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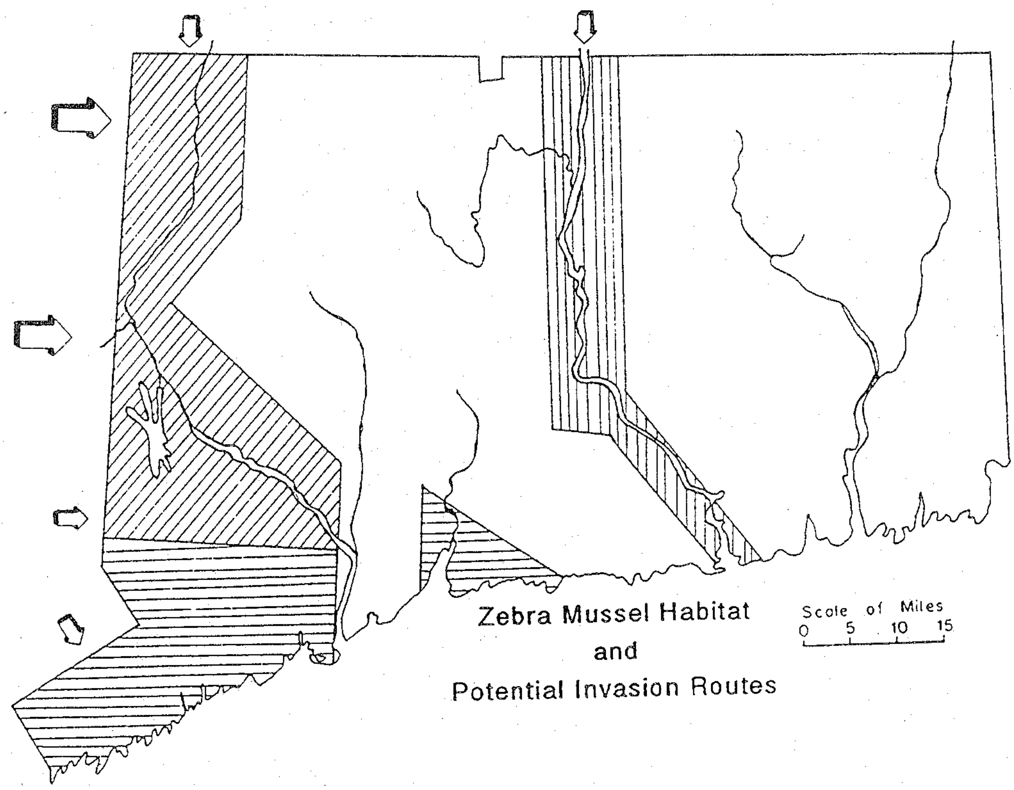

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Summary

The zebra mussel, *Dreissena polymorpha* (Pallas), is a biofouling organism which was introduced into the Laurentian Great Lakes in 1986. It has spread rapidly since its introduction, and is projected to invade surface waters from southern Canada to Texas. Its range is limited predominantly by water temperature and calcium ion concentration. If the concentration of calcium in surface waters is < 12 mg/L, survival of *Dreissena* is "unlikely" (Neary and Leach, 1992). If calcium is between 12-20 mg/L, successful invasion is "possible", and if greater than 20 mg/L, "probable" (Neary and Leach, 1992).

We have used the concentration of calcium in surface waters to predict the potential habitat and invasion routes for *Dreissena* in the State of Connecticut. The Housatonic River drainage system and associated hardwater lakes are probable mussel habitat and the most threatened in the state. The Housatonic receives hardwater and interstate boat traffic from New York and Massachusetts. The proximity of the adjacent Hudson River drainage (where *Dreissena* has already invaded) increases the likelihood of invasion within the next 12-18 months.

Marginal *Dreissena* habitat is also found in the south-western and south-central regional drainage basins, although recreational access (and therefore potential transport) is more restricted, reducing the likelihood of invasion. The Connecticut River will serve as the easternmost boundary for the spread of *Dreissena* in the state. The softwater of eastern Connecticut contains far less calcium than the 12 mg/L limitation demonstrated by Sprung (1987). Data on 230 lake and river sites in Connecticut are included.

Introduction

The zebra mussel, *Dreissena polymorpha* (Pallas), is a bivalve mollusc native to the Black Sea and Caspian Sea (Stancyzkowska, 1977). In the 19th Century, the construction of canals and the expansion of international shipping facilitated the westward spread of the zebra mussel, which today has invaded most of Europe, the western portion of the Commonwealth of Independent States, and Turkey (Miller *et al.*, 1992). The mussel invaded North America in 1986, after being introduced by international shipping into Lake St. Clair, near Detroit, Michigan. The first adult mussels were detected in Lake St. Clair in June of 1988 (Hebert *et al.*, 1989). By 1990, the mussel had spread throughout Lake Erie, the Welland Canal, Niagara River, and into Lake Ontario (Neary and Leach, 1992). By January, 1993, the mussel was found in all five Laurentian Great Lakes, a number of lakes in Ontario, the Erie Canal, two of New York's five Finger Lakes (Cayuga and Seneca), as well as in major river systems (Mohawk, St. Lawrence, Ottawa, Susquehana, Hudson, Illinois, Mississippi, Cumberland, Tennessee, Ohio, and Arkansas) (New York Sea Grant, 1993).

The zebra mussel is a pest organism infamous for its biofouling ability. The small (<5 cm) mussels are a formidable biofouling threat for several reasons. Females can release up to 10^6 eggs per season, which along with the 10^{10} sperm released by males, results in tremendous numbers of progeny (Miller *et al.*, 1992). The developing larvae (veligers) are very small (40-70 μm) and free swimming, spending 5-16 days in the water column (Griffiths *et al.*, 1991). Once the veligers settle, the developing adult attaches itself to a solid surface using upward of 100 proteinaceous byssal threads.

They will attach to natural surfaces like rocks, logs, aquatic plants, shells, and crayfish, as well as artificial substrates including plastic, concrete, glass, fiberglass, iron, and polyvinylchloride (PVC) pipe (Miller *et al.*, 1992). As a consequence, the mussels are a biofouling threat for submerged pipes, dams, locks, trash racks, and other commercial and industrial structures using raw water.

In addition to biofouling, the filtration capacity of the mussels may affect the cycling of energy in lake ecosystems. *Dreissena* feeds on particles in the water column, particularly algae in the 15-40 µm size range. The removal of algal cells in large numbers increases water clarity. Appearance of the mussels in western Lake Erie was followed by a doubling in mean Secchi disk transparency (Leach, 1991). One consequence of the voracious filtering ability of the mussels is the transport of organic carbon and nutrients from the water of a lake to the lake bottom. Large numbers of *Dreissena* deplete the food sources of other filter feeders, like zooplankton, in the open water. Reduction in zooplankton populations has an impact on the predators that prey on zooplankton. More research is required to determine the impact of *Dreissena* on higher trophic levels, but the threat to fisheries management is obvious. High reproductive rate and filtering capacity give *Dreissena* a competitive advantage over native unionids (Neary and Leach, 1992; Mackie, 1990).

High filtering capacity causes an accumulation of pollutants and nutrients in *Dreissena*. Organic pollutants have been measured in zebra mussel tissue in concentrations 300,000 times greater than the concentration in surrounding water (Snyder *et al.*, 1991). The impact of that biomagnification on higher trophic levels has yet to be determined.

Impacts of the mussel on recreation are also negative. By 1989, large piles of *Dreissena* shells were washing up on Lake Erie beaches (Snyder *et al.*, 1991). Decomposing mussels are an olfactory nuisance, and their sharp shells are forcing beach patrons to wear protective footwear. By the year 2000, the tenacious mussel could cause 5 billion dollars in damage in the U.S. (Miller *et al.*, 1992). Now that it has arrived in the U.S., dealing with *Dreissena* poses two questions. First, can the mussel be stopped? And second, if we are unable to stop the progress of the mussel, can we predict where and when it will spread?

Dreissena has proven itself an excellent disperser. It has moved into all of the contiguous canals and rivers of the Great Lakes within a few years of introduction. In terms of human-assisted transport, the mussel has hitchhiked in or on live wells, bait buckets, bilges, aquatic weeds, boat trailers, boat hulls (particularly river barges), outdrives, etc. from one lake and river to another.

