10-14-2003

Environmental Indicator Report: Shellfish

Phil Trowbridge
NH Department of Environmental Sciences

Environmental Indicator Report

SHELLFISH

Final

October 14, 2003

Prepared by:

Phil Trowbridge
NHEP Coastal Scientist
New Hampshire Department of Environmental Services

This document was funded in part by the U.S. Environmental Protection Agency
through a cooperative agreement with the New Hampshire Estuaries Project.

ACKNOWLEDGMENTS

This report was peer-reviewed by the NHEP Technical Advisory Committee. The members of this committee deserve thanks for their time and thoughtful input.

NHEP Technical Advisory Committee

Name	Organization
Steve Jones, Chair	UNH-JEL
Tom Ballestero	UNH
Gregg Comstock	NHDES
Paul Currier	NHDES
Ted Diers	OSP-NHCP
Jennifer Hunter	OSP-NHEP
Natalie Landry	NHDES
Richard Langan	UNH-CICEET
Chris Nash	NHDES
Jon Pennock	UNH
Fay Rubin	UNH-CSRC
Fred Short	UNH-JEL
Brian Smith	NHF&G
Sally Soule	OSP-NHCP

Special thanks also to Paul Geoghegan of Normandeau Associates, Ron Sher of Seabrook Station, Bruce Smith of NHF&G, and Brian Beal of University of Maine and Machias for providing data and advice on the shellfish indicators.

INTRODUCTION

During the fall and winter of 2001-2002, the New Hampshire Estuaries Project's Technical Advisory Committee (TAC) developed a suite of environmental indicators to track progress toward the NHEP's management goals and objectives. These indicators were fully described in terms of their performance criteria, statistical methods, and measurable goals in the NHEP's Monitoring Plan published in March 2003 (NHEP, 2003).

From September 2002 to April 2003, the NHEP Coastal Scientist prepared four "Indicator Reports" that summarized the available information and results of statistical tests for each of the indicators. The TAC reviewed and commented on these reports, and then recommended a subset of the most important or illustrative indicators to be presented to the Management Committee. Finally, after being presented to both the TAC and the Management Committee, 12 key indicators were incorporated in the 2003 State of the Estuaries report.

The NHEP Coastal Scientist will update each indicator report at least every 3 years. A new State of the Estuaries report will be produced every three years.

This report is an update to the first Shellfish Indicator Report, which was first published in September 2002. The indicators covered in this report are listed in the following table. Lists of tables and figures are provided on the following page.

In an effort to be brief, the details of the monitoring programs for each indicator are not included in this report. Please refer to the NHEP Monitoring Plan for additional details for each indicator.

<u>List of NHEP Shellfish Indicators</u>

SHL1 – Area of Oyster Beds in Great Bay
SHL2 – Density of Harvestable Oysters at Great Bay Beds
SHL3 – Density of Harvestable Clams at Hampton Harbor Flats
SHL4 – Area of Clam Flats in Hampton Harbor
SHL5 – Standing Stock of Harvestable Oysters in Great Bay
SHL6 – Standing Stock of Harvestable Clams in Hampton Harbor
SHL7 – Abundance of Shellfish Predators
SHL8 – Clam and Oyster Spatfall
SHL9 – Recreational Harvest of Oysters
SHL10 – Recreational Harvest of Clams
SHL11 – Prevalence of Oyster Disease
SHL12 – Prevalence of Clam Disease

List of Tables

List of Figures

ENVIRONMENTAL INDICATORS

SHL1. Area of Oyster Beds in Great Bay

a. Monitoring Objectives

The objective of this indicator is to track the area of the six major oyster beds in Great Bay relative to their areas in 1997. This is directly relevant to the following management objective:

- SHL1-3: No net decrease in acreage of oyster beds from 1997 amounts for Nannie's Island, Woodman Point, Piscataqua River, Adams Point, Oyster River, Squamscott River, and Bellamy River beds

b. Measurable Goal

The goal is for each bed to at least maintain its 1997 area as reported in Langan (1997). However, the TAC decided that it was not worthwhile to track the size of the oyster bed in the Bellamy River because of its small size even though it was included in the management objective above.

c. Data Analysis and Statistical Methods

A rigorous statistical test to test for differences between 1997 and subsequent oyster bed areas is not possible. Instead, the error bars for the area estimate will be used to establish an approximate "confidence interval" of possible values for the estimate.

d. Results

The six main oyster beds in Great Bay were mapped in 1997 by Langan (1997). In 2001, NHF&G and UNH, with partial support from NHEP, completed a new set of maps of four oyster beds using a method that combined information from acoustic sonar, videography, and divers (NHF&G, 2002). The remaining two oyster beds will be mapped by UNH during 2003.

The following table contains the oyster bed areas as measured in 1997 and 2001.

Table 1: Area of the major oyster beds in Great Bay

Oyster Bed	Size in 1997 (acres)	Size in 2001 (acres)
Nannie Island	37.3	24.7
Woodman Point	6.6	7.3
Piscataqua River	12.8	NA[1]
Adams Point	4.0	13.1
Oyster River	1.8	1.7
Squamscott River	1.7	NA[1]
TOTAL	64.2	61.3[2]

1. This bed will be mapped in 2003.
2. Total for 2001 uses 1997 areas for the Piscataqua River and Squamscott River beds.

The total area of oyster beds in the Bay has not changed significantly. The 2001 total of 61.3 acres is within 10% of the 1997 total of 64.2 acres. Ten percent is considered a reasonable estimate of the uncertainty in the results. For individual beds, the coverage of the Nannie Island and Adams Point beds decreased and increased, respectively. These discrepancies may be the result of changes in the mapping methods.

The general locations of the six oyster beds that are being tracked by the NHEP are shown in Figure 1 from the Monitoring Plan. The 2001 outlines for the Adams Point and Nannie Island beds are shown in Figure 2 and Figure 3.

Figure 1: Major oyster beds in Great Bay

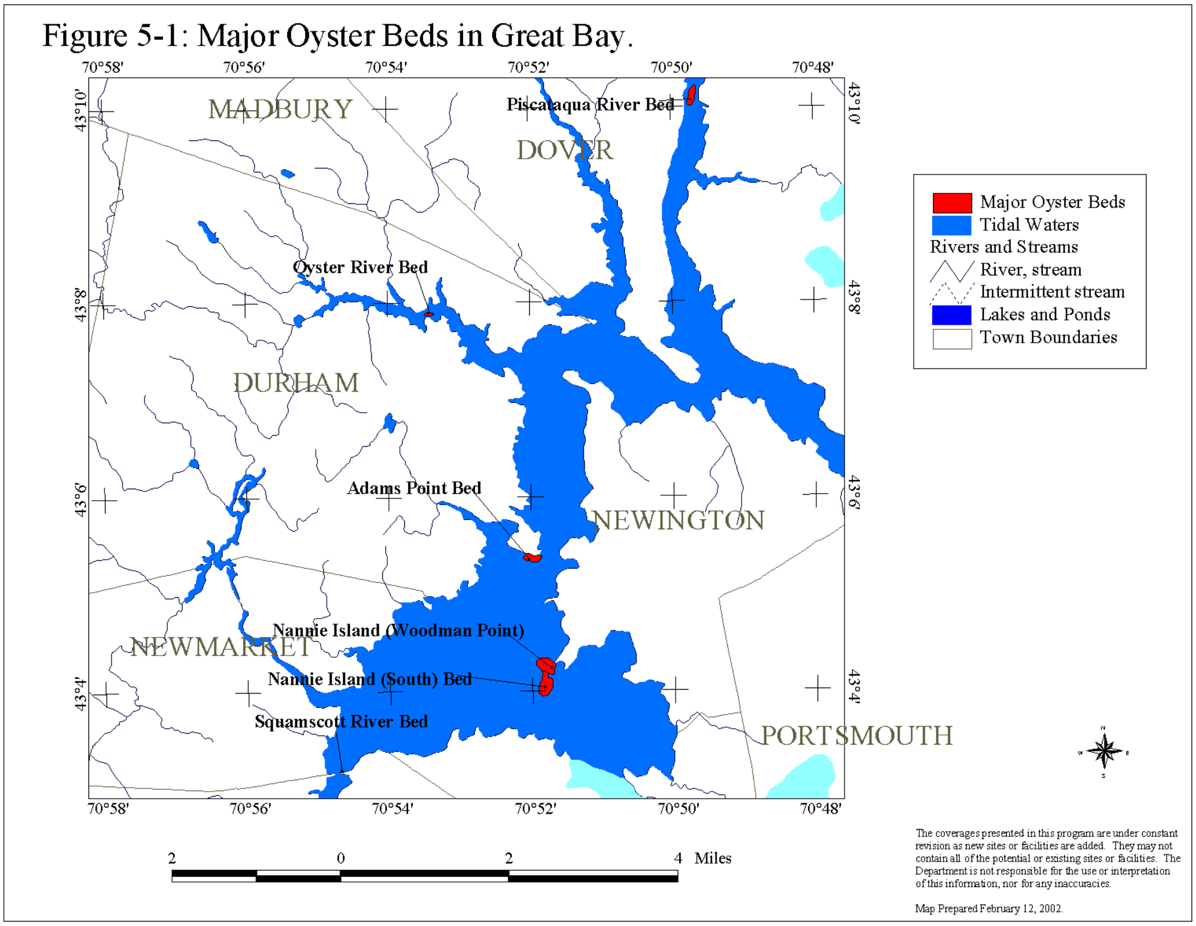


Figure 2: Boundaries of the Adams Point oyster bed in 2001

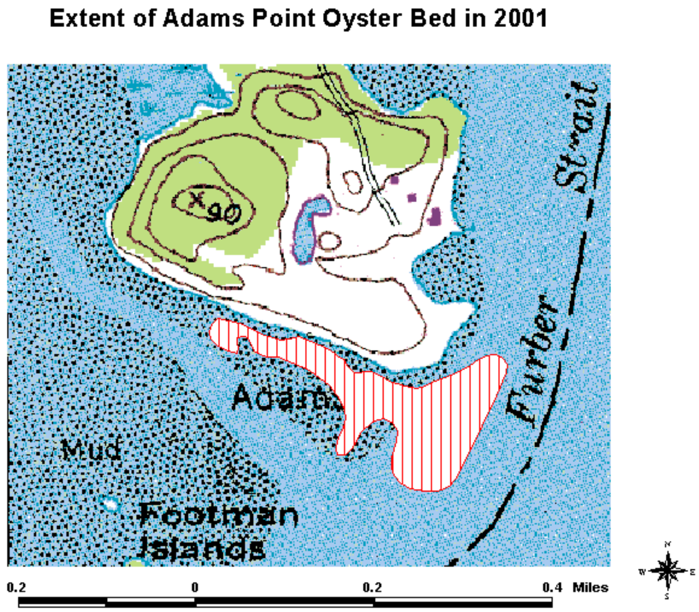
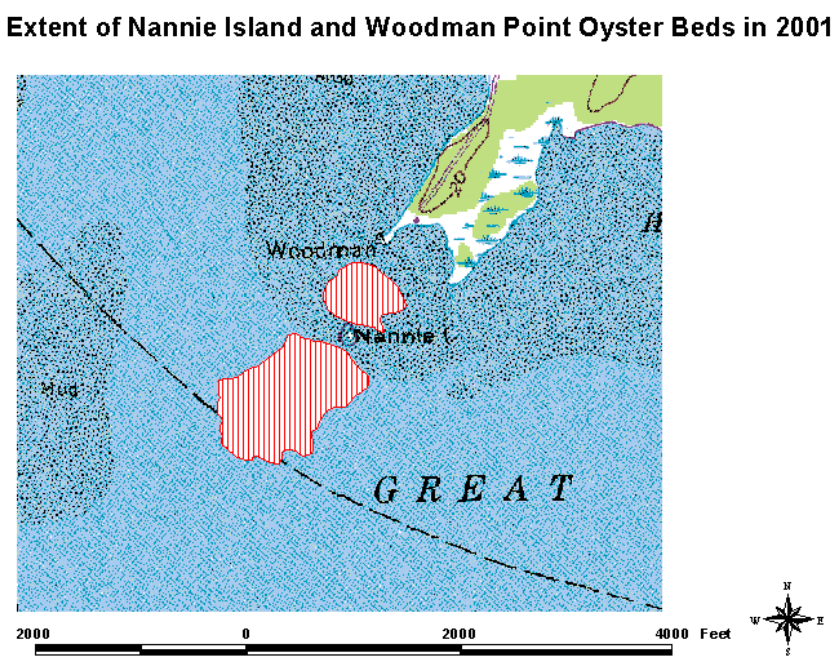


Figure 3: Boundaries of the Nannie Island and Woodman Point oyster beds in 2001



SHL2. Density of Harvestable Oysters at Great Bay Beds

a. Monitoring Objectives

The objective of this indicator is to estimate the average density of harvestable oysters at the six major oyster beds in Great Bay. This indicator reports directly on the following management objective:

- SHL1-4a: No net decrease in oysters (>80 mm shell height) per square meter from 1997 amounts at Nannie's Island, Woodman Point, Piscataqua River, Adams Point, and Oyster River.

b. Measurable Goal

The goal is for each bed to maintain its 1997 density (for oysters >80mm shell height).

c. Data Analysis and Statistical Methods

For each bed, the arithmetic mean and standard deviation of the number of oysters >80mm shell height per quadrat will be calculated. A one-sample, two-sided t-test with an alpha level of 0.05 will be used to determine whether the densities are significantly different from the goals (1997 levels).

d. Results

Oysters have suffered a significant decline in recent years. Table 2 illustrates that densities are well below the NHEP goal of 1997 levels (statistically significant difference). The cause for this decline has been mainly attributed to the protozoan pathogens MSX and Dermo. On average, the harvestable oyster densities in 2002 were 12% of the management goal (1997 levels).

