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U.S. Geological Survey

NATIONAL WATER-QUALITY ASSESSMENT PROGRAM

Inventory of Selected Freshwater- Ecology Studies from the New England Coastal Basins (Maine, New Hampshire, Massachusetts, Rhode Island), 1937-97

Open-File Report 99-467

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Cover photograph shows the bridge/walkway used for the National Water-Quality Assessment Program sampling of the Charles River in Watertown, Massachusetts. (Photograph is by Kimberly Campo, U.S. Geological Survey)

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By Steven Tessler, James F. Coles, *and* Karen M. Beaulieu

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**Pembroke, New Hampshire
1999**

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
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Information regarding the National Water-Quality Assessment (NAWQA) Program is available on the Internet via the World Wide Web. You may connect to the NAWQA Home Page using the Universal Resources Locator (URL) at <http://wwwrvares.er.usgs.gov/nawqa/nawqa_home.html>

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.

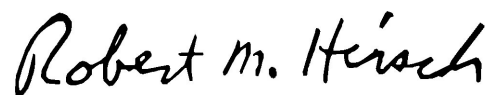
- Describe how water quality is changing over time.
- Improve understanding of the primary natural and human factors that affect water-quality conditions.

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
Chief Hydrologist

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CONVERSION FACTORS

Multiply	By	To obtain
inch (in.)	25.4	millimeter
ounce (oz)	28.35	gram
square mile (mi ²)	12.590	square kilometer

Inventory of Selected Freshwater-Ecology Studies from the New England Coastal Basins (Maine, New Hampshire, Massachusetts, Rhode Island), 1937-97

By Steven Tessler, James F. Coles, *and* Karen M. Beaulieu

Abstract

An inventory of published studies that address freshwater ecology within the New England Coastal Basins was created through computerized bibliographic literature searches and consultation with environmental agencies. Assembled papers were classified to associate their contents with one or more states, ecoregions, river basins, and ecological topics. Full references and their classifications were entered into a bibliographic software program and then exported to a data-base application to generate a checklist summary of study contents. This report presents a listing and classification of 154 selected studies, published between 1937 and 1997, that provide background knowledge and serve as general aquatic-ecology references for the New England Coastal Basins study area.

INTRODUCTION

The National Water-Quality Assessment (NAWQA) Program of the U.S. Geological Survey (USGS) is designed to assess the status and trends in the quality of the Nation's water resources and to develop an understanding of the major factors that affect water quality (Hirsch and others, 1988; Leahy and others, 1990). To achieve these goals, the NAWQA program uses an integrated approach of investigating physical, chemical, and biological components of an aquatic system to assess water

quality on a basinwide scale (Gurtz, 1994). Nationally, the NAWQA program consists of 59 river basins or aquifer systems, termed "study units," that collectively account for about two-thirds of the Nation's population served by public water supply (Leahy and Wilber, 1991). The New England Coastal Basins (NECB) Study Unit encompasses 23,000 mi² in western and central Maine, central and eastern New Hampshire, eastern Massachusetts, most of Rhode Island, and a small part of Connecticut (fig. 1). The study unit includes the drainage basins of the Kennebec, Androscoggin, Saco, Merrimack, Charles, Blackstone, Taunton, and Pawcatuck Rivers, as well as small coastal drainages between these larger river basins (fig. 2).

One of the tasks in the planning stages for the NECB study was to identify and review previous studies that are relevant to understanding water quality and aquatic ecosystems within the study unit. This information is used to help identify prevailing water-quality issues, to assess the status of water-quality conditions and biological communities in streams, and to allocate NAWQA resources to complement previous or existing studies. These previous studies can be identified through a combination of computerized literature searches and consultation with agencies and researchers in the region. Organizing and classifying references by their relevance to particular geographic regions or subject areas allows the references to be used more efficiently.