The zebra mussel has few natural enemies. It is preyed upon by some fish species, such as freshwater drum (*Aplodinotus grunniens*), catfish (*Ictalurus nebulosus*), and lake sturgeon (*Acipenser oxyrhynchus*). In addition, it is a food source for dabbling and diving ducks like scaup (*Athya marila*) and canvasbacks (*Athya valisineria*) (Snyder *et al.*, 1992). It is unlikely that natural predation will be able to contain the spread of the zebra mussel (Miller *et al.*, 1992). The only biocide documented to be effective to date is chlorine, in either low concentration doses over several weeks, or high concentration slugs over shorter duration. However, either approach can have downstream consequences on non-target organisms. In terms of treating boats and trailers, the choices are antifouling coatings and/or diligent cleaning. Antifouling

coatings containing copper or tributyltin are effective at preventing settlement. However, the coatings with tributyltin are restricted or banned in many states. Boats and trailers can also be cleaned with high pressure steam, and/or left to dry in hot, dry air (Snyder *et al.*, 1991). To be truly effective, however, all hulls, trim tabs, outdrives, and outboard lower units must be inspected and cleaned (O'Neill and MacNeill, 1991). The possible vectors multiplied by the number of recreational boat users in affected areas indicate the probability that *Dreissena* will continue its march out of the Great Lakes area. The next logical step is to predict where and when the mussel will spread.

Object of This Study

The goal of our study was to make predictions about the eastward spread of *Dreissena* out of the Hudson River drainage into New England. In particular, we are concerned with the surface waters of the State of Connecticut, which as of April, 1993, have not recorded any sitings of *Dreissena*. Predictions require a knowledge of environmental variables that limit the existence of the zebra mussel. Temperature limits *Dreissena* growth below 10°C (Morton, 1969). The females do not lay eggs until water temperature reaches 11-12°C (Miller *et al.*, 1992). McMahon and Tsou (1990) indicated that water temperatures greater than 26-32°C may kill either larvae or adults. Strayer (1991) explored the existing environmental data for European lakes where *Dreissena* is found. Both Strayer (1991) and McMahon and Tsou (1990) indicate that the comparison of climate, and the thermal biology of *Dreissena* indicate a potential range in North America from southern Canada and most of the continental U.S., to approximately mid-Texas.

Dreissena is a shell-bearing organism that also requires calcium. Sprung (1987) found larval development in the lab was limited below pH 7.4, and minimal larval survival occurred below 12 mg/L Ca^{++}. Neary and Leach (1992) inferred from Sprung's (1987) data that 10% of total rearing success occurred at approximately 20 mg/L Ca^{++}. In a recent multivariate analysis, Ramcharan *et al.* (1992) indicated that European lakes with populations of *Dreissena* for at least 50 years are characterized by calcium concentrations greater than 28 mg/L . That range of calcium data in the literature leave critical questions unanswered. For example, the 28 mg/L Ca^{++} cited by Ramcharan *et al.* (1992) may reflect the concentration of calcium required to

support existing populations. No evidence to date documents the concentration required for colonists to become established, since Sprung's (1987) data were from laboratory studies only.

Neary and Leach (1992) used calcium and pH data for 6151 lakes in Ontario to predict the potential habitat for *Dreissena*. They used a geographic information system (GIS) to predict the likelihood of invasion and survival based on three categories. Survival likelihood was "unlikely" if $pH < 7.4$, and $Ca^{++} < 12$ mg/L. Survival was "possible" if $pH \geq 7.4$ and $Ca^{++} = 12\text{-}20$ mg/L. And survival was "probable" if $Ca^{++} > 20$ mg/L (Neary and Leach, 1992). Their classification scheme bridges the range of calcium concentrations in the existing laboratory studies (Sprung, 1987) and the analysis of European data (Ramcharan *et al.*, 1992). We have adopted Neary and Leach's (1992) scheme for the following analysis.

We have used the total calcium concentration in surface waters to predict the likelihood of successful invasion of *Dreissena* into the State of Connecticut. We have included both lakes and rivers in our study, although limitations of *Dreissena* in running waters have not been adequately described to date, as observed by Strayer (1991). We assume that calcium concentrations that limit growth in rivers and streams are the same as those documented for lake systems and in laboratory studies. pH data were also collected since pH is often variable in freshwater, but our results and discussion focus primarily on the calcium ion concentration. We have also attempted to assess the likelihood of *Dreissena* invasion in Connecticut waters based on available transport vectors (predominantly recreational boat use).

Materials and Methods

A survey of existing water quality data was augmented with field sampling from portions of the state where little historical data were available. A majority of our data was obtained from Jokinen (1983) who documented water chemistry data for over 200 stream and lake sites in Connecticut. Various state publications and data from water companies were also combined into one large data set of 230 sites (Appendix A). Regions in the state where data were lacking, or where we suspected high Ca^{++} concentrations (western CT) were sampled during the summer of 1992. Lake and river sites were sampled between 13 August and 19 September, 1992. One liter surface samples were taken in acid-washed polyethylene bottles and returned to the laboratory on ice. The focus of the chemical analyses was on calcium, although we also performed analyses for other variables that correlate with calcium ion concentration including other cations, alkalinity, dissolved inorganic carbon, and conductivity.

Dissolved inorganic carbon (DIC) was determined with a MSA Model 202 infrared CO_2 analyzer. DIC results are reported as mg C/L. Alkalinity was determined using a modified Gran titration (Wetzel and Likens, 1991). Alkalinity, or acid neutralizing capacity (ANC) results are reported as mg $CaCO_3$/L. Cations (Ca^{++}, Mg^{++}, Na^+, K^+) were determined in acidified (HNO_3) samples by atomic absorption and emission with a Perkin Elmer Model 306 Atomic Absorption Spectrophotometer. Cation analyses were calibrated with standard curves constructed with known standards for each element (APHA, 1980) (R^2=0.99 for each element). Cation results are reported as mg/L. Conductivity was determined with a MSI Model 31

conductivity bridge with a cell constant = 0.1. pH was determined with a Corning Model 10 pH meter and combination electrode.

Results

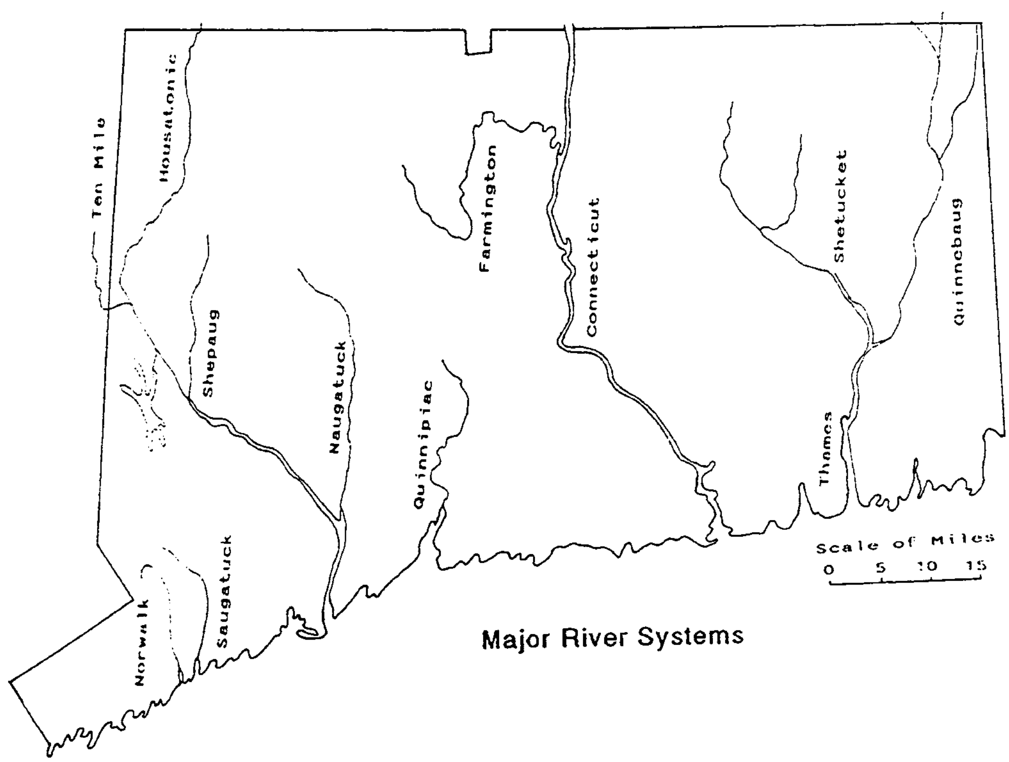

Figure 1. River Systems of Connecticut: Major rivers are both potential habitat and transport vectors for *Dreissena.*

We divided the state into regions based on the major river basins (Figure 1). Eastern Connecticut is drained by the Thames River and its tributaries, the Quinnebaug, Shetucket, and Willimantic Rivers. Central Connecticut is drained by the Connecticut, Farmington, and Quinnipiac Rivers. And western Connecticut is dominated by the Housatonic River, its tributaries the Shepaug and the Naugatuck,