Table 2: Average density of harvestable size oysters at Great Bay beds

Year	Adams Point	Nannie Island	Oyster River	Piscataqua River	Squamscott River	Woodman Pt	Source
1993	120.0	119.3	109.5			66.4*	NHF&G
1995		48.0	46.7			34.3	NHF&G
1996	52.7	67.0	40.8			39.0	NHF&G
1997	38.0	50.0	29.0	20.0		63.0	Langan (1997)
1998	27.5	28.7	26.0	5.1	9.3	28.7	NHF&G
1999		13.6	10.4	0.0		22.4	NHF&G
2000	5.3	4.8	12.0	1.3		4.0	NHF&G
2001	7.0	13.3	17.6	1.0	8.0	8.6	NHF&G
2002	2.8	3.2	9.6	0.8		6.4	NHF&G

Units: #/m2 (arithmetic average)
1. Green cells are the Management Goals for harvestable oyster density from Langan (1997)
2. Yellow cells are statistically significant ($p<0.05$) decreases below management goals using a one sample, two-sided t-test.
* Value from NHF&G reports. Raw data for individual quadrats not available for boxplot and statistical significance analysis.

The mean densities of harvestable oysters from 1993 to 2002 are presented in Figure 4.

Figure 5 illustrates the variance in harvestable oyster density at the six major beds over time. The data source for this graph is the NHF&G Oyster Resource Database. Data from Langan (1997) are not included in this figure, although the mean densities from 1997 are indicated by dashed lines.

Figure 4: Average density of harvestable size oysters in Great Bay beds

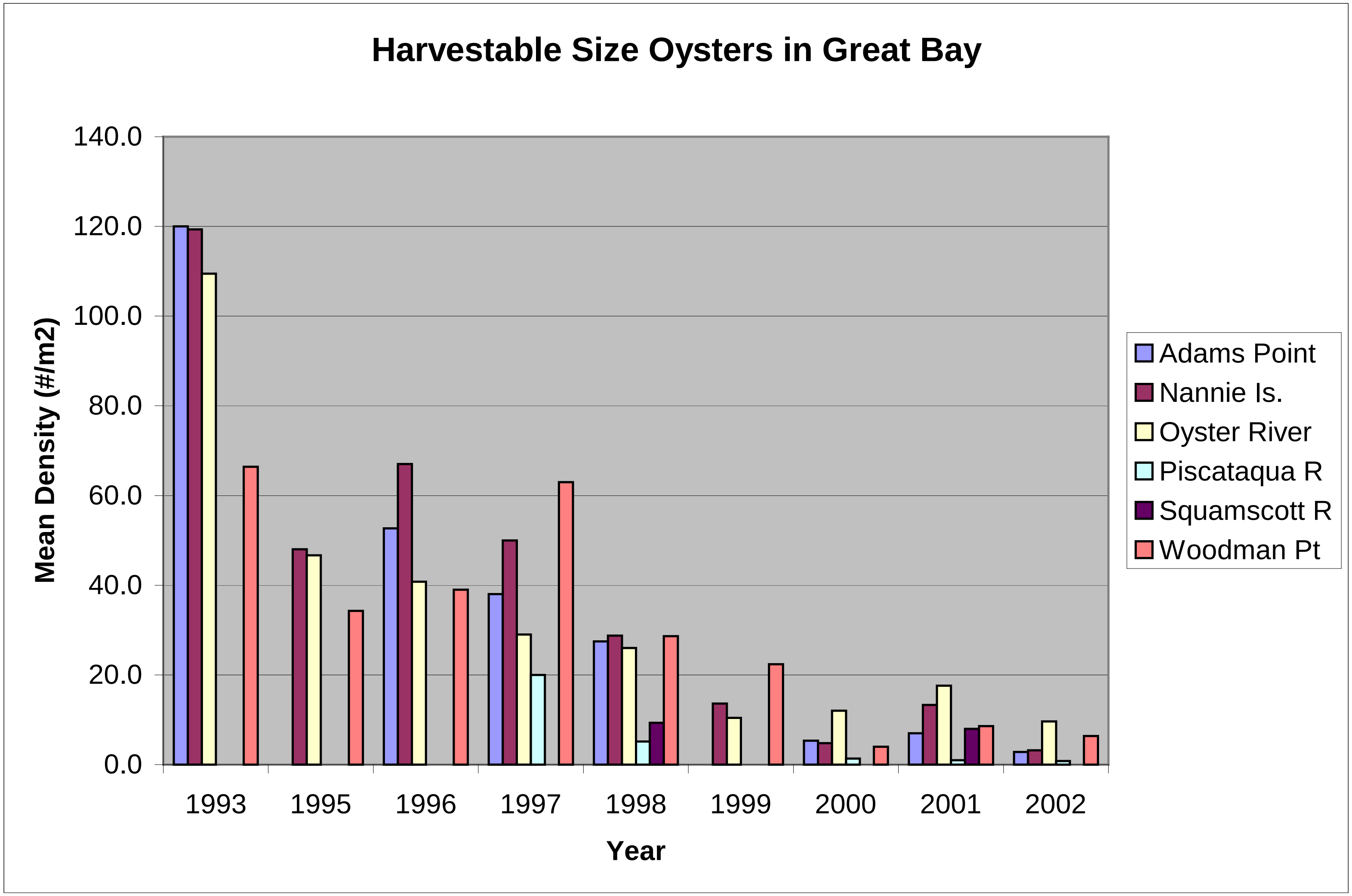
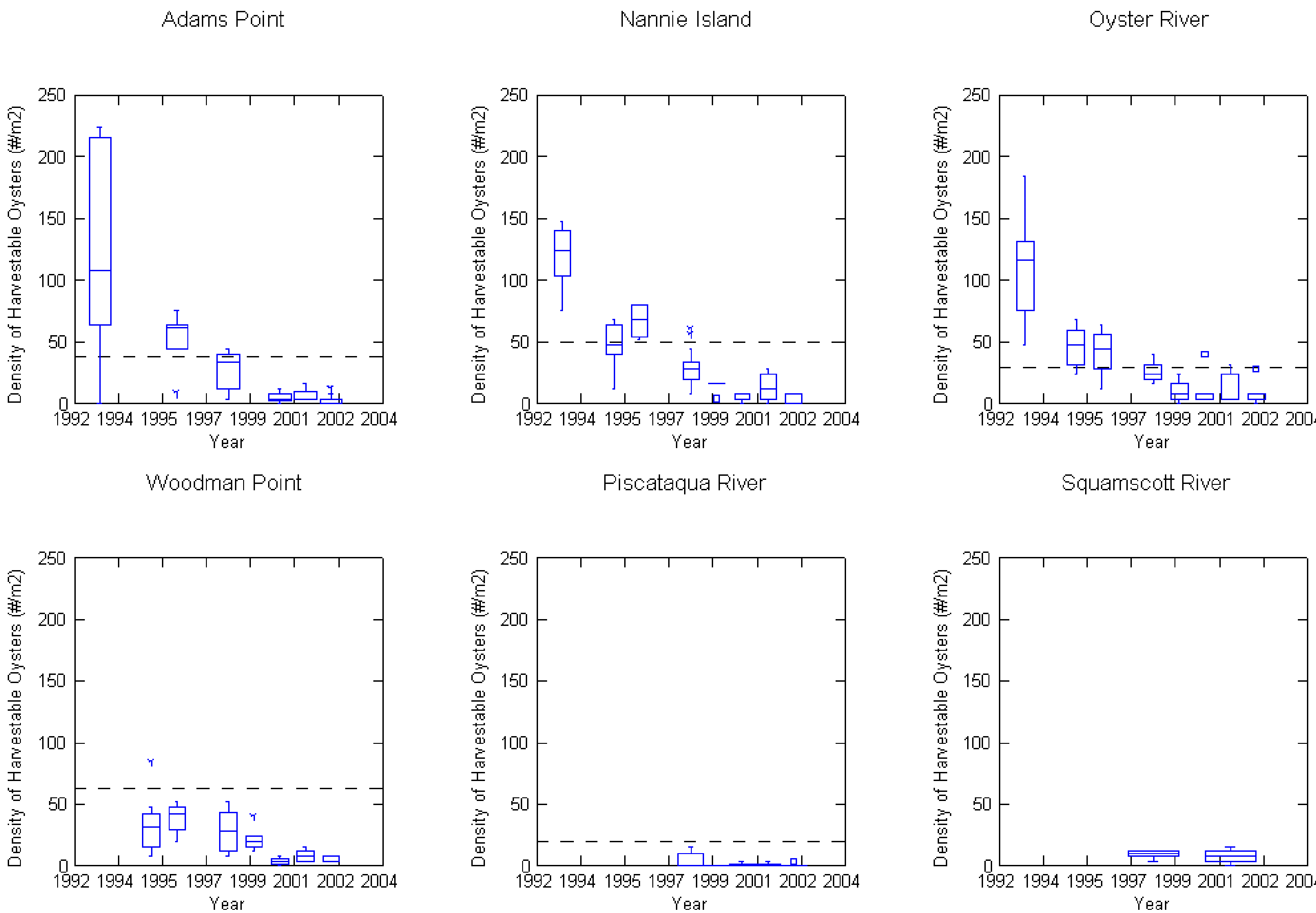


Figure 5: Variability of harvestable size oyster density in Great Bay beds



Note: To read this box plot, the bottom, middle, and top of each box indicate the 25th, 50th, and 75th percentiles, respectively, of oyster density measured at a specific bed during a year. The lines extending from the box reach as far as the 5th and 95th percentiles. Points beyond the box and lines are outlier values.

SHL3. Density of Harvestable Clams at Hampton Harbor Flats

a. Monitoring Objectives

The objective of this indicator is to estimate the mean density of clams of harvestable size (>50mm shell length) from the NH's major clam flats in Hampton Harbor. This indicator will report directly on the following management objective:

- SHL1-4b: No net decrease in adult clams (>50 mm shell length) per square meter from the 1989-1999 10-year average at Common Island, Middle Ground, and Confluence flats.

b. Measurable Goal

The goal is for each flat to at least maintain the 10-year average density for clams of harvestable size (>50mm shell length) that was recorded between 1990 and 1999.

c. Data Analysis and Statistical Methods

For each flat, the arithmetic mean of the number of clams >50mm per quadrat will be calculated. Ultimately, a one-sample t-test with an alpha level of 0.05 will be used to determine whether the densities are significantly different from the goal. However, information on the variance in density between quadrats is not currently available, therefore only the mean density will be reported for this analysis. The mean density values will be compared to the goal.

d. Results

Table 3 shows that densities in 2001 were well below the most recent 10 year average (1990-1999) and falling for all three main flats. The 2001 densities at Common Island and Middle Ground were also lower than the longer-term baseline densities recorded between 1974 and 1989.

Table 3: Average density of harvestable size clams in Hampton/Seabrook Harbor

Flat	Current Status (2001)	10 year Average (1990-1999)	Longer Term Baseline (1974-1989)
Common Island	5.2	21.3	15.3
Hampton-Browns Confluence	9.6	11.0	9.8
Middle Ground	6.0	38.6	9.9

Units: #/m2 (arithmetic average)
Source: Seabrook Station

Table 4 and Figure 6 illustrate the trends in harvestable clam populations over the last 30 years. The densities have followed a cyclical pattern with a period of approximately 12 years. For instance, at Common Island, peak densities between 35.5 and 59.9 clams per square meter were observed in 1972, 1983, and 1997. Between these peaks, the harvestable clam density fell to 1-2 clams per square meter. All the flats were closed to harvesting due to bacterial pollution in 1989. The Common Island, Confluence, and Middle Ground flats were reopened in 1994, 1995, and 1998, respectively. The high clam densities in the 1990s occurred during this period. However, densities have decreased since their peak in 1997 even though the harvest from the flats has been relatively low since 1998.

