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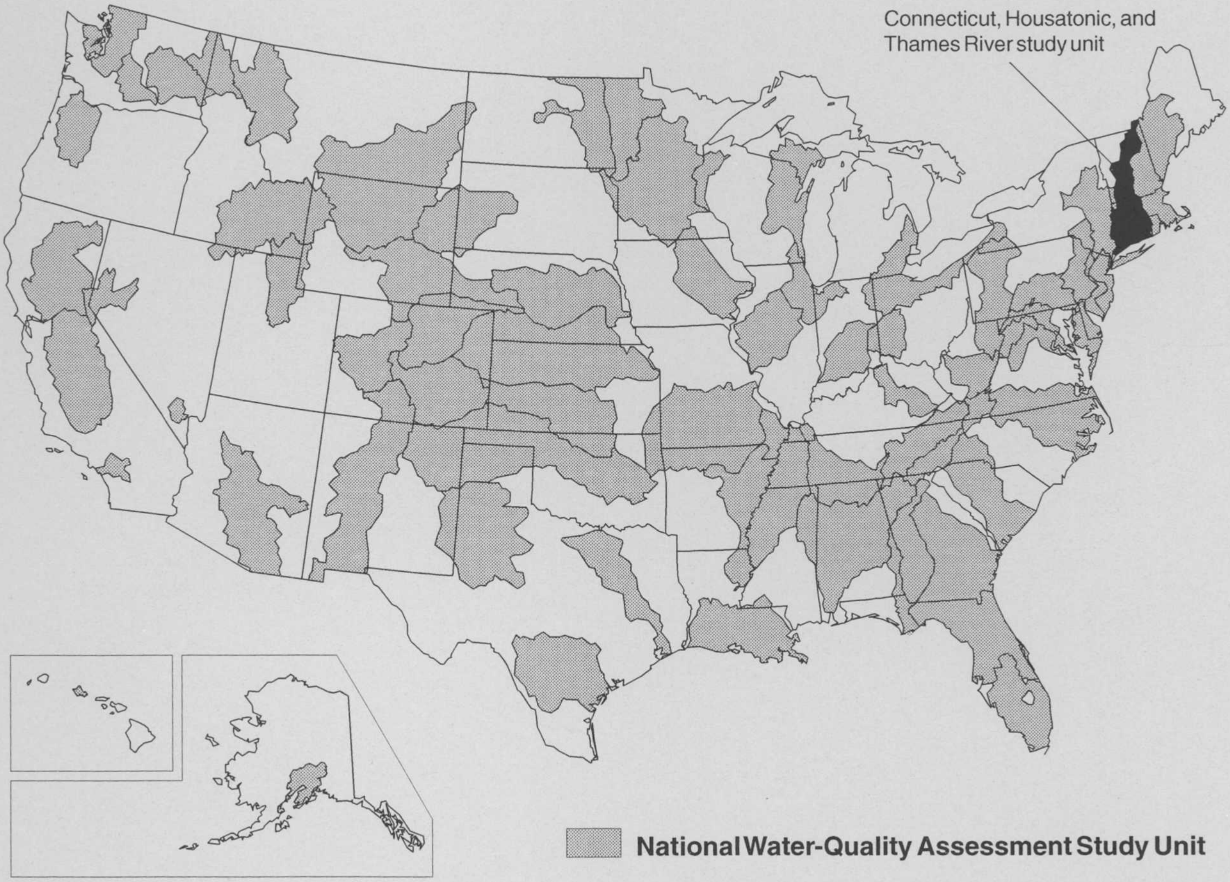
Organochlorine Compounds in Fish Tissue from the Connecticut, Housatonic, and Thames River Basins Study Unit, 1992-94

Water-Resources Investigations Report 98-4075



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Organochlorine Compounds in Fish Tissue from the Connecticut, Housatonic, and Thames River Basins Study Unit, 1992-94

By JAMES F. COLES

Water-Resources Investigations Report 98-4075

National Water-Quality Assessment Program

Marlborough, Massachusetts
1998

U.S. DEPARTMENT OF THE INTERIOR
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FOREWORD

The mission of the U.S. Geological Survey (USGS) is to assess the quantity and quality of the earth resources of the Nation and to provide information that will assist resource managers and policymakers at Federal, State, and local levels in making sound decisions. Assessment of water-quality conditions and trends is an important part of this overall mission.

One of the greatest challenges faced by water-resources scientists is acquiring reliable information that will guide the use and protection of the Nation's water resources. That challenge is being addressed by Federal, State, interstate, and local water-resource agencies and by many academic institutions. These organizations are collecting water-quality data for a host of purposes that include: compliance with permits and water-supply standards; development of remediation plans for specific contamination problems; operational decisions on industrial, wastewater, or water-supply facilities; and research on factors that affect water quality. An additional need for water-quality information is to provide a basis on which regional- and national-level policy decisions can be based. Wise decisions must be based on sound information. As a society we need to know whether certain types of water-quality problems are isolated or ubiquitous, whether there are significant differences in conditions among regions, whether the conditions are changing over time, and why these conditions change from place to place and over time. The information can be used to help determine the efficacy of existing water-quality policies and to help analysts determine the need for and likely consequences of new policies.

To address these needs, the U.S. Congress appropriated funds in 1986 for the USGS to begin a pilot program in seven project areas to develop and refine the National Water-Quality Assessment (NAWQA) Program. In 1991, the USGS began full implementation of the program. The NAWQA Program builds upon an existing base of water-quality studies of the USGS, as well as those of other Federal, State, and local agencies. The objectives of the NAWQA Program are to:

- Describe current water-quality conditions for a large part of the Nation's freshwater streams, rivers, and aquifers.
- Describe how water quality is changing over time.
- Improve understanding of the primary natural and human factors that affect water-quality conditions.

This information will help support the development and evaluation of management, regulatory, and monitoring decisions by other Federal, State, and local agencies to protect, use, and enhance water resources.

The goals of the NAWQA Program are being achieved through ongoing and proposed investigations of 59 of the Nation's most important river basins and aquifer systems, which are referred to as study units. These study units are distributed throughout the Nation and cover a diversity of hydrogeologic settings. More than two-thirds of the Nation's freshwater use occurs within the 59 study units and more than two-thirds of the people served by public water-supply systems live within their boundaries.

National synthesis of data analysis, based on aggregation of comparable information obtained from the study units, is a major component of the program. This effort focuses on selected water-quality topics using nationally consistent information. Comparative studies will explain differences and similarities in observed water-quality conditions among study areas and will identify changes and trends and their causes. The first topics addressed by the national synthesis are pesticides, nutrients, volatile organic compounds, and aquatic biology. Discussions on these and other water-quality topics will be published in periodic summaries of the quality of the Nation's ground and surface water as the information becomes available.

This report is an element of the comprehensive body of information developed as part of the NAWQA Program. The program depends heavily on the advice, cooperation, and information from many Federal, State, interstate, Tribal, and local agencies and the public. The assistance and suggestions of all are greatly appreciated.

Robert M. Hirsch

Robert M. Hirsch
Chief Hydrologist

CONTENTS

Abstract 1
Introduction 2
Background 2
Purpose and Scope 3
Selection of Sampling Sites 3
Results of Previous Study 5
Data Collection and Analysis 6
Sample Collection and Processing 6
Site Characterization 6
Data Analysis 6
Organochlorine Compounds in Fish Tissue 8
Total DDT 8
Total Chlordane 12
Total PCBs 14
Comparison With Results of Other Studies 17
Summary and Conclusions 20
References Cited 21

FIGURES

1. Map showing sampling sites where fish were collected for contaminants analyses in tissue, Connecticut, Housatonic, and Thames River Basins NAWQA study unit 4
2. Graph showing concentrations of DDT and related compounds in fish tissue of sampled fish 11
3. Box plots showing distribution of total DDT concentrations in the drainage-basin population density categories 12
4. Graph showing concentrations of chlordane and related compounds in fish tissue of sampled fish 13
5. Box plots showing distribution of total chlordane concentrations in the drainage-basin population density categories 14
6. Graph showing concentrations of total PCBs in fish tissue of sampled fish 15
7. Box plots showing distribution of total PCB concentrations in the drainage-basin population density categories 16
8. Box plots showing distribution of total PCB concentrations in the drainage-basin size categories 17

TABLES

1. National guidelines for maximum organochlorine concentrations in fish tissue 2
2. Sites where fish samples were collected for organochlorine compound analysis in the Connecticut, Housatonic, and Thames River Basins study unit, 1992–94 5
3. Summary of organochlorine compounds assayed in whole fish samples from the 32 sites 5
4. Drainage-basin characteristics of the sites where fish samples were collected for organochlorine compound analysis 7
5. Concentrations of organochlorine compounds (DDT, chlordane, and PCBs) in composited whole fish samples and data associated with the sampled fish 9
6. Analysis of variance (ANOVA) statistics from tests for categorical differences in organochlorine concentrations among sites characterized by major basins, drainage-basin population density, and drainage-basin size 10
7. Range and median for concentrations of total DDT, total chlordane, and total PCBs for site characterization categories 12

8. Selected studies of organochlorine concentrations in fish tissue from the Connecticut and Housatonic River Basins study unit, 1992–94 18
9. Comparison of organochlorine concentrations in whole fish between current study sites and complementary sites from earlier studies 20

CONVERSION FACTORS AND WATER-QUALITY UNITS

CONVERSION FACTORS

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch
gram (g)	0.03527	ounce, avoirdupois
square kilometer (km^2)	0.3861	square mile

WATER-QUALITY UNITS

Concentrations of chemical constituents in tissue are given micrograms per kilogram (µg/kg).

Organochlorine Compounds in Fish Tissue from the Connecticut, Housatonic, and Thames River Basins Study Unit, 1992–94

By James F. Coles

ABSTRACT

Organochlorine compound concentrations were assayed in the tissues of fish collected at 32 sites in the Connecticut, Housatonic, and Thames River Basins study unit during 1992–94. The study was part of a survey of organic and inorganic contaminants in biological tissues, a component of the U.S. Geological Survey's National Water Quality Assessment (NAWQA) program. Concentrations of 28 organochlorines were measured in composite samples of whole fish collected at the sites. The organochlorine compounds most commonly detected in the tissue samples were total DDT (sum of *o,p*'- and *p,p*'-DDD, DDE, DDT), total chlordane (sum of *cis*- and *trans*-chlordane, *cis*- and *trans*-nonachlor, oxychlordane, and heptachlor epoxide), and total PCBs (Aroclors 1242, 1254, and 1260).

At 31 sites, at least one component of total DDT was detected in fish tissue at concentrations greater than the method reporting limit of 5 micrograms per kilogram of wet weight. The highest concentration of total DDT detected in fish tissue was 300 micrograms per kilogram. Although total DDT was detected at all but one site, concentrations were lowest in areas of low population densities. The DDT metabolite *p,p*'-DDE was detected most frequently and at the highest percentage of all DDT components, possibly indicating that DDT inputs into the aquatic system were not recent. At 25 sites, at least one component of total chlordane was detected in fish tissue at concentrations greater than the reporting limit of 5.0 micrograms per kilogram. The highest concentration of total chlordane detected in fish tissue was 390 micrograms per kilogram.

Concentrations of the total chlordane in fish tissue showed a strong positive correlation with the drainage basin population density for a site, supporting the premise that chlordane was used extensively in suburban and urban areas before its use was restricted. Of the components comprising total chlordane, *trans*-nonachlor (the least degradable component) was detected most frequently and at the highest concentrations, indicating that chlordane inputs into the aquatic system were not recent.

At 28 sites, total PCBs were detected in fish tissue at concentrations greater than the method reporting limit of 50 micrograms per kilogram of wet weight; the highest concentration measured was 72,000 micrograms per kilogram. Concentrations of total PCBs generally were high in fish from the largest rivers; the highest concentrations were in tissures of fish from the Housatonic River; concentrations in tissue samples from three sites exceeded 10,000 micrograms per kilogram. Although most PCBs in the Housatonic River are from a documented source, high concentrations of total PCBs at other large river sites probably originate in the urban and industrial areas along these rivers.