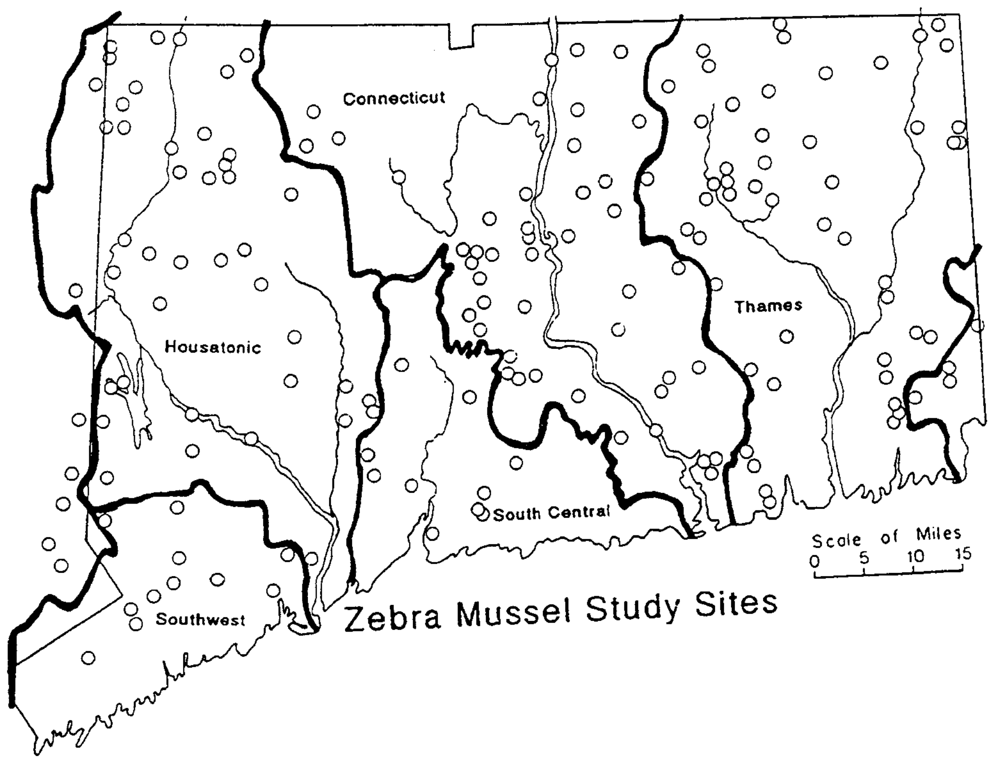

Figure 2. Zebra Mussel Study Sites: The open circles are sites for which Ca^{+2} data have been determined.

and the coastal Norwalk, and Saugatuck River basins. We have collected data from sites in the Thames, Connecticut, South Central, Housatonic, and Southwest Major Drainage Basins (State of Connecticut, 1982) (Figure 2). Many of our study sites are contiguous, and are plotted as a single location in Figure 2. The data from all lake sites are listed in Appendix A1. Data from all river sites are listed in Appendix A2.

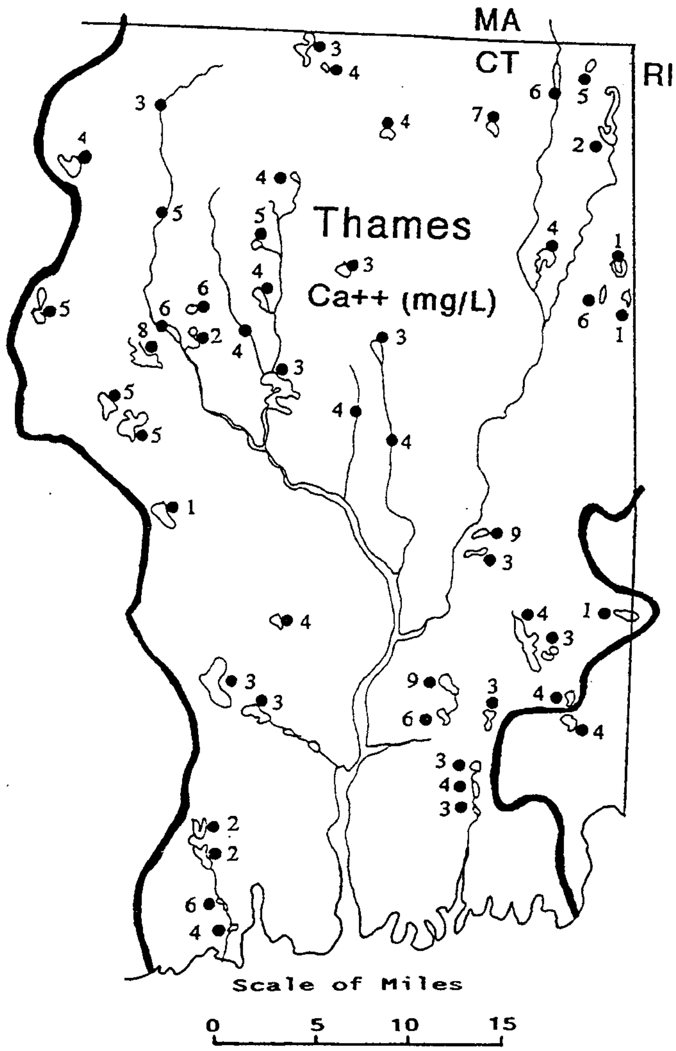

Figure 3. Thames Major Basin: Calcium Concentration (mg/L) in the Thames Drainage System.

The Thames drainage basin is the easternmost drainage in Connecticut, borders the Pawcatuck Basin in Rhode Island, and includes parts of Massachusetts and Rhode Island. The Thames drains hard rock gneiss and schist and contains the softest water in Connecticut (Figure 3). Calcium concentrations in the Thames basin are all less than 10 mg/L and the majority of samples are below 5 mg/L. One site in the adjacent Pawcatuck drainage basin, which is predominantly in Rhode Island, was

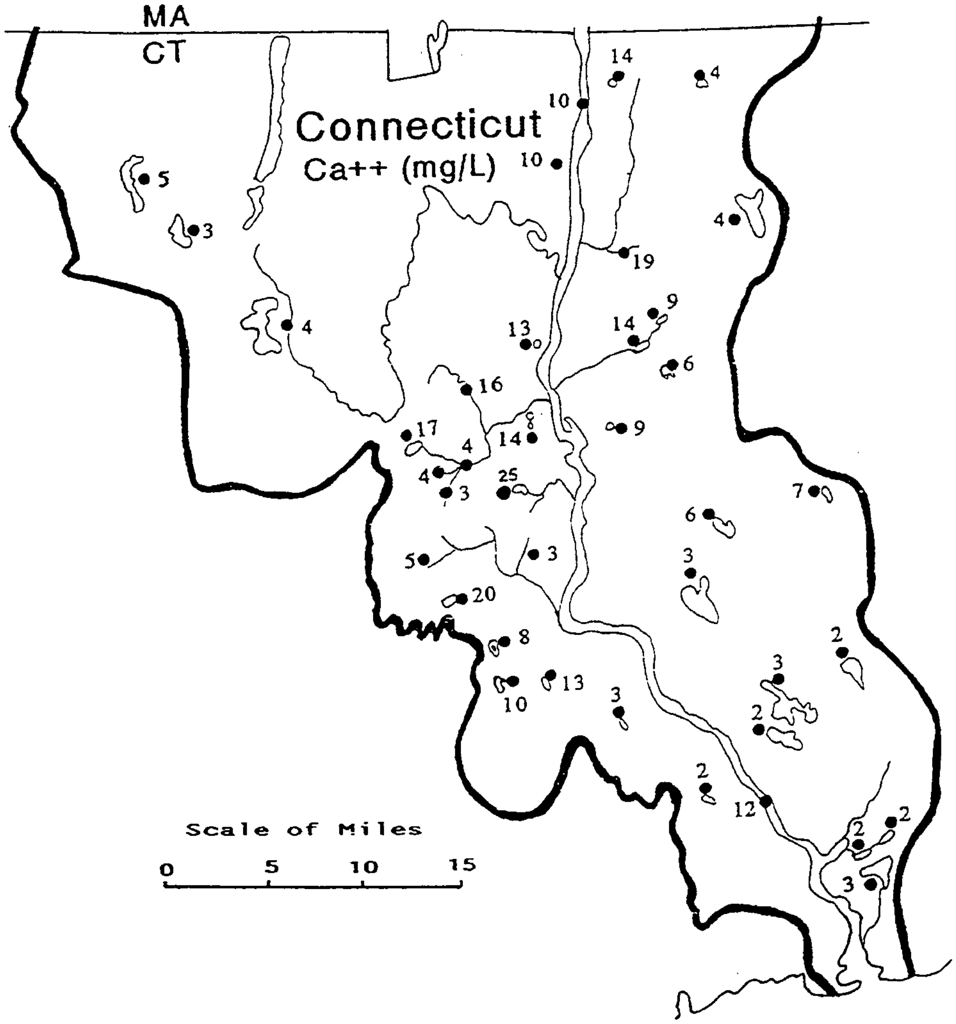

Figure 4. Connecticut Major Basin: Calcium Concentration (mg/L) in the Connecticut Drainage System.

also low in Ca^{++}, with a concentration of 4 mg/L. Using the Neary and Leach (1992) predictive terminology, *Dreissena* invasion and survival in the Thames basin is unlikely.