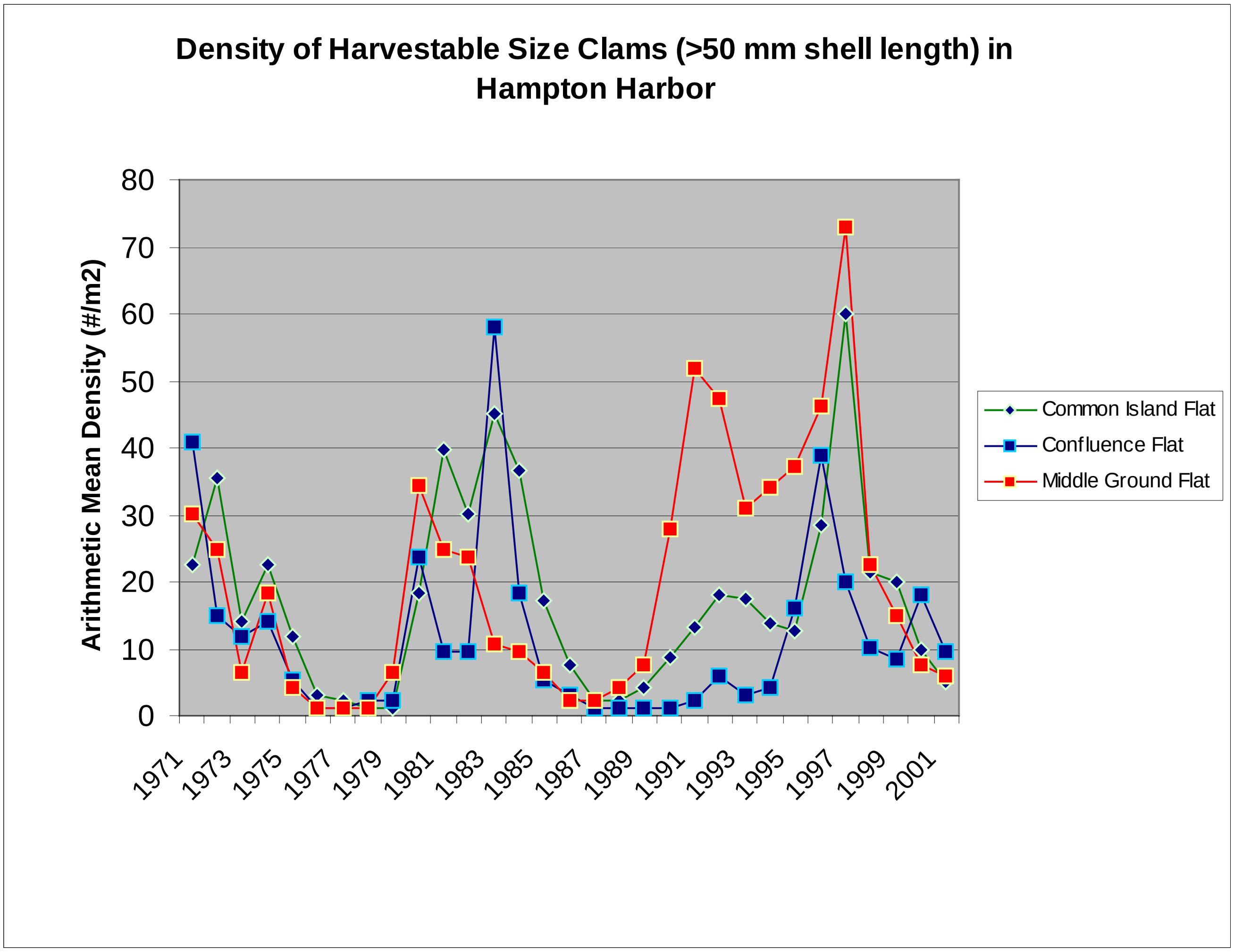
The NHEP Management Goal is the 10-year average between 1990 and 1999. During this period, the clam densities grew to unprecedented levels, due in part to the clam flats being closed for harvest. To capture the effects of the growth and decline cycles, a more suitable period for comparison would be the longer-term baseline period of 1974 and 1989. The average values for 1974-1989 are not very different from the 1990-1999 period for the Common Island and Confluence flats. However, there is a big difference for the Middle Ground flat.

Table 4: Average density of harvestable size clams in Hampton/Seabrook Harbor

Year	Common Island Flat	Confluence Flat	Middle Ground Flat	Source
1971	22.6	40.9	30.1	Seabrook Station
1972	35.5	15.1	24.8	Seabrook Station
1973	14.0	11.8	6.5	Seabrook Station
1974	22.6	14.0	18.3	Seabrook Station
1975	11.8	5.4	4.3	Seabrook Station
1976	3.2	1.1	1.1	Seabrook Station
1977	2.2	1.1	1.1	Seabrook Station
1978	1.1	2.2	1.1	Seabrook Station
1979	1.1	2.2	6.5	Seabrook Station
1980	18.3	23.7	34.4	Seabrook Station
1981	39.8	9.7	24.8	Seabrook Station
1982	30.1	9.7	23.7	Seabrook Station
1983	45.2	58.1	10.8	Seabrook Station
1984	36.6	18.3	9.7	Seabrook Station
1985	17.2	5.4	6.5	Seabrook Station
1986	7.5	3.2	2.2	Seabrook Station
1987	2.2	1.1	2.2	Seabrook Station
1988	2.2	1.1	4.3	Seabrook Station
1989	4.3	1.1	7.5	Seabrook Station
1990	8.6	1.1	27.9	Seabrook Station
1991	13.1	2.4	51.9	Seabrook Station
1992	18.1	5.8	47.2	Seabrook Station
1993	17.4	3.2	30.9	Seabrook Station
1994	13.7	4.2	34.1	Seabrook Station
1995	12.6	16.0	37.1	Seabrook Station
1996	28.5	38.8	46.3	Seabrook Station
1997	59.9	19.9	72.9	Seabrook Station
1998	21.3	10.0	22.5	Seabrook Station
1999	20.1	8.4	14.8	Seabrook Station
2000	9.8	18.1	7.7	Seabrook Station
2001	5.2	9.6	6.0	Seabrook Station

Units: #/m2 (arithmetic average)
Shaded cells are less than the management goal for that flat. No tests of statistical significance could be performed.

Figure 6: Average density of harvestable size clams in Hampton/Seabrook Harbor



SHL4. Area of Clam Flats in Hampton Harbor

a. Monitoring Objectives

The objective of this supporting variable is to track the size of the three major clam flats in Hampton Harbor. This information will be combined with data on clam densities to estimate the standing stock of harvestable clams for another indicator.

b. Measurable Goal and Statistical Methods

This is a supporting variable so no measurable goal has been established.

c. Data Analysis and Statistical Methods

These data will be collected to provide additional information to help interpret the results of other indicators. The area of each flat will be reported along with the error in the estimate. No statistical tests will be applied.

d. Results

Table 5 and Figure 7 show the area of the three major clam flats mapped during 7 surveys. The latest available data on flat areas is from 2002. There are no apparent system-wide trends. During the last 7 years, the size of the Common Island flat decreased by 19% while the Middle Ground flat grew by 22% and the Confluence flat maintained a relatively constant area. As a result, the total acreage covered by these three flats did not change appreciably between 1995 and 2002. The general location of these three major flats is shown in Figure 8.

Table 5: Area of major clam flats in Hampton/Seabrook Harbor

Year	Common Island Flat	Confluence Flat	Middle Ground Flat	Total	Source
1977	54.9	27.2	49.7	131.8	Seabrook Station
1979	54.8	26.7	53.5	135.0	Seabrook Station
1981	54	24.7	50.8	129.5	Seabrook Station
1983	52.7	26.4	49.9	129.0	Seabrook Station
1984	50	21.7	47.9	119.6	Seabrook Station
1995	45.7	26.4	47.3	119.4	Seabrook Station
2002	36.9	23.4	57.8	118.1	Seabrook Station

Units: acres

Figure 7: Area of clam flats in Hampton/Seabrook Harbor

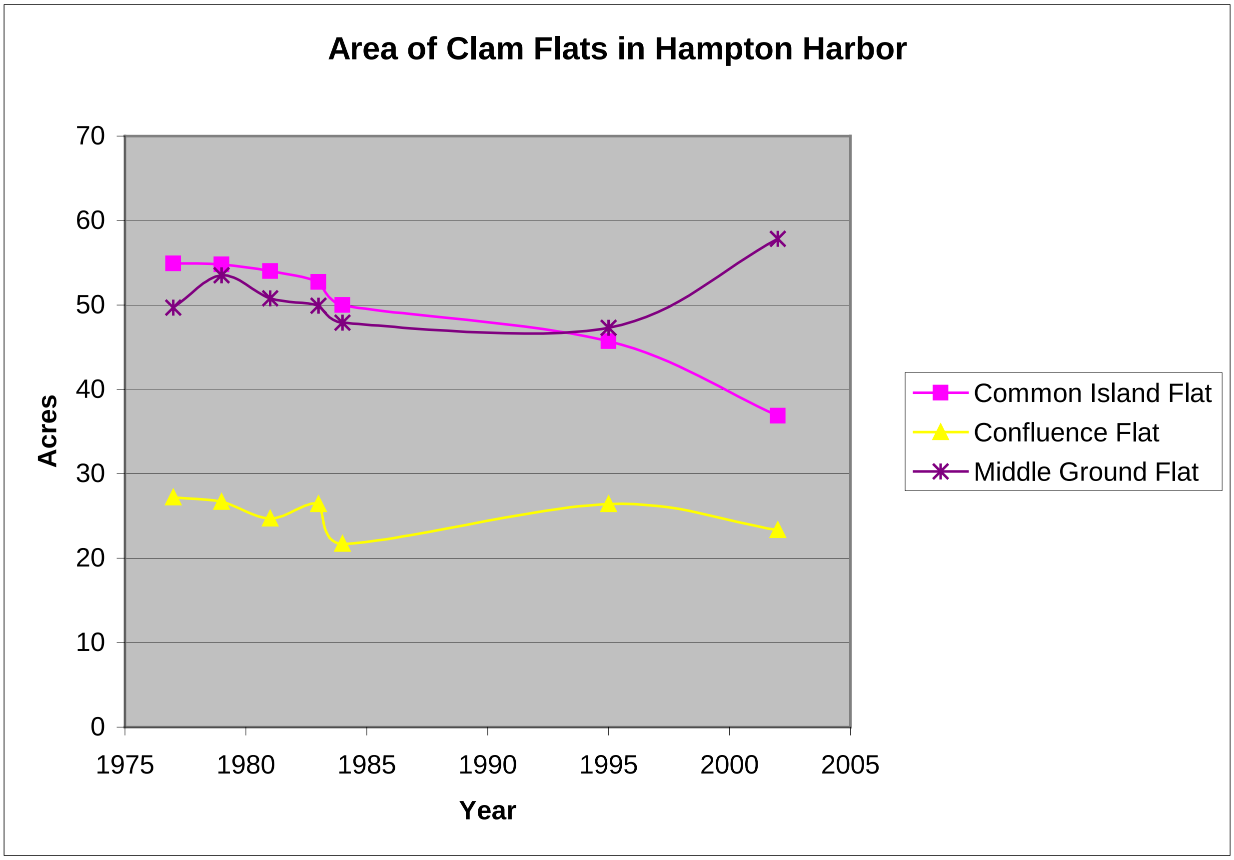
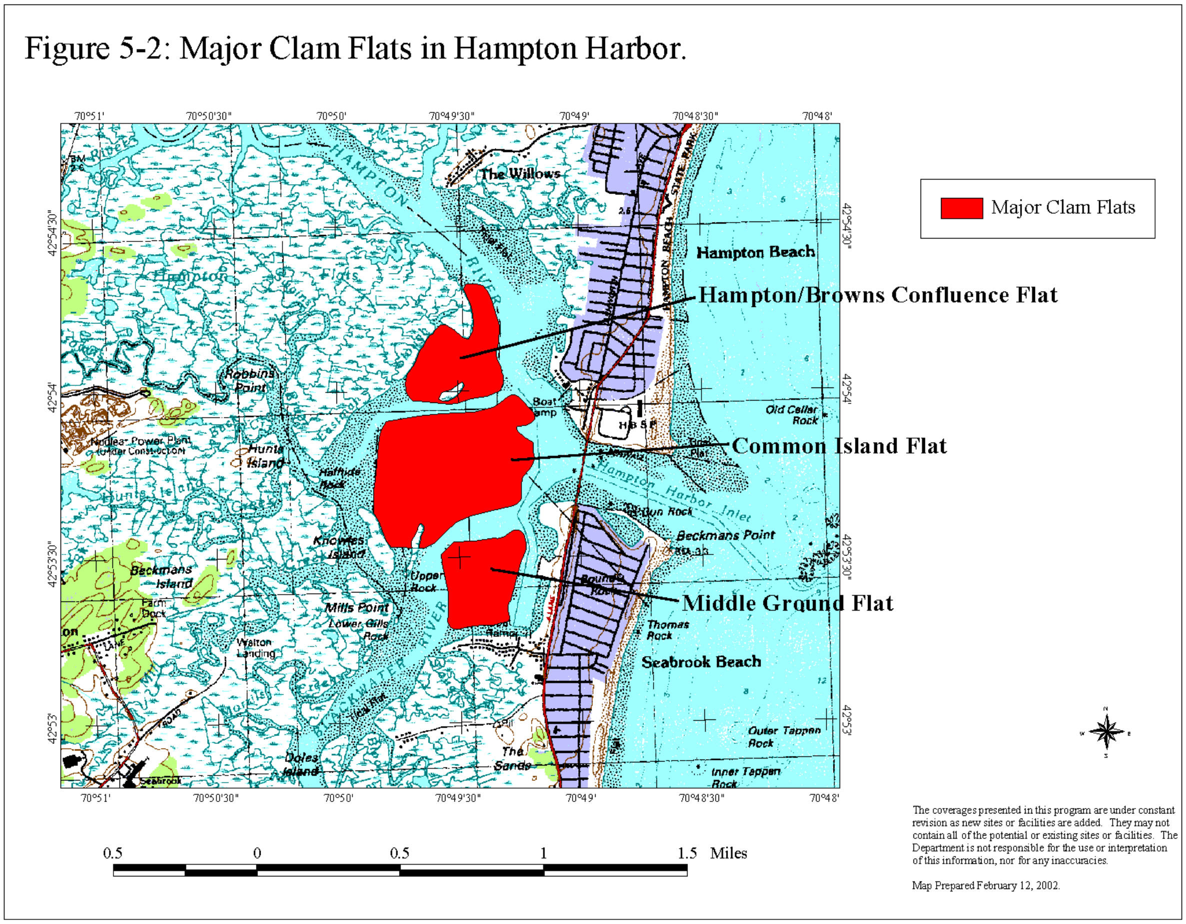