INTRODUCTION

The U.S. Geological Survey's (USGS) National Water-Quality Assessment (NAWQA) program uses an integrated approach of investigating physical, chemical, and biological components of an aquatic system to assess water quality on a basin-wide scale (Gurtz, 1994). Nationally, the NAWQA program consists of 59 individual study unit investigations of hydrologic systems that account for about two-thirds of the Nation's water use and population served by public water supply (Leahy and Wilber, 1991). One component of the NAWQA program is the study of contaminants in biological tissues, which examines the occurrence and spatial distribution of selected organochlorines and trace elements in a study unit (Crawford and Luoma, 1993). These objectives are met by measuring contaminant concentrations in the tissues of aquatic organisms that are known to bioaccumulate organochlorines and trace elements. This type of study was conducted in the Connecticut, Housatonic, and Thames River Basins study unit.

The Connecticut, Housatonic, and Thames River Basins study unit includes all drainage basins flowing into Long Island Sound from the coast of Connecticut. The study area includes eastern Vermont, western New Hampshire, west-central Massachusetts, nearly all of Connecticut, and small parts of New York and Rhode Island—a total of about 15,750 mi^2. The area was colonized and the land divided into small farms and small, closely spaced town centers more than 200 years ago. During the intervening years, the number of farms has decreased with a concurrent increase in forested land (Zimmerman and others, 1996). Although the study area constitutes less than 0.5 percent of the total area of the Nation, it is inhabited by about 4.5 million people—about 2 percent of the Nation's population (Grady and Garabedian, 1991). The major urban centers are Springfield, Mass., and Hartford, New Haven, and Bridgeport, Ct., all in the southern part of the study area.

Background

Organochlorine compounds, which include organochlorine insecticides and PCBs, have been in widespread use since World War II, but the manufacture and use of many compounds have been restricted or banned because of their toxic effects on wildlife and human health. A common property of organochlorines is resistance to biochemical degradation, which—although prolonging their effectiveness—contributes to excessive buildup in aquatic environments. Additionally, these compounds are prone to atmospheric transport, which accounts for their distribution in remote areas on a global scale (Wania and Mackay, 1996). Organochlorines are characterized by relatively low aqueous solubilities, low vapor pressures, and a high affinity for sediment organic matter. Furthermore, they tend to partition strongly into the lipid component of aquatic organisms. Because organochlorine insecticides and PCBs are among some of the most persistent anthropogenic organic compounds, they can be passed up the food chain to higher trophic feeders through bioaccumulation when introduced into an aquatic system (Smith and others, 1988).

Organochlorine contamination in fish tissue is a concern not only because of the hazards to human health but to wildlife as well. Existing national and State guidelines are based on risk assessments that consider the levels of contamination in fish as well as the rate of consumption by humans (table 1). The U.S. Environmental Protection Agency's (USEPA) fish tissue concentrations are guidelines designed to protect human health under the conditions of daily ingestion of 6.5 g by a 70 kg adult for a lifetime of 70 years. These

Table 1. National guidelines for maximum organochlorine concentrations in fish tissue

[USEPA and Food and Drug Administration (FDA) figures based on edible portion, National Academy of Sciences/National Academy of Engineering (NAS/NAE) figures based on whole fish. Concentrations are in micrograms per kilogram, wet weight]

Organochlorine compound	USEPA 10^{-6} excess human cancer risk level	FDA Action level for Interstate commerce	NAS/NAE Guideline for protection of fish-eating wildlife
p,p'-DDD	44.9	[3]5,000	[3]1,000
p,p'-DDE	31.6	[3]5,000	[3]1,000
p,p'-DDT	31.6	[3]5,000	[3]1,000
Chlordane	8.3	[1]300	[2]100
Heptachlor epoxide	1.2	300	[2]100
PCBs, total	[4]1.4	2,000	500

[1]Includes *cis*- and *trans*-chlordane, *cis*- and *trans*-nonachlor, oxychlordane, but not heptachlor epoxide.

[2]Applies to total residues of aldrin, BHC, chlordane, dieldrin, endosulfan, endrin, heptachlor, heptachlor epoxide, lindane, and toxaphene, either singly or in combination.

[3]Applies to total residues of DDT, DDE, and DDD.

[4]Includes Aroclors 1232, 1242,1248, 1254, 1260, 1016.

guidelines are concentrations expected to result in an incremental cancer risk of 10^{-6}, indicating that the increased risk of cancer may exceed 1 in a million with higher concentrations. The USEPA guidelines are not Federal standards and are not legally enforceable, but can be used to calculate risk factors for individuals based on the levels of contamination and the rates of consumation. The Food and Drug Administration (FDA) action levels for contaminants in fish tissue are legally enforceable, in that the FDA can at their discretion take action to remove fish from Interstate commerce. FDA action levels are substantially higher than the USEPA fish tissue guidelines because FDA action levels consider both health risks to consumers and the economics of banning a foodstuff from a specific source (Nowell and Resek, 1994). The FDA action levels for PCBs and chlordane are used as the basis for fish advisories in Connecticut and Massachusetts. Use of the FDA action level for PCBs is currently under review in Connecticut (Gary Ginsburg, Connecticut Department of Public Health, written commun., 1996). Massachusetts uses one-half the FDA action level for PCBs as the basis for advisories for the consumption of fish by children younger than 12 years, pregnant women, and nursing mothers.

Because the USEPA and FDA values apply only to the edible portions of fish, they are not directly comparable to the results of this study. The National Academy of Science/National Academy of Engineering's (NAS/NAE) recommended guidelines for protection of fish-eating wildlife do apply to whole fish tissue, and consequently can be directly compared to the results of this study. These guidelines are based on experimental studies showing induction of eggshell thinning in birds by DDT and metabolites. More conservative guidelines for other organochlorines were set by analogy to DDT, based on their greater toxicity to wildlife.

Purpose and Scope

This paper describes the occurrence and distribution of three classes of organochlorine compounds—DDT, chlorddane, and PCBs—that were detected most frequently and in highest concentration in samples of whole fish tissue collected from sites in the Connecticut, Housatonic, and Thames River Basins study unit. The specific objective of this study was to determine the occurrence and distribution of these organochlorines in fish tissue along a latitudinal (north–south) gradient in the study area. The findings were compared among sites categorized by drainage-basin characteristics to determine if relations exist that explain the distributions and concentrations of organochlorines. A further comparison of the findings was made with selected previous studies within the area to assess any apparent trends through time.

To achieve comparability among sites in a study area, as well as among study areas across the Nation, a National target taxa list was developed for the NAWQA program that includes species of fish, mollusks, aquatic insects, and vascular plants that bioaccumulate contaminants (Crawford and Luoma, 1993). A field reconnaissance of rivers in the study area during the summer of 1992 showed that the sucker (*Catostomus* sp.)—a priority taxon from the National target taxa list—was prevalent throughout the region. Consequently, the sucker was selected as the organism for assessments of contaminants in tissue for this study area.

Selection of Sampling Sites

Sampling sites were selected on the basis of drainage-basin areas, land use, and spatial distribution throughout the study area. The distribution of sites was concentrated in the southern part of the study area, where the water quality is most affected by human activity (Zimmerman and others, 1996). Several sites were selected along a downstream gradient on large rivers of the study area to determine if contaminant concentrations changed as the rivers flowed through more densely populated areas. Using these criteria, 32 sites were selected for this study (fig. 1). These sites were in four major hydrologic river basins that comprise the study area: Thames River Basin, Connecticut River Basin, Housatonic River Basin, and Long Island Sound Coastal (LISC) Rivers Basin (table 2). Fish samples were collected during low-flow conditions in early autumn of 1992 and the summers of 1993 and 1994. Olsson and others (1978) found that concentrations peaked in the springtime in a study that monitored seasonal variation of PCB concentrations in fish, and concluded that an aquatic ecosystem should be monitored when it is most stable and not during the reproductive period of the species. Therefore, the sampling periods were selected so as not to interfere with the spring spawning periods of the fish.

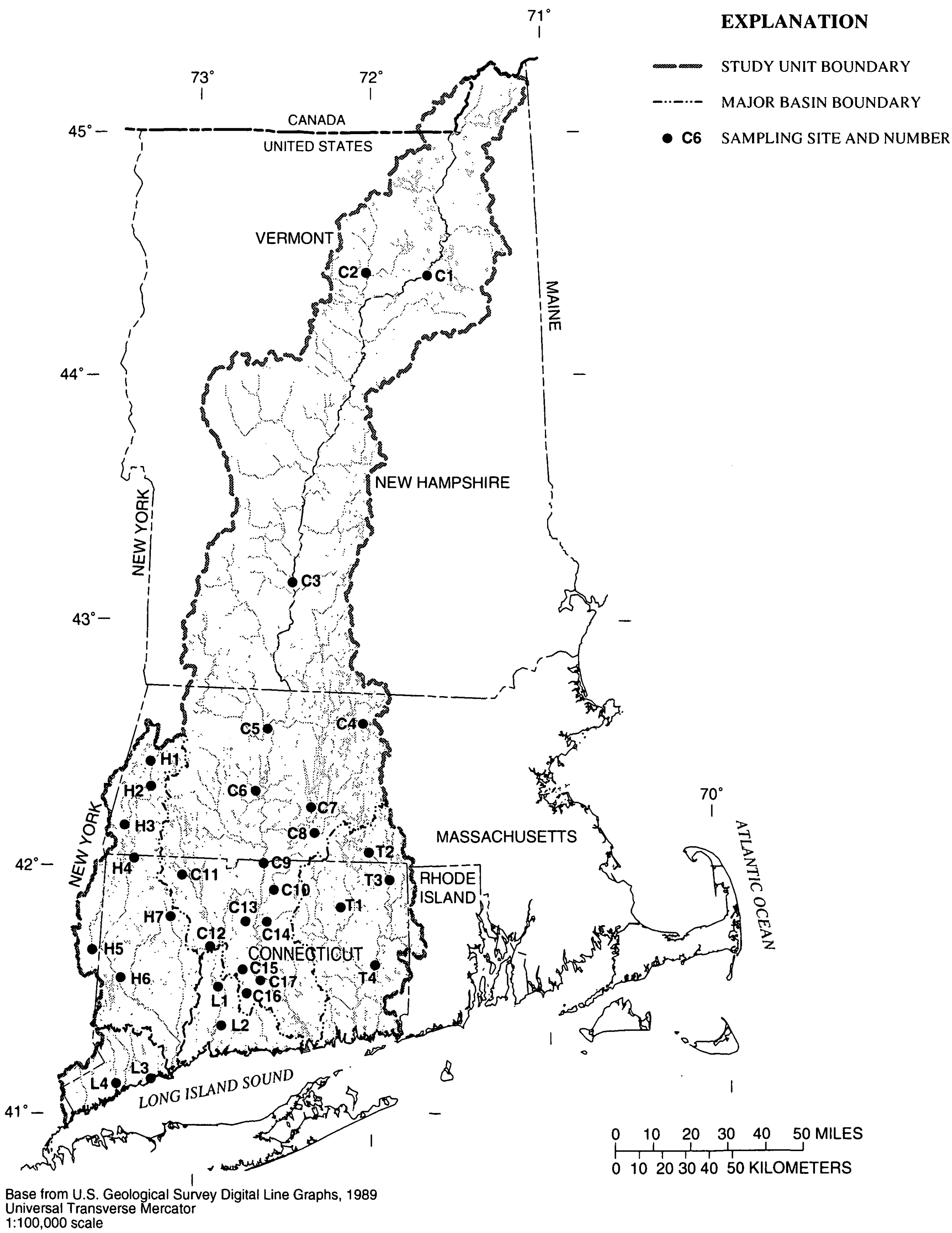

Figure 1. Sampling sites where fish were collected for contaminants analyses in tissue, Connecticut, Housatonic, and Thames River Basins NAWQA study unit.

