study area for the environmental exposure assessment.

The species distribution throughout this study area is governed by the physical and chemical parameters mentioned above. Species survival often is limited to a small range in these parameter values and thus, species will distribute in areas throughout the estuary/harbor area best suited for their growth and reproduction. Areas of high salinity, such as those observed in Buzzards Bay, are inhabited by species such as the striped bass which have developed osmoregulatory mechanisms suitable for dealing with such conditions. Low saline tolerant species, such as the Mummichog, could not survive in Buzzards Bay and therefore are found in the estuarine areas near the fresh water/salt water interface. While the fully developed adult species may be able to tolerate certain physical and chemical parameters, the survival of the egg and juvenile stages of the same organisms may be dependent upon less stressful areas of the environment. Many anadromous fish inhabit Buzzards Bay but come into the estuary to spawn. The eggs hatch and juveniles develop in this area, utilizing the low salinity and high nutrient conditions for optimal growth.

Salinity, depth and temperature gradients observed in New Bedford Harbor are three major physical/chemical parameters which dictate species distribution and are used to discuss the poten-

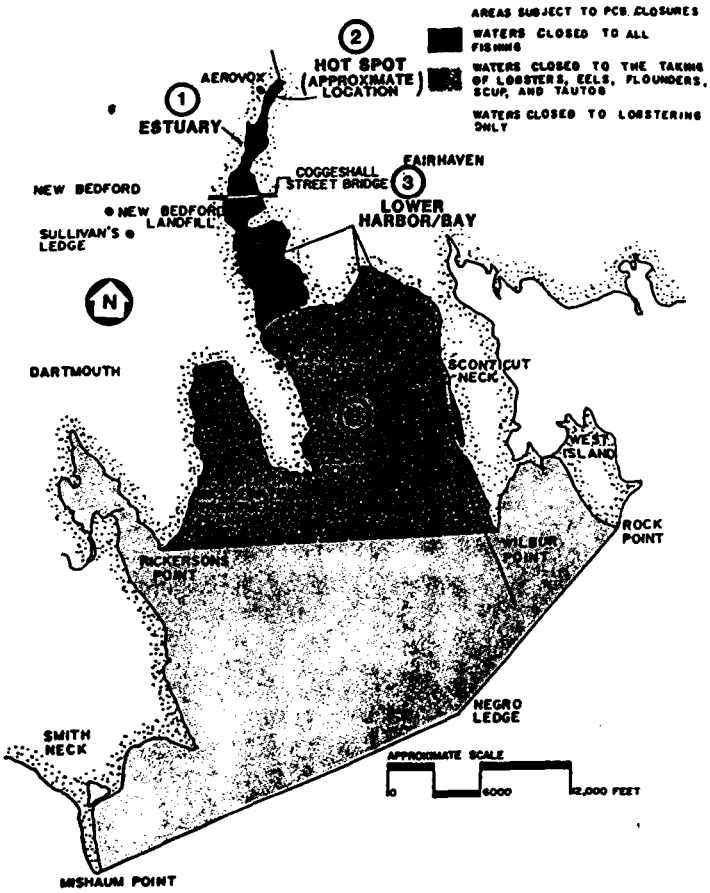


Figure 1
New Bedford Harbor
Areas Subject to PCB Closures

tial range and distribution of species inhabiting the New Bedford Harbor. This information is important because the location of organisms in the harbor will dictate contaminant exposure concentrations.

EXPOSED SPECIES ANALYSIS

The exposed species analyses provide information on how species may be exposed to the contaminants in New Bedford Harbor. To determine this information, both the routes of contaminant exposure and the receptor organisms (species) were identified. The species profiles are important not only to insure accurate illustrations of benthic (bottom-dwelling) and pelagic (open-water) food chain interactions, but also are essential to determine how the different life history characteristics of aquatic organisms can aid or impede exposure to contaminants at New Bedford Harbor.

There are three primary routes through which aquatic organisms may become exposed to contaminants:

- Water column (direct contact with the water column via the gills or epithelial tissue)
- Sediments (direct contact or ingestion of sediments)
- Food Webs (ingestion of forage species)

Organisms in New Bedford Harbor can be exposed by any or all of these routes of exposure depending upon the habitat and life cycle stages of the organism. The interrelation of these three routes makes it difficult to definitively assess exposure. In terms of species/exposure relationships at New Bedford Harbor, direct contact with dissolved or particulate contaminants in the water column is the primary route of exposure for pelagic fish, bivalves and plankton. A secondary route of exposure for pelagic fish and bivalves is consumption of contaminated biota. For benthic fish and invertebrates, direct contact and ingestion of contaminated sediments are the primary routes of exposure while direct contact with the water column is a secondary route of exposure. Forage species such as the mummichogs and grass shrimp are food for secondary a[illegible] tertiary consumers. Ingestion of these species can result in the b[illegible] magnification of PCBs and metals.