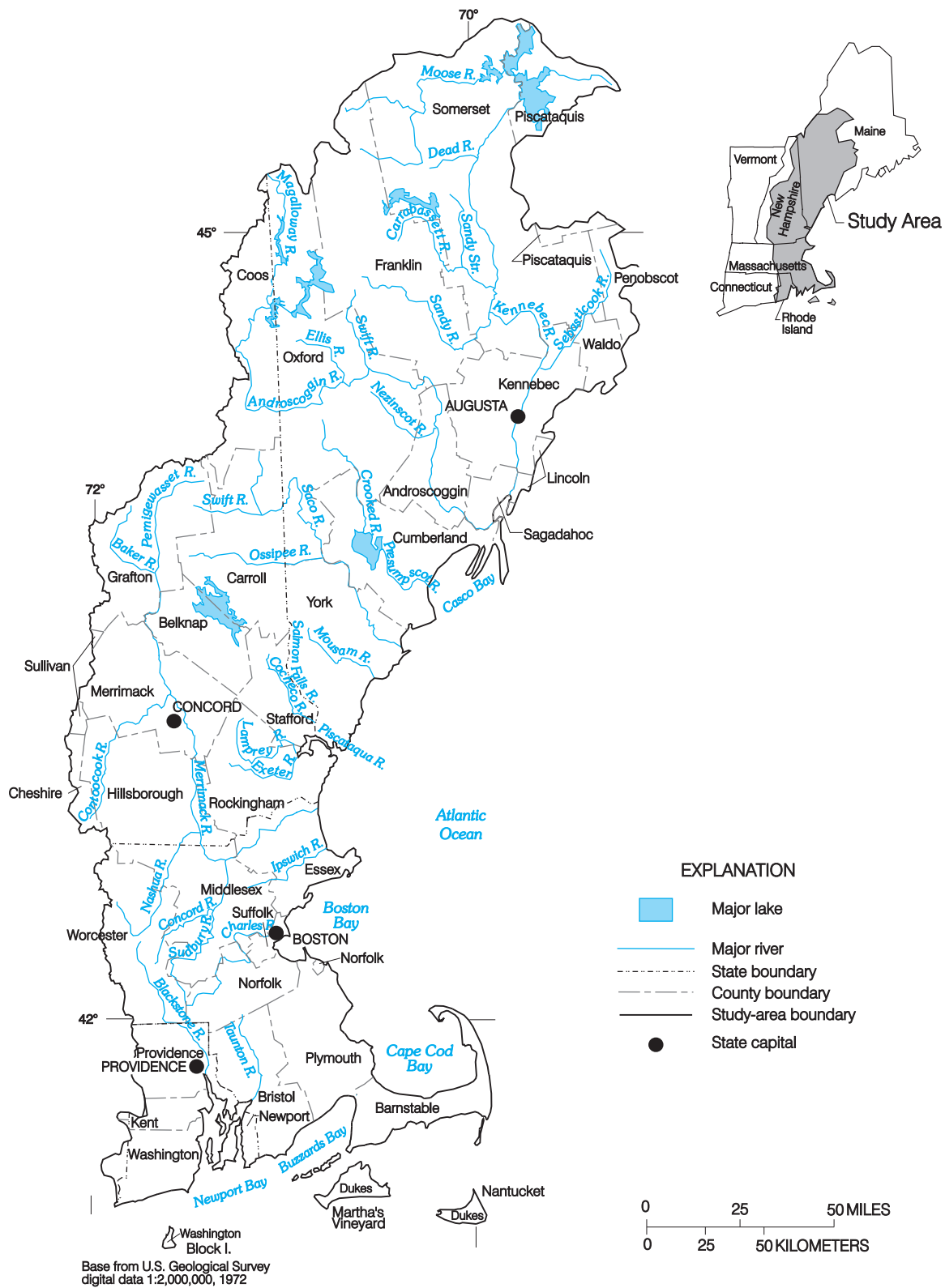


Figure 1. Location and major rivers of the New England Coastal Basins Study Unit.

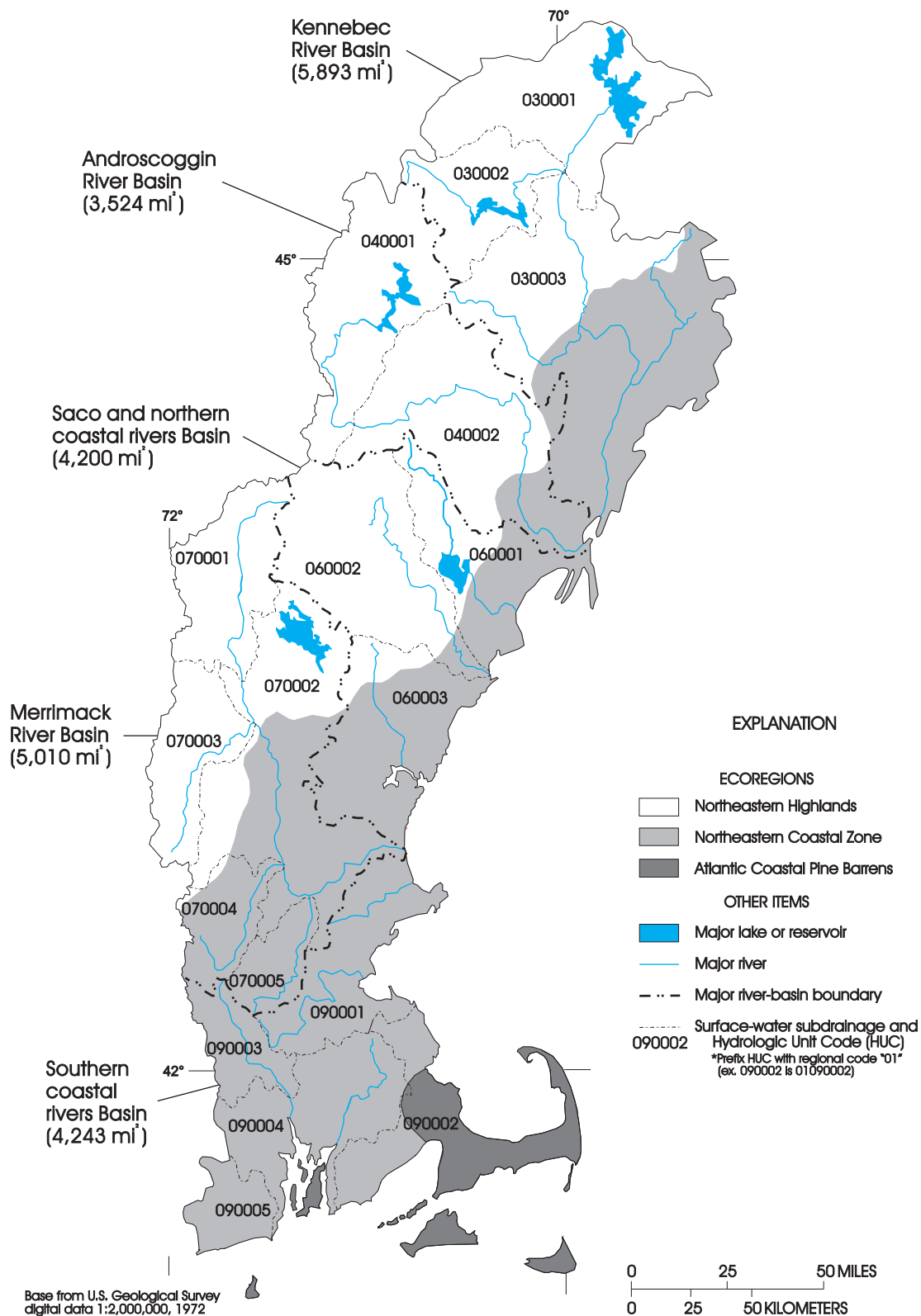


Figure 2. Ecoregions and river basins of the New England Coastal Basins Study Unit.

Purpose and Scope

This report presents an inventory of selected published freshwater ecological studies within the NECB Study Unit. Selection of a citation for inclusion in this report required that the work had been done in a freshwater system (river, stream, lake, or pond) and focused on at least one of the following ecological subjects of field study relevant to the NAWQA program: algae, macroinvertebrates, fish, habitat, and tissue or sediment contaminants. Therefore, studies focused solely on wetlands, estuarine or marine coastal waters, microbiology, or nonfish vertebrates were not targeted. Studies were identified through a computerized literature search and by contacting state and Federal agencies and researchers who collect freshwater ecological data in the NECB Study Unit. Citation and classification information for the studies was entered into a computerized reference library and then processed to create tables that facilitate quick identification of the scope of each study. The general methods used to assemble the bibliography and classify citations are presented in this report, along with tables that summarize the collection of references found and the information in each reference by state, ecoregion, major river basin, and ecological topic. The listings in this report provide NECB staff and others with a means to (1) quickly identify previous or ongoing studies with a focus on particular water-quality issues in geographic, ecoregion, or hydrologic-basin areas, (2) identify references reporting the known status of biological communities and contaminant conditions, (3) identify researchers with a working knowledge of the area and issues, and (4) assess the potential for allocation of field personnel and laboratory resources to complement previous and ongoing studies.