Results of Previous Study

Coles (1996) reported the organochlorine compound and trace-element concentrations in fish tissue collected from the 32 sites in the study area. Of 28 organochlorine compounds assayed in fish tissue, three classes of compounds based on congener groupings were predominant in terms of occurrence, frequency, and concentration (table 3). DDT-related compounds were detected at 31 sites and included *o,p'*- and *p,p'*-homologs of DDT, DDE, and DDD. Chlordane-related compounds were detected at 25 sites and included *cis*- and *trans*-chlordane, *cis*- and *trans*-nonachlor, oxychlordane, and heptachlor epoxide. Total polychlorinated biphenyls (PCBs) were detected at 28 sites and included Aroclors 1242, 1254, and 1260. On the basis of these findings, this paper addresses these three predominant classes of organochlorines as total DDT, total chlordane, and total PCBs.

Table 2. Sites where fish samples were collected for organochlorine compound analysis in the Connecticut, Housatonic, and Thames River Basins study unit, 1992–94

Site No.	Site name and location	Date sampled
	Thames River Basin	
T-1	Mount Hope River near Warrenville, Ct.	8-03-94
T-2	Quinebaug River at Sandersdale, Mass.	8-08-94
T-3	French River at North Grosvenordale, Ct.	8-04-94
T-4	Quinebaug River at Clayville, Ct.	7-20-93
	Connecticut River Basin	
C-1	Connecticut River near Lancaster, N.H.	7-22-93
C-2	Sleepers River near St. Johnsbury, Vt.	8-05-93
C-3	Connecticut River at South Charlestown, N.H.	7-16-93
C-4	Otter River at Otter River, Mass.	8-01-94
C-5	Connecticut River at Montague City, Mass.	7-15-93
C-6	Mill River at Northampton, Mass.	8-15-94
C-7	Swift River at West Ware, Mass.	8-02-94
C-8	Quaboag River at Palmer, Mass.	8-02-94
C-9	Connecticut River near Longmeadow, Mass.	7-14-93
C-10	Broad Brook at Broad Brook, Ct.	10-23-92
C-11	Still River at Nelsons Corner, Ct.	8-17-94
C-12	Pequabuck River at Forestville, Ct.	11-17-92
C-13	North Branch Park River at Hartford, Ct.	8-11-94
C-14	Hockanum River near East Hartford, Ct.	10-22-92
C-15	Mattabesset River at Little River, Ct.	8-10-94
C-16	Coginchaug River at Middlefield, Ct.	8-10-94
C-17	Connecticut River near Portland, Ct.	7-13-93
	Housatonic River Basin	
H-1	East Branch Housatonic River at Pittsfield, Mass.	8-16-94
H-2	Housatonic River (Woods Pond) at Lenox, Mass.	9-13-94
H-3	Green River at Great Barrington, Mass.	8-16-94
H-4	Konkapot River at Ashley Falls, Mass.	8-17-94
H-5	Tenmile River near Gaylordsville, Ct.	10-20-92
H-6	Housatonic River near Town Hill, Ct.	7-21-93
H-7	West Branch Naugatuck River at Torrington, Ct.	8-17-94
	Long Island Sound Coastal Rivers Basin	
L-1	Quinnipiac River at Stillmans Corner, Ct.	8-09-94
L-2	Muddy River near North Haven, Ct.	8-09-94
L-3	Rooster River near Fairfield, Ct.	6-29-93
L-4	Norwalk River at Winnipauk, Ct.	10-20-92

Table 3. Summary of organochlorine compounds assayed in whole fish samples from the 32 sites in the Connecticut, Housatonic, and Thames River Basins study unit, 1992–94

[Concentrations are in micrograms per kilogram, wet weight]

Organochlorine compound	Sites with detects	Reporting limit	Maximum	Median
DDT, total				
o,p'-DDD	7	5.0	9.8	< 5.0
p,p'-DDD	23	5.0	100	15
o,p'-DDE	4	5.0	8.4	< 5.0
p,p'-DDE	31	5.0	250	51.5
o,p'-DDT	2	5.0	18	< 5.0
p,p'-DDT	21	5.0	33	8.0
Chlordane, total				
cis-Chlordane	21	5.0	150	8.0
trans-Chlordane	11	5.0	40	< 5.0
cis-Nonachlor	12	5.0	37	< 5.0
trans-Nonachlor	25	5.0	120	13.5
Oxychlordane	12	5.0	22	< 5.0
Heptachlor epoxide	1	5.0	24	< 5.0
Total PCBs	28	50	72,000	220
Aldrin	0	5.0	< 5.0	< 5.0
alpha-BHC	0	5.0	< 5.0	< 5.0
beta-BHC	0	5.0	< 5.0	< 5.0
delta-BHC	0	5.0	< 5.0	< 5.0
DCPA (Dacthal)	0	5.0	< 5.0	< 5.0
Dieldrin	13	5.0	140	< 5.0
Endrin	0	5.0	< 5.0	< 5.0
Heptachlor	0	5.0	< 5.0	< 5.0
Hexachlorobenzene	2	5.0	15	< 5.0
Lindane	0	5.0	< 5.0	< 5.0
o,p'-Methoxychlor	0	5.0	< 5.0	< 5.0
p,p'-Methoxychlor	0	5.0	< 5.0	< 5.0
Mirex	0	5.0	< 5.0	< 5.0
Pentachloroanisole	7	5.0	24	< 5.0
Toxaphene	0	200	< 200	< 200

DATA COLLECTION AND ANALYSIS

Sample Collection and Processing

Fish were collected at each site by electroshocking with a backpack unit at wadable sites, and with an electrofishing boat at the impounded sites on the large rivers. Mature individuals were selected for analyses because these fish would have had a long exposure period for contaminant bioaccumulation. The white sucker (*Catastomus commersoni*) was collected at 31 sites, and the longnose sucker (*Catostomus catostomus*) was collected at one site, the Sleepers River near St. Johnsbury, Vt. (table 2, site C-2). The white sucker was not found at the Sleepers River, but the longnose sucker was deemed an appropriate alternative.

Fish were processed in the field for laboratory analysis following the NAWQA guidelines (Crawford and Luoma, 1993). The length, weight, and gender of each fish was recorded. Age was determined from the left pectoral fin ray, using the method of Deelder and Willemse (1973). Fish tissue samples consisted of a composite of five to eight whole individuals that were wrapped in aluminium foil, packed on dry ice, and shipped to the laboratory for analyses. Samples were analyzed for 28 individual organochlorine compounds by dual column gas chromatography with electron capture detection at the USGS National Water-Quality Laboratory (NWQL) in Arvada, Colo. The method used by the NWQL for analysis of organochlorines in aquatic tissues, and the associated method performance and quality control evaluations, are described in Leiker and others (1995).

Site Characterization

Land-use data for the drainage basin of each site were obtained from the USGS Geographical Information Retrieval and Analysis System (Mitchell and others, 1977), which had been updated by Hitt (1994) to include areas of recent urban/suburban development using 1990 United States census data. The data retrieval was based on land-use characteristics used in the Level II Land Use and Land Cover Classification System from Anderson and others (1976). Site characteristics derived were drainage-basin area, drainage-basin population, population density (people per square kilometer), and percentage of land-use type (agriculture, urban, and forest) in the drainage basin (table 4). Drainage-basin area was used as a surrogate for river magnitude at a site, and drainage-basin population density was used as a surrogate for the extent of drainage-basin development. Population density and percentage of urban land use in a drainage basin were highly correlated, as determined by linear regression ($R^2 = 0.923$, $t\text{-ratio}_{slope} = 19.0$, $p < 0.001$). Conversely, population density was negatively correlated to forest land use ($R^2 = 0.731$, $t\text{-ratio}_{slope} = -9.027$, $p < 0.001$), but not to agriculture land use ($R^2 = 0.031$, $t\text{-ratio}_{slope} = -0.972$, $p = 0.339$).

Three methods were used to categorically group sites on the basis of drainage-basin characteristics so that organochlorine concentrations could be compared among the categories. The first method categorized sites by the major basin in which the site was located: Thames River Basin, Connecticut River Basin, Housatonic River Basin, and LISC Rivers Basin (table 2). The second method categorized sites by drainage basin population density on the basis of the number of people per square kilometer in the drainage basin—low (less than 50), medium (50 to 200), and high (greater than 200) (table 4). Furthermore, the medium population density sites generally represented a greater mixture of land uses than sites in the other categories. The third method categorized sites by drainage-basin size on the basis of drainage-basin area in square kilometers—small (less than 100), medium (100 to 1,000), and large (greater than 1,000) (table 4). Small- and medium-size drainage-basin sites were wadable, except site H-2 (Housatonic River at Lenox, Mass.), which was an impounded site. Large drainage-basin sites were on impoundments, except C-17 (Connecticut River near Portland, Ct.), which was in the tidally influenced part of the Connecticut River.

Data Analysis

The relation between the percentage of agricultural land use in the drainage basin of a sampling site and the concentrations of total DDT and total chlordane in fish tissues at the site was tested by linear regression analysis. For each organochlorine group (total DDT, total chlordane, total PCBs), a three-factor ANOVA was used to simultaneously test for categorical differences in concentrations among sites characterized by major basins (Thames, Housatonic, Connecticut, LISC), by drainage-basin population

Table 4. Drainage-basin characteristics of the sites where fish samples were collected for organochlorine compound analysis in the Connecticut, Housatonic, and Thames River Basins study unit, 1992–94

[Drainage-basin size categories were determined by small, less than 100 km^2; medium, 100 to 1,000 km^2; large, greater than 1,000 km^2. Drainage-basin population density units are people per square kilometer. Population density categories were determined by low, less than 50 people per km^2; medium, 50 to 200 people per km^2; high, greater than 200 people per km^2. Agriculture, urban, and forest are percentages of the drainage-basin area. km^2, square kilometer]

Site No.	Drainage-basin area (km^2)	Drainage-basin size category	Drainage-basin population	Drainage-basin population density	Population density category	Percentage of land-use type		
						Agriculture	Urban	Forest
T-1	70.2	Small	3,096	44.1	Low	11.5	2.6	83.5
T-2	316	Medium	34,468	109	Medium	7.4	11.4	70.9
T-3	262	Medium	49,732	190	Medium	5.2	17.4	68.8
T-4	1667	Large	160,936	96.5	Medium	11.7	8.6	73.0
C-1	3,924	Large	21,908	5.58	Low	5.5	.5	82.2
C-2	111	Medium	1,168	10.5	Low	27.8	.2	72.0
C-3	13,722	Large	209,434	15.3	Low	11.4	1.8	82.0
C-4	88.4	Small	18,967	215	High	3.3	21.7	65.5
C-5	20,390	Large	421,273	20.7	Low	10.3	2.6	82.7
C-6	139.8	Medium	11,502	82.3	Medium	8.9	11.9	77.0
C-7	490	Medium	4,367	8.91	Low	2.6	0.8	72.9
C-8	537	Medium	40,162	74.8	Medium	16.8	8.5	66.6
C-9	24,992	Large	1,072,943	42.9	Low	10.6	4.8	79.6
C-10	38.1	Small	6,618	174	Medium	54.9	8.0	32.3
C-11	116.2	Medium	11,404	98.1	Medium	6.1	10.0	79.0
C-12	116.4	Medium	54,161	465	High	6.6	42.6	48.4
C-13	68.9	Small	32,371	470	High	22.5	48.2	25.6
C-14	190.7	Medium	97,365	511	High	11.0	51.3	35.2
C-15	147.2	Medium	66,798	454	High	24.3	37.6	35.6
C-16	77.8	Small	8,020	103	Medium	37.7	7.1	54.2
C-17	28,215	Large	2,023,710	71.7	Medium	11.3	7.4	76.4
H-1	181.2	Medium	26,388	146	Medium	7.6	18.5	66.1
H-2	436.2	Medium	62,674	144	Medium	10.3	19.1	64.3
H-3	132.2	Medium	2,704	20.4	Low	20.9	4.3	72.7
H-4	157	Medium	2,988	19.0	Low	12.9	3.0	80.6
H-5	518	Medium	19,348	37.4	Low	41.8	3.1	53.1
H-6	2,902	Large	164,578	56.7	Medium	19.4	8.2	67.8
H-7	142.2	Medium	28,796	202	High	10.8	15.2	71.0
L-1	148.3	Medium	65,840	444	High	10.1	46.1	41.2
L-2	43.0	Small	8,929	208	High	38.1	15.2	43.2
L-3	21.0	Small	25,325	1,200	High	.0	97.4	1.4
L-4	85.1	Small	21,734	255	High	4.2	50.4	44.3