Although the focus of this exposed species analysis, is to evaluate the primary route of exposure, the research also addresses the secondary and tertiary routes of exposure to provide an accurate description of exposure to the species in New Bedford Harbor. Primary exposure routes are determined based on the habitat requirements of adult species while the secondary and tertiary exposure routes are determined based on the different life stages of the species.

As indicated above, the primary route of contaminant exposure changes over the course of the species' life cycle. For example, direct contact with contaminants in the water column is the primary route of exposure for anadromous fish using the estuary for a spawning ground, while the eggs released by these adults are highly susceptible to the contaminants in the sediments? Thus, the same species may be exposed by different routes of exposure depending upon its life stage. The exposure assessment for New Bedford Harbor therefore considers not only which species are exposed, but also how exposure occurs given the life stage of an organism. To evaluate contaminant exposure and to construct the appropriate food chains, species profiles were developed for selected organisms which discuss the unique life cycle characteristics of each species and how these dictate species/exposure relationships.

To conduct a food chain exposure assessment, it is not necessary to complete a species profile for every organism associated with the site. Therefore, a representative subset of species (Table 1) was identified as the focus of this assessment. The subset of species fall into four selected classes of aquatic organisms: fin fish, crustaceans, molluscs and plankton. These species classes were chosen as they provide representative organisms from each trophic le[illegible] and include species exhibiting both pelagic and benthic habitatio[illegible] Focusing the exposed species analyses on these organism ensures that all routes of contaminant exposure are assessed.

Eight organisms were selected for the exposed species analyses A species profile was developed for each organism, describing both the species/exposure relationships and the life cycle characteristics which include contaminant exposure. The following criteria were used to make the final selection of organizations for the exposed species analyses:

- Commonality to New Bedford harbor
- Distribution within the study area
- Food chain importance (producer, primary consumer, secondary consumer or tertiary consumer
- Exposure considerations (contact with water, sediment or ingestion of biota)
- Commercial and recreational utilization
- Availability of ecotoxicity data
- Availability of biological and ecological information

The results of the exposed species analysis are summarized below for water column, sediment and food web exposures.

Water Column Exposure

Many of the fish associated with New Bedford harbor swim between the surface and deeper water and contribute organic matter by egestion, excretion and death. The stripped bass (*Morone saxatilis*) and blueback herring (*Alosa aestivalis*) are two examples of fish representatives of this pelagic life style. Organisms which are unable to maintain their distribution against the movement of water masses are referred to as plankton. Included in this group are phytoplankton (plants) and zooplankton (animals). General[illegible] all plankton are very small and, in many cases, microscopic. Th[illegible] following plankton from New Bedford Harbor are representative of this free-floating existence: copopod (*Arcartia tonsa*), diatom

(*Rhizosolenia alata*) and the diatom (*Skeletonema costatum*). Many bivalves are found on hard rock bottoms or semi-hard mud, normally settling on areas already inhabited by other bivalves. These organisms are filter feeders, filtering large quantities of water daily to extract the edible particles. Direct contact to the visceral organs from water-bound contaminants is a primary source of exposure. The blue mussel (*Mytilus edulis*) is representative of this life style. Brief profiles for these species, describing factors affecting their exposure, are presented below.

Striped Bass (*Morone saxatilis*). In New Bedford Harbor, the striped bass has been observed in areas 1 and 3 and is thought to be absent from area 2 (Hot Spot)[2]. Striped bass caught in Massachusetts waters have ranged up to 20 years of age and 127 cm. in length[6]. The pelagic and benthic characteristics of striped bass adults and eggs can subject them to PCB and heavy metal exposure by both surface water contact and direct contact with contaminated sediments (Fig. 3 and 4). The striped bass is a voracious feeder, consuming both fish and invertebrates in the shore zone and estuaries. This top carnivore may be subject to high tissue burdens from the consumption of various prey organisms at New Bedford Harbor.