Methods Used to Assemble the Bibliography

Most of the references were identified by means of data-base searches over the Internet, although direct contacts with state- and Federal-agency personnel resulted in useful and important references that otherwise would have been overlooked. Although bibliographic data bases provide a rapid means of assembling lists of citations that are candidates for a focused reference collection, the process of

assembling a useful list of uniformly formatted references from those available is challenging and involves several additional steps. An appendix in this report provides a more detailed explanation of the strategy and some of the methods and mechanics that were used to assemble the computerized bibliography and produce the citation tables for this report, including search-string development, a listing of the bibliographic data bases that contributed citations to this report, use of bibliographic software for basic citation management, and a custom data-base application to enable other uses and format options for the bibliography that are not supported in the citation-management tool.

Acknowledgments

Several individuals and agencies helped with resources or reference material for this report. Lee Regan, USGS Library, and the Woods Hole Oceanographic Institute Library both provided assistance with the initial literature search. Emily Banks, Student Assistant, USGS, compiled and organized references. Reports of studies relevant to the New England Coastal Basin study area were provided by U.S. Fish and Wildlife Service, Concord, N.H.; U.S. Environmental Protection Agency, Lexington, Mass.; Maine Department of Inland Fish and Wildlife, Augusta, Maine; Maine Department of Environmental Protection, Augusta, Maine; New Hampshire Department of Environmental Services, Concord, N.H.; Massachusetts Department of Fish and Wildlife, Westborough, Mass.; Massachusetts Department of Environmental Protection, Worcester, Mass.; Rhode Island Fish and Wildlife Service, West Kingston, R.I.; and Rhode Island Department of Environmental Management, Providence, R.I.

CLASSIFICATION OF ECOLOGICAL STUDIES

For all citations to be included in our bibliographic data base, the states, ecoregions, and river basins in which the studies took place were identified, as well as the ecological topics addressed in the studies. By assigning each ecological study to multiple categories, studies can be identified as relevant to a specific topic and location.

Table 1. Summary of states and counties in the New England Coastal Basins study unit

State	Counties either partly or totally within the New England Coastal Basins Study Unit
Maine	Androscoggin, Cumberland, Franklin, Kennebec, Lincoln, Oxford, Penobscot, Piscataquis, Sagadahoc, Somerset, Waldo, York
New Hampshire	Belknap, Carroll, Cheshire, Coos, Grafton, Hillsborough, Merrimack, Rockingham, Strafford, Sullivan
Massachusetts	Barnstable, Bristol, Dukes, Essex, Middlesex, Nantucket, Norfolk, Plymouth, Suffolk, Worcester
Rhode Island	Bristol, Kent, Newport, Providence, Washington

States

Each citation is classified as containing information in one or more of four states. The NECB Study Unit includes 11,236 mi² of Maine, 6,181 mi² of New Hampshire, 4,482 mi² of Massachusetts, 1,030 mi² of Rhode Island, and 57 mi² of Connecticut. Connecticut was not included in the data base because of its small presence in the study unit (Flanagan and others, 1999). A list of counties that are at least partly within the NECB Study Unit is given in table 1.

Ecoregions

Each citation is classified as containing information in one or more of three ecoregions. Ecoregions (Omernik, 1987) were developed for the conterminous United States to partition the landscape into areas having relatively similar characteristics of landform, land use, soil, and potential natural vegetation (the type of climax forest that would eventually develop after removal of human influence). The approach used to define ecoregions delineates spatial areas with reference to biotic and abiotic factors. These factors include geology, physiography, vegetation, climate, soils, land use, wildlife, and hydrology.

Ecoregions in the NECB Study Unit are the Northeastern Highlands, Northeastern Coastal Zone, and Atlantic Coastal Pine Barrens¹ (U.S. Environmental Protection Agency-National Health and Environmental Effects Research Laboratory, 1998) (fig. 2). The Northeastern Highlands and Northeastern

Coastal Zone ecoregions make up more than 95 percent of the NECB Study Unit and respectively distinguish the inland mountainous forested regions from the coastal lowland hills and plains. The Atlantic Coastal Pine Barrens ecoregion is represented in the southeastern part of the study unit and includes Cape Cod and the islands off of the southern Massachusetts and Rhode Island coasts. General patterns of vegetation and aquatic habitat in the NECB Study Unit can be broadly defined by these ecoregions.

River Basins

Each citation is classified as containing information for one or more of 18 river-basin areas. The United States can be divided into a nested hierarchy of river basins, or hydrologic units, organized at four levels: regions, subregions, accounting units, and cataloging units (U.S. Geological Survey, 1982). Each hydrologic unit is identified by a unique hydrologic unit code (HUC) consisting of two, four, six, or eight digits based on the four levels of classification in the hydrologic-unit system. Ecological studies in the NECB Study Unit were classified by their association with 18 river basins at the cataloging-unit level (8-digit HUC) (table 2). For the tables presented in this report, the ecological studies were aggregated into subregions representing the larger river basins (4-digit HUC): the Kennebec, Androscoggin, Saco, Merrimack, and Massachusetts-Rhode Island Coastal Basins.

Ecological Topics

Each citation is classified as containing information under one or more of six ecological topics. The NAWQA program surveys surface- and ground-water quality, physical stream habitat, biological communities, and contaminants in bed sediments and tissues. Studies selected for inclusion in the bibliographic data base addressed one or more of the following topics that are relevant to the NAWQA field work: (1) algae, (2) macroinvertebrates, (3) fish, (4) habitat, (5) tissue contaminants, and (6) sediment contaminants.

¹The area of the NECB study unit within the Atlantic Coastal Pine Barrens ecoregion had previously been part of the Northeastern Coastal Zone ecoregion, and later, the Middle Atlantic Coastal Plain ecoregion.