The next major basin to the west is the Connecticut. The Connecticut River drains most of the Central Valley (which is predominantly sandstone) before entering into the harder rock of the eastern highlands at Middletown.

Site	Location	Ca^{++} (mg/L)	pH	Habitat
Freshwater Pond	Enfield	14	7.3	Possible
Hilliard's Pond	Manchester	19	7.6	Possible
Center Sp.Pk.Pd.	Manchester	14	7.1	Possible
Batterson Pk.Pd.	Farmington	17	-	Possible
Trout Bk.	W.Hartford	16	7.3	Possible
Keney Pk. Pond	Hartford	13	7.1	Possible
Goodwin Pk.Pond	Hartford	14	6.9	Possible
Silver Lake	Berlin	20	-	Possible
1860 Res.	Wethersfield	25	-	Probable
Dooley Pd.	Middletown	13	7.6	Possible
Connecticut River	Deep River	12	7.2	Possible

Table 1. Connecticut River Drainage: Chemical Data and Habitat Potential Based on Calcium Concentration.

All of the lake sites sampled east of the Connecticut river had Ca^{++} less than 10 mg/L, much like the Thames drainage (Figure 4). Some of the tributary streams and ponds had Ca^{++} above 12 mg/L, which indicates local deposits of calcareous rock interbedded in the sandstone, and/or contributions from point sources like sewage (Table 1). Nine lake and pond sites would be possible *Dreissena* habitats, and one (the 1860 Reservoir) would be classified as probable. The Connecticut River had 10 mg/L Ca^{++} at Windsor Locks and 12 mg/L at Deep River (Figure 4). The river currently supports a population of the Asian clam *Corbicula fluminea,* an indication it could

likely support *Dreissena* (McMahon, pers. comm.). Since the river receives drainage from an area stretching north to the Canadian border, and receives both commercial and recreational boat traffic, we classify the Connecticut River as possible habitat, although it is unlikely that large populations of *Dreissena* could be supported. The Connecticut River, therefore, will be the easternmost boundary for the spread of *Dreissena* in the state.

Lake	Location	Ca++ (mg/L)	pH	Habitat
Linsley Pond	N. Branford	12	7.8	Possible
Lake Whitney	Hamden	14	7.4	Possible
Black Pond	Middlefield	14	7.5	Possible
Cedar Pond	N.Branford	16	8.9	Possible
N. Farms Res.	Wallingford	19	7.2	Possible
Lake Saltonstall	E. Haven	21	8.4	Probable

Table 2. South Central Drainage: Chemical Data and Habitat Potential Based on Calcium Concentration.

Below the Connecticut drainage is the South Central Major Basin (Figure 5). The range of calcium concentrations in the drainage is 3-21 mg/L Ca^{++}. Possible habitat in the South Central Basin includes North Farms Reservoir, Linsley Pond, Cedar Pond, Black Pond, and Lake Whitney (Table 2). Lake Saltonstall is probable habitat (21 mg/L), although the source of the calcium is unknown (Table 2).

The westernmost major drainage basin in Connecticut is the Housatonic system (Figure 6). The Housatonic River is probable habitat throughout its length

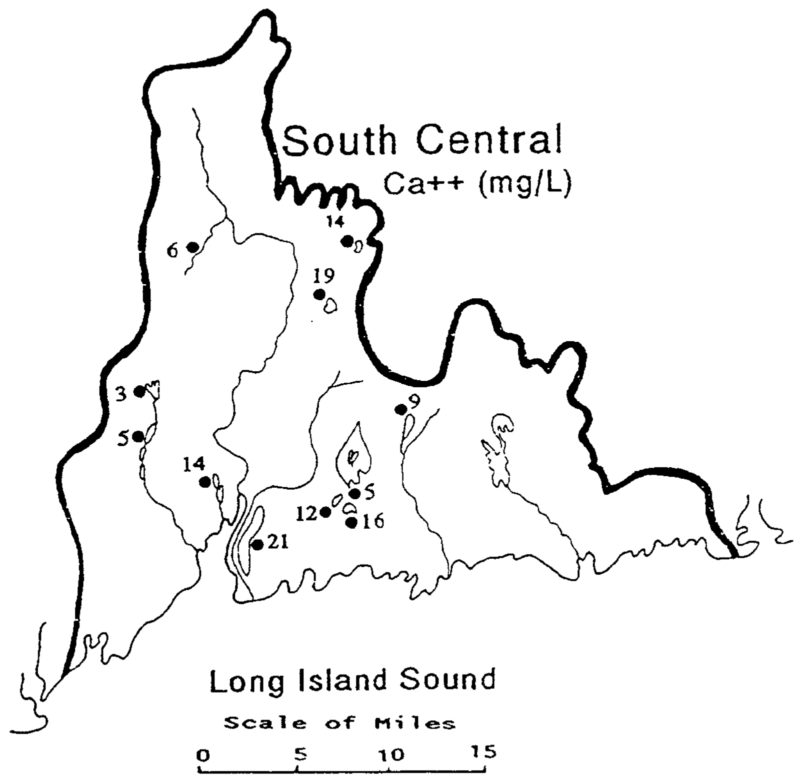

Figure 5. South Central Major Basin: Concentration of Calcium (mg/L) in the South Central (Quinnipiac R.) Drainage.

(Table 3). The Housatonic River receives drainage from the Ten Mile River, which enters from New York near Kent, CT. The Ten Mile River is a potential vector for *Dreissena* into the Housatonic system. At least sixteen potential pond and lake sites could be habitat for *Dreissena* in the Housatonic system (Figure 6). The northwestern corner of the state has most of the hardwater lakes, and consequently, most of the probable habitat (Table 4). Lakes immediately across the border in New York state

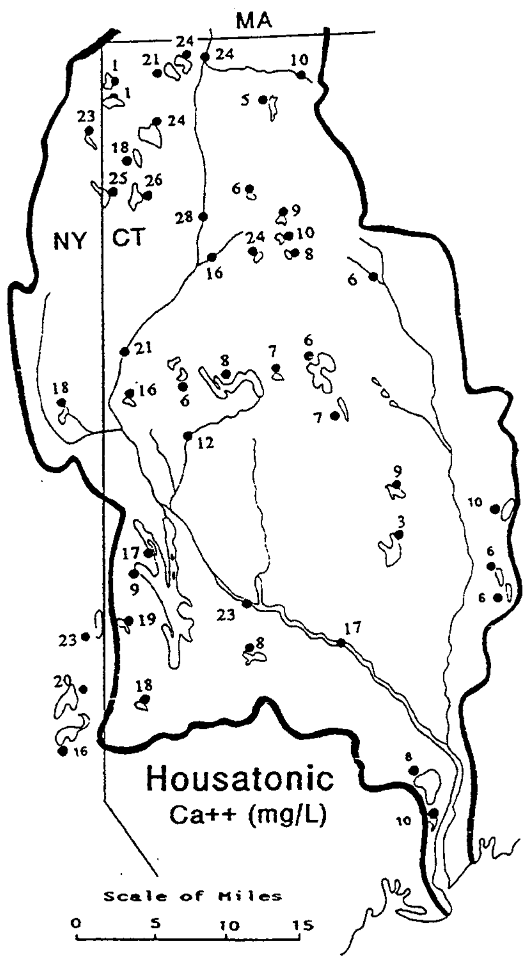

Figure 6. Housatonic Major Basin: Concentration of Calcium (mg/L) in the Housatonic, Naugatuck, and Shepaug Drainages.

are also hardwater, and probable *Dreissena* habitat once the mussel moves out of the Hudson River. The Naugatuck River drains harder rock (schist and gneiss, similar to eastern CT) (Figure 6) and will act as a barrier to *Dreissena*.

The last drainage system to be discussed is the Southwestern Basin (Figure 7). Four locations in southwestern CT can be classified as possible habitat (Table 5). These sites are important because they were sampled at or near major water supply

Site	Location	Ca^{++} (mg/L)	pH	Habitat
Housatonic R.	Norfolk	24	7.4	Probable
Housatonic R.	Cornwall	28	8.3	Probable
Furnace Bk.	Cornwall	16	7.1	Possible
Housatonic R	Kent	21	7.7	Probable
E. Aspetuck R.	New Milford	12	7.3	Possible

Table 3. Housatonic Drainage, River Sites: Concentration of Calcium (mg/L) and Invasion Potential of the Housatonic River and Two Tributaries.