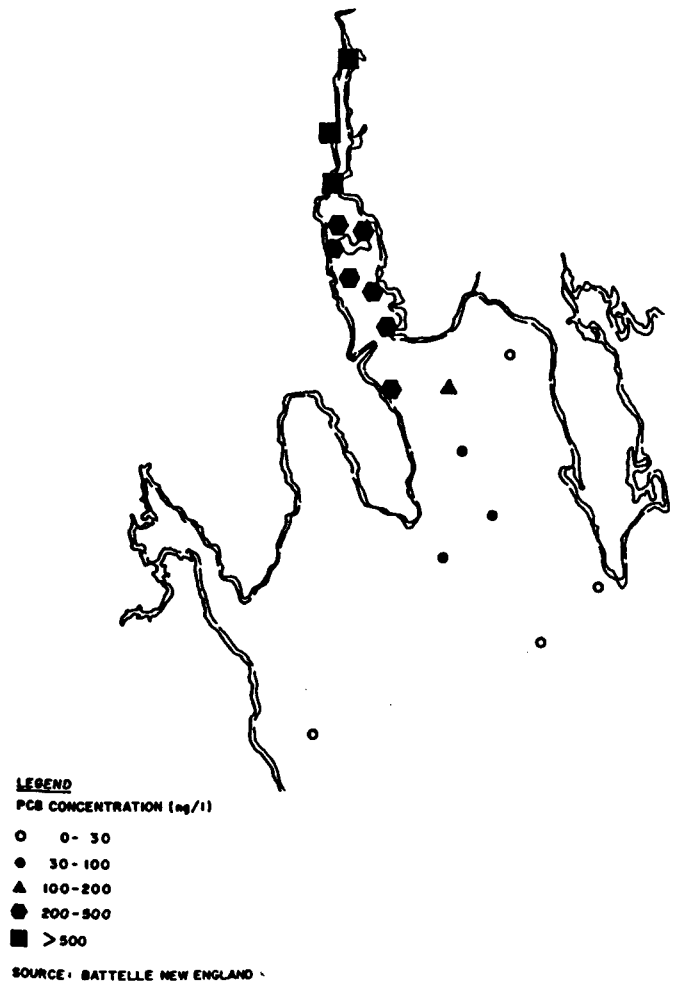


Figure 2
Total PCBs in Water
New Bedford Harbor

Blueback Herring (*Alsoa aestivalis*). In the spring, the blueback herring enters New Bedford Harbor to spawn and can be found in areas 1, 2 and 3, thus being exposed to varied concentrations of PCBs and heavy metals (Figs. 2, 3 and 4)[6]. As an anadromous species, the blueback herring enters brackish water in the spring, usually by mid-May in New Bedford Harbor, when water temperatures reach 21 to 24°C[6]. It is probably the long journey from the harbor entrance to the saltwater/freshwater interface in area 1 that is responsible for the greatest exposure (via the water column) to PCBs and heavy metals. Blueback herrings eggs are demersal (benthic), somewhat adhesive, semi-transparent and yellow. Since areas 1 and 2 water temperatures are conducive to spawning and incubation, this may cause blueback eggs and juveniles to be in direct contact with the highest level of PCB and heavy metal contaminated sediments and surface waters (Figs. 3 and 4). Juvenile bluebacks frequently eat crustaceans (Cladocera and Anostraca) and it appears that food items remain the same throughout the seasons[6]. Adult food consists primarily of copepods, pelagic shrimp, fish eggs and larvae.