density (low, medium, high), and by drainage-basin size (small, medium, large). Organochlorine concentrations were log transformed to their natural logarithm for the ANOVA computations. The level of significance (α) was set at 0.05, meaning that organochlorine concentrations among categories were considered significantly different when the probability value was less than 0.05. Total DDT concentration in fish tissue was defined as the sum of *o,p*'- and *p,p*'-homologs of DDT, DDE, and DDD. At sites C-10, C-14, and L-4, co-elution interference during laboratory analysis of the samples prevented determination of *p,p*'-DDD. Consequently, *p,p*'-DDD was not included as a component of total DDT at these sites. Total chlordane concentration was defined as the sum of *cis*- and *trans*-chlordane, *cis*- and *trans*-nonachlor, oxychlordane, and heptachlor epoxide. In adding the respective component concentrations to provide total DDT and total chlordane, concentrations less than the method reporting limit (typically 5.0 μg/kg) were assigned a value of 0. Total PCB concentrations included Aroclors 1242, 1254, and 1260 and were reported only as total PCBs from the NWQL. For computations used in this study, total PCB concentrations were assigned a value of 0 at sites where concentrations were less than the reporting limit of 50 μg/kg.

The range and median concentrations of total DDT, total chlordane, and total PCBs (actual concentrations instead of log transformed) were determined for each category of sites characterized by major basin, drainage-basin population density, and drainage-basin size. Bar charts were used to show concentrations of total DDT, total chlordane, and total PCBs among sites. For total DDT and total chlordane, the bar representing total concentration at each site was segmented to show the relative concentrations of the individual constituents. Box and whisker plots were used to show the ranges of total DDT, total chlordane, and total PCBs concentrations among the sites categorized by drainage-basin population density. Box and whisker plots also were used to show ranges of total PCBs concentrations among the sites categorized by drainage-basin size, because sources of PCBs are commonly along larger rivers. A log scale (base 10) was used with the plots and charts showing total PCB concentrations because concentrations varied by four orders of magnitude. Zero concentrations were incorporated on the log scale by converting concentrations to total PCBs plus 1 μg/kg.

ORGANOCHLORINE COMPOUNDS IN FISH TISSUE

Concentrations of total DDT, total chlordane, and total PCB detected in fish tissue samples from the Connecticut, Housatonic, and Thames River Basins study unit are reported in micrograms per kilogram, wet weight (table 5). The number of fish in the composite samples ranged from 5 to 8 whole fish, and the lipid portion of the samples ranged from 2.4 to 12.3 percent. The average length of white suckers in each composite sample ranged from 22.5 to 49.7 cm and the average weight ranged from 128 to 1,381 g. The longnose suckers collected at the Sleepers River near St. Johnsbury, Vt. (site C-2) were smaller than the white suckers, with an average length of 18.4 cm and an average weight of 66.4 g. The average age of white suckers in each composite sample ranged from 7.5 to 22 years and the average age of the longnose suckers was 9.2 years.

Total DDT

Total DDT concentrations in fish tissue were not correlated with agricultural land use ($R^2 = 0.006$) in the study unit, although DDT was used in the past as an agricultural insecticide. The detection of total DDT at the more remote sites in the study area indicates that widespread distribution was probably due to atmospheric transport from areas of application. Furthermore, the results of the ANOVA indicated that there was no statistical difference ($p = 0.999$) in the ranges of total DDT concentrations at sites among the major basins (Thames, Housatonic, Connecticut, LISC) (table 6). Of the total DDT components, *p,p*'-homologs were detected more frequently and in higher concentrations than *o,p*'-homologs (table 3, fig. 2). Technical grade DDT contains about 80 percent *p,p*'-DDT and 15 to 20 percent *o,p*'-DDT, and the degradation products are homolog specific DDD and DDE. At most sites, the *p,p*'-DDE component accounted for most of the total DDT concentration. Schmitt and others (1990) reported that *p,p*'-DDE was detected in fish samples collected from 110 of 112 stations in major rivers throughout the United States and the Great Lakes during 1984. Furthermore,

Table 5. Concentrations of organochlorine compounds (DDT, chlordane, and PCBs) in composited whole fish samples and data associated with the fish in the Connecticut, Housatonic, and Thames River Basins study unit, 1992–94

[Concentrations are in micrograms per kilogram, wet weight. nd, concentrations less than reporting limits. cm, centimeter; g, gram]

Site No.	Number of fish in sample	Average length (cm)	Average weight (g)	Average age (years)	DDT, total	Chlordane, total	PCB, total	Lipid (percent)
T-1	8	31.6	350	13.6	14	nd	nd	6
T-2	5	35.9	482	15.8	210	27	1,000	5.9
T-3	6	44.6	910	19.3	300	24	240	8.2
T-4	8	42.3	750	19.4	69	5	670	6.7
C-1	8	33.5	367	15.4	16	nd	nd	4.1
C-2	8	18.4	66.4	9.2	nd	nd	nd	8.1
C-3	8	49.7	1,381	22.0	80	14	690	10
C-4	5	35.5	507	17.0	63	13	580	6.6
C-5	8	44.8	1015	20.0	140	14	820	12.3
C-6	8	36.6	455	16.9	170	130	190	3.6
C-7	8	42.2	953	18.8	110	12	170	9
C-8	5	39.4	638	18.6	70	15	160	6.1
C-9	8	43.3	901	17.6	260	63	1,400	10.9
C-10	8	24.5	157	7.8	180	67	93	4.1
C-11	8	28.7	257	12.1	40	17	150	4.9
C-12	8	37.2	563	13.8	33	65	160	5.1
C-13	8	30.7	308	13.5	190	130	140	4.8
C-14	8	28.6	236	11.6	58	46	440	2.4
C-15	8	40.9	706	17.6	120	76	1,100	5.8
C-16	8	37.8	611	14.8	88	9.1	nd	9
C-17	8	43.1	821	16.5	160	64	940	8.4
H-1	8	30.8	294	13.4	78	21	55,000	2.8
H-2	8	36.7	485	19.1	260	nd	72,000	2.5
H-3	8	38.0	608	15.9	23	nd	620	5.7
H-4	8	31.9	345	12.8	17	nd	50	6.3
H-5	8	32.1	396	11.1	16	nd	170	4.5
H-6	8	40.2	830	16.6	190	26	12,000	10.5
H-7	8	22.5	128	7.5	29	67	93	4.8
L-1	5	40.8	718	17.8	56	59	1,400	5.9
L-2	8	41.3	712	17.9	240	81	200	4.7
L-3	8	28.7	298	12.0	98	390	200	9.1
L-4	8	28.5	251	8.9	29	33	260	4.1

p,p'-DDE accounted for 73 percent of the total DDT in those samples. Because DDE is an extremely stable metabolite of DDT (U.S. Environmental Protection Agency, 1992), a high percentage of DDE has been interpreted to mean that DDT contamination in an aquatic system has not been recent. (Aguilar, 1984). However, this view has recently been scrutinized by Foreman and Gates (1997) who have shown that *p,p*'-DDT may partially degrade to *p,p*'-DDE during gas-chromatographic analysis.

Table 6. Analysis of variance (ANOVA) statistics from tests for categorical differences in organochlorine concentrations among sites characterized by major basins, drainage-basin population density, and drainage-basin size in the Connecticut, Houstatonic, and Thames River Basins study unit, 1992–94

[Log transformed organochlorine values (natural logarithms) were used for the ANOVA computations. LISC, Long Island Sound Coastal; n, number of sites in category; *df*, degrees of freedom,; F-ratio, the categorical mean square divided by the error mean square; *p*-value, probability that organochlorine concentrations were not different among the categories. Values in **bold** are considered significantly different at the 0.05 level of significance; <, less than the associated value]

Source of variance	*df*	Total DDT				Total chlordane				Total PCBs			
		Sum of squares	Mean square	F-ratio	*p*-value	Sum of squares	Mean square	F-ratio	*p*-value	Sum of squares	Mean square	F-ratio	*p*-value
Major Basin	3	0.025	0.008	0.007	0.999	8.454	2.818	1.971	0.145	36.033	12.011	2.568	0.078
Thames (n=4)													
Housatonic (n=7)													
Connecticut (n=17)													
LISC (n=4)													
Population Density	2	12.831	6.416	5.505	**.011**	32.327	16.163	11.304	**<.001**	50.146	25.073	5.360	**.012**
low (n=10)													
medium (n=12)													
high (n=10)													
Drainage-Basin Size	2	3.588	1.794	1.539	.235	3.073	1.536	1.074	.357	38.529	19.264	4.118	**.029**
small (n=8)													
medium (n=17)													
large (n=7)													
Error	24	27.971	1.165	--	--	34.316	1.430	--	--	112.271	4.678	--	--

The NAS/NAE recommended guideline of 1,000 µg/kg of total DDT for the protection of fish-eating wildlife was not exceeded at any site in the study unit. Ranges of total DDT concentrations were similar in magnitude among the four major basins, where minimum concentrations were less than 30 µg/kg and maximum concentrations ranged from 240 to 300 µg/kg (table 7, fig. 2). Concentrations were less than 30 µg/kg at seven sites, six of these having low population density drainage basins: T-1 (14 µg/kg), C-1 (16 µg/kg), C-2 (nd), H-3 (23 µg/kg), H-4 (17 µg/kg), and H-5 (16 µg/kg) (table 5). All sites in the LISC Basin were densely populated, although the concentration at site L-4 was low (29 µg/kg). This relatively low concentration for a densely populated drainage basin could be related to the drainage basin of the site, which is characterized by small ponds and wetland areas that could effectively restrict transport of organochlorines sorbed to sediment particles. The Connecticut River mainstem sites (C-1, C-3, C-5, C-9, C-17), whose drainage-basin population densities increase progressively to about 10-fold, showed a downstream trend of increasing total DDT concentrations from 0 (nd) to 260 µg/kg at site C-9 (highest of the Connecticut River Basin sites). Downstream at site C-17, the concentration decreased to 160 µg/kg.

The results of the ANOVA indicated that there was a significant difference in total DDT concentrations among the low, medium, and high population density categories for the site drainage basins (table 6). Concentrations were lowest in the low density category (median = 20.0) and highest in the medium density category (median = 165) (table 7, fig. 3). The concentration of 260 µg/kg at site C-9 was a high outlier in the low density category and the highest of all concentrations at sites in the Connecticut River Basin. Site C-9 is a Connecticut River mainstem site that effectively integrates the entire drainage basin north of the Massachusetts-Connecticut border. Although categorized as a low population density drainage basin because of its large area, the drainage basin of site C-9 contained more than 1 million people (table 4). Between the upstream sites C-5 and C-9—the area that includes the urban areas of central Massachusetts—the drainage-basin size increased 23 percent while the population density increased 154 percent. Thus, use of DDT probably was concentrated in the densely populated lower part of the Connecticut River drainage basin at site C-9, leading to the high concentration of total DDT in fish tissue at the site.