Table 2. Hydrologic subregions and cataloging units in the New England Coastal Basins Study Unit
[HUC, Hydrologic Unit Code; mi², square mile]

Hydrologic subregion (HUC)	Cataloging unit	HUC	Area (mi ²)
Kennebec (0103)	Upper Kennebec	01030001	1,590
	Dead	01030002	182
	Lower Kennebec	01030003	3,454
Androscoggin (0104)	Upper Androscoggin	01040001	1,474
	Lower Androscoggin	01040002	2,004
Saco (0106)	Presumpscot	01060001	1,063
	Saco	01060002	1,702
	Piscataqua-Salmon Falls	01060003	1,406
Merrimack (0107)	Pemigewasset	01070001	1,003
	Merrimack	01070002	2,317
	Contoocook	01070003	762
	Nashua	01070004	533
	Concord	01070005	403
Massachusetts-Rhode Island Coastal (0109)	Charles	01090001	1,005
	Cape Cod	01090002	1,229
	Blackstone	01090003	475
	Narragansett	01090004	1,203
	Pawcatuck-Wood	01090005	370

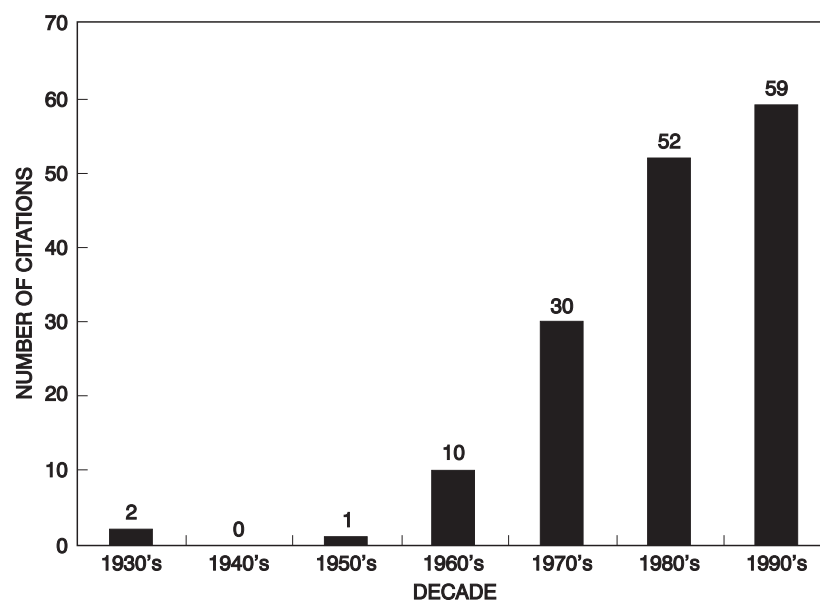


Figure 3. Number of citations to freshwater-ecology studies in the New England Coastal Basins, by decade.

INVENTORY OF FRESHWATER ECOLOGICAL STUDIES

A total of 154 studies were found that met our selection criteria of reporting on data collected in the NECB Study Unit for six ecological topics. The publication years range from 1937 to 1997, and the number of citations found increases over the decades (fig. 3). This pattern indicates that, in general, ecological assessments have become more commonplace in our study area over time, but the pattern may also represent a bias in using online citation sources and a corresponding lag in incorporating older references into those data bases. The number of citations grouped by decade and ecological topic is listed in table 3; studies with multiple topical coverage are counted multiple times, so the totals are greater than the actual number of 154 citations. The summary statistics indicate that ecological assessments in the NECB area began to increase in the 1960's and 1970's and that studies with a focus or component dealing with contamination of tissues and sediments increased greatly in the 1990's.

A summary of the number of studies found for this report grouped by our classification categories is given in table 4. A few general facts are evident from

the publication record: (1) each state within the NECB Study Unit is well represented, (2) studies appear to have been concentrated in the Northeastern Coastal Zone ecoregion, (3) each major river basin is well represented, but the greatest number of studies were within the Merrimack and Massachusetts-Rhode Island Coastal subregions, and (4) studies including fish and macroinvertebrates dominated the topics of investigation.

A checklist classification of individual studies by location (state, ecoregion, hydrologic region) and ecological topic is given in table 5, full citations are presented in table 6, and an author index to all citations is provided in table 7. These lists provide NECB staff and others with a means to (1) quickly identify published studies with a focus on particular water-quality issues in geographic, ecoregional, or hydrologic-basin areas; (2) identify references reporting the known status of biological communities and contaminant conditions; (3) identify researchers with a working knowledge of the area and issues; and (4) assess the potential for allocation of field personnel and laboratory resources to complement previous and ongoing studies.

Table 3. Number of citations of freshwater-ecology studies in the New England Coastal Basins by decade and ecological topic

[--, no citations found]

Decade	Algae	Macroinvertebrates	Fish	Habitat	Tissue	Sediment
1930's	2	--	2	2	--	--
1940's	--	--	--	--	--	--
1950's	--	--	1	--	--	--
1960's	1	1	9	2	3	--
1970's	6	15	14	6	7	3
1980's	12	21	24	18	6	6
1990's	9	26	35	17	22	13
Total	30	63	85	45	38	22

Table 4. Summary of the number of citations found, by classification category

Classification category	Item	Number of citations
State	Maine	48
	New Hampshire	40
	Massachusetts	49
	Rhode Island	30
Ecoregion	Northeastern Highlands	75
	Northeastern Coastal Zone	119
	Atlantic Coastal Pine Barrens	8
Hydrologic subregion (Major river basin)	Kennebec	45
	Androscoggin	32
	Saco	58
	Merrimack	73
	Massachusetts-Rhode Island coastal	90
Ecological topic	Algae	30
	Macroinvertebrates	63
	Fish	85
	Habitat	45
	Tissue contaminants	38
	Sediment contaminants	22

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- U.S. Environmental Protection Agency, 1998 (revised), Level III Ecoregions of the continental United States: Corvallis, Oreg., National Health and Environmental Effects Research Laboratory, 1 map sheet.
- U.S. Geological Survey, 1982, Hydrologic unit map of the United States: scale 1:7,500,000.

data-base names and years for which citations were available are given in table 9. The ending year of

Table 5. Classification of selected ecological studies in the New England Coastal Basins Study Unit

[MADEP, Massachusetts Department of Environmental Protection; NHDES, New Hampshire Department of Environmental Services; U.S.F.&W.S., U.S. Fish and Wildlife Service]

Citation number	Author and year	Ecoregions			State				River basin					Subject					
		Northeastern Highlands	Northeastern Coastal Zone	Atlantic Coastal Pine Barrens	Maine	New Hampshire	Massachusetts	Rhode Island	Kennebec	Androscoggin	Saco	Merrimack	Massachusetts-Rhode Island coastal	Algae	Macroinvertebrates	Fish	Habitat	Tissue contaminants	Sediment contaminants
1	Albers and Camardese, 1993	X			X					X					X			X	
2	Anderson, 1964	X			X						X					X		X	
3	Anderson and Everhart, 1966	X			X						X					X		X	
4	Anderson, 1966	X			X						X					X		X	
5	Anderson and Fenderson, 1970	X			X						X					X		X	
6	AuClair, 1980	X			X				X							X			
7	AuClair, 1982	X			X				X							X	X		
8	Baevsky, 1991			X			X						X			X	X		
9	Bauer and Granett, 1979	X	X		X				X	X	X				X				
10	Beskenis and Nuzzo, 1984		X				X						X	X	X				
11	Bilger, 1976		X				X					X			X				
12	Bilger and Travis, 1978	X	X			X	X					X			X				
13	Boobar and others, 1996	X	X		X						X				X		X		
14	Brett, 1989	X	X		X				X	X					X	X			
15	Bridges, 1970		X				X					X	X			X		X	
16	Bridges and Palermo, 1973		X	X			X					X	X		X	X		X	
17	Burian, 1990	X	X		X				X	X	X				X				
18	Burkholder and Sheath, 1984		X					X					X	X					
19	Burmester and others, 1991		X				X						X					X	
20	Courtemanch, 1986		X		X				X					X			X		
21	Custer and others, 1986		X					X					X					X	
22	Davis and others, 1978	X	X		X				X	X	X			X	X		X		
23	Davis and others, 1996		X				X						X			X		X	X
24	DeRoche, 1960	X			X						X					X			
25	DeRoche, 1967a	X	X		X	X				X						X	X		
26	DeRoche, 1967b	X	X		X						X					X	X		