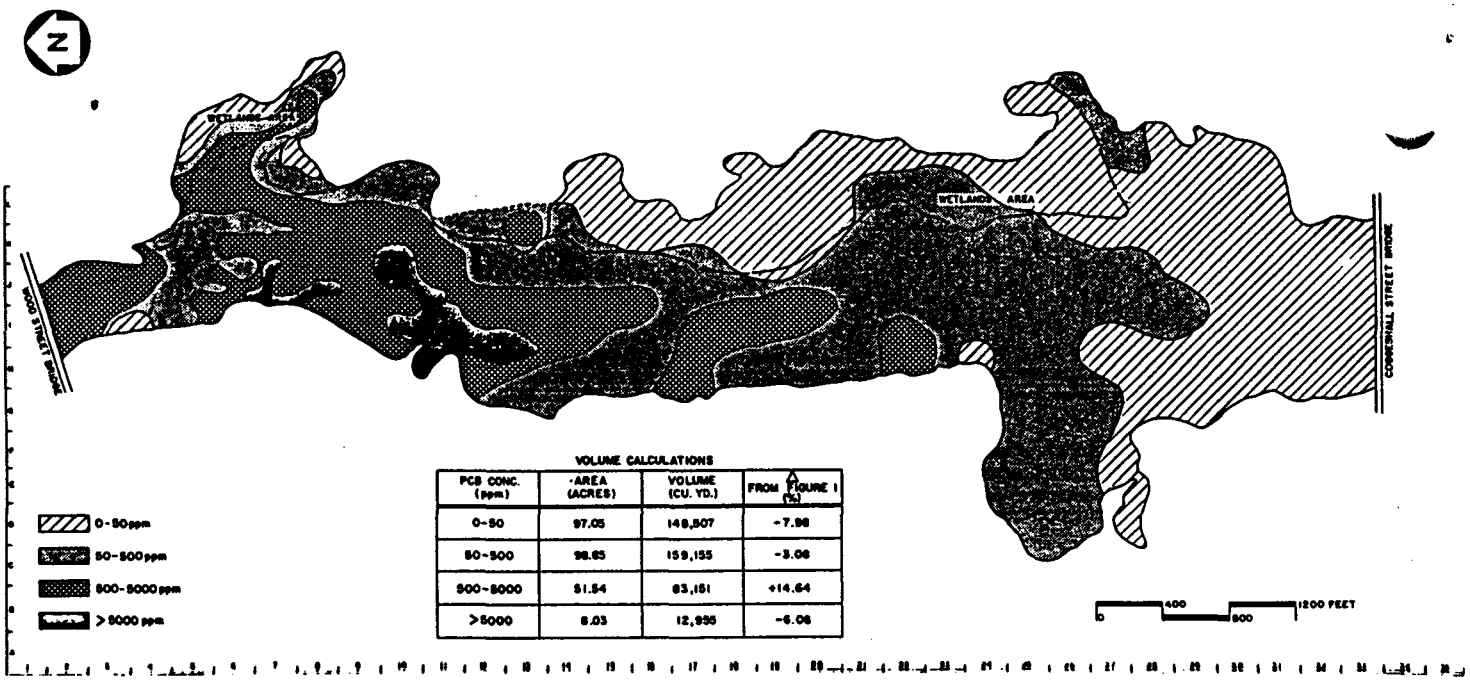
Copepod (*Acartia tonsa*). This marine calanoid dominates the zooplankton biomass in Buzzards Bay from May to November[5]. Acartia has been observed in area 3, however there is evidence available for its presence or absence from other areas of the harbor. Calanoid copepod eggs are laid several hours to days after copulation. The resting eggs go through diapause in the sediments, which could result in increased exposure via direct contact with sediments. The larvae are free-swimming and progress from one stage to the next by molting[8]. The timing of these molts can depend on seasonal conditions[15]. During these molts, the copepod can be more susceptible to contaminant exposure through direct contact with the water mass. *Acartia* is a predatory copepod[8]. It does not strain its food from the water, but propels water past the body by flapping four pairs of feeding appendages. The second maxillae captures "parcels" of water containing food. Particles of food are placed in the mouth by the first maxillae[15]. Calanoids feed on diatoms, radiolarians, coccolithophorids, tintinnids and small crustaceans[8].

Blue Mussel (*Mytilus edulis*). Large beds of mussels exist in areas 1 and 3 in New Bedford Harbor and are absent from area 2 (Hot Spot)[2]. Blue mussel beds are found from the low tide mark to depths of several meters. Subtidal beds are known in New Bedford Harbor. The blue mussel has planktonic larvae with a long larval life of up to 2 or 3 months before finding a settling site[13]. This extended exposure in the water column can be deleterious to juvenile mussels which may be more sensitive than adults to PCB and metal exposure. The feeding mechanisms of the blue mussel resemble those of many other lamellibranchs (bivalves) in that it relies upon the separation of small particles of detritus and plankton from a current of water that flows through the gills[10]. This process of filtration is continuous and allows exposure to PCBs and metals through direct contact with contaminated water, food and sediments.

Diatoms (*Skeletonema costatum*) and (*Rhizosolenia alata*). Both of these chlorophyll-bearing phytoplankton are chain-forming diatoms. In New Bedford Harbor, *Skeletonema* and *Rhizosolenia* have been observed sporadically throughout area 1 and 2[9]. In general, phytoplankton abundance depends on nutrient availability, light mixing, zooplankton grazing and concentrations of man-made contaminants[11]. Diatoms are photosynthetic primary producers and play an important role as a food resource for macrozooplankton (i.e., copepods) and planktivores (i.e, herring)[12]. PCB exposure can have wide reaching effects on phytoplankton roles in food chains and food webs. PCB exposure can result in a shift to smaller phytoplankton taxa. The change from large to small taxa causes variation in the food web which favors gelatinous predators and reduces the harvestable fish biomass[11]. *Neomysis americana* (oppossum shrimp) and *Acartia tonsa* (a copepod) are two of many zooplanktons which prey upon diatoms in New Bedford Harbor.