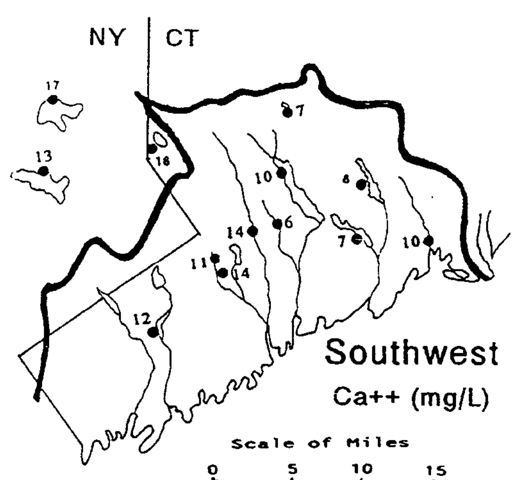

Figure 7. Southwest Major Basin: Concentration of Calcium (mg/L) in the Southwestern Corner of Connecticut.

reservoirs. The habitat is marginal, but it is within a few miles of probable hardwater sites.

Lake	Location	Ca^{++} (mg/L)	pH	Habitat
East Twin Lake	Salisbury	24	7.7	Probable
West Twin Lake	Salisbury	21	7.4	Probable
Lake Wononscopomuc	Salisbury	24	8.1	Probable
Lake Wononpakook	Salisbury	18	-	Possible
Rudd Pond	Millerton, New York	23	8.4	Probable
Indian Lake	Sharon	25	7.2	Probable
Ellis Pond	Dover, New York	18	8.5	Possible
Mudge Pond	Sharon	26	7.5	Probable
Hatch Pond	Kent	16	7.6	Possible
Candlewood Lake	New Fairfield	17	7.4	Possible
Ball Pond	New Fairfield	19	7.7	Possible
Putnam Lake	Patterson, New York	23	8.0	Probable
Lake Kenosia	Danbury	18	7.0	Possible
E. Branch Res.	Southeast, New York	20	7.8	Possible
Lake Lillinonah	Brookfield	23	7.5	Probable
Lake Zoar	Southbury	17	7.6	Possible

Table 4. Housatonic Drainage, Lake Sites: Chemical Data and Habitat Potential Based on Calcium Concentration.

Site	Location	Ca^{++} (mg/L)	pH	Habitat
Titicus Res.	N. Salem, New York	17	8.0	Possible
Cross River Res.	Lewisboro, New York	13	8.1	Possible
Norwalk River	Wilton	14	7.1	Possible
Silvermine Bk.Pd.	Wilton	14	8.3	Possible
N. Stamford Res.	Stamford	12	7.4	Possible

Table 5. Southwest Drainage: Chemical Data and Habitat Potential Based on Calcium Concentration.

Discussion

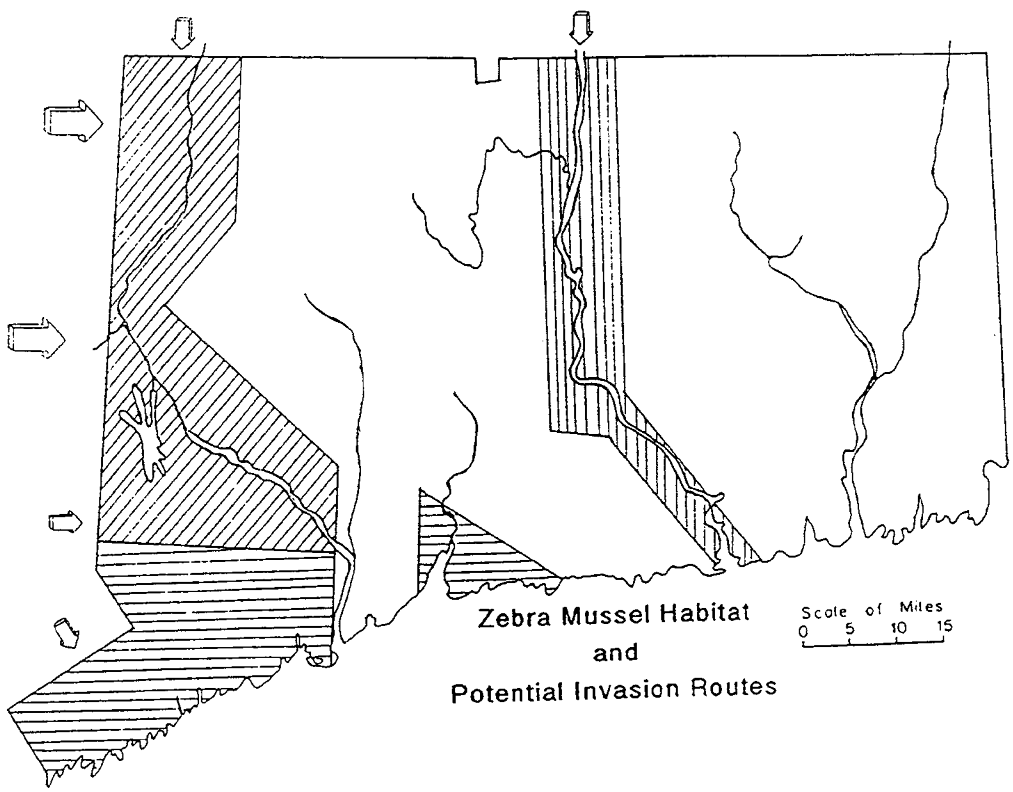

Figure 8. Zebra Mussel Habitat and Potential Invasion Routes: Potential Habitat Indicated by Hatching. Invasion Routes Marked by Arrows.

We summarize by considering both potential habitat and invasion routes together (Figure 8). The biggest threat to the state is in the marble valleys of the Housatonic drainage. Invasion potential via the Housatonic River is also high. The Housatonic River receives drainage from 535 mi^2 in western Massachusetts, 210 mi^2 of

the Ten Mile River system in New York, and another 485 mi^2 (above the Shepaug Dam) from streams in Connecticut (Thomas, 1972). Much of that total drainage area is probable habitat for *Dreissena.*

Recreational use of the surface waters in the Housatonic system is extensive, and includes interstate boat traffic. The adjacent Hudson River drainage is already colonized by *Dreissena*. The mussel has found its way into similar habitat throughout the Great Lakes area in just a few years. Thus it is likely the mussel will be found in the Housatonic River, the river impoundments, or in the recreational lakes along the New York border before the end of 1994.

The next most susceptible region in the state is the southwestern corner, below the Housatonic drainage. The habitat is far less suitable than the Housatonic basin in general. However, hardwater exists just to the north and west, which means potential colonizers will be at the edges of the Southwestern Drainage system soon after invading the state. Possible habitat may exist in the reservoirs of the southwestern corner missed in our survey.

Our study, like other surveys to date, focussed on surface water chemistry, with the assumption that the concentration of calcium at the surface reflects the entire water column. However, during summer, decomposition of organic matter at the bottoms of low calcium lakes may produce enough additional calcium to support *Dreissena*. This would be worth investigating in the deep reservoirs of the southwestern corner of the state. It is also a possibility in other lakes in the state, but without a continual source of potential colonizers, it is doubtful that within-lake microhabitat will sustain nuisance populations.

In the South-Central region, Lake Saltonstall is the primary resource at risk. It is probable habitat, but recreational boating is limited to on-site livery only. Little is known about the ability of waterfowl to carry *Dreissena* from lake to lake, but they are a potential vector in the absence of recreational boat use, particularly from the Housatonic estuary to the west. Migration of *Dreissena* from the Housatonic estuary to the Quinnipiac estuary is not considered to be a high probability.

Lastly, the Connecticut River represents the easternmost boundary for the spread of *Dreissena* in Connecticut. There is softwater to the east and west (through the Naugatuck drainage), which will limit the direct access of the mussel to the Connecticut River. Some could be carried into the lower river by commercial boat traffic, and some could enter the upper river from Massachusetts. However, calcium concentrations in the river are minimal for habitat. It is possible that some colonization could occur locally at sewage treatment plant outfalls, although it is doubtful that a large population could be supported.

We have shown that there is suitable habitat for the zebra mussel to invade the State of Connecticut. The experience from the Great Lakes indicates that if the habitat is suitable and vectors for transport exist, such as commercial shipping or recreational boating, the mussels will migrate readily and promptly. We have used what is currently the best known predictor of zebra mussel habitat; the concentration of calcium. Neary and Leach (1992) who used a similar rationale in predicting the potential habitat in Ontario acknowledged that calcium and pH are variables that change both spatially and temporally in lakes. We hope that by using the classification system based on the 12, 12-20 and >20 mg/L Ca^{++}, we have accounted

for some of that variability. If further research indicates that the mussels have different limitations, then the interpretation in this report can be readjusted accordingly. We will know the strength of our predictions in the very near future.