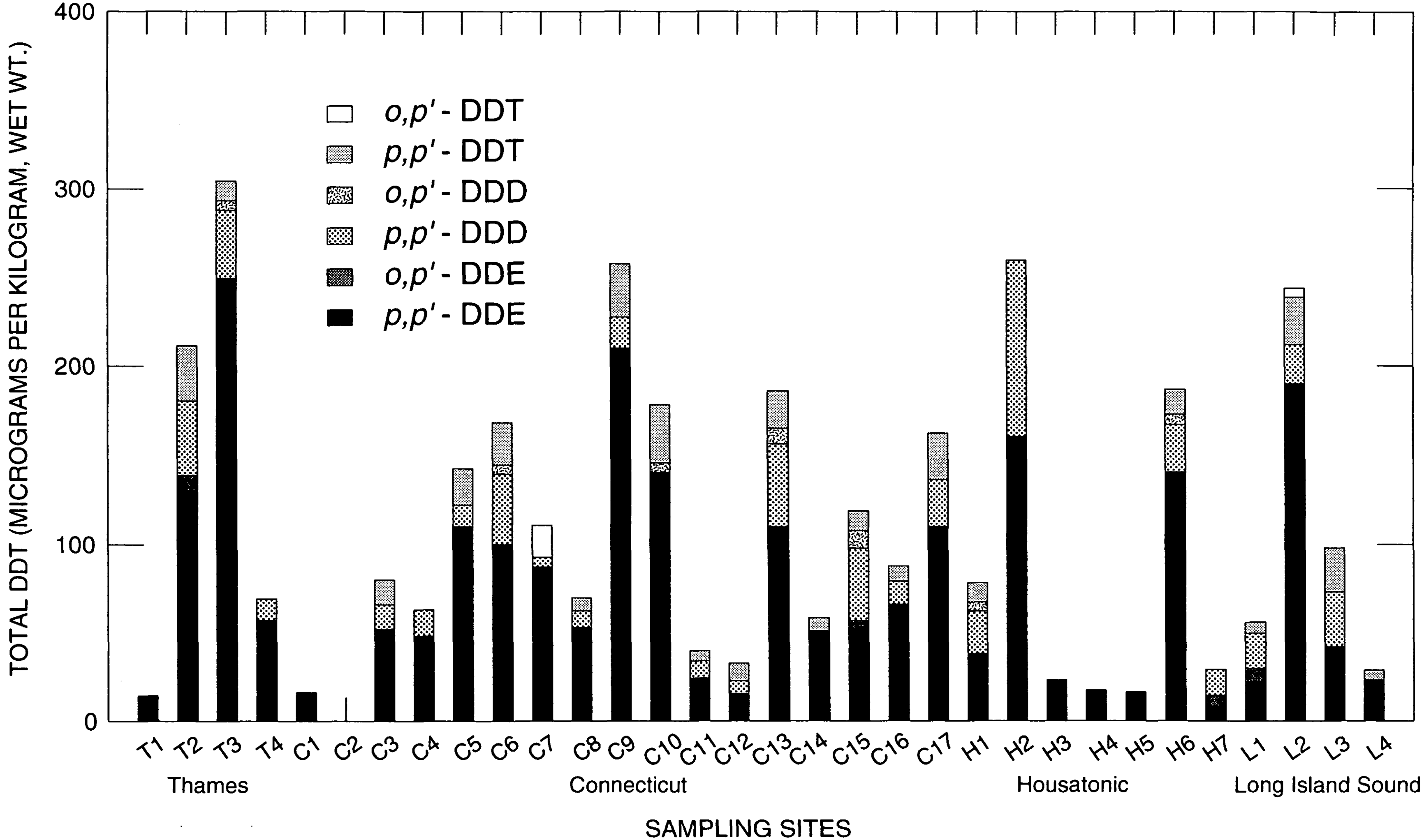

Figure 2. Concentrations of DDT and related compounds in fish tissue collected at sites in the Connecticut, Housatonic, and Thames River Basins study unit.

Table 7. Range and median for concentrations of total DDT, total chlordane, and total PCBs for site characterization categories in the Connecticut, Housatonic, and Thames River Basins study unit, 1992–94

[Concentrations are in micrograms per kilogram, wet weight. Population density is people per square kilometer. Drainage-basin size is square kilometers. ( )*, indicates that concentrations were 1.5 to 3.0 times the interquartile range; ( )°, indicates that concentrations were more than 3 times the interquartile range. LISC, Long Island Sound Coastal. <, actual value is less than value shown; >, actual value is greater than value shown]

Site drainage-basin characterization category	Number of sites in category	DDT, total			Chlordane, total			PCBs, total		
		Minimum	Maximum	Median	Minimum	Maximum	Median	Minimum	Maximum	Median
Major Basin										
Thames River	4	14	300	140	0	27	14.5	0	1,000	455
Connecticut River	17	0	260	86.6	0	130	16.5	0	1,400	170
Housatonic River	7	16	260	29.1	0	67	0	50	72,000	620
LISC Rivers	4	29	240	77.0	33	390	69.8	200	1,400	230
Population Density										
Low, <50	10	0	(260)*	20.0	0	(63)°	0	0	1,400	170
Medium, 50 to 200	12	40	300	165	0	(130)*	22.7	(0)*	72,000	455
High, >200	10	29	240	60.7	13	(390)°	66.0	93	1,400	230
Drainage-Basin Size										
Small, <100	8	14	240	92.3	0	(390)°	50.2	0	580	170
Medium, 100 to 1,000	17	0	(300)*	58.4	0	130	21.4	(0)*	(72,000)*	190
Large, >1,000	7	16	260	143	0	64	14.0	(0)°	(12,000)°	820

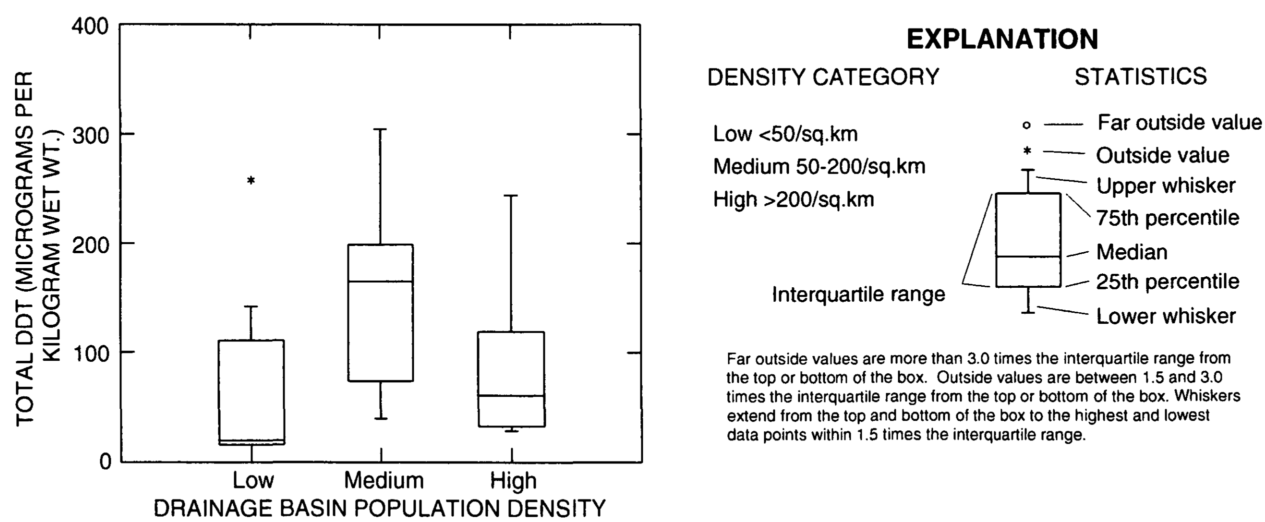

Figure 3. Distribution of total DDT concentrations in the drainage-basin population density categories in the Connecticut, Housatonic, and Thames River Basins study unit.

Total Chlordane

Total chlordane concentrations in fish tissue were not correlated with agricultural land use (R^2 = 0.016) in the study area. Of the individual components comprising total chlordane, *cis*-chlordane and *trans*-nonachlor were detected most frequently and in higher concentrations than the other components (table 3, fig. 4). Nonachlor is the most recalcitrant of the chlordane components and is expected to account for an increasing percentage of total chlordane over time. Results reported from the National Contaminant Biomonitoring Program (NCBP) for 1976–84 showed that *cis*-chlordane was the most abundant chlordane component in fish tissue before 1980, although afterwards, concentrations of *trans*-nonachlor equaled or exceeded those of *cis*-chlordane (Schmitt and others, 1990). Oxychlordane was detected in fish tissue at 12 sites from the current study but accounted for less than 10 percent of total chlordane for all samples.

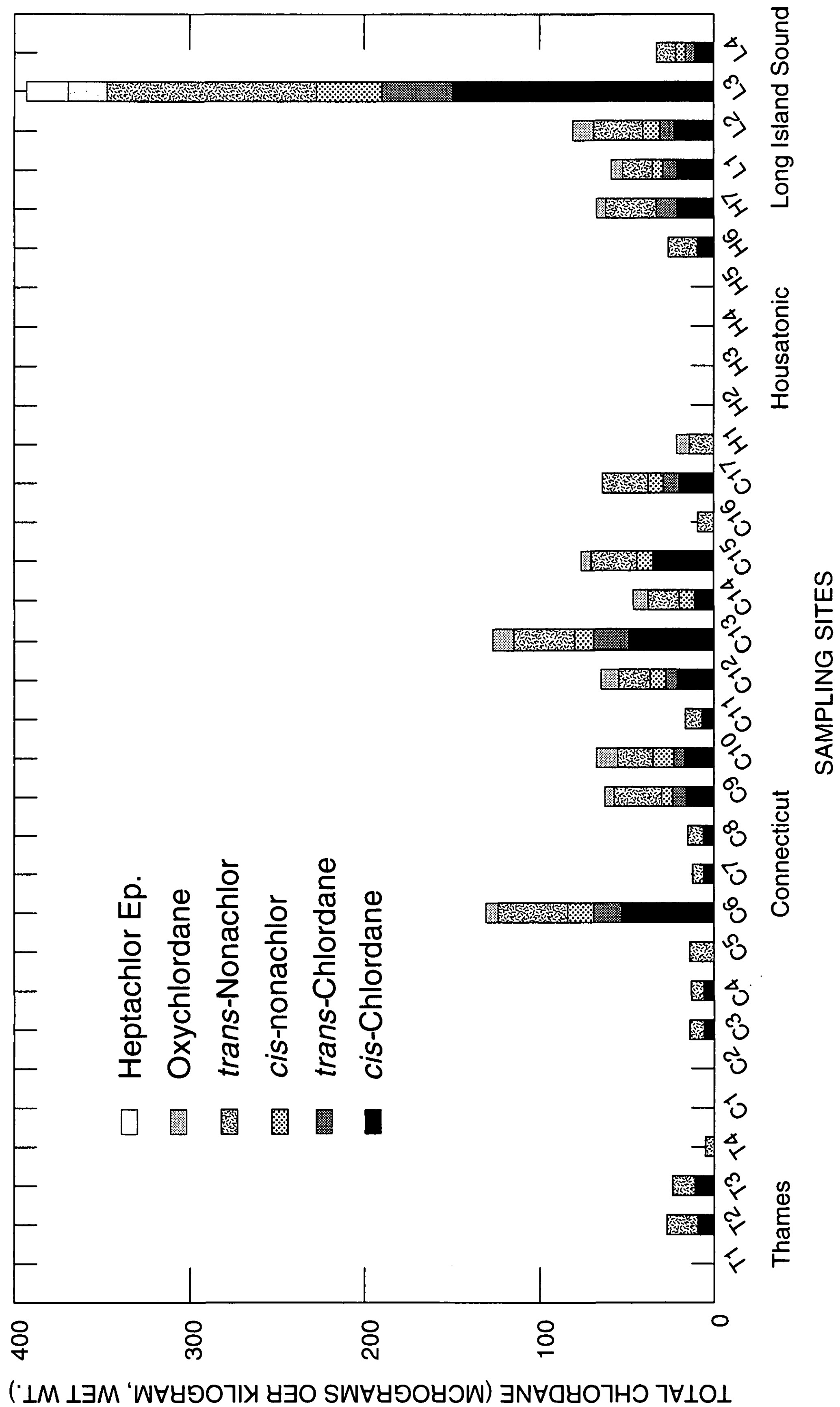

Figure 4. Concentrations of chlordane and related compounds in fish tissue collected at sites in the Connecticut, Housatonic, and Thames River Basins study unit.