Sediment Exposure

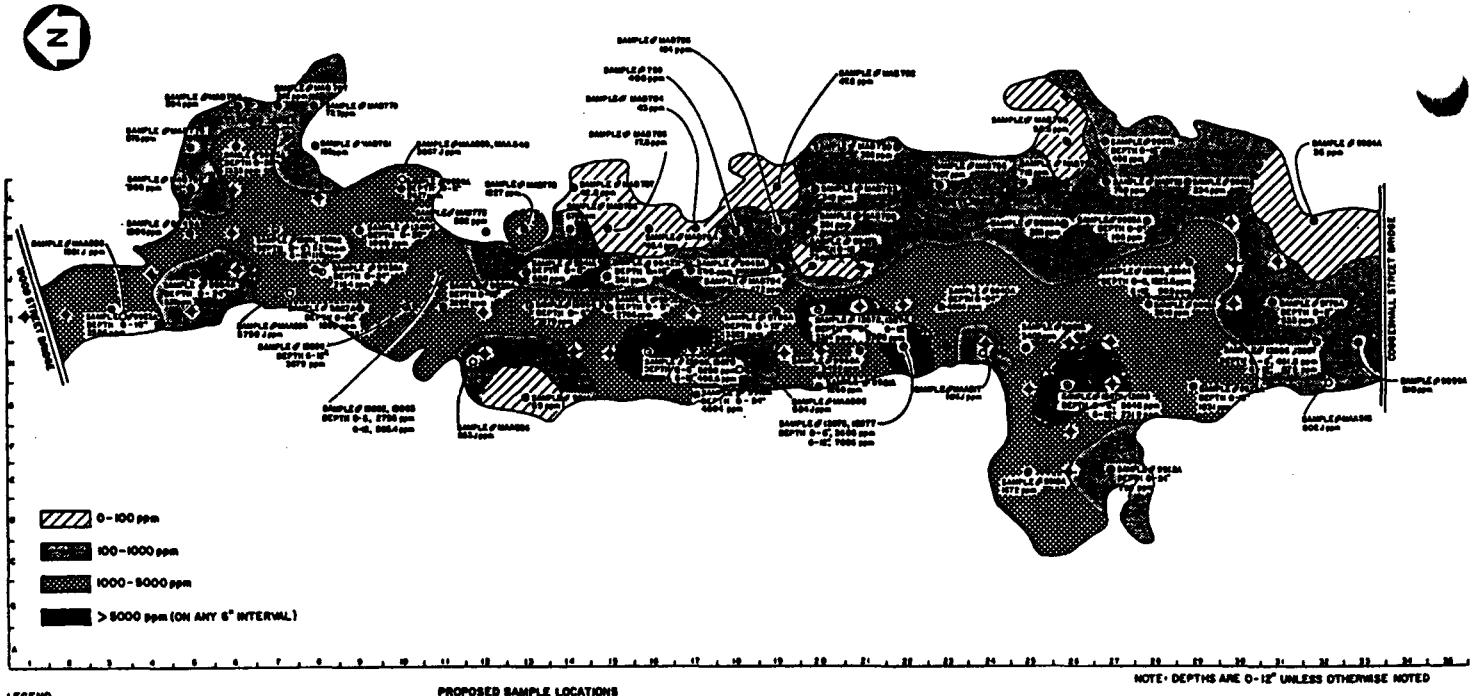
Many species of benthic fish and invertebrates are found in New Bedford Harbor. The uptake and retention of PCBs and metals is via direct contact with and ingestion of contaminated sediments; however, direct contact with the water mass will contribute to exposure. Below is a concise description of the winter flounder (*Pseudopleuronectes americanus*) and how its life cycle characteris-



VOLUME CALCULATIONS

PCB CONC. (ppm)	AREA (ACRES)	VOLUME (CU. YD.)	FROM FIGURE 1 (%)
0-50	97.05	148,507	-7.98
50-500	98.65	159,155	-3.06
500-5000	51.54	83,151	+14.64
>5000	8.03	12,955	-6.06

Figure 3
Total PCB Concentrations*, 0–12"



PROPOSED SAMPLE LOCATIONS

E-26
F-26
G-25, G-27
H-12, H-14, H-15, H-17, H-19, H-20, H-23, H-24, H-26
H-27
I-1, I-2, I-6, I-12, I-17, I-21, I-23, I-30
J-4, J-6, J-21, J-30, J-31
K-6, K-30
L-6, L-9, L-26
M-26

Figure 4
Total Metals Concentrations, 0–12"
(Cd, Cu, Cr, Pb)

tics can aid or impede PCB and heavy metal exposure in New Bedford Harbor.

Winter flounder (*Pseudopleuronectes americanus*). The winter flounder has been observed in areas 1, 2 and 3 in New Bedford Harbor[7]. However, juvenile flounders remain in the estuaries until their third year[6]. As a result, this may expose juveniles to significant levels of PCBs and metals in New Bedford Harbor via the water column and sediments at an important stage in the development of the individual.

The Acushnet River estuary and New Bedford Harbor provide a spawning ground for the winter flounder from January to May. Winter flounder eggs are demersal and adhesive, ranging from 0.75 to 0.85 mm. in diameter. Eggs can be found from late April to June in most New England estuaries. Direct exposure to contaminated sediments and water is likely in New Bedford Harbor.