Figure 8: Major clam flats in Hampton/Seabrook Harbor



Note: The boundaries of the clam flats have shifted since this map was created due to tidal currents.

SHL5. Standing Stock of Harvestable Oysters in Great Bay

a. Monitoring Objectives

The objective of this indicator is to estimate the total number of harvestable oysters in Great Bay (i.e., oyster of harvestable size in beds that are open for harvesting). This indicator will answer the following monitoring question:

- "Has the number of harvestable clams and oysters tripled from 1999 levels?"

This question will, in turn, report on progress towards a component of Shellfish Goal#1 which calls for the quantity of harvestable clams and oysters in NH's estuaries to be tripled.

b. Measurable Goal and Performance Criteria

In the NHEP Management Plan, Shellfish Goal #1 states that the quantity of harvestable clams and oysters in NH's estuaries should be tripled. The standing stock of harvestable oysters in 1999, the year the Management Plan was written, was 15,883 bushels. Tripling 15,883 bushels is approximately 50,000 bushels. Therefore, the goal for this indicator is triple this amount to reach 50,000 bushels.

c. Data Analysis and Statistical Methods

The standing stock of harvestable oysters in each bed will be estimated by multiplying the average density of oysters >80mm shell height by the most recent estimate of the bed size. Results will be reported in bushels (for Great Bay, approximately 200 oysters equal 1 bushel). If data on density or area are missing for a bed for a particular year, the standing stock will be estimated from the closest other available data for that bed. The standing stock will be summed for beds in areas open for harvesting. A separate standing stock calculation will be made for oysters >80mm in areas that are closed to harvesting. Rigorous statistical tests for differences are not possible.

d. Results

Data from 1993 to 2002 illustrate that the oyster fishery in Great Bay has suffered a serious decline. The 2002 standing stock is approximately 7% of the management goal of 50,000 bushels. The trends over time for oyster standing stock are shown in Table 6 and Figure 9.

Using an cost estimate of $0.45/oyster, the wholesale value of the fishery has dropped from over $11m in 1993 to $0.4m in 2002. (Note: This cost estimate is hypothetical because there is no commercial oyster harvesting in NH.)

The major cause of this decline is thought to be the protozoan pathogens MSX and Dermo which have caused similar declines in oyster fisheries in the Chesapeake and other mid-Atlantic estuaries. Most of the remaining standing stock is in the beds that are open for harvesting.

Table 6: Harvestable size oyster standing stock in Great Bay

Year	Adams Point	Nannie Island	Oyster River	Piscataqua River	Squamscott River	Woodman Point	Total - open beds	Total – all beds
1993	10,577	98,081	4,341	5,641	350	9,657	118,314	128,646
1995	7,609	39,451	1,851	5,641	350	4,986	52,047	59,889
1996	4,642	55,068	1,618	5,641	350	5,672	65,382	72,990
1997	3,349	41,095	1,150	5,641	350	9,162	53,607	60,748
1998	2,424	23,622	1,031	1,451	350	4,169	30,215	33,046
1999	1,447	11,178	412	0	325	3,258	15,883	16,620
2000	1,540	2,612	450	376	325	643	4,795	5,946
2001	2,021	7,257	659	282	300	1,379	10,656	11,897
2002	808	1,742	360	226	300	1,029	3,579	4,464

Units: bushels

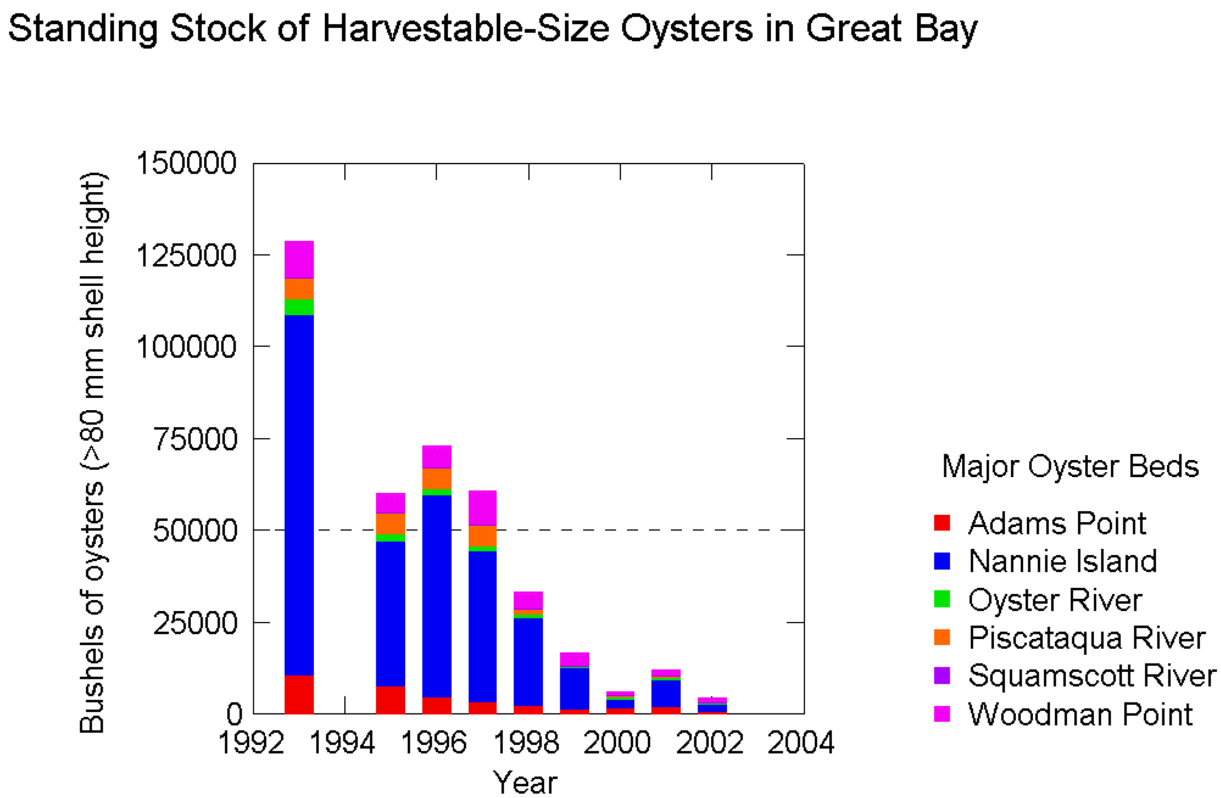
All values except 1997 and 2001 are approximate. The only years for which both size and density of the beds were measured were 1997 and 2001. The area estimates from 1997 were applied to other years before 2001 in order to estimate the standing stock, but this requires the assumption that the bed sizes have not changed over 5 years, which may not be justified. Area estimates from 2001 were used to estimate the standing stock in 2001 and 2002. The average harvestable oyster density for Woodman Point in 1993 was taken from NHF&G reports because raw data were not available to calculate this value independently.

Yellow cells indicate that an assumption regarding the density of oysters was needed to calculate the standing stock because density measurements were not taken at that bed in that year. Either the closest standing stock calculation from another year or an average of two bracketing standing stocks was used.

Sources: Langan (1997) for 1997 values and NHF&G for all other years.

Open beds include Adams Point, Nannie Island, and Woodman Point. Closed beds are: Oyster River, Piscataqua River, and Squamscott River.

Figure 9: Harvestable size oyster standing stock in Great Bay



SHL6. Standing Stock of Harvestable Clams in Hampton Harbor

a. Monitoring Objectives

The objective of this indicator is to estimate the total number of harvestable clams in Hampton Harbor (i.e., clams of harvestable size in Hampton Harbor flats that are open for harvesting). This indicator will answer the following monitoring question:

- "Has the number of harvestable clams and oysters tripled from 1999 levels?"

This question will, in turn, report on progress towards a component of Shellfish Goal#1 which calls for the quantity of harvestable clams and oysters in NH's estuaries to be tripled.

b. Measurable Goal

No measurable goal has been set for this indicator because the TAC and the Shellfish Team do not believe that the factors controlling the clam fishery in NH are well enough understood at this time.

c. Data Analysis and Statistical Methods

Seabrook Station calculates the the standing stock of harvestable clams in Hampton Harbor using the average density for each size clam on the flats (with 1 mm shell length increments for each size class), volume estimates for each size clam from Belding (1930), and the most recent area of each flat. The value of the clam fishery can be estimated by multiplying the standing crop value from Seabrook Station by the extremes of clam wholesale prices: summer ($250/bu) and winter ($50/bu). Please note that the value of the clam fishery is hypothetical because there is no commercial clam harvesting in New Hampshire.

d. Results

Table 7 and Figure 10 show the history of harvestable clam standing stock over the past 33 years. The standing stock has undergone several 12-15 year cycles of growth and decline. Peak standing stocks of approximately 23,000, 13,000, and 27,000 bushels occurred in 1967, 1983,and 1997 respectively. Between the peaks, there have been crashes of the fishery in 1978 and 1987, with standing stock less than 1,000 bushels. Since 1997, the standing stock has been dropping once again but the 2001 levels (the most recent available data) are still approximately five times the levels observed during the crashes in 1978 and 1987. During the summer season when wholesale prices are approximately $250/bushel, the value of the fishery has been as high as $6.6m. The 2001 value was approximately $1.4m. (Note: This cost estimate is hypothetical because there is no commercial clam harvesting in NH.)