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Appendix A: Chemical Data

The chemical data from all sites are presented in the following tables. Appendix A.1. lists lakes and ponds alphabetically and Appendix A.2. lists rivers and streams alphabetically. Appendix A.3. lists lake and pond sites sampled in New York.

The following abbreviations are used in Appendix A:

Ca = concentration (mg/L) of calcium ions determined by atomic absorption

Mg = concentration (mg/L) of magnesium ions determined by atomic absorption

Na = concentration (mg/L) of sodium ions determined by atomic absorption

K = concentration (mg/L) of potassium ions determined by atomic absorption

ANC = acid neutralizing capacity determined by Gran titration, expressed as mg/L $CaCO_3$

DIC = concentation of inorganic carbon determined by Infrared Analyzer, expressed as mg/L carbon

Conduct = Specific Conductance in µmhos/cm

Source = numbers refer to sources listed below

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Other Abbreviations Used in the Following Tables:

Bk = Brook
Lk = Lake
Pk = Park
Pd = Pond
R. = River
Res = Reservoir
Trib = Tributary

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Table A.1. Chemical Data for Connecticut Lake Sites

Site	Township	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	ANC (mg /L)	DIC mg C/L	Conduct µmhos/cm	pH	Source
1860 Reservoir	Wethersfield	24.6	8.2	7.4	1.2	71.5	-	-	-	6
Addison Pond	Glastonbury	8.8	2.1	7.4	1.3	-	7.1	139.0	7.0	1
Alexander Lake	Killingly	3.8	1.2	3.7	1.0	6.0	-	46.4	6.4	2
Amos Lake	Preston	9.4	6.1	8.3	1.7	5.4	-	84.5	-	2
Andover Lake	Andover	5.4	3.2	6.9	1.4	5.4	-	84.9	-	2
Ashford Lake	Ashford	3.8	2.4	3.9	1.4	-	3.3	-	-	1
Aspinook Pond	Griswold	6.0	1.9	10.5	2.4	-	2.4	91.0	6.5	1
Avery Pond	Preston	5.8	2.3	6.0	1.7	-	4.8	89.0	6.5	1
Ball Pond	New Fairfield	18.6	13.7	19.1	1.8	51.5	10.8	190.7	7.7	3
Bantam Lake	Litchfield	9.0	3.9	6.2	-	-	-	96.0	-	1
Bashan Lake	East Haddam	2.2	1.7	5.1	1.1	1.4	-	52.7	-	2
Batterson Pk Pd	Farmington	16.8	4.7	10.1	0.8	33.0	-	-	-	6
Beach Pond	Voluntown	1.4	0.5	5.3	1.1	1.4	-	48.6	7.0	2
Beaver Dam Lake	Stratford	9.6	3.8	9.7	2.5	-	1.8	191.0	6.6	1
Beseck Lake	Middlefield	10.8	6.1	9.2	0.8	26.8	6.1	122.0	7.2	3
Bethany, Lake	Bethany	3.3	1.7	5.5	-	10.0	-	78.0	6.8	11
Bicentennial Pond	Mansfield	7.7	2.2	7.9	1.4	-	5.1	107.0	6.1	1
Bigelow Pond	Union	4.2	1.4	6.2	0.8	5.0	-	-	-	6
Billings Lake	North Stonington	4.4	0.8	4.1	0.8	5.0	-	-	-	6
Black Pond	Middlefield	14.0	8.4	12.5	1.0	41.8	9.3	130.2	7.5	3
Black Pond	Woodstock	3.8	1.3	5.3	0.8	7.0	-	-	-	6
Bog Meadow Pond	Killingly	1.3	0.4	2.7	0.5	-	3.2	38.0	5.6	1
Bridge Street Pd	Suffield	4.6	2.9	6.0	1.0	-	10.7	88.0	6.3	1
Brown Hill Pond	Hampton	1.5	0.6	3.7	1.1	-	0.1	30.0	6.4	1
Bunnell's Pond	Bridgeport	9.9	3.3	22.0	2.9	-	3.5	207.0	-	1
Burr Pond	Torrington	3.6	3.6	16.4	1.2	7.4	2.2	102.0	6.4	3
Candlewood Lake	New Fairfield	17.2	17.2	11.3	1.1	47.7	10.4	150.0	7.4	3
Cedar Lake	Chester	2.4	0.9	2.4	0.7	-	6.4	43.0	6.1	1
Cedar Pond	North Branford	16.0	4.2	29.2	1.3	-	19.0	262.0	8.9	1
Center Sprg Pk Pd	Manchester	14.2	3.2	7.3	2.1	-	2.7	201.0	7.1	1
Chase Reservoir	Killingly	5.8	0.8	2.2	1.0	-	3.6	65.0	6.6	1
Clayville Pond	Griswold	2.7	1.1	7.7	2.0	-	1.1	95.0	5.7	1
Columbia Lake	Columbia	5.4	1.9	5.3	1.1	2.8	-	64.1	6.6	2
Cream Hill Pond	Cornwall	9.0	2.6	5.1	0.8	46.0	-	-	-	6
Crystal Lake	Ellington	3.6	2.4	9.7	1.6	3.2	-	114.8	6.1	2
Dodge Pond	East Lyme	4.0	1.5	4.4	0.9	3.0	4.5	79.0	6.0	1
Dog Pond	Goshen	8.5	4.9	6.8	-	-	7.6	162.0	7.3	1
Dooley Pond	Middletown	13.0	5.8	9.1	0.8	29.5	6.0	96.0	7.6	3
Dunham Pond	Mansfield	2.0	1.0	3.0	1.0	-	1.5	40.0	6.2	1
Eagleville Lake	Coventry	5.6	5.0	10.6	2.0	6.0	-	127.3	6.8	2
East Twin Lake	Salisbury	24.2	18.7	3.2	1.2	97.2	20.9	194.3	7.7	3
Eddy Pray Pond	Killingly	0.8	0.1	2.3	0.5	-	0.3	34.0	5.4	1
Fitchville Pond	Bozrah	4.1	1.3	3.9	1.6	-	4.4	76.0	6.1	1
Freshwater Pond	Enfield	14.3	3.6	40.5	3.0	-	9.5	310.0	7.3	1
Gaillard, Lake	North Branford	4.8	1.8	3.4	0.6	11.0	-	69.0	7.2	9
Gardner Lake	Salem	3.4	2.5	6.7	1.2	3.2	-	70.1	-	2
Glasgo Pond	Griswold	3.4	3.2	6.0	1.9	4.0	-	68.3	-	2
Glenville Pond	Stafford	2.8	1.9	5.8	1.5	-	1.6	65.0	5.2	1
Globe Hollow Res.	Manchester	6.0	2.4	5.8	1.1	-	5.6	103.0	7.0	1
Golf Course Pond	East Hartford	19.6	2.9	8.0	2.8	-	15.2	220.0	7.0	1
Goodwin Pk Pd A	Wethersfield	19.6	4.2	11.9	2.0	-	14.2	280.0	7.0	1
Goodwin Pk Pd B	Hartford	14.0	3.7	5.4	0.9	-	7.5	170.0	6.9	1
Gorton Pond	East Lyme	6.0	1.8	6.4	1.6	9.5	-	-	-	6
Gravel Pit Pond	Glastonbury	13.2	3.9	13.8	5.3	-	10.5	199.0	7.2	1
Hall's Pond	Eastford	2.5	1.0	2.6	0.5	-	0.2	-	-	1
Hatch Pond	Kent	15.8	8.8	8.1	1.3	-	12.7	274.0	7.6	1
Hayward Lake	East Haddam	2.4	1.0	4.4	1.2	-	0.9	45.0	6.2	1

Table A.1. Chemical Data for Connecticut Lake Sites (Continued)