Table 5. Classification of selected ecological studies in the New England Coastal Basins Study Unit--Continued

Citation number	Author and year	Ecoregions			State				River basin					Subject					
		Northeastern Highlands	Northeastern Coastal Zone	Atlantic Coastal Pine Barrens	Maine	New Hampshire	Massachusetts	Rhode Island	Kennebec	Androscoggin	Saco	Merrimack	Massachusetts-Rhode Island coastal	Algae	Macroinvertebrates	Fish	Habitat	Tissue contaminants	Sediment contaminants
27	DeRoche, 1970	X			X						X					X		X	
28	DeRoche, 1971	X			X						X					X		X	
29	DeRoche, 1976	X			X						X					X		X	
30	DeSandre and others, 1977	X			X					X						X			
31	DeStasio, 1989a		X					X					X		X				
32	DeStasio, 1989b		X					X					X		X				
33	DiFranco and others, 1995	X	X		X				X	X	X					X		X	
34	Dorfman and Nuzzo, 1988		X				X					X			X	X		X	X
35	Dunham, 1994		X				X						X		X				
36	Duval and others, 1980		X		X				X						X				X
37	Eiler, 1986		X		X				X							X	X		
38	Erdmann and others, 1977		X				X						X	X	X				
39	Findlay and others, 1993	X				X						X		X					
40	Forrester and others, 1994		X			X					X				X	X			
41	Foye and others, 1969	X	X		X				X							X			
42	Frakes and others, 1993	X	X		X				X	X	X					X		X	
43	Gleich, 1972	X	X		X				X						X				
44	Golet and Parkhurst, 1981		X					X					X				X		
45	Gould, 1991		X					X					X		X		X		X
46	Gould, 1993a		X					X					X		X		X		X
47	Gould, 1993b		X					X					X		X		X		X
48	Gould, 1994		X					X					X		X		X		X
49	Gould, 1995		X					X					X		X		X		X
50	Gruendling and Mathieson, 1969	X				X						X		X					
51	Guthrie and others, 1973		X					X					X			X		X	
52	Guthrie and Stolgitis, 1997		X					X					X			X			

Table 5. Classification of selected ecological studies in the New England Coastal Basins Study Unit--Continued

Citation number	Author and year	Ecoregions			State				River basin					Subject					
		Northeastern Highlands	Northeastern Coastal Zone	Atlantic Coastal Pine Barrens	Maine	New Hampshire	Massachusetts	Rhode Island	Kennebec	Androscoggin	Saco	Merrimack	Massachusetts-Rhode Island coastal	Algae	Macroinvertebrates	Fish	Habitat	Tissue contaminants	Sediment contaminants
53	Haack and others, 1988	X				X						X		X			X		
54	Haines, 1983	X			X	X			X	X						X		X	
55	Hall and others, 1980	X				X						X		X	X	X			
56	Haro, 1987		X					X					X			X			
57	Haro and Krueger, 1991		X					X					X			X			
58	Hartman and others, 1991		X				X	X					X		X	X		X	X
59	Havas and Likens, 1985		X			X						X			X				
60	Havens, 1991	X				X					X	X			X				
61	Hoff, 1988			X			X						X			X			
62	Hoover, 1937	X	X			X				X	X			X		X	X		
63	Hoover, 1938	X	X			X						X		X		X	X		
64	Issac and others, 1994		X	X			X					X	X			X		X	
65	Jimenez, 1978		X				X					X				X			
66	Johnson, 1986	X					X					X		X	X				X
67	Johnson and others, 1986		X				X						X	X	X	X		X	X
68	Johnson and others, 1990		X				X					X		X		X	X	X	
69	Johnson and others, 1992		X				X						X		X	X		X	
70	Johnson and others, 1996	X	X			X						X				X			
71	Jop and others, 1995		X		X						X				X	X		X	
72	Kennedy and others, 1995		X				X						X	X	X	X	X	X	X
73	Kesler, 1980		X					X					X		X				
74	Kesler and Bailey, 1993		X					X					X		X				
75	Kieffer and Kynard, 1993		X				X					X				X			
76	Kieffer and Kynard, 1996		X				X					X				X	X		
77	Korch and Sheath, 1989		X					X					X	X			X		
78	Lowe, 1975		X					X					X			X			
79	Mairs, 1968	X	X		X					X	X				X	X			

Table 5. Classification of selected ecological studies in the New England Coastal Basins Study Unit--Continued

Citation number	Author and year	Ecoregions			State				River basin					Subject					
		Northeastern Highlands	Northeastern Coastal Zone	Atlantic Coastal Pine Barrens	Maine	New Hampshire	Massachusetts	Rhode Island	Kennebec	Androscoggin	Saco	Merrimack	Massachusetts-Rhode Island coastal	Algae	Macroinvertebrates	Fish	Habitat	Tissue contaminants	Sediment contaminants
80	Major and Carr, 1991	X	X			X	X					X				X		X	
81	Martin, 1995a		X					X					X			X			
82	Martin, 1995b		X					X					X			X			
83	MADEP, 1973		X				X						X	X	X				X
84	MADEP, 1977a		X				X					X		X	X				X
85	MADEP, 1977b		X				X					X	X		X				X
86	MADEP, 1983	X					X						X	X	X		X		
87	MADEP, 1984		X				X						X			X		X	X
88	MADEP, 1997		X				X						X			X		X	X
89	Mathieson and Fralick, 1973		X				X					X		X			X		
90	McCall and others, 1996	X	X		X				X								X		
91	McKnight, 1981		X				X						X	X					
92	McLaughlin and others, 1987	X	X		X	X					X					X	X		
93	McMasters, 1996	X	X		X					X						X		X	
94	Mierzykowski and others, 1997	X			X					X						X		X	
95	Mingo, 1979	X	X		X				X	X	X				X		X		
96	Moore, 1983	X	X				X				X						X		
97	Moring and others, 1986	X	X		X				X						X	X	X		
98	Mosher, 1976		X				X						X			X			
99	Mowatt, 1973	X	X		X				X						X				
100	Mower and others, 1997	X	X		X				X	X	X					X		X	
101	Muzzall, 1978		X			X						X				X			
102	Muzzall, 1979		X			X					X					X			
103	Muzzall, 1980a		X			X					X					X			
104	Muzzall, 1980b		X			X					X					X			
105	Muzzall, 1980c		X			X					X					X			