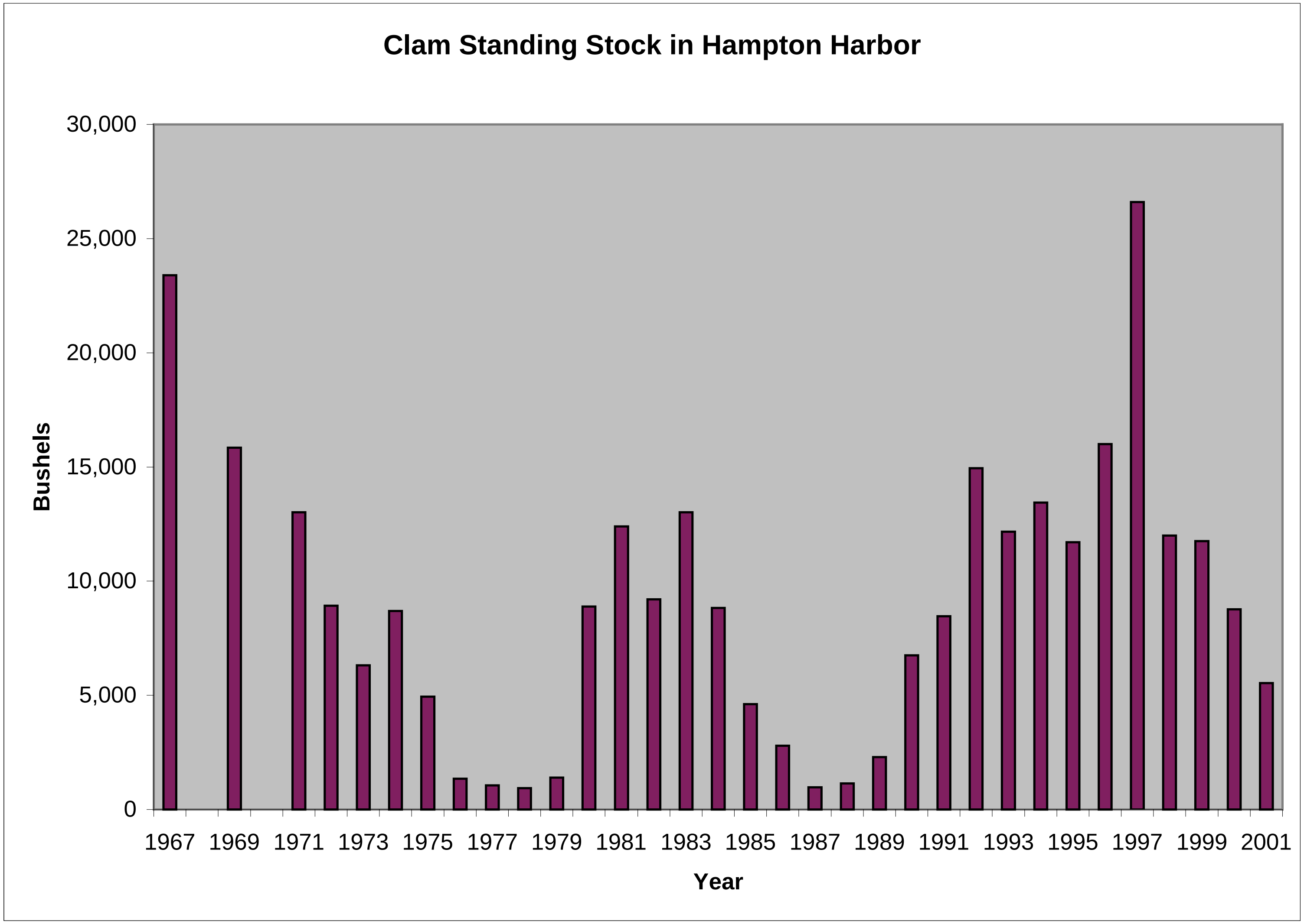
Table 7: Harvestable size clam standing stock in Hampton/Seabrook Harbor

Year	Standing Stock	Source
1967	23,400	Seabrook Station
1969	15,840	Seabrook Station
1971	13,020	Seabrook Station
1972	8,920	Seabrook Station
1973	6,310	Seabrook Station
1974	8,690	Seabrook Station
1975	4,945	Seabrook Station
1976	1,350	Seabrook Station
1977*	1,060	Seabrook Station
1978	940	Seabrook Station
1979*	1,400	Seabrook Station
1980	8,890	Seabrook Station
1981*	12,400	Seabrook Station
1982	9,200	Seabrook Station
1983*	13,019	Seabrook Station
1984*	8,821	Seabrook Station
1985	4,615	Seabrook Station
1986	2,793	Seabrook Station
1987	976	Seabrook Station
1988	1,137	Seabrook Station
1989	2,295	Seabrook Station
1990	6,752	Seabrook Station
1991	8,462	Seabrook Station
1992	14,942	Seabrook Station
1993	12,161	Seabrook Station
1994	13,440	Seabrook Station
1995*	11,701	Seabrook Station
1996	16,001	Seabrook Station
1997	26,606	Seabrook Station
1998	11,992	Seabrook Station
1999	11,756	Seabrook Station
2000	8,765	Seabrook Station
2001	5,539	Seabrook Station

Units: bushels

* Clam flat maps were made in this year so the standing stock estimate is accurate. All other values are estimates extrapolated using area estimates from the next closest year(s).

Figure 10: Harvestable size clam standing stock in Hampton/Seabrook Harbor



SHL7. Abundance of Shellfish Predators

a. Monitoring Objectives

The objective of this supporting variable is to track the relative abundance of the dominant clam predator and incidental oyster predator in NH tidal waters: green crabs (*Carcinus maenus*). This information will be used to help interpret changes in other indicators of shellfish density or standing stock, and will help to answer the following monitoring question:

- "Are NH shellfish healthy, growing, and reproducing at sustainable levels?"

Mud crabs and the oyster drill (*Urosalpinx cinerea*) are more important than green crabs as oyster predators but there are no systematic monitoring programs for these species.

b. Measurable Goal

This is a supporting variable so no measurable goal has been established. These data will be collected to provide additional information to help interpret the results of other indicators.

c. Data Analysis and Statistical Methods

The monthly catch-per-unit-effort (CPUE) of green crabs in various locations throughout the Great Bay and Hampton Harbor will be tracked versus time. No statistical tests will be applied.

d. Results

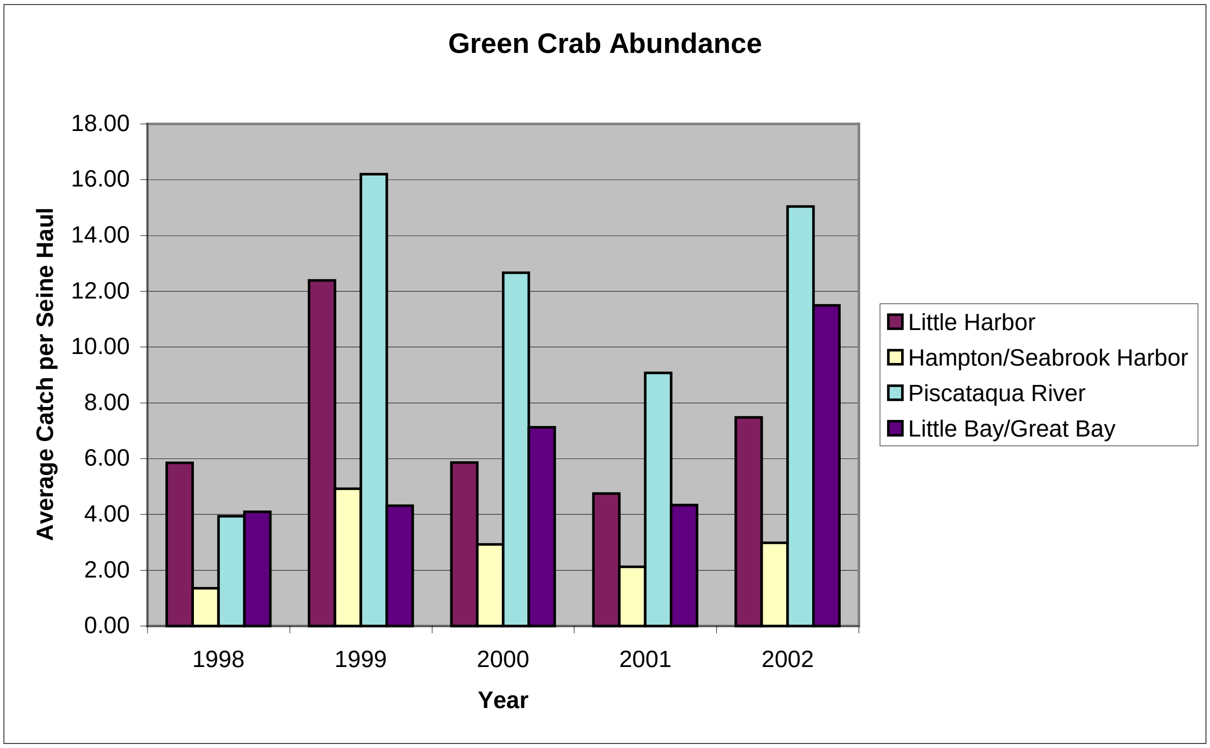
NHF&G data for the Juvenile Finfish Seine Survey Program from throughout the estuary are shown in Table 8 and Figure 11. These data are generated from monthly seine hauls at 15 stations around the estuaries during the months of June through November. These data indicate that green crab abundance is lowest in Hampton Harbor. None of the seine hauls were taken directly from oyster beds so the prevalence of green grabs on the actual oyster beds is unknown, although there is anecdotal evidence of green crabs on oyster beds from diver observations.

Table 8: Green crab abundance throughout NH's estuaries

Location	1998	1999	2000	2001	2002
Little Harbor	5.85	12.39	5.86	4.75	7.48
Hampton/Seabrook Harbor	1.36	4.92	2.93	2.12	2.98
Piscataqua River	3.93	16.20	12.67	9.07	15.04
Little Bay/Great Bay	4.10	4.31	7.12	4.33	11.49

Source: NHF&G Juvenile Fish Seine Surveys
Units: Annual average catch per seine haul

Figure 11: Green crab abundance throughout NH's estuaries



Time series data on green crab abundance in Hampton Harbor monitored by Seabrook Station show an increase in abundance over time (Table 9). The Mann-Kendall Test indicates that this increase is statistically significant at the $p<0.05$ level with a median increase over the past 20 years of 150%. These data are generated by green crab traps set at four stations two times per month April through January.

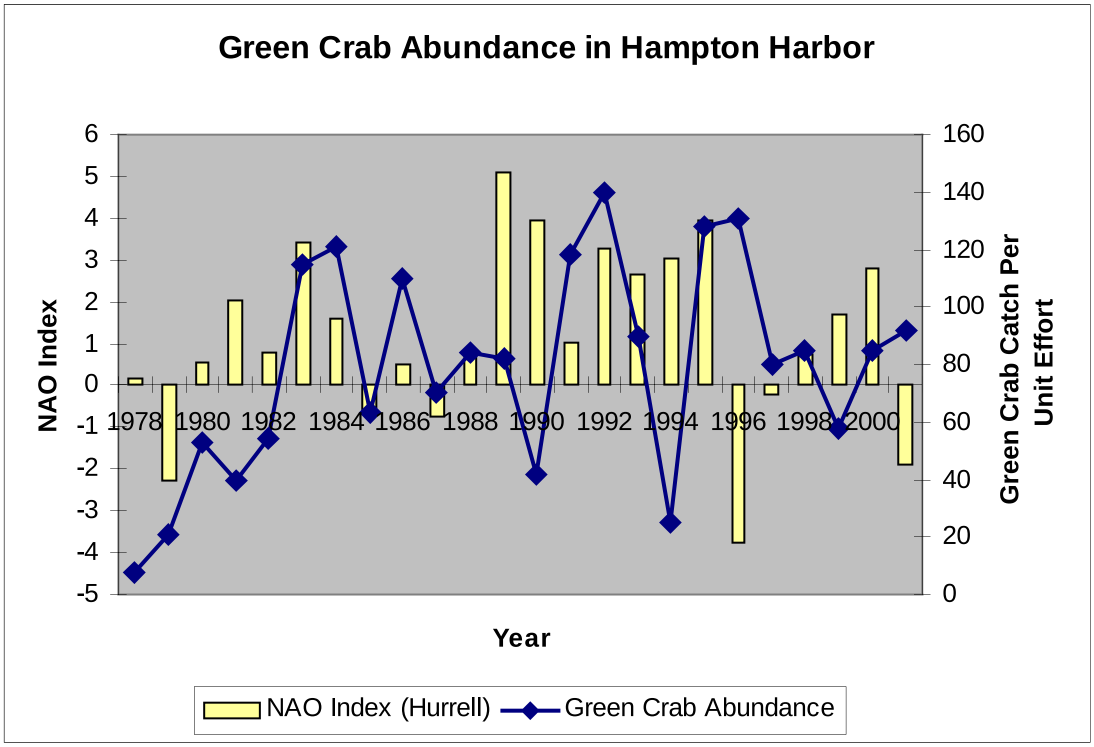
Seabrook Station and others have observed that green crab abundance is correlated with yearly minimum water temperatures (NAESCO, 2001). Temperatures in New England are affected by the North Atlantic Oscillation (NAO) weather pattern. During periods with a negative NAO index, the winters tend to be colder and dryer, which would result in a decrease in the green crab abundance. Figure 12 illustrates the relationship between green crab abundance and the NAO winter index.