Site	Township	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	ANC (mg /L)	DIC mg C/L	Conduct µmhos/cm	pH	Source
Hemlock Reservoir	Easton	7.5	4.7	5.2	0.8	17.4	4.5	92.8	7.0	3
Higganum Res.	Haddam	3.2	1.7	4.9	1.2	-	4.2	89.0	6.3	1
Highland Lake	Winchester	4.6	4.6	11.9	1.0	11.5	3.1	98.6	6.8	3
Hill Road Pond	Glastonbury	2.6	1.0	4.4	0.7	-	0.8	56.0	6.2	1
Hilliard's Pond	Manchester	19.8	4.2	10.5	1.8	-	16.7	403.0	7.6	1
Hillyndale Rd Pd	Mansfield	3.5	0.9	3.9	1.1	-	1.6	85.0	6.4	1
Hitchcock Lake	Wolcott	10.2	2.0	10.8	1.2	20.0	-	-	-	6
Holbrook Pond	Hebron	7.1	2.0	4.8	0.3	-	4.5	74.0	6.4	1
Housatonic, Lake	Shelton	21.2	7.9	7.8	1.6	80.9	-	-	-	6
Indian Pond	Sharon	24.8	19.8	7.6	1.1	109.8	24.8	224.2	7.2	3
Keney Park Pond	Hartford	13.4	3.3	6.5	1.7	-	10.0	169.0	7.1	1
Kenosia, Lake	Danbury	18.0	7.6	7.1	1.8	-	12.5	252.0	7.0	1
Lake of Isles	North Stonington	2.5	1.1	3.4	0.2	-	1.4	39.0	6.6	1
Lakeville Res #2	Salisbury	12.1	2.6	1.0	0.7	45.0	-	88.4	7.5	8
Lantern Hill Pond	Ledyard	3.2	1.3	5.1	0.5	-	2.3	57.0	6.3	1
Leatherleaf Bog	Killingly	0.9	0.1	3.3	0.4	-	0.9	37.0	5.2	1
Lillinonah, Lake	Brookfield	23.1	19.5	12.9	1.4	77.4	16.8	202.0	7.5	3
Linsley Pond	North Branford	12.0	4.2	18.5	2.0	-	21.8	241.0	7.8	1
Little Pond	Thompson	4.7	1.5	4.2	1.4	-	5.0	85.0	6.1	1
Long Hill Res	Naugatuck	6.4	-	-	-	-	-	-	7.0	7
Long Meadow Pd	Bethlehem	6.6	1.7	5.1	1.6	9.0	-	-	-	6
Long Pond	Ledyard	3.8	2.3	5.1	0.4	9.5	-	-	-	6
Lower Bolton Lake	Bolton	4.8	2.9	7.8	1.5	3.6	-	89.3	-	2
Lower Candee Res	Naugatuck	9.6	-	-	-	17.0	-	-	6.8	7
Lower Stamfd Res	New Canaan	16.6	6.8	22.3	1.5	14.4	10.8	245.0	6.5	3
Mamanasco Lake	Ridgefield	17.6	6.0	8.6	1.5	-	11.1	261.0	7.2	1
Mansfield Hollow	Mansfield	3.2	1.7	4.8	1.1	-	-	61.0	6.2	1
Middle School Pd	Mansfield	8.5	2.8	4.0	2.0	-	2.4	53.0	6.7	1
Maple Road Pd A	Mansfield	8.2	2.0	7.0	2.8	-	7.2	123.0	7.2	1
Maple Road Pd B	Mansfield	5.1	2.0	5.2	1.8	-	6.8	81.0	6.8	1
Mashapaug Pond	Union	2.6	3.1	7.1	1.3	1.6	-	46.8	7.1	2
McLaughlin Pond	Mansfield	5.2	2.7	4.0	3.0	-	6.6	78.0	6.6	1
Middle Bolton Lk	Vernon	3.6	2.6	7.6	1.4	2.8	-	76.2	-	2
Middle Reservoir	Killingly	1.7	0.3	3.5	0.5	-	1.1	45.0	6.0	1
Mohawk Pond	Cornwall	2.4	1.1	1.8	0.2	-	0.3	38.0	7.0	1
Moodus Reservoir	East Haddam	3.0	2.5	5.8	1.1	2.6	-	55.8	6.3	2
Moody Reservoir	Naugatuck	6.0	-	-	-	-	-	-	6.9	7
Moritz Pond	Ashford	4.3	3.0	-	0.7	-	5.1	74.0	6.1	1
Mt. Higby Res	Middlefield	8.1	4.6	9.9	0.8	27.4	6.7	89.8	7.0	3
Mt. Tom Pond	Morris	7.2	2.9	7.7	1.6	-	5.4	104.0	6.7	1
Mudge Pond	Sharon	25.9	10.1	7.0	1.2	136.9	26.7	272.0	7.5	3
Mulberry Res	Naugatuck	8.4	-	-	-	-	-	-	6.8	7
North Farms Res	Wallingford	19.1	5.5	6.4	0.8	45.1	9.8	114.1	7.2	3
N. Stamford Res	Stamford	11.8	3.1	10.4	1.4	31.0	-	156.4	7.4	8
Norwich Pond	Lyme	2.2	1.2	2.0	0.7	-	2.9	45.0	6.2	1
Pachaug Pond	Griswold	4.2	3.5	5.5	1.1	3.6	-	66.1	-	2
Pataganset Lake	East Lyme	1.6	1.1	3.9	0.9	-	1.2	60.0	5.8	1
Peck's Meadow Pd	East Haddam	1.3	0.6	3.5	0.6	-	3.1	37.0	5.1	1
Pilgrim Manor Pd	Cromwell	15.7	3.2	6.2	3.6	-	8.6	141.0	-	1
Pine Acres Lake	Hampton	2.5	0.9	3.5	1.1	-	0.7	33.0	6.1	1
Pinks Ravine Pond	Mansfield	6.0	2.4	9.0	2.0	-	3.3	89.0	6.3	1
Pipeline Pond	Mansfield	12.1	3.3	9.7	4.1	-	7.8	-	6.4	1
Pocotopaug, Lake	East Hampton	3.4	0.8	7.1	1.1	-	1.5	69.0	6.4	1
Podunk Pond	South Windsor	19.4	4.1	9.2	3.0	-	2.9	257.0	7.1	1
Powers Lake	East Lyme	2.0	0.6	2.1	0.6	-	0.7	40.0	6.1	1
Putnam Park Pond	Redding	7.3	3.3	6.4	1.3	-	5.7	127.0	7.3	1
Quaddick Res	Thompson	1.9	0.5	2.3	0.7	-	2.1	40.0	6.0	1

Table A.1. Chemical Data for Connecticut Lake Sites (Continued)

Site	Township	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	ANC (mg /L)	DIC mg C/L	Conduct µmhos/cm	pH	Source
Quassapaug Pond	Middlebury	3.3	1.5	3.7	1.0	-	7.1	53.0	7.1	1
Quonnipaug, Lake	Guilford	9.1	4.0	6.2	0.6	-	8.1	119.0	7.0	1
Riga Lake	Salisbury	1.0	0.1	0.2	0.4	0.4	-	24.2	-	2
Riverside Pond	Stafford	3.0	2.4	7.4	1.8	-	3.8	67.0	6.2	1
Rogers Lake	Lyme	3.4	1.0	-	-	4.4	-	-	-	6
Roseland Lake	Woodstock	7.2	1.4	5.0	1.9	-	4.8	78.0	6.4	1
Route 168 Pond	Suffield	4.4	0.9	31.0	0.5	-	0.9	154.0	7.1	1
Sabo Pond	Ashford	4.5	2.9	3.5	1.1	-	3.3	-	-	1
Saltonstall, Lake	East Haven	21.1	6.7	10.5	1.3	75.0	-	241.0	8.4	9
Saugatuck Res	Weston	10.2	7.1	10.8	0.9	29.8	7.2	129.7	7.1	3
Saw Mill Pk Pond	Ledyard	3.3	2.0	8.3	1.1	-	3.3	98.0	6.3	1
Shenipsit, Lake	Vernon	4.0	3.8	7.4	1.4	2.6	-	83.5	-	2
Silver Lake	Berlin	20.0	5.9	11.0	0.8	36.5	-	-	-	6
Silvermine Bk Pd	Wilton	14.5	6.9	16.3	1.2	35.4	8.2	185.8	8.3	3
South Pond	Salisbury	1.0	0.6	0.5	0.5	0.4	-	26.2	-	2
South Spectacle Pd	Kent	6.0	3.8	2.7	1.3	-	4.5	75.0	6.6	1
Squantz Pond	New Fairfield	8.6	10.0	7.7	0.9	38.9	8.9	92.7	7.2	3
Straitsville Res	Naugatuck	6.4	-	-	-	10.0	-	-	6.8	7
Taunton Pond	Newtown	8.0	2.9	6.9	1.2	-	5.2	115.0	7.0	1
Terramuggus,Lake	Marlborough	5.8	1.5	11.9	1.8	-	2.8	119.0	6.4	1
Thrall Pond	Suffield	23.2	10.6	40.0	7.8	-	6.6	346.0	6.6	1
Trap Falls Res	Shelton	7.8	2.5	10.7	1.6	15.0	-	145.4	7.4	8
Tyler Pond	Goshen	9.9	12.9	3.0	0.7	38.9	8.9	92.7	7.4	3
Uncas Pond	Lyme	1.9	1.2	2.4	0.8	-	4.2	46.0	6.2	1
Union Pond	Manchester	8.6	3.0	8.4	2.1	-	7.2	171.0	6.5	1
Unnamed Pond	Wilton	11.0	3.7	17.1	1.2	19.0	7.3	159.0	6.5	3
Upper Candee Res	Naugatuck	9.6	-	-	-	19.0	-	-	6.8	7
Wangum Res	Norfolk	4.5	1.9	1.6	0.5	14.0	-	48.8	7.5	8
Waramaug, Lake	Warren	7.6	6.6	7.4	1.4	8.4	-	64.0	6.5	2
Waumgumbaug,Lk	Coventry	7.8	3.8	9.2	1.7	5.0	-	122.9	-	2
West Hill Pond	New Hartford	2.5	2.5	2.8	0.5	2.2	1.7	46.8	6.2	3
West Side Pond	Goshen	8.6	4.4	4.3	0.5	-	7.2	125.0	7.0	1
West Twin Lake	Salisbury	20.6	13.0	-	-	-	20.1	178.0	7.4	1
Whitney, Lake	Hamden	14.6	2.1	9.8	-	39.0	-	161.0	7.4	10
William's Lake	Lebanon	1.1	0.7	3.7	0.8	-	2.1	47.0	6.3	1
Willington Quarry	Willington	5.5	2.1	9.5	2.1	-	2.3	81.0	6.3	1
Winnemaug,Lake	Watertown	8.9	5.9	14.3	1.1	21.4	5.2	130.2	7.7	3
Wononpakook,Lk	Salisbury	38.0	18.0	5.3	2.8	143.0	-	-	-	6
Wonoscopomuc,Lk	Salisbury	23.6	19.9	10.6	1.2	105.2	23.4	229.2	8.1	3
Woods Pond	Salisbury	42.0	-	4.5	3.3	-	30.5	256.0	7.3	1
Woods Pool	Thompson	3.4	1.0	8.3	1.6	-	1.2	64.0	7.3	1
Wyassup Lake	North Stonington	4.0	1.1	4.6	0.8	5.0	-	-	-	6
Zoar, Lake	Southbury	16.8	8.5	9.9	1.0	63.0	11.0	184.8	7.6	3