Table 5. Classification of selected ecological studies in the New England Coastal Basins Study Unit--Continued

Citation number	Author and year	Ecoregions			State				River basin					Subject					
		Northeastern Highlands	Northeastern Coastal Zone	Atlantic Coastal Pine Barrens	Maine	New Hampshire	Massachusetts	Rhode Island	Kennebec	Androscoggin	Saco	Merrimack	Massachusetts-Rhode Island coastal	Algae	Macroinvertebrates	Fish	Habitat	Tissue contaminants	Sediment contaminants
106	Muzzall, 1982		X			X					X					X			
107	Negus, 1987	X	X		X				X							X	X		
108	NHDES and others, 1996a	X	X			X	X					X			X				
109	NHDES and others, 1996b	X	X			X	X					X			X				
110	NH Fish and Game, 1985	X	X			X					X	X			X	X	X		
111	NH Fish and Game, 1986	X	X			X					X	X			X	X	X		
112	Newell, 1970	X	X			X					X	X				X	X		
113	Normandeau, 1963	X				X						X				X			
114	Nuzzo, 1985		X				X						X		X				X
115	Nuzzo and Kennedy, 1992		X				X						X		X	X	X	X	X
116	Nuzzo and others, 1997		X			X	X					X			X	X	X	X	
117	Ochs, 1991	X				X						X		X					
118	Ochs and others, 1995	X				X						X		X					
119	Oliveira, 1994		X					X					X			X			
120	Oliveira, 1996		X					X					X			X			
121	Oliveira, 1997		X					X					X			X	X		
122	Organ, 1989		X	X			X					X	X					X	
123	Packard, 1992	X				X						X		X					
124	Pauwels and Haines, 1986	X	X		X				X		X					X			
125	Pivetz and Kelly, 1986		X				X						X	X					
126	Reed, 1988a	X	X		X				X	X	X						X		
127	Reed, 1988b		X					X					X				X		
128	Ropes, 1989		X					X					X		X				
129	Rottiers and Redell, 1993	X				X						X				X			
130	Samad and Stanley, 1986	X	X		X				X						X				
131	Sayers and others, 1989	X			X				X							X			
132	Scarola and others, 1987	X	X			X					X	X				X			

Table 5. Classification of selected ecological studies in the New England Coastal Basins Study Unit--Continued

Citation number	Author and year	Ecoregions			State				River basin					Subject					
		Northeastern Highlands	Northeastern Coastal Zone	Atlantic Coastal Pine Barrens	Maine	New Hampshire	Massachusetts	Rhode Island	Kennebec	Androscoggin	Saco	Merrimack	Massachusetts-Rhode Island coastal	Algae	Macroinvertebrates	Fish	Habitat	Tissue contaminants	Sediment contaminants
133	Sheath and Burkholder, 1985		X					X					X	X			X		
134	Smith, 1990		X				X					X			X	X	X		
135	Smith, 1993	X	X	X			X					X	X		X		X		
136	Sorensen and Bianchini, 1986		X					X					X			X			
137	Sorrie, 1994	X	X	X	X	X	X	X			X		X	X					
138	Sowles, 1987	X	X		X				X								X		
139	Sowles and others, 1996	X	X		X					X	X				X	X		X	X
140	Sowles and others, 1997	X	X		X					X	X				X	X		X	X
141	Stafford and Haines, 1997	X	X		X				X	X	X					X		X	
142	Stallsmith and others, 1996		X	X			X						X			X			
143	Strayer, 1984	X				X						X			X				
144	Strayer, 1985	X				X						X			X				
145	Strayer, 1994	X				X						X		X	X				
146	Stroud, 1952		X				X					X	X			X			
147	Szal, 1984		X				X						X		X		X		
148	Tammi and others, 1995		X					X					X		X				
149	Tennant and others, 1974		X				X						X		X				
150	Travis, 1978		X				X					X	X		X		X		
151	Trotzky and Gregory, 1974	X			X				X						X		X		
152	U.S.F.&W.S., 1991	X	X			X	X					X				X		X	X
153	Ulrich and others, 1993	X				X						X		X			X		
154	Yeo, 1971	X				X						X		X					

Table 6. Citations of selected ecological studies in the New England Coastal Basins Study Unit

Citation number	Citation
1	Albers, P.H., and Camardese, M.B., 1993, Effects of acidification on metal accumulation by aquatic plants and invertebrates. 2. Wetlands, ponds and small lakes: <i>Bulletin of Environmental Contamination and Toxicology</i> , v. 12, no. 6, p. 969-976.
2	Anderson, R.B., 1964, Study of salmon in Sebago Lake—Effects of DDT: Maine Department of Inland Fisheries and Game, 7 p.
3	Anderson, R.B. and Everhart, W.H., 1966, Concentrations of DDT in landlocked salmon (<i>Salmo salar</i>) at Sebago Lake, Maine: <i>Transactions of the American Fisheries Society</i> , v. 95, no. 2, p. 160-164.
4	Anderson, R.B., 1966, Study of salmon in Sebago Lake—Effects of DDT: Maine Department of Inland Fisheries and Game, 2 p.
5	Anderson, R.B., and Fenderson, O.C., 1970, Analysis of variation of insecticide residues in landlocked Atlantic salmon (<i>Salmo salar</i>): <i>Journal of the Fishery Research Board of Canada</i> , v. 27, p. 1-11.
6	AuClair, R.P., 1980, Moosehead Lake study—Maine inland fisheries operation plan—Moosehead Lake fishery management: Maine Department of Inland Fish and Wildlife, 185 p.
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8	Baevsky, Y.H., 1991, Physical and water-quality characteristics affecting trout-spawning habitat in the Quashnet River, Cape Cod, Massachusetts: U.S. Geological Survey Water-Resources Investigations Report 91-4045, 21 p.
9	Bauer, L.S., and Granett, J., 1979, The blackflies of Maine: Maine Life Sciences and Agriculture Experimental Station Technical Bulletin, v. 95, p. 1-18.
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15	Bridges, C.H., 1970, Coldwater fisheries investigations—Pesticide analysis: Massachusetts Division of Fish and Game, 3 p.
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18	Burkholder, J.M., and Sheath, R.G., 1984, The seasonal distribution, abundance and diversity of desmids (Chlorophyta) in a soft-water, north temperate stream: <i>Journal of Phycology</i> , v. 20, no. 2, p. 159-172.
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21	Custer, T.W., Franson, J.C., and Moore, J.F., 1986, Reproductive success and heavy metal contamination in Rhode Island common terns: <i>Environmental Pollution, Series A</i> , v. 41, no. 1, p. 33-52.
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25	DeRoche, S.E., 1967a, Fishery management in the Androscoggin River: Maine Department of Inland Fisheries and Game, Fisheries Research Bulletin 7, 52 p.
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Table 6. Citations of selected ecological studies in the New England Coastal Basins Study Unit--Continued