Winter flounders feed primarily by day. The adult flounder is limited to smaller invertebrates such as shrimps, amphipods and clams, due to its gape size. Larvae will feed on copepod nauplii, polychaetes and eggs of invertebrates. After metamorphosis, the fish eat mainly crustaceans and polychaetes[6]. As a result of the winter flounder's feeding habits, this species may bioaccumulate PCBs and metals in New Bedford Harbor, via ingestion of contaminated sediments and prey.

Food Web Exposure

Within the marine environment, a major role of many organisms is as a food source (forage) for other fish and invertebrates. These prey organisms (fish and invertebrates) inhabit the estuaries providing an important feeding ground for many other species. These organisms contribute to the uptake of PCBs and metals within the food web and may even be responsible for increasing concentrations of PCBs and metals in organisms related to their trophic status. The individual life cycle characteristics of these organisms is indicative of their PCB exposure and how they become transmitters via their consumption by other organisms. Below is a description of the clam worm (*Nereis succinea*) illustrating its ecological niche and how it may be a transmitter of contamination in New Bedford Harbor.

Clam worm (*Nereis succinea*). The clam worm occurs in all areas of New Bedford Harbor[14]. The presence of this organism in areas where the contamination of PCBs and metals is in excess of 5,000 ppm in the sediments (Figs. 3 and 4) may substantiate studies previously completed in New Bedford Harbor calling this and other polychaetes "pollution tolerant organisms"[4]. Throughout the developmental period of *Nereis*, from fertilized egg to trochopore, exposure to surface waters is enhanced by this pelagic growth period. Once developed into a young worm, exposure probably is accelerated since sediments at New Bedford Harbor are contaminated with PCBs and heavy metals (Figs. 3 and 4).

These voracious predators prey on other burrowing animals including others of their own species[1]. When prey is detected, the worm everts its pharynx or proboscis, on the end of which its jaws are located. *Nereis* seizes prey and retracts its proboscis, thus drawing the prey into its mouth[1]. Animals found in New Bedford Harbor which prey on polychaetes include: *Anguilla rostrata* (American eel), *Menidia* (Atlantic silverside), *Stenotomus chrysops* (scud) and *Pseudopleuronectes americanus* (winter flounder).

Summary of Exposed Species Analysis

These species profiles provide information relating to a particular species' exposure to contaminants in the water or sediment throughout its life stages. As described earlier, exposure via the ingestion of forage species also must be evaluated as this may present a significant route of contaminant exposure. These food chain interactions often result in the bioaccumulation and biomagnification of contaminants throughout the ecosystem. These species profiles identified the primary, secondary and tertiary routes of contaminant exposure for the species in New Bedford Harbor. In addition, these profiles illustrate the important exposure routes for the different trophic levels and describe the potential for biomagnification of contaminants through food chain interactions. This exposure information was used to construct hypothetical food chains in the following section to illustrate the potential toxicity and/or biomagnification of contaminants detected throughout the New Bedford Harbor area.

FOOD CHAIN ANALYSIS

The ecological data on feeding and predation described in the profiles above can be used to illustrate a pelagic and benthic food chain for the New Bedford Harbor. Figure 5 depicts a hypothetical food chain for the species identified within New Bedford Harbor. This food chain illustrates how PCBs and metals may biomagnify up trophic levels. The implications of this route of exposure can be illustrated by the lifestyle/exposure relationship involving predatory fish that feed in the estuary. For example, the striped bass may be exposed to low concentrations of contaminants from the water column, but because of biomagnification, this organism may incur potentially toxic levels of contaminants from the consumption of contaminated prey. This hypothetical food chain is the framework for assessing toxicity and bioaccumulation of not only individual organisms, but also the entire food chain. In the following section, ecotoxicity data for the species of concern will be discussed for PCBs and metals at New Bedford Harbor.