Table 9: Green crab abundance in Hampton/Seabrook Harbor

Year	Catch per Unit Effort	Source
1978	8	Seabrook Station
1979	21	Seabrook Station
1980	53	Seabrook Station
1981	40	Seabrook Station
1982	54	Seabrook Station
1983	115	Seabrook Station
1984	121	Seabrook Station
1985	63	Seabrook Station
1986	110	Seabrook Station
1987	70	Seabrook Station
1988	84	Seabrook Station
1989	82	Seabrook Station
1990	42	Seabrook Station
1991	118	Seabrook Station
1992	140	Seabrook Station
1993	90	Seabrook Station
1994	25	Seabrook Station
1995	128	Seabrook Station
1996	131	Seabrook Station
1997	80	Seabrook Station
1998	85	Seabrook Station
1999	58	Seabrook Station
2000	85	Seabrook Station
2001	92	Seabrook Station

Note: values for this table were estimated from graphs in Seabrook Station reports because tabular data were not available.

Figure 12: Green crab abundance in Hampton/Seabrook Harbor



NAO Index Data provided by the Climate Analysis Section, NCAR, Boulder, USA (Hurrell, 2003). Seasonal index (December, January, February, March) of the NAO based on the difference of normalized sea level pressures (SLP) between Ponta Delgada, Azores and Stykkisholmur/Reykjavik, Iceland since 1865.

SHL8. Clam and Oyster Spatfall

a. Monitoring Objectives

The objective of this supporting variable is to track the yearly spatfall of clams in Hampton Harbor and oysters in Great Bay. This information will be used to help interpret changes in other indicators of shellfish density or standing stock, and will help to answer the following monitoring question:

- "Are NH shellfish healthy, growing, and reproducing at sustainable levels?"

b. Measurable Goal

This is a supporting variable so no measurable goal has been established. These data will be collected to provide additional information to help interpret the results of other indicators.

c. Data Analysis and Statistical Methods

For oysters, spatfall is measured by the density of oysters less than or equal to 20 mm shell height during the fall season. For clams, the spat size is defined as 1-25 mm shell length. This range is relatively large and may include some clams from the yearling age class. The average spat density at each major clam flat and oyster bed will be tracked versus time. No statistical tests will be applied.

d. Results

Oyster Spatfall

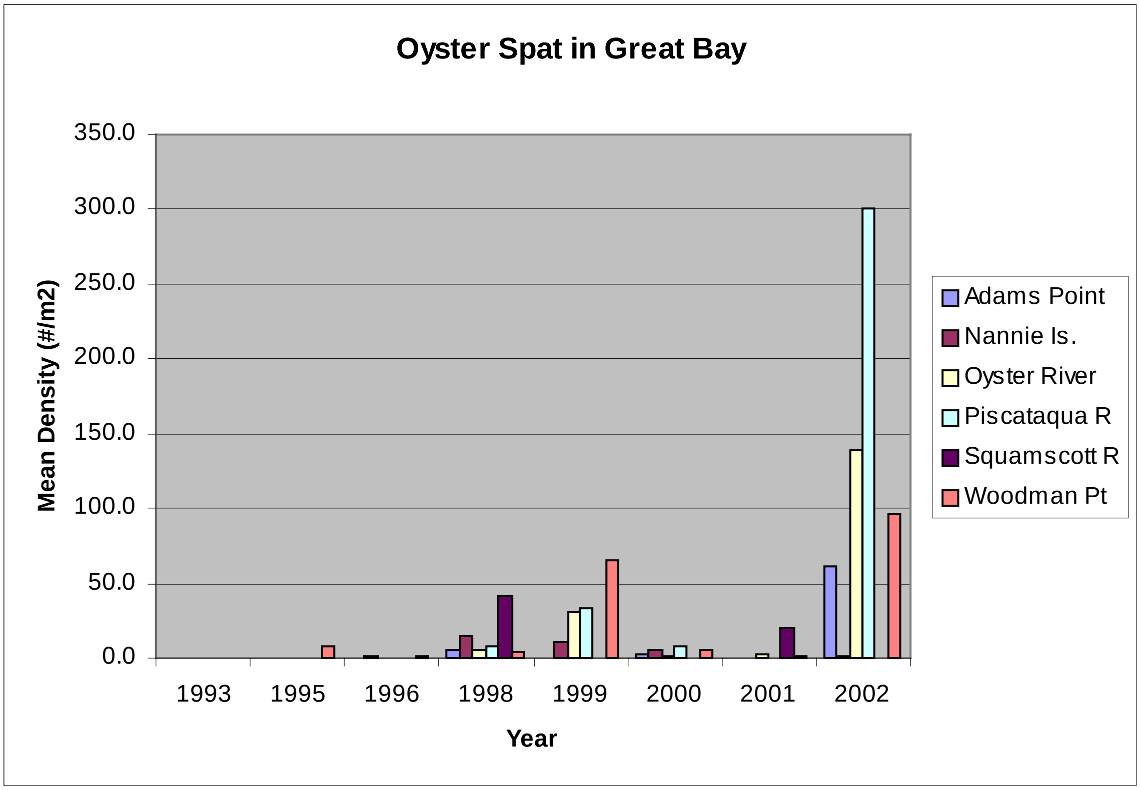
Table 10 and Figure 13 show that there was a large spat set at almost all of the Great Bay oyster beds in 2002. The last major spat set before 2002 in was in 1998 and 1999.

Table 10: Average oyster spat density in Great Bay

Year	Adams Point	Nannie Island	Oyster River	Piscataqua River	Squamscott River	Woodman Point	Source
1993	0.0	0.7	0.0				NHF&G
1995		0.0	0.7			8.0	NHF&G
1996	0.0	1.0	0.0			1.0	NHF&G
1998	6.0	14.1	5.3	7.4	41.3	4.0	NHF&G
1999		11.2	31.2	32.8		65.6	NHF&G
2000	2.7	5.6	1.6	8.0		5.3	NHF&G
2001	0.0	0.7	2.4	0.0	20.0	1.1	NHF&G
2002	62.0	0.8*	139.2	300.8		96.0	NHF&G

Source: NHF&G Oyster Resource Surveys
Units: #/m2
Mean values are arithmetic averages. Spat is defined as oysters with 1-20 mm shell height.
** The apparently low spat set at Nannie Island may be due to the timing of the survey at this bed. Nannie Island was surveyed on October 29 and few spat were found. However, abundant spat were found at Woodman Point (adjacent to Nannie Island) on December 19. It is possible that the spatset at Nannie Island was missed because the spat were too small during the initial survey.*

Figure 13: Average oyster spat density in Great Bay



Clam Spatfall

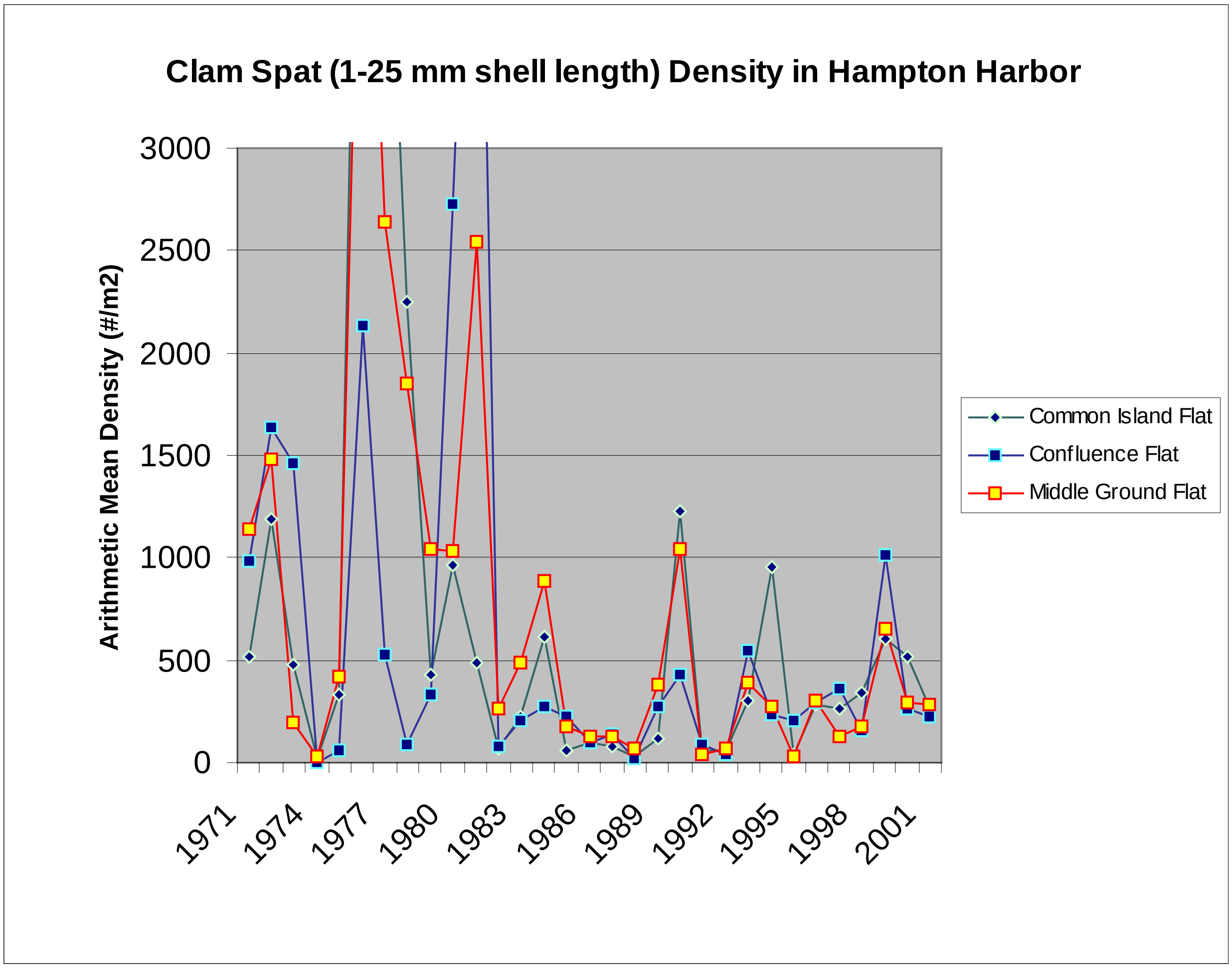
The following table and figure illustrate that spatfall has fluctuated on approximately four year intervals over the past 30 years. Very large spatfalls occurred in the late 1970s and early 1980s.

Table 11: Average clam spat density in Hampton/Seabrook Harbor

Year	Common Island Flat	Confluence Flat	Middle Ground Flat	Source
1971	517	979	1,141	Seabrook Station
1972	1,184	1,636	1,485	Seabrook Station
1973	474	1,464	194	Seabrook Station
1974	22	0	32	Seabrook Station
1975	334	54	420	Seabrook Station
1976	6,243	2,131	5,113	Seabrook Station
1977	4,704	527	2,637	Seabrook Station
1978	2,250	86	1,851	Seabrook Station
1979	431	334	1,044	Seabrook Station
1980	969	2,723	1,033	Seabrook Station
1981	484	5,586	2,540	Seabrook Station
1982	65	75	258	Seabrook Station
1983	226	205	484	Seabrook Station
1984	614	269	883	Seabrook Station
1985	54	226	172	Seabrook Station
1986	97	97	129	Seabrook Station
1987	75	140	129	Seabrook Station
1988	32	22	65	Seabrook Station
1989	118	269	377	Seabrook Station
1990	1,227	431	1,044	Seabrook Station
1991	62	86	38	Seabrook Station
1992	59	41	70	Seabrook Station
1993	298	542	392	Seabrook Station
1994	956	235	275	Seabrook Station
1995	36	200	25	Seabrook Station
1996	279	289	304	Seabrook Station
1997	267	359	123	Seabrook Station
1998	336	153	171	Seabrook Station
1999	605	1,016	654	Seabrook Station
2000	514	261	291	Seabrook Station
2001	271	225	282	Seabrook Station

Units: #/m2 (arithmetic average)
Clam spat is defined as clams with 1-25 mm shell length. Mean values are arithmetic averages.