Citation number	Citation
27	DeRoche, S.E., 1970, Study of salmon in Sebago Lake—Effects of DDT: Maine Department of Inland Fisheries and Game, 5 p.
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36	Duval, R.L., Ferris, C.R., Owen, R.B., Jr., Gibbs, K.E., Furk, L.K., Jr., and Woodard, F.E., 1980, Effects of a cattle skin tannery on stream quality and benthic macroinvertebrates in central Maine: Bulletin of Environmental Contamination and Toxicology, v. 25, no. 2, p. 269-279.
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44	Golet, F.C., and Parkhurst, J.A., 1981, Freshwater wetland dynamics in South Kingstown, Rhode Island, 1939-1972: Environmental Management, v. 5, no. 3, p. 245-251.
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Table 6. Citations of selected ecological studies in the New England Coastal Basins Study Unit--Continued

Citation number	Citation
52	Guthrie, R.C. and Stolgitis, J.A., 1997, Fisheries investigations and management in Rhode Island lakes and ponds: Rhode Island Department of Fish and Wildlife Fisheries Report 3, 256 p.
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60	Havens, K.E., 1991, Crustacean zooplankton food web structure in lakes of varying acidity: <i>Canadian Journal of Fisheries and Aquatic Sciences</i> , v. 48, no. 10, p. 1846-1852.
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62	Hoover, E.E., 1937, Biological survey of the Androscoggin, Saco and Coastal Watersheds: New Hampshire Fish and Game Department, Survey Report 2, 160 p.
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Table 6. Citations of selected ecological studies in the New England Coastal Basins Study Unit--Continued

Citation number	Citation
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76	Kieffer, M.C., and Kynard, B., 1996, Spawning of the shortnose sturgeon in the Merrimack River, Massachusetts: <i>Transactions of the American Fisheries Society</i> , v. 125, no. 2, p. 179-186.
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81	Martin, M.H., 1995a, Validation of daily growth increments in otoliths of <i>Anguilla rostrata</i> (Lesueur) elvers: <i>Canadian Journal of Zoology</i> , v. 73, no. 1, p. 208-211.
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Table 6. Citations of selected ecological studies in the New England Coastal Basins Study Unit--Continued

Citation number	Citation
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Table 6. Citations of selected ecological studies in the New England Coastal Basins Study Unit--Continued

Citation number	Citation
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128	Ropes, J.W., 1989, The food habits of five crab species at Pettaquamscutt River, Rhode Island: Fisheries Bulletin, v. 87, no. 1, p. 197-204.
129	Rottiers, D.V., and Redell, L.A., 1993, Volitional migration of Atlantic salmon from seasonal holding ponds: North American Journal of Fisheries Management, v. 13, no. 2, p. 238-252.
130	Samad, F., and Stanley, J.G., 1986, Loss of freshwater shellfish after water drawdown in Lake Sebasticook, Maine: Journal of Freshwater Ecology, v. 3, no. 4, p. 519-523.
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134	Smith, J.B., 1990, Assessment of unassessed waters in the Merrimack Basin using rapid biological monitoring: Massachusetts Department of Environmental Protection, Division of Water Pollution Control, Technical Services Branch Report 84-C-3, 88 p.
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138	Sowles, J., 1987, Restoration of Salmon Lake, Maine: Maine Department of Environmental Protection, 83 p.
139	Sowles, J.; Mower, Barry; Davies, S.P.; Tsomides, Leonidas; and Hague, D., 1996, surface water ambient toxic monitoring program—1994: Maine Department of Environmental Protection, 71 p.
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Table 6. Citations of selected ecological studies in the New England Coastal Basins Study Unit--Continued

Citation number	Citation
150	Travis, S.C., 1978, Environmental preferences of selected freshwater benthic macroinvertebrates: Massachusetts Department of Environmental Quality Engineering, Division of Water Pollution Control, Report MS Q-1, 94 p.
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152	U.S. Fish and Wildlife Service, 1991, Contaminant concentrations in two isolated bog ponds in New England: Concord, N.H., New England Field Offices, 6 p.
153	Ulrich, K.E., Burton, T.M., and Oemke, M.P., 1993, Effects of whole-tree harvest on epilithic algal communities in headwater streams: Journal of Freshwater Ecology, v. 8, no. 2, p. 83-92.
154	Yeo, H.W., 1971, The composition, abundance, and seasonal periodicity of phytoplankton at Lake Winnepesaukee, New Hampshire: Durham, N.H., University of New Hampshire, Ph.D. dissertation, 88 p.

Table 7. Author index to citations in the inventory of freshwater-ecology studies from the New England Coastal Basins

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Albers, P.H.	1
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APPENDIX

APPENDIX: DETAILS OF ELECTRONIC SEARCHES AND COMPILATION OF RESULTS

In addition to manual collection of some important references through various personal contacts, assembly of the bibliography and tables presented in this report involved computerized searches, two primary software applications, and some custom programming. In general, most computerized sources allow searching for words or phrases in article titles, abstracts, and author-supplied keywords, and some provide additional categorical classifications of their own that are used in the search. However, the results of a search can vary among bibliographic search tools even when identical search terms are used, and duplicate returns are always possible from the use of different search criteria within the same data base. For that reason, the initial return of references must be followed by procedures for culling the list to relevant articles and removing duplicates. Even after an initial set of references is identified, further manipulation is required to produce properly and uniformly formatted citations and to classify each for their relevance to different geographic and topical areas. Ultimately, a process is also needed to generate textual output in a desired format that can be incorporated into a paper report. Developing a methodology to automate as many of these procedures as possible allows updates to the New England Coastal Basins Study Unit bibliography to be transferred quickly to current and future-use applications, such as presenting the bibliography by way of a Web page.