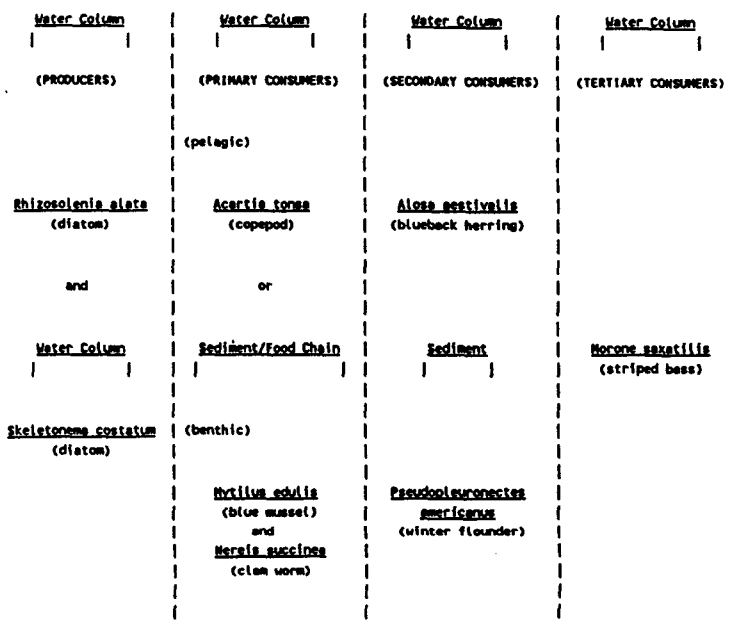


Figure 5
Hypothetical Food Chain Interactions at New Bedford Harbor

ECOTOXICITY ASSESSMENT

This assessment provides the toxicity data that elucidate the potential toxic effects to aquatic organisms associated with exposure to PCBs, cadmium, copper and lead. A plethora of the toxicity data for the species and chemicals of concern are for direct contact with the water column. Therefore, the concentration/response relationship for these organisms is based on direct contact with contaminants in the water column and potential bioaccumulation of those contaminants. To evaluate the potential toxicity of water-bound contaminants to the species of concern, toxicity data for benthic and pelagic organisms must be presented. Table 2 illustrates the toxicity and bioaccumulation factors (BCF) for the food chain members described in Figure 5.

Table 1:
Species of Concern for New Bedford Harbor

Water Column	Sediments	Food Webs
Striped Bass (*Morone saxatilis*)	Winter Flounder (*Pseudopleuronectes americanus*)	Clam Worm (*Nereis succinea*)
Blueback Herring (*Alosa aestivalis*)		
Copepod (*Acartia tonsa*)		
Diatom (*Rhizosolenia alata*)		
Diatom (*Skeletonema costatum*)		
Blue Mussel (*Mytilus edulis*)		

Table 2:
Toxicity and Bioaccumulation of PCBs and Heavy Metals Between Trophic Levels

Trophic Levels	Species	Ecotoxicity	BCF[a]
Producers	Diatom (*Rhizosolenia alata*)	0.05-6.5 ppb (water/PCBs)	1,000-16 (PCBs)
		10-175 ppb (water/Cd)	no data available-Cu
	Diatom (*Skeletonema costatum*)	4.6-50 ppb (water/Cu)	617 (Cu)
		20-23.3 ppb (water/Pb)	725-1,050 (Pb)
Primary Consumers	Copepod (*Acartia tonsa*)		
	Amphipod (*Ampelisca vadorum*)	4.0-50 ppb (water/PCBs)	8,700-165,000 (PCBs)
		90-135,000 ppb (water/Cd)	160-3260 (Cd)
	Blue Mussel (*Mytilus edulis*)	5.8-480 ppb (water/Cu)	70-28,200 (Cu)
		476-668 ppb (water/Pb)	1,500-2,570 (Pb)
	Clam Worm (*Nereis succinea*)		
Secondary Consumers	Winter flounder (*Pseudopleuronectes americanus*)	0.06-10 ppb (water/PCBs)	30,000-43,100 (PCBs)
		5.0-602 ppb (water/Cd)	15 (Cd)
		52-280 ppb (water/Cu)	no data available-Cu
	Sheepshead Minnow (*Cyprinidon variegatus*)	315-3,140 ppb (water Pb)	no data available-Pb
Tertiary Consumers	Striped Bass (*Morone saxatilis*)	50-1,000 ppb (water/PCBs)	no data available-PCBs
		0.5-5.0 ppb (water/Cd)	no data available-Cd
	Tomcod (*Microgadus tomcod*)	100-270 ppb (water/Cu)	no data available-Cu
		no data available-Pb	no data available-Pb

[a]Bioconcentration factor
Source: Ambient Water Quality Criteria documents for PCBs, Cadmium, Copper, and Lead

Toxicity of PCBs and the three metals occurs at very low concentrations for diatoms when compared to other food chain members. Concentrations as low as 0.05 ppb for PCBs and 4.6 ppb for copper have exhibited toxicity to *Rhizosolenia* and *Skeletonema*. Primary consumers also appear to be sensitive to PCBs and heavy metals; however, as with producers, PCB toxicity occurs at much lower concentrations than heavy metals. Toxicity data for secondary consumers occurred as low as 0.06 ppb (PCBs) and 5.0 ppb (Cadmium). Except for cadmium, toxicity values for tertiary consumers occur at concentrations several times greater than for secondary and primary consumers or producers.

Bioconcentration factors for producers are as high as 16,000 for PCBs and 1,050 for lead. Primary consumers appear to bioconcentrate PCBs and metals to a much higher extent than other trophic levels. Little data are available for secondary consumers. However, BCFs for PCBs at this trophic level are high when compared to other organisms. No BCF data were identified in the literature for tertiary consumers. However, because of trophic position of these organisms and their food requirements, bioaccumulation of PCBs and metals is expected.