Oxychlordane is a direct metabolite of chlordane, and although it has no insecticidal properties, it is more toxic and persistent than the parent compound (World Health Organization, 1984). Heptachlor epoxide was detected only at Rooster River near Fairfield, Ct. (site L-3). Total chlordane concentration was 390 μg/kg at this site (table 5), the highest of all sites in the study area, although heptachlor epoxide only accounted for about 6 percent of this total. Heptachlor epoxide is the metabolite of heptachlor, which itself was marketed as an insecticide in addition to being a component (about 10 percent) of technical chlordane. Although the origin of heptachlor epoxide in the environment is often questionable, studies have reported that the primary source found in tissue samples was likely from heptachlor as a component of chlordane (Schmitt and others, 1985).

Total chlordane concentrations exceeded the NAS/NAE recommended guideline of 100 μg/kg for the protection of fish-eating wildlife at sites C-6 (130 μg/kg), C-13 (130 μg/kg), and L-3 (390 μg/kg) (table 5, fig. 4)[1]. Total chlordane concentrations were not detected at six of the seven sites with low population densities: T-1, C-1, C-2, H-3, H-4, and H-5. Furthermore, these sites corresponded to those sites where total DDT was detected at the lowest concentrations (described above). Total chlordane also was not detected at site H-2, although the total DDT concentration was high. The Connecticut River mainstem sites (C-1, C-3, C-5, C-9, C-17) showed a downstream trend of increasing total chlordane concentrations from 0 (nd) to 64 μg/kg.

The results of the ANOVA indicated that there was a significant difference in total chlordane concentrations among the low, medium, and high population density categories for the site drainage basins (table 6). Total chlordane concentrations among the three categories were lowest in the low density category (median = 0) and highest in the high density category (median = 66.0), indicating that total chlordane increased with population density (table 7, fig. 5). Furthermore, the highest concentration within each category (outliers) increased with population

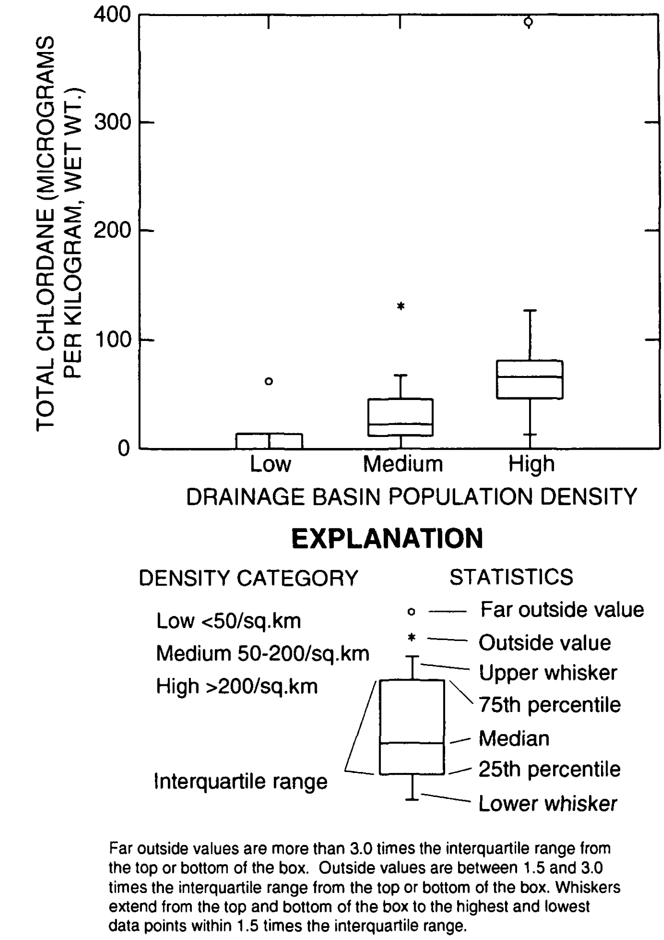

Figure 5. Distribution of total chlordane concentrations in the drainage-basin population density categories in the Connecticut, Housatonic, and Thames River Basins study unit.

density. The highest concentration was at site L-3 (390 μg/kg), which had a population density (1,200 people/km^2) more than twice as high as any other site in the study unit. This relation between chlordane concentration and population density supports the findings of other studies (Arruda and others, 1987; Schmitt and others, 1990; Tate and Heiny, 1996), where chlordane in fish tissue was higher in more urban settings than in other land-use settings.

Total PCBs

PCB contamination has received special attention in the study unit, where manufacturing and commercial uses were likely sources of contamination from industrial areas along rivers. The primary source of PCB contamination in the Housatonic River has been identified as coming from a General Electric

[1] Because the NAS/NAE guideline of 100 μg/kg includes organochlorine compounds other than those related to chlordane (table 1), this concentration would also be exceeded at site L-2 if dieldrin were included as a component. The dieldrin concentration was relatively high at site L-2 (40 μg/kg) and site L-3 (140 μg/kg).

Company (GE) facility at Pittsfield, Mass., which used PCBs in manufacturing electrical transformers (Connecticut Academy of Science and Engineering, 1978). Leakage from electrical transformers also is a source of PCBs in storm drains of large urban areas, as well as from transformers used at electrical power plants. The Connecticut River is typical of a major waterway subject to these sources of PCBs, flowing through several metropolitan areas and having 11 hydroelectric and 2 nuclear power plants along its mainstem.

Total PCBs were the most dominant organochlorine compound detected in fish tissue in the study in terms of the number of sites with relatively high concentrations (table 5, fig. 6). Total PCB concentrations exceeded the combined concentrations of total DDT and total chlordane at 21 sites. Although total PCBs were detected at 28 sites and total DDT was detected at 31 sites, total DDT was detected at 9 sites with concentrations less than the reporting limit for total PCBs (50 µg/kg). Total PCBs concentrations exceeded the NAS/NAE recommended guideline of 500 µg/kg for the protection of fish-eating wildlife at 13 sites: T-2, T-4, C-3, C-4, C-5, C-9, C-15, C-17, H-1, H-2, H-3, H-6, and L-1. Total PCBs were not detected at sites T-1, C-1, C-2, and C-16. These sites had low population density drainage basins except C-16, which had a medium population density drainage basin. The Connecticut River mainstem sites (C-1, C-3, C-5, C-9, C-17) showed a downstream trend of increasing total PCB concentrations from 0 (nd) to 1,400 µg/kg at site C-9, the highest in the Connecticut Basin. The

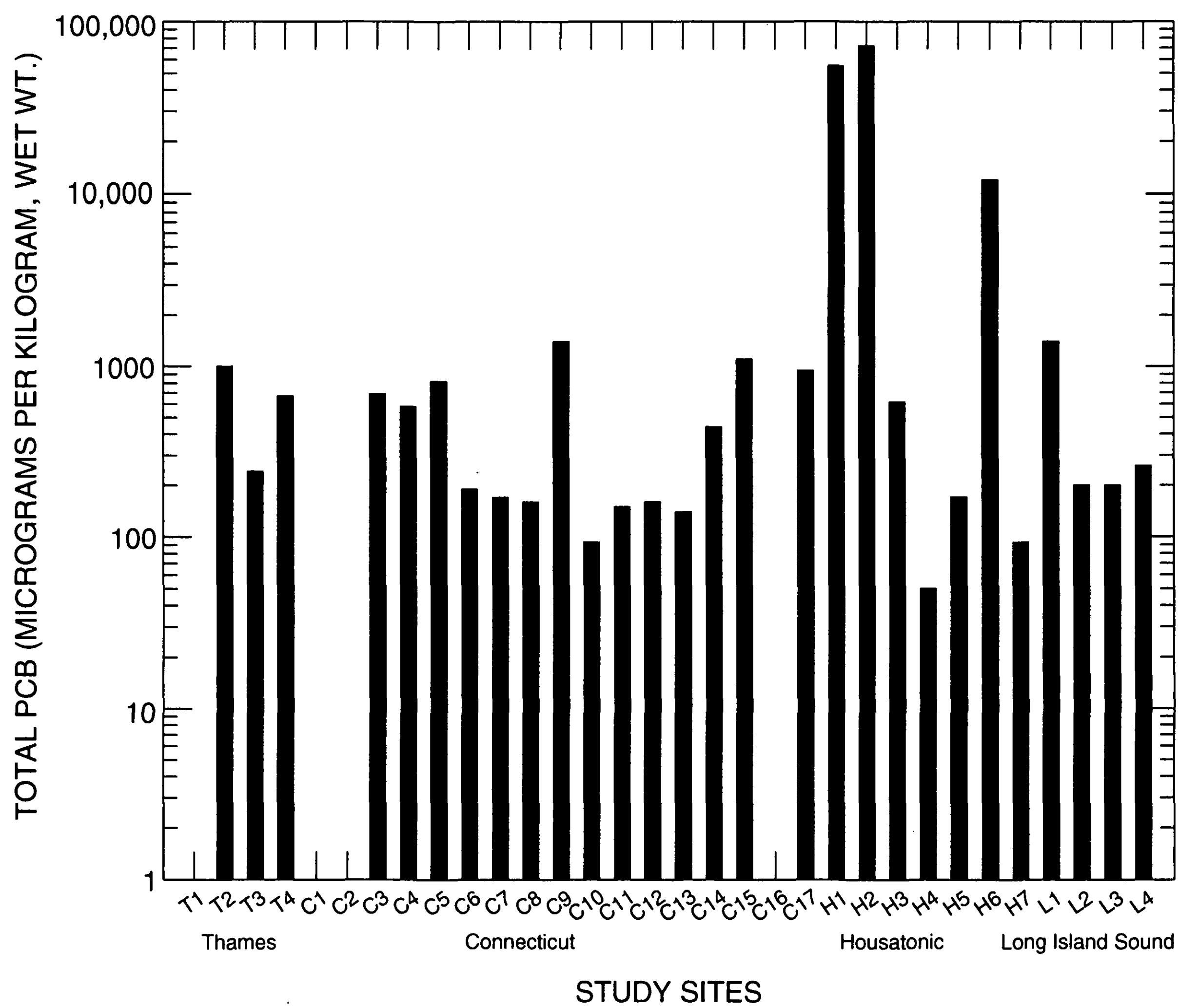

Figure 6. Concentrations of total PCBs in fish tissue collected at sites in the Connecticut, Housatonic, and Thames River Basins study unit.

concentration decreased to 940 µg/kg downstream at site C-17, which was the second highest concentration among the Connecticut River mainstem sites.

The findings at the Housatonic River mainstem sites present a unique case because of the local source of PCBs to that river. Total PCB concentration at site H-1, on the East Branch Housatonic River near the PCB source, was 55,000 µg/kg. The concentration at site H-2, on the first major impoundment (Woods Pond) downstream from site H-1, was 72,000 µg/kg—the highest concentration in the study unit. The concentration site H-6, farther downstream, decreased to 12,000 µg/kg. This trend is similar to the trend seen in the PCB concentrations in sediments collected from the Housatonic River. Harris (1997) reported a PCB concentration of 13,000 µg/kg in Housatonic River sediment collected near the GE facility in 1994. Gay and Frimpter (1985) reported that PCB concentrations were high in Housatonic River sediments between the GE facility and Woods Pond, with the highest concentrations—as much as 110,000 µg/kg—in the sediments behind Woods Pond Dam. Below the dam, PCB concentrations in sediment sharply decreased, but were still as high as 9,600 µg/kg. Results from the current study showed that total PCB concentrations at the Housatonic River tributary sites (H-3, H-4, H-5, H-7) were substantially lower than concentrations at Housatonic River mainstem sites. Although the concentration was relatively high at site H-3 (620 µg/kg), concentrations at the Housatonic tributary sites were in the range of those seen in the Connecticut River tributaries.