Table A.2. Chemical Data for Connecticut Stream and River Sites

Site	Township	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	ANC (mg /L)	DIC mg C/L	Conduct µmhos/cm	pH	Source
Bass Brook	New Britain	3.0	8.0	28.0	1.5	-	-	-	-	5
Bigelow Bk Trib	Ashford	2.6	0.8	1.1	0.5	-	1.3	24.0	6.0	1
Blackberry River	Norfolk	10.0	7.7	4.3	2.2	-	2.6	65.0	6.6	1
Blackberry River	Norfolk	8.2	8.2	4.1	0.6	35.0	7.6	100.5	7.0	3
Coles Brook, West	Rocky Hill	4.0	5.0	37.0	2.0	-	-	-	-	5
Coles Brook, East	Cromwell	3.0	3.0	17.0	1.3	-	-	-	-	5
Connecticut River	Deep River	12.0	2.0	-	-	-	-	115.0	7.2	1
Connecticut River	Suffield	10.0	2.0	7.0	1.0	-	-	111.0	7.0	1
Dunham Pond Bk	Mansfield	3.7	1.2	3.0	1.1	-	4.0	72.0	6.6	1
E.Aspetuck River	New Milford	12.1	12.1	12.1	1.0	36.8	8.7	128.3	7.3	3
Farmington River	Canton	4.1	1.8	5.8	1.3	-	2.4	59.0	6.0	1
Farmington River	Canton	3.5	3.5	5.9	0.7	9.3	2.9	66.0	6.6	3
Fenton River	Mansfield	4.0	2.5	5.0	1.3	-	4.8	83.0	7.0	1
Furnace Brook	Cornwall	16.3	10.3	13.1	1.3	64.1	15.8	182.1	7.1	3
Furnace Brook	Stafford	3.0	2.4	7.4	1.8	-	3.8	67.0	6.2	1
Furnace Brook	Stafford	2.7	2.0	6.7	1.7	-	2.5	72.0	6.1	1
Furnace Brook	Stafford	2.3	1.6	5.5	1.3	-	3.9	58.0	6.0	1
Furnace Bk Trib	Stafford	2.0	1.1	5.0	1.0	-	1.9	46.0	6.6	1
Furnace Bk Trib	Stafford	4.8	1.3	6.1	2.8	-	4.9	91.0	6.4	1
Hockanum River	Manchester	16.2	3.9	18.4	5.6	-	1.2	311.0	6.5	1
Housatonic River	Cornwall	28.2	13.0	7.0	2.6	-	22.8	250.0	8.3	1
Housatonic River	North Canaan	23.6	19.9	10.6	1.5	105.2	20.9	219.4	7.4	3
Housatonic River	Kent	21.0	19.7	12.2	1.4	79.3	15.7	204.0	7.7	3
Housatonic River	Cornwall	18.6	8.9	7.3	2.1	-	14.4	269.0	7.2	1
Lewer's Brook	Somers	3.5	1.5	5.0	1.1	-	-	71.0	6.6	1
Little River	Canterbury	4.0	1.3	4.9	1.9	-	2.4	59.0	-	1
Mattabesset River	Berlin	12.3	8.7	-	-	-	15.3	242.0	7.9	1
Merrick Brook	Scotland	4.2	1.3	5.1	1.9	-	2.8	60.0	6.3	1
Meshaddock Bk	Naugatuck	16.0	-	-	-	-	-	-	7.0	7
Middle River	Stafford	2.8	1.1	5.4	1.1	-	1.6	54.0	5.9	1
Mt Hope River	Ashford	3.2	1.7	6.4	0.9	-	0.7	129.0	6.7	1
Muddy Brook	Wallingford	25.7	0.5	16.7	1.9	-	14.9	387.0	7.3	1
Naugatuck River	Torrington	5.0	5.0	6.2	0.8	17.1	4.4	70.8	7.0	3
Norwalk River	Wilton	19.0	8.5	17.6	1.4	32.6	12.9	241.1	7.1	3
Oxoboxo Brook	Montville	2.7	1.8	7.8	1.2	-	3.1	83.0	6.4	1
Park River	Hartford	15.6	4.2	7.2	3.8	-	9.4	215.0	7.2	1
Pebble Brook	New Britain	4.0	13.0	38.0	2.0	-	-	-	-	5
Peqounnock River	Bridgeport	9.9	3.3	22.0	2.9	-	3.5	207.0	7.1	1
Piper Brook	Newington	4.0	12.0	32.0	1.7	-	-	-	-	5
Podunk River Trib	East Windsor	16.5	3.7	7.6	3.1	-	9.9	222.0	7.0	1
Quinnipiac R.Trib	Cheshire	6.0	11.0	31.0	2.2	-	-	-	-	5
Rattlesnake Brook	Suffield	23.0	9.4	5.3	4.9	-	8.5	270.0	6.7	1
Sandy Brook	New Britain	4.0	13.0	28.0	1.7	-	-	-	-	5
Saugatuck River	Weston	5.6	5.9	8.6	0.7	14.6	5.3	80.8	6.7	3
Scantic River	Somers	10.5	3.2	5.2	1.1	-	-	148.0	6.7	1
Taylor Brook	Woodstock	3.6	1.6	4.0	1.6	-	2.3	70.0	6.3	1
Ten Mile River	Columbia	7.0	0.9	4.9	1.2	-	3.6	66.0	6.3	1
Trout Brook	West Hartford	16.5	16.5	11.7	1.2	40.1	9.6	163.2	7.3	3
Unnamed Brook	New Britain	3.0	11.0	21.0	1.3	-	-	-	-	5
Warren Brook	Killingly	5.8	0.8	2.3	1.0	-	3.6	65.0	6.5	1
West River	Woodbridge	5.5	1.6	5.4	-	13.0	-	81.0	7.0	10
Willimantic River	Ellington	5.0	1.0	-	-	-	-	70.0	6.6	1
Willimantic River	Mansfield	5.0	1.0	-	-	-	-	70.0	6.8	1
Willimantic River	Tolland	5.0	1.0	-	-	-	-	70.0	6.6	1

Table A.3. Chemical Data for New York Sites

Site	Township	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	ANC (mg /L)	DIC mg C/L	Conduct µmhos/cm	pH	Source
Bog Brook Res	Southeast, NY	19.7	10.4	16.5	1.6	61.7	13.2	225.0	7.9	3
Cross River Res	Lewisboro,NY	13.5	7.6	12.0	1.2	10.7	8.4	155.9	8.1	3
East Branch Res	Southeast, NY	16.4	11.1	17.0	1.7	76.0	15.3	247.5	7.8	3
Ellis Pond	Dover, NY	18.7	10.9	9.8	1.3	117.9	25.6	248.7	8.5	3
Putnam Lake	Patterson, NY	22.9	10.5	33.5	1.6	69.0	13.6	373.6	8.0	3
Rudd Pond	Millerton, NY	23.0	10.9	6.0	1.1	101.2	22.6	217.6	8.4	3
Titicus Reservoir	North Salem, NY	16.8	9.4	14.0	1.4	52.7	10.1	186.8	8.0	3