ENVIRONMENTAL RISK CHARACTERIZATION

The final step in the food chain exposure process is to compare analytical data with toxicity data in New Bedford Harbor. Direct comparisons between toxicity data and observed concentrations in New Bedford are difficult, because toxicity values in Table 2 are for Aroclors (e.g., 1254 and 1210) and analytical results are for total PCBs. Since historical data for discharges in New Bedford Harbor indicate that most of the PCBs present were 1254 and 1210, this comparison is less tenuous. Similar difficulties are present for metal because toxicity values usually are presented for metal compounds and analytical data are presented for individual metals. This problem does not preclude an evaluation, and this type of assessment still offers an accurate assessment of potential toxicity to aquatic organisms and entire food chains in New Bedford Harbor. Analytical results for copper were not available at the time of this writing and therefore will not be discussed here.

Dissolved PCB concentrations for area 1 were 1.2 ppb and total PCB concentrations were 13.75 ppb (see Table 3). Lead and cadmium concentrations in this same area were 923 and 139 ppb, respectively. These data indicate that producers (in particular, diatoms) may be at risk from direct contact to PCBs and metal concentrations in excess of those that have caused toxicity in the laboratory. More importantly, these contaminant levels may result in elevated tissue burdens especially in the case of PCBs, which appear to be readily bioaccumulated [1,000—16,000 (PCBs)].

Table 3:
Pollutant Concentration in Areas 1, 2, 3[a]

Pollutant	Mean for all areas (17 Stations)	Area 1 (2 Stations)	Area 2 (8 Stations)	Area 3 (7 Stations)
Lead, Total (ug/L)	335.03	923.17	406.22	195.76
Cadmium, Total (ug/L)	10.21	139.48	6.87	4.76
PCB, Total (ng/L)	592.50	13754.05	236.32	58.40
PCB, Particulate (ng/L)	479.34	12545.94	118.96	31.64
PCB, Dissolved (ng/L)	114.13	1208.12	396.04	26.79

(all values are mean values)
[a]
Source:
Data Reduction For Risk Assessment In New Bedford Harbor. Battelle Ocean Sciences, 397 Washington Street, duxbury, Massachusetts 02332. September 1987.

The pelagic copepod (*Acartia tonsa*) also may be at risk from elevated levels of metals and PCBs in the water column, both from direct contact and bioaccumulation. The blue mussel is also at risk from direct contact with contaminated water and the consumption of contaminated biota (in particular, diatoms). Toxicity values for the polychaete worm occur at much higher concentrations of metals and PCBs than those observed in New Bedford Harbor. This probably is an asset for the clam worm but a debit for organisms which consume this species and, therefore, can incur high tissue burdens.

Risk of exposure to PCBs and metals by secondary consumers like the blueback herring and the winter flounder comes in the form of direct exposure to contaminants in the water column and consumption of contaminated biota. These organisms, in turn, will fall prey to large migratory fish like the striped bass. Striped bass are particularly sensitive to cadmium (0.5-5.0 ppb) and concentrations ranging from 4.76-139.48 ppb (Table 3) could be deleterious to this species. Also, because BCFs for many of the organisms the striped bass eats are relatively high, the striped bass probably is receiving large doses of contaminants via the consumption of contaminated biota.

Area 1 contains the greatest overall risk to aquatic organisms and food chains (benthic and pelagic) in New Bedford Harbor. Concentrations of PCBs and metals in this area are high enough to exhibit toxicity to several organisms illustrated in Figure 5 and more importantly, producers who serve as the primary link in food chains appear to be at the greatest risk. Diminished numbers of diatoms can lead to ecosystem instability and a domino effect within the entire food chain [16]. Although the probability of toxicity beyond

the producer level seems to be reduced based on the toxicity data, the effects of contaminant bioaccumulation and biomagnification can be expected to be deleterious to higher trophic level species. The toxicity data and the food chain interactions, when compared to observed water concentrations, indicate that present conditions are potentially harmful to individual organisms and food chains in New Bedford Harbor.

CONCLUSIONS

Assessment of impacts to aquatic organisms and food chains caused by environmental contaminants has become an important component of remedial investigations and feasibility studies. This proposed methodology allows for a more accurate assessment of the potential and/or actual effects to aquatic organisms and food chains at hazardous waste sites. Information generated on the multi-species/multi-contaminant level can help facilitate more accurate and cost-effective analysis of proposed remedial alternatives at hazardous waste sites. The level of detail discussed in this paper provides the necessary information upon which to base sound engineering decisions in the development and evaluation of remedial alternatives.

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