Figure 14: Average clam spat density in Hampton/Seabrook Harbor



SHL9. Recreational Harvest of Oysters

a. Monitoring Objectives

The objective of this supporting variable is to estimate how many oysters are harvested by recreational harvesters each year (Great Bay is not a commercial oyster fishery). This information is needed to answer the following monitoring question:

- "Are NH shellfish being harvested at sustainable levels?"

b. Measurable Goal

This is a supporting variable so no measurable goal has been established. These data will be collected to provide additional information to help interpret the results of other indicators.

c. Data Analysis and Statistical Methods

The total number of oysters harvested yearly will be estimated for the entire Great Bay Estuary. The harvest will be tracked over time and compared to the annual estimate to standing stock. No statistical tests will be applied to these data.

d. Results

In Table 12, the historical record of recreational harvest license sales was combined with the available estimates of oyster harvest. For the years when estimates of oyster harvest were made, the results have been compared to oyster standing stock estimates from indicator SHL-5.

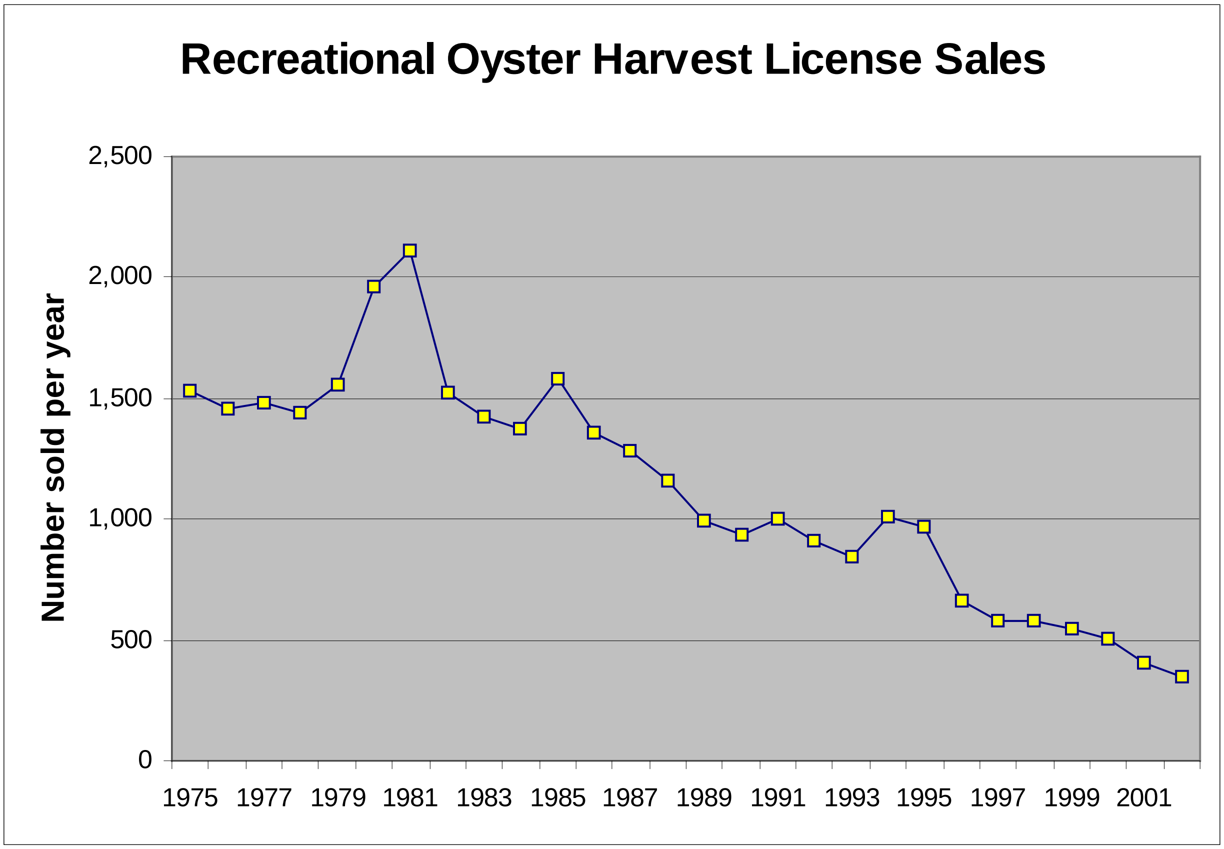
The data indicate a progressive decline in license sales and a proportional decline in total harvest. In 1996, the total harvest amounted to approximately 4% of the standing stock. Based on this comparison, the current levels of harvest appear to be sustainable.

Table 12: Recreational oyster harvest - license sales and harvest estimates

Year	License Sales*	Harvest (bushels)	Standing Stock (bu)	Sources
1975	1532			NHF&G
1976	1460			NHF&G
1977	1479			NHF&G
1978	1440			NHF&G
1979	1553			NHF&G
1980	1961			NHF&G
1981	2109			NHF&G
1982	1522			NHF&G
1983	1426			NHF&G
1984	1373			NHF&G
1985	1582			NHF&G
1986	1358			NHF&G
1987	1285			NHF&G
1988	1157			NHF&G
1989	992	>4,000	128,646 (1)	NHF&G, Manalo et al, 1991
1990	932			NHF&G
1991	1001			NHF&G
1992	907			NHF&G
1993	847			NHF&G
1994	1009			NHF&G
1995	971			NHF&G
1996	661	2,727	72,990 (2)	NHF&G, NHF&G 1997
1997	582			NHF&G
1998	579			NHF&G
1999	545			NHF&G
2000	506			NHF&G
2001	406			NHF&G
2002	344			NHF&G

* Oyster harvest license sales total provided by Sue Martin at NHF&G
(1) Using earliest standing stock estimate (1993) from indicator SHL-5 to represent the "late 1980's"
(2) Using standing stock estimate for 1996 from indicator SHL-5

Figure 15: Recreational oyster harvest license sales



SHL10. Recreational Harvest of Clams

a. Monitoring Objectives

The objective of this supporting variable is to estimate how many clams are harvested from Hampton Harbor flats by recreational harvesters each year (Hampton Harbor is not a commercial clam fishery). This information is needed to answer the following monitoring question:

- "Are NH shellfish being harvested at sustainable levels?"

b. Measurable Goal

This is a supporting variable so no measurable goal has been established. These data will be collected to provide additional information to help interpret the results of other indicators.

c. Data Analysis and Statistical Methods

The total number of clams harvested yearly will be estimated for the Hampton Harbor flats based on the number of harvesters observed and estimated by the Seabrook Station monitoring program during the clamming season. Assuming that each harvester takes his limit (10 liquid quarts per person per day), the total harvest for the day can be estimated. The daily harvests are totaled to estimate the yearly harvest. The annual harvest will be tracked over time and compared to annual estimates of standing stock. The number of recreational clam harvest licenses sold state-wide is provided by NHF&G. No statistical tests will be applied to these data.

d. Results

In Table 13, data from Seabrook Station and NHF&G have been compiled for the past 25 years. The data show that harvests during the 1980's were a high percentage of the standing stock before the fishery crashed in the late 1980s. Harvests were zero during the early 1990's because the flats were closed. Following the re-opening of the flats, harvests have increased but have remained low, presumably because the flats are often closed due to high bacteria concentrations. Both the harvest and standing stock values are estimates, and the error in these estimates is well illustrated by the data for 1987 which shows a harvest value greater than the standing stock value.

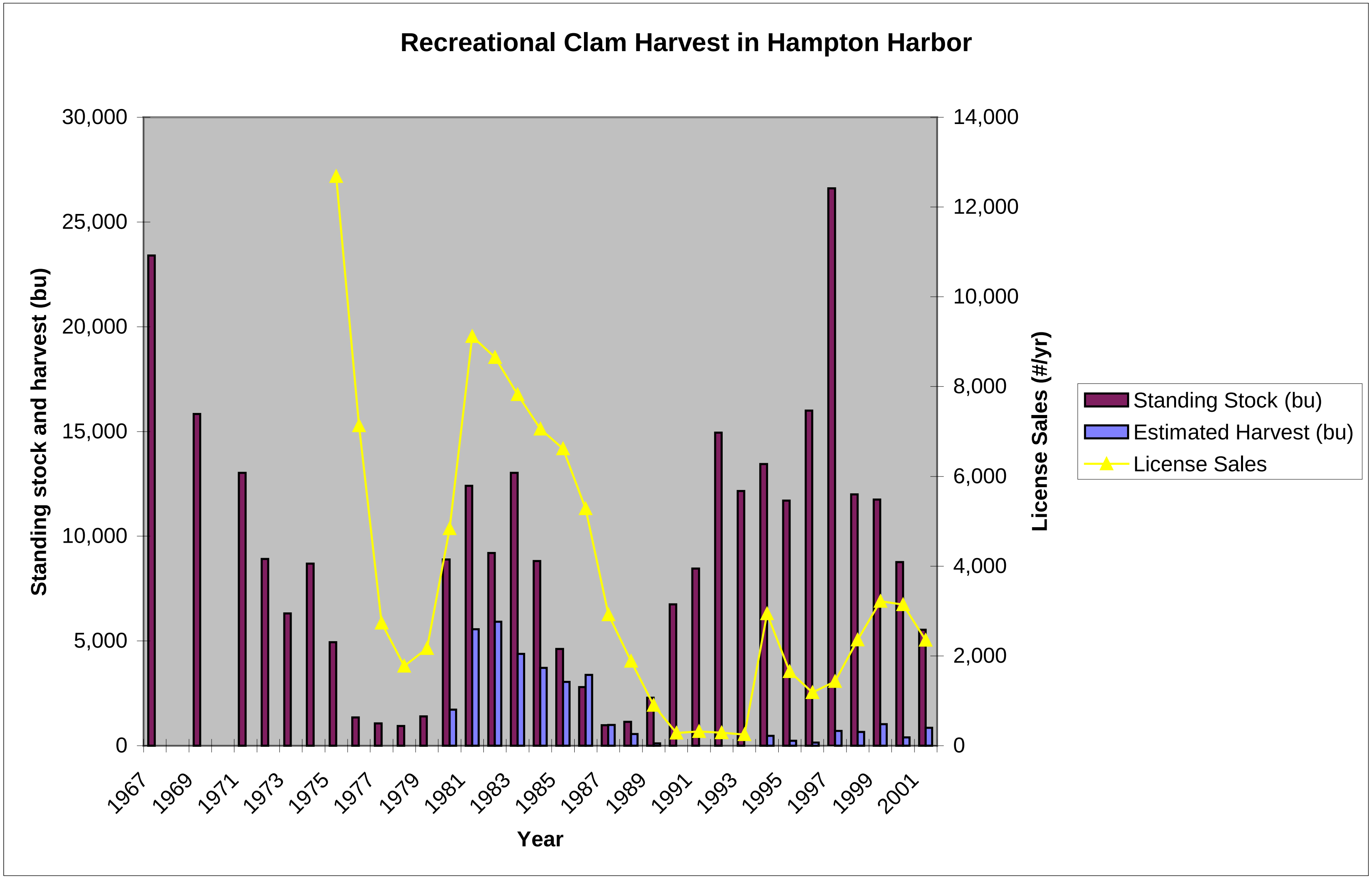
License sales provide a slightly longer record back to 1975. While license sales are not directly related to harvest in Hampton Harbor, license sales correlate well with the harvest estimates by Seabrook Station. These data provide an indication that harvest pressure was high preceding the other documented crash of the fishery in the late 1970's.