This section describes some of the strategy developed and mechanical details used for the computer-based processes that produced the citation and indexed tables presented in this report, specifically, development of search strings to locate relevant citations, bibliographic data bases used for our search, use of bibliographic software for organizing and standardizing the collection of references, and use of a data-base application to generate customized tables and indices.

Search Strings

The first step in a computerized search is to develop a “search string” that is used by a bibliographic data base to identify relevant articles. To use

these data bases effectively, one must recognize that each has specific limitations on (1) search-string length, (2) number of Boolean operators and levels of parenthetical nesting allowed per string, (3) characters used to indicate “wildcards” and delimiters for words and multiword phrases, and (4) maximum number of references returned per search. A standardized set of search terms that would work with minimal modification in any bibliographic data base was developed to streamline the effort.

We found through trial and error that the most effective search strings for our work, in terms of usable references returned, were the combination of state names with either water-body terms or subject terms. The qualifier “not marine” was also needed with the subject terms to limit returns to those dealing with freshwater. In many instances, a search had to be restricted to an individual state to stay below the limits for the maximum number of references returned per search for a particular bibliographic data base. Therefore, we ultimately used a set of 5 term phrases combined with each of 4 state names to produce 20 search strings that were applied to each bibliographic data base (table 8). The term “waterfowl” was included in the set of search strings because it assisted in identifying studies related to general aquatic habitat or predation on fish, invertebrates, and aquatic macrophytes for our evaluation; because birds are not a focus of NAWQA activities, studies exclusively concerning waterfowl were not presented in this report. Additional terms and “not” qualifications were tested and either did not improve the search returns regarding relevant articles or added significant numbers of irrelevant articles that needed to be evaluated before being culled. Overall, we found that the standard search strings in table 8 performed well in consistently returning citations that were already known to us and relevant to NAWQA objectives (an indication that those strings would also yield similar studies), and that using a variety of different bibliographic data bases increased the likelihood of getting comprehensive results.

Data Sources

Eleven bibliographic data bases were used to identify relevant articles on aquatic ecology topics in the NECB Study Unit. All bibliographic data bases contributed citations to our list in this report. The

Table 8. General search strings used in computerized literature searches

[Five basic strings were used for each of four states. Where “(state name)” is shown, we used the actual state name (for example, Maine) for the search. The “+” sign indicates a wildcard operation, where any additional characters are allowed for that term during the search]

Term category	Search string
1 Water body - lentic	(state name) and (pond+ or lake+ or reservoir+)
2 Water body - lotic	(state name) and (river+ or stream+ or tributary+)
3 Primary aquatic taxa	(state name) and (fish+ or alga+ or macroinvert+) not marine
4 Other terms	(state name) and (waterfowl or habitat or tissue) not marine
5 Toxics	(state name) and (contamina+) not marine

data-base names and years for which citations were available are given in table 9. The ending year of the range may not be indicative of a full calendar year of published articles available through a data base, because each is updated on its own schedule (from weekly to annually), and the earliest years may not have returned citations within the scope of this work. The precise format and amount of detail returned for each citation also varied considerably, both between data bases and for different citations within a single data base. For example, unlike more recent articles, older citations may lack abstracts and certain data-base-specific classification terms, and some citations would appear in all capital letters along with mixed-case citations in the same search results. Because of this variability, it was necessary to edit the original returns and consider which item in a set of duplicates contained the most complete and correct representation of a citation’s information.

Use of Bibliographic Software

Use of EndNote (version 3.0, Niles Software), a specialized bibliographic software package, facilitated our ability to store and edit citations, assured uniformity in the information stored, provided a simple means to identify and cull duplicates, and offered a variety of formatting and export options.

Table 9. Alphabetical listing of data bases used in the literature search for freshwater-ecology studies in the New England Coastal Basins

Data base	Years covered by search
AGRICOLA	1970 – 1997
Aquatic Sciences & Fisheries Abstracts	1991 – 1997
Article1st	1990 – 1998
BasicBIOSIS	1994 – 1997
Biological & Agricultural Index	1983 – 1997
BIOSIS Previews	1997
Dissertation Abstracts Online	1861 – 1998
Ecology Abstracts	1992 – 1997
Environment	1993 – 1998
Fish & Fisheries Worldwide	1971 – 1997
GeoRef	1785 – 1998

Two primary methods were used to get citation information into an EndNote bibliographic library: manual entry and importing from external files. Manual entry was used for citations located by some means other than online bibliographic searches, and importing was done whenever possible with citations gathered in an electronic format. Because of the structure of text exports from various bibliographic data bases, some manual manipulation of the raw citation information was usually required before the text could be imported into the EndNote citation record structure. Once the data were imported, each citation was then examined individually and, if needed, edited manually to remove extraneous characters representing special formatting (for example, italics, superscripts) and parsed to split combined data into separate fields in the EndNote record.

After the citations were in the library file, cleansed of errors, and processed for uniformity, two user-defined fields associated with each citation record were used to enter information about the scope of the reference and to hold comments. Each state, ecoregion, river basin, and ecological topic was assigned a letter/number code, and these codes were entered into a single field in the citation record to classify the citation. These codes would ultimately be matched with more detailed information about the classification items stored within the data-base application. A second user-defined EndNote field was

used to record a brief internal comment about the citation to aid in consideration for inclusion in the main classification table presented in this report. Finally, six tab-delimited text-file export formats were developed in EndNote and used to generate a set of coded reference information to feed a data-base application that processed them further.

Custom Data-base Application

Although the EndNote software is useful for organizing and standardizing citations, it is fairly inflexible in how data can be organized for display or summarization. A data-base application was developed by use of Microsoft Access (MS Access, version 8.0) to import the six tab-delimited text files generated from the EndNote library, to reorganize that

information in a simplified manner for easy manipulation and custom display formats, and to generate author and classification indexes. Import procedures developed using the Access programming language (Visual Basic for Applications) loaded the text files created from EndNote and parsed the data into prepared tables in a relational design. The import procedure identified the individual codes used to classify each citation by state, ecoregion, river basin, and ecological topic and indexed those items to allow citations to be grouped by those criteria. Finally, output routines in the Access application produced text files with fully formatted and numbered citations, an author index, and a matrix of citations and presence/absence information relating to the coded items (state, ecoregion, river basin, and ecological topic). Those output files served as the basis for the lists presented in this report.