The results of the ANOVA indicated that there was significant difference in total PCB concentrations among the low, medium, and high population density categories for the site drainage basins (table 6). Concentrations were lowest in the low density category (median = 170) and highest in the medium density category (median = 455) (table 7, fig. 7). The highest concentrations in the medium density category were from the East Branch and mainstem Housatonic River sites that were contaminated by the source at Pittsfield, Mass. (H-1, H-2, H-6). Because PCBs at these sites came from a local source, their high concentrations are assumed not to be directly related to population density. These high concentrations undoubtedly skew the range of concentrations in the medium density category, but their effect on the median concentration cannot be discerned. Excluding sites H-1, H-2, and H-6 from the medium density category (n = 9) reduces the

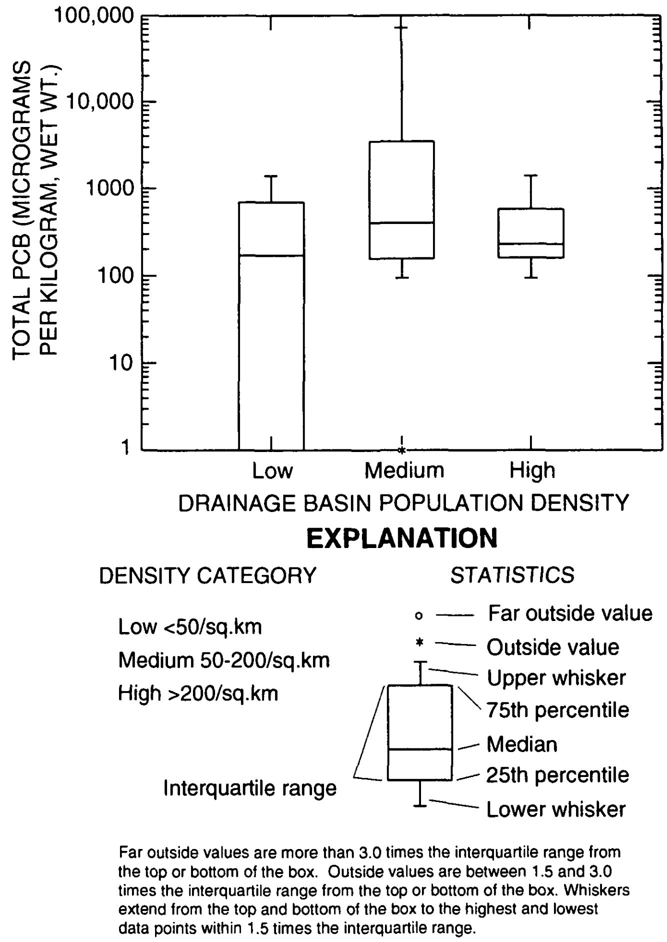

Figure 7. Distribution of total PCB concentrations in the drainage-basin population density categories in the Connecticut, Housatonic, and Thames River Basins study unit.

median from 455 to 190 µg/kg for that category. Under these circumstances, total PCB concentrations would be lowest in the low density category (median = 170) and highest in the high density category (median = 230), indicating a marginally positive correlation between concentrations and population density. Regardless, the low population density category contained three of the four sites where total PCBs were not detected (T-1, C-1, C-2) and the site with the lowest detected concentration (H-4).

In addition to the finding that PCB concentrations may vary significantly with the population density of site drainage basins, the results of the ANOVA also indicated that there was significant difference in total PCB concentrations among the small, medium, and large size categories for the site drainage basins (table 6). Concentrations were lowest in the small drainage-basin category (median = 170) and highest in the large drainage-basin category (median = 820), indicating a positive correlation between concentrations and drainage-basin size (table 7, fig. 8). The highest concentration among sites in the small drainage-basin category was 583 µg/kg (C-4) and this concentration was exceeded at all sites in the large drainage-basin category except one (C-1). Of the 13 sites where total PCB concentrations exceeded the NAS/NAE recommended guideline for the protection of fish-eating wildlife, only one site (C-4) was categorized as a small drainage basin. Conversely, PCBs were not detected at sites C-2 and C-1, which were outliers in the medium and large drainage-basin categories. Because these sites had the least densely populated drainage basin in the study unit, however, their position as outliers supports the conclusion that population density also is a factor in PCB contamination in the study unit.

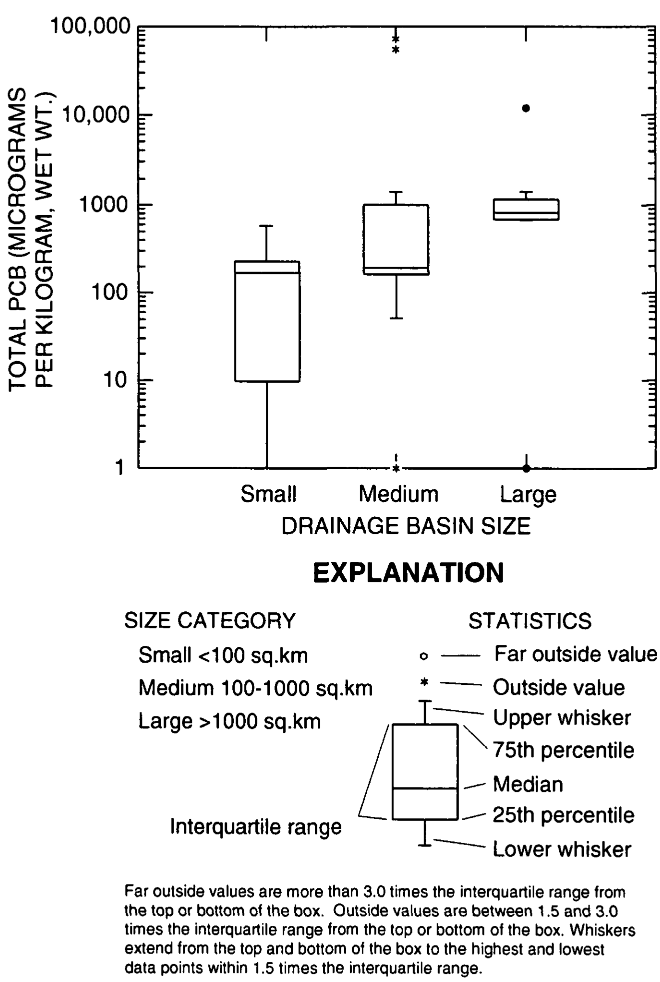

Figure 8. Distribution of total PCB concentrations in the drainage-basin size categories in the Connecticut, Housatonic, and Thames River Basins study unit.

Comparison With Results Other Studies

Several factors need to be considered when comparing results from different studies of organochlorine compounds in fish. The analytical capability of the laboratory processing the samples determines which compounds can be detected, the limits of detection, and the reproducibility of reported concentrations. Furthermore, studies commonly target a particular species of fish and submit tissue portions for analysis that will meet specific study objectives. Fish species may accumulate organochlorines at different rates depending on physiological differences and trophic feeding levels. Studies relating to human health typically use a game species and analyze only the edible portion (fillet). Studies relating to hazards to wildlife may use a non-game species and analyze the whole fish. Whole fish samples usually show higher organochlorine concentrations than the leaner fillets because of the lipophilic nature of organochlorines. Although lipid normalization of samples has been used to account for different lipid fractions by dividing the organochlorine concentration by the lipid fraction, commonly little or no precision has been shown with this adjustment (Schmitt and others, 1990; Hebert and Keenleyside, 1995). With regard to these precautions, results from several other studies were selected to compare with the current study (Schmitt and others, 1981; 1983; 1985; 1990; U.S. Fish and Wildlife Service, 1986; Isaza and Dreisig, 1989; Blasland and Bouck Engineers, P.C., 1991; U.S. Environmental Protection Agency, 1992; Academy of Natural Sciences of Philadelphia, 1995).

Results from the current study were compared with those of other studies on the Connecticut and Housatonic Rivers to determine if the changes in concentrations along those rivers were consistent among studies and if concentrations have changed with time (table 8). Although some of the samples from other studies on the Connecticut River included composited smallmouth bass, the results were consistent with the findings of the current study where organochlorines showed a downstream trend of increasing concentrations. Because the other studies were conducted 7 to 10 years earlier than the current study, a temporal component can be discerned from the results. During this period, concentrations of total DDT and total PCBs did not change notably, but total chlordane concentrations appear to have decreased. This finding possibly can be explained by the fact that chlordane has been in general

Table 8. Selected studies of organochlorine concentrations in fish tissue from the Connecticut and Housatonic Rivers Basins study unit, 1992–94

[Organochlorine concentrations are given in micrograms per kilogram, wet weight. Sites are listed in downstream order. Values from current study are in **bold**. Sample type: C, composite; I, individual; LMB, largemouth bass; SMB, smallmouth bass; WS, white sucker. Values in parentheses represent the number of individual fish analyzed. Concentrations are arithmetic means of these samples. nd, none detected; --, not analyzed]

Site location	Year	Fish species	Sample type	Sample portion	DDT, total	Chlordane, total	PCBs, total	Reference
Connecticut River								
near Lancaster, N.H. (C-1)	**1994**	**WS**	**C**	**Whole**	**16**	**nd**	**nd**	**NAWQA, this study**
at Hanover, N.H.	1986	SMB	C	Whole	80	--	380	Isaza and Dreisig, 1989
at West Lebanon, N.H.	1986	SMB	C	Whole	21	--	300	Isaza and Dreisig, 1989
at Claremont, N.H.	1986	SMB	C	Whole	40	--	260	Isaza and Dreisig, 1989
at South Charlestown, N.H. (C-3)	**1993**	**WS**	**C**	**Whole**	**80**	**14**	**690**	**NAWQA, this study**
at Brattleboro, Vt.	1986	SMB	C	Whole	80	--	580	Isaza and Dreisig, 1989
north of Massachusetts–New Hampshire border	1986	SMB	C	Whole	100	--	800	Isaza and Dreisig, 1989
at Montague City, Mass. (C-5)	**1993**	**WS**	**C**	**Whole**	**140**	**14**	**820**	**NAWQA, this study**
at Holyoke, Mass.	1985	WS	C	Whole	210	70	1,060	USFWS, 1986
at Chicopee, Mass.	1985	WS	C	Whole	200	160	1640	USFWS, 1986
near Longmeadow, Mass. (C-9)	**1993**	**WS**	**C**	**Whole**	**260**	**63**	**1,400**	**NAWQA, this study**
at Enfield, Ct.	1985	WS	C	Whole	160	120	880	USFWS, 1986
near Portland, Ct. (C-17)	**1993**	**WS**	**C**	**Whole**	**160**	**64**	**940**	**NAWQA, this study**
above Middletown, Ct.	1985	WS	C	Whole	140	120	1,160	USFWS, 1986
at Haddam, CTt.	1985	WS	C	Whole	160	150	1,580	USFWS, 1986
Housatonic River								
East Branch, at Pittsfield, Mass. (H-1)	**1994**	**WS**	**C**	**Whole**	**78**	**21**	**55,000**	**NAWQA, this study**
(Woods Pond) at Lenox, Mass.	1982	LMB	C	Fillet	--	--	20,000	Blasland and Bouck, 1991
	1990	LMB	I(8)	Fillet	--	--	10,800	Blasland and Bouck, 1991
(Woods Pond) at Lenox, Mass. (H-2)	**1994**	**WS**	**C**	**Whole**	**260**	**nd**	**72,000**	**NAWQA, this study**
(Rising Pond) at Risingdale, Mass.	1980	LMB	C	Fillet	--	--	7,400	Blasland and Bouck, 1991
	1990	LMB	I(8)	Fillet	--	--	16,000	Blasland and Bouck, 1991
near Cornwall, Ct.	1984	SMB	I(16)	Fillet	--	--	2,400	ANSP, 1995
	1988	SMB	I(13)	Fillet	--	--	4,760	ANSP, 1995
	1994	SMB	I(13)	Fillet	--	--	1,560	ANSP, 1995
near Kent, Ct.	1984	SMB	I(12)	Fillet	--	--	1,910	ANSP, 1995
	1988	SMB	I(14)	Fillet	--	--	2,830	ANSP, 1995
	1994	SMB	I(8)	Fillet	--	--	1,380	ANSP, 1995
near Town Hill, Ct. (H-6)	**1993**	**WS**	**C**	**Whole**	**190**	**26**	**12,000**	**NAWQA, this study**
near Brookfield Center, Ct.	1984	SMB	I(25)	Fillet	--	--	1,180	ANSP, 1995
	1988	SMB	I(25)	Fillet	--	--	1,400	ANSP, 1995
	1994	SMB	I(9)	Fillet	--	--	560	ANSP, 1995
near Lakeside, Ct.	1984	SMB	I(24)	Fillet	--	--	500	ANSP, 1995
	1988	SMB	I(16)	Fillet	--	--	970	ANSP, 1995
	1994	SMB	I(10)	Fillet	--	--	450	ANSP, 1995

use more recently than DDT and PCBs. A decrease in total chlordate would be apparent if its components were undergoing metabolic degradation over the decade that the samples were collected, whereas metabolism of total DDT components would have already stabilized to a larger degree. If this is the case, total chlordane concentrations are expected to show an increasingly smaller change in the future.