Table 13: Recreational clam harvest from Hampton/Seabrook Harbor

Year	Digger Trips per Year			Estimated Harvest (bushels)	License Sales*	Sources
	Common Island	Confluence Flat	Middle Ground			
1975					12,681	Seabrook Station, NHF&G
1976					7,128	Seabrook Station, NHF&G
1977					2,735	Seabrook Station, NHF&G
1978					1,773	Seabrook Station, NHF&G
1979					2,164	Seabrook Station, NHF&G
1980	246	371	1,098	1,715	4,837	Seabrook Station, NHF&G
1981	686	894	3,982	5,561	9,118	Seabrook Station, NHF&G
1982	1,198	686	4,029	5,913	8,648	Seabrook Station, NHF&G
1983	1,353	478	2,554	4,385	7,824	Seabrook Station, NHF&G
1984	920	1,040	1,757	3,716	7,056	Seabrook Station, NHF&G
1985	1,686	290	1,066	3,041	6,616	Seabrook Station, NHF&G
1986	2,006	218	1,159	3,384	5,283	Seabrook Station, NHF&G
1987	404	78	510	992	2,920	Seabrook Station, NHF&G
1988	122	73	368	563	1,881	Seabrook Station, NHF&G
1989	25	12	73	109	904	Seabrook Station, NHF&G
1990	0	0	0	0	286	Seabrook Station, NHF&G
1991	0	0	0	0	318	Seabrook Station, NHF&G
1992	0	0	0	0	287	Seabrook Station, NHF&G
1993	0	0	0	0	248	Seabrook Station, NHF&G
1994	470	0	0	470	2,940	Seabrook Station, NHF&G
1995	232	0	0	232	1,652	Seabrook Station, NHF&G
1996	11	143	0	153	1,183	Seabrook Station, NHF&G
1997	106	602	0	708	1,433	Seabrook Station, NHF&G
1998	471	133	55	659	2,355	Seabrook Station, NHF&G
1999	498	194	330	1,022	3,217	Seabrook Station, NHF&G
2000	348	13	33	394	3,144	Seabrook Station, NHF&G
2001	2,453	199	96	859	2,350	Seabrook Station, NHF&G

* Clam harvest license sales total provided by Sue Martin at NHF&G

Figure 16: Recreational clam harvest from Hampton/Seabrook Harbor



SHL11. Prevalence of Oyster Disease

a. Monitoring Objectives

The objective of this supporting variable is to estimate the prevalence of the oyster diseases, MSX and Dermo. This information is needed to answer the following monitoring question:

- “Has the incidence of shellfish diseases changed significantly over time?”

b. Measurable Goal

This is a supporting variable so no measurable goal has been established. These data will be collected to provide additional information to help interpret the results of other indicators.

c. Data Analysis and Statistical Methods

For each oyster bed, the percent of oysters infected with MSX or Dermo will be reported and tracked over time. No statistical tests will be applied.

d. Results

MSX

The disease MSX was first detected in Delaware Bay in 1957 and since then has spread throughout the Atlantic coast. The protozoa that causes MSX (*Haplosporidium nelsoni*) is mainly controlled by salinity. The protozoa cannot survive in low salinity water (<10 ppt), has limited virulence at salinities between 10 and 20 ppt, and is fully infectious at salinities >20 ppt (Haskin and Ford, 1982). Therefore, droughts tend to increase the prevalence of MSX infections and allow for expansion of the protozoa’s range.

Unspeciated haplosporidian plasmodia were observed in the Piscataqua River as early as 1979 by Maine DMR. MSX was first conclusively determined in the Great Bay in 1983. However the first oyster mortality from the disease was observed in 1995 following a severe drought (Barber et al., 1997).

No significant change in MSX infection rates has occurred since the disease was first detected in Great Bay in 1995 (the trend at Nannie Island was tested by the Mann-Kendall Test with $p>0.05$). Approximately forty percent of the oysters in Great Bay are currently infected. The rate of systemic infection (7% on average in 2002) is also important because systemic infection is a portent of imminent death, whereas oysters with low grade infections will often survive for at least another year.

Table 14: Prevalence of MSX infection in Great Bay oysters

Year	Location	Number Tested	Percent Infected	Percent with Systemic Infection	Source
1995	Nannie Island	20	15%	5%	NHF&G, Barber et al., 1997
1996	Nannie Island	40	8%	0%	NHF&G
1997	Nannie Island	25	52%	28%	NHF&G
1998	Nannie Island	25	44%	8%	NHF&G
1999	Nannie Island	20	35%	30%	NHF&G
2000	Nannie Island	20	30%	25%	NHF&G
2001	Nannie Island	24	21%	17%	NHF&G
2002	Nannie Island	24	37%	17%	NHF&G
1995	Oyster River	20	50%	30%	NHF&G, Barber et al., 1997
1997	Oyster River	25	36%	8%	NHF&G
2000	Oyster River	20	35%	10%	NHF&G
2001	Oyster River	20	25%	20%	NHF&G
2002	Oyster River	20	45%	5%	NHF&G
1995	Adams Point	20	40%	15%	NHF&G, Barber et al., 1997
1996	Adams Point	10	0%	0%	NHF&G
1997	Adams Point	25	40%	20%	NHF&G
1998	Adams Point	25	28%	8%	NHF&G
2000	Adams Point	20	35%	25%	NHF&G
2001	Adams Point	20	25%	20%	NHF&G
2002	Adams Point	20	45%	0%	NHF&G
1995	Piscataqua River	45	71%	33%	NHF&G, Barber et al., 1997
1997	Piscataqua River	25	60%	20%	NHF&G
1998	Piscataqua River	18	39%	17%	NHF&G
2000	Piscataqua River	20	30%	15%	NHF&G
1997	Squamscott River	25	44%	20%	NHF&G
1998	Squamscott River	25	68%	28%	NHF&G

Figure 17: Prevalence of MSX infection in Great Bay oyster beds

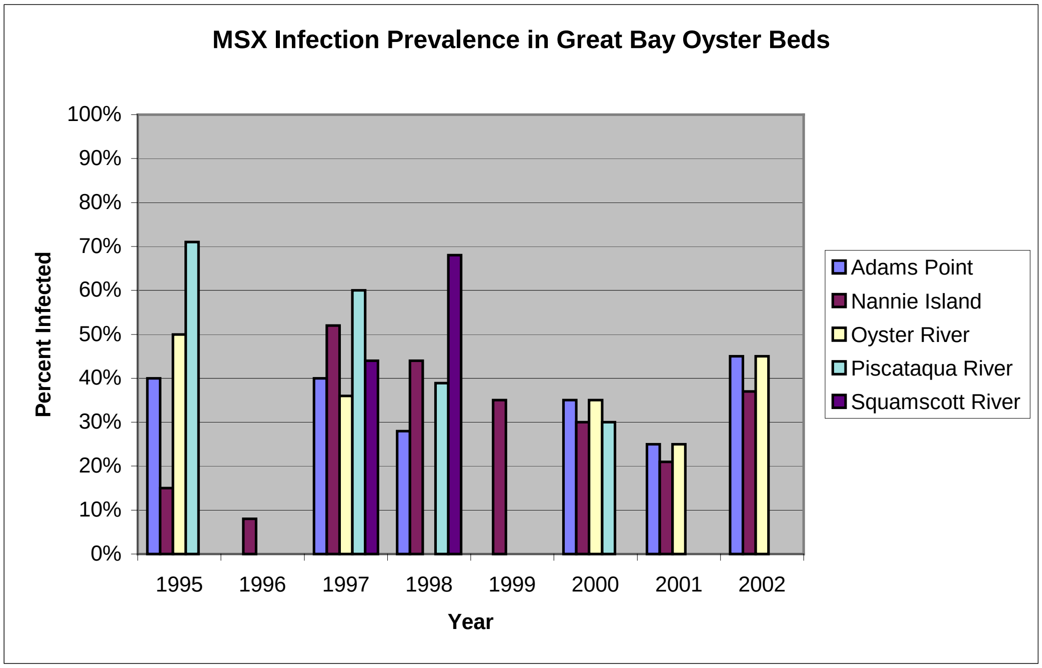
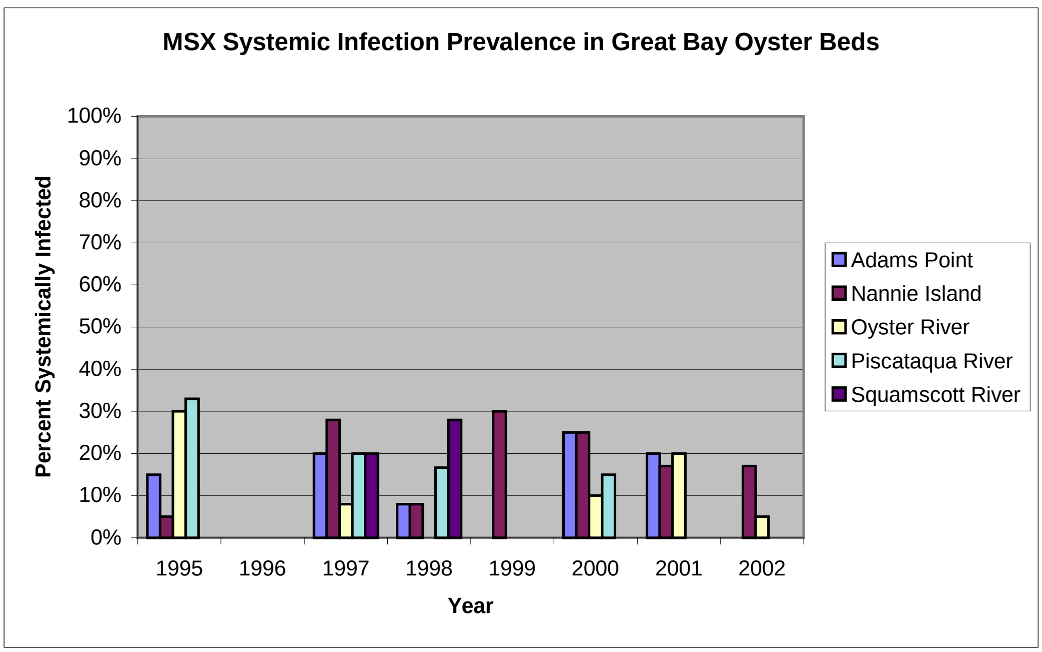


Figure 18: Prevalence of systemic MSX infection in Great Bay oyster beds



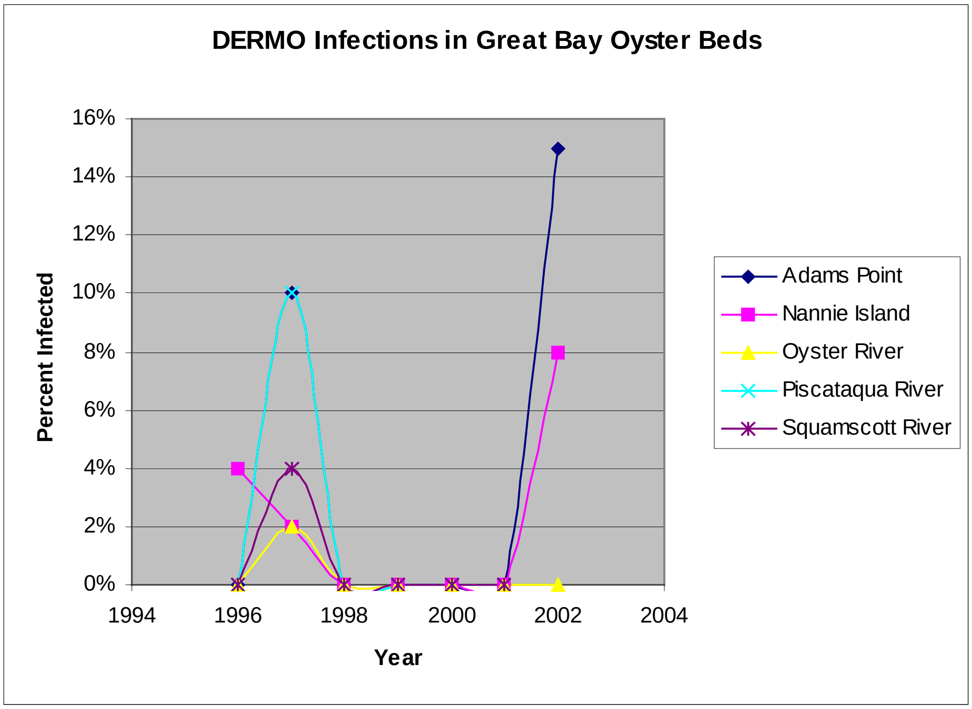
Dermo

The other major oyster disease present in Great Bay is Dermo which is caused by the protozoa *Perkinsus marinus*. However, the infection of Great Bay oysters by Dermo has been less severe than MSX. In 1997, only 10% of oysters from any bed were infected with the disease. Between 1998 and 2001, Dermo was not found in NH waters except at the Salmon Falls River bed (not shown). In 2002, oysters from Adams Point, Nannie Island, and the Salmon Falls River were found to be infected with Dermo again (NHF&G, 2003).

Table 15: Prevalence of Dermo infection in Great Bay oysters

Year	Location	Number Tested	Percent Infected	Percent Heavily Infected	Source
1996	Nannie Island	25	4%	0%	NHF&G
1997	Nannie Island	50	2%	0%	NHF&G
1998	Nannie Island	25	0%	0%	NHF&G
1999	Nannie Island	20	0%	0%	NHF&G
2000	Nannie Island	20	0%	0%	NHF&G
2001	Nannie Island	25	0%	0%	NHF&G
2002	Nannie Island	24	8%	0%	NHF&G
1997	Oyster River	50	2%	0%	NHF&G
2000	Oyster River	20	0%	0%	NHF&G
2001	Oyster River	