Results reported in Blasland and Bouck Engineers, P.C. (1991) for Housatonic River sites in Massachusetts, and in Academy of Natural Sciences of Philadelphia (1995) for Housatonic River sites in Connecticut are not directly comparable to results from the current study because the samples used in the earlier studies were fillet portions from game species. These data, however, show a trend that is consistent with the findings of the current study—the highest total PCB concentrations were at Woods Pond but decreased downstream (table 8). Total PCB concentrations in fish tissue from these studies were lower than those detected in the current study, even though some of the sampling was as recent. A primary reason for this difference can be attributed to the analysis of fillet portions which typically have a lower lipid component. For example, a composite sample of trout fillets collected at Woods Pond in 1982 showed a total PCB concentration of 119,000 μg/kg and a lipid content of 7.9 percent (Blasland and Bouck Engineers, P.C., 1991). This lipid content value was as much as 10 times higher than in the largemouth and smallmouth bass samples used in the other studies but is similar to the lipid content in fish samples collected for the current study (table 5).

Total PCB concentrations in largemouth bass reported in Blasland and Bouck Engineers, P.C. (1991) for the Massachusetts section of the Housatonic River showed that concentrations at Woods Pond decreased from 1982 to 1990, whereas downstream at Rising Pond, concentrations increased from 1980 to 1990 (table 8). Total PCB concentrations in smallmouth bass reported in Academy of Natural Sciences of Philadelphia (1995) for four sites in the Connecticut section of the Housatonic River showed that concentrations increased from 1984 to 1988, but decreased from 1988 to 1994 to concentrations less than those in 1984. Mobilization of PCB-contaminated sediment and the control of PCB-contaminated material from entering the river at the source are processes that have complicated the interpretation of PCB concentrations at sites along the Housatonic River. The concentrations reported in Academy of Natural Sciences of Philadelphia (1995), however, do indicate that PCB concentrations have recently decreased in fish in the Housatonic River.

Four sites from the current study (T-4, C-4, C-9, L-1) were near sites previously used in National studies that serve as complements in comparing concentrations of *p,p*'-DDE, total chlordane, and total PCBs with time (table 9). Sites that complemented sites T-4, C-4, and L-1 were used in the National Study of Chemical Residues in Fish, administered by the U.S. Environmental Protection Agency, and were sampled once during the mid-1980s (U.S. Environmental Protection Agency, 1992). The complement to site C-9 is the Connecticut River at Windsor Locks, Ct., which was used in the National Contaminant Biomonitoring Program (NCBP), administered by the U.S. Fish and Wildlife Service, and was sampled from 1970 to 1984 (Schmitt and others, 1981, 1983, 1985, 1990). Concentrations of *p,p*'-DDE were higher at site C-4 and C-9, about the same at site T-4, and lower at site L-1 than concentrations at the respective complementary sites from about a decade earlier. However, because *p,p*'-DDE is a metabolite of DDT, the concentrations at sites C-4 and C-9 are not necessarily evidence of recent DDT inputs into the river. Comparison of total chlordane concentrations indicates a decreasing trend over time (table 9), similar to what was seen in the entire Connecticut River (table 8). Concentrations from the current study sites compared to their complement sites were about one-half at site C-9 and about one-third at sites T-4, C-4, and L-1. Concentrations of total PCBs were about the same at the current study sites compared to concentrations at the complementary sites from about a decade earlier (table 9). At the Connecticut River site at Windsor Locks, Ct., PCB concentrations were highest in the early 1970s, but showed about a 10-fold decrease by 1984, presumably because of the ban on PCBs by the USEPA.

As discussed earlier, results from the current study showed that PCBs were detected in higher concentrations than the organochlorine pesticides. These findings are similar to those reported at several sites in the Hudson River Basin in New York. The NCBP monitored a site on the Hudson River at Poughkeepsie, N.Y., and reported total PCB concentrations in largemouth bass regularly exceeded 10,000 μg/kg throughout the 1970s (Schmitt and others, 1981, 1983, 1985). The NAWQA program study area for the Hudson River Basin, conducted concurrently with the present study, reported that total PCB concentrations in common carp were 14,000 μg/kg in a sample collected from the Hudson River at Poughkeepsie, N.Y., in 1992 (Firda and others, 1993). In common carp sampled in 1992 from the Mohawk River—a western Hudson River tributary—total PCB concentrations were 33,000 μg/kg near Utica, N.Y., and 26,000 μg/kg near Little Falls, N.Y. In common carp sampled from the

Table 9. Comparison of organochlorine concentrations in whole fish between current study sites and compliment sites from earlier studies

[Values from current study are in bold. Sample type: WS, white sucker; WC, white catfish; I, individual; C, composite. Composite sample types followed by the number 2 indicates that two composite samples were collected. Values are the arithmetic means of the two samples. µg/kg, micrograms per kilogram, wet weight]

Site location	Year	Fish species	Sample type	*p,p'*-DDE	Chlordane, total	PCBs, total	Reference
Thames River Basin							
Quinebaug River at Jewett City, CT	1984	WS	I	63	16.4	797	USEPA, 1992
Quinebaug River at Clayville, CT (T-4)	**1993**	**WS**	**C**	**57**	**5**	**670**	**Coles, 1996**
Connecticut River Basin							
Otter River at Baldwinville, MA	1986	WS	C	19.1	35.1	670	USEPA, 1992
Otter River at Otter River, MA (C-4)	**1994**	**WS**	**C**	**48**	**13**	**580**	**Coles, 1996**
Connecticut River at Windsor Locks, CT	1970	WC	C(2)	685	--	6,845	Schmitt and others, 1981
	1971	WC	C(2)	695	--	11,700	Schmitt and others, 1981
	1972	WC	C(2)	810	--	10,550	Schmitt and others, 1981
	1973	WC	C	630	--	7,600	Schmitt and others, 1981
	1974	WC	C(2)	205	--	5,600	Schmitt and others, 1981
	1976	WC	C(2)	265	205	5,500	Schmitt and others, 1983
	1980	WC	C(2)	400	350	4,250	Schmitt and others, 1985
	1984	WC	C(2)	125	115	1,250	Schmitt and others, 1990
Connecticut River near Longmeadow, MA (C-9)	**1993**	**WS**	**C**	**210**	**63**	**1,400**	**Coles, 1996**
Long Island Sound Coastal Rivers Basin							
Quinnipiac River at North Haven, CT	1984	WS	C	39	155	1,110	USEPA 1992
Quinnipiac River at Stillmans Corner, CT (L-1)	**1994**	**WS**	**C**	**22**	**58.8**	**1,400**	**Coles 1996**

Hoosic River—an eastern Hudson River tributary—the total PCB concentration was 1,500 µg/kg near Hoosick Falls, N.Y. (Firda and others, 1993). These Hudson River Basin sites, like those from the current study where PCB concentrations were high, contain urban and industrial areas in their drainage basins that were probable sources of PCBs to the rivers (Phillips and others, 1997).

SUMMARY AND CONCLUSIONS

Concentrations of 28 organochlorine compounds were assayed in the whole-body tissue of fish collected at 32 sites in the Connecticut, Housatonic, and Thames River Basins study unit during 1992–94. The predominant compounds detected were those related to DDT, chlordane, and PCBs. Total DDT concentrations were detected in fish tissue at 31 sites in the study unit, indicating widespread distribution of this insecticide. Total DDT concentrations and agriculture land use were not correlated, but concentrations were highest at sites with medium population density drainage basins and lowest in low population density drainage basins. The finding that the ranges of total DDT concentrations did not vary significantly among the four major basins of the study unit is indicative of the widespread distribution and transport of this pesticide. Furthermore, the finding that the metabolite *p,p'*-DDE accounted for the highest percentage of total DDT components indicates that DDT probably was not from recent applications in the study unit.

Total chlordane was detected at 25 of 32 sites in the study unit. Concentrations tended to be high at sites that had densely populated drainage basins. Of the four major basins, total chlordane concentrations were highest in the LISC Basin, which is in the densely populated southern part of the study area. The finding that *trans*-nonachlor (the least degradable component of total chlordane) was the component generally detected at the highest concentration indicates that chlordane probably was not from recent applications in the study unit.

Total PCBs were detected at 28 of 32 sites in the study unit, but with a wide range of concentrations among sites. Highest concentrations were seen in fish from the Housatonic River, the major source of which was the GE facility along the East Branch Housatonic River at Pittsfield, Massachusetts. Total PCB concentrations tended to be high at sites that had a large drainage basin, with highest concentrations at the mainstem sites along the large rivers in the study unit. Furthermore, PCB concentrations were less in streams with low population density drainage basins, presumably because undeveloped drainage basins have fewer sources of contamination. Probable sources of PCBs in the study area were from the major industrial, commercial, and urban areas along the large rivers.

Concentrations of total DDT and total chlordane were lowest at sites Mount Hope River near Warrenville, Ct., Connecticut River near Lancaster, N.H., Sleepers River near St. Johnsbury, Vt., Green River at Great Barrington, Mass, Konkapot River at Ashley Falls, Mass., and Tenmile River near Gaylordsville, Ct. Total DDT concentrations were less than 24 µg/kg and total chlordane was not detected at these sites. Furthermore, total PCBs were not detected at three of these sites (Mount Hope River near Warrenville, Ct., Connecticut River near Lancaster, N.H., and Sleepers River near St. Johnsbury, Vt.). The common characteristic among these six sites was a low population density drainage basin. Concentration of total chlordane was highest at site Rooster River near Fairfield, Ct., where the drainage basin population density was more than twice as high as any other site in the study area. Concentrations of total PCBs were highest at sites East Branch Housatonic River at Pittsfield, Mass., Housatonic River (Woods Pond) at Lenox, Mass., and Housatonic River near Town Hill, Ct. and are attributed to the PCB source along the East Branch Housatonic River at Pittsfield, Massachusetts. Overall, sites in the southern part of the study area were more affected than sites in the northern part. This finding is best exemplified by the Connecticut River mainstem sites, where the organochlorines showed a downstream trend of increasing concentrations.

On the basis of comparisons with other studies, total PCB and total DDT concentrations have not changed substantially during the last decade in the Connecticut River. A similar assessment of PCBs in the Housatonic River was not possible because of the difference in sample types. Total chlordane appears to be decreasing in rivers in the study area on the basis that concentrations in fish tissue were lower in the more recent samples at every comparable site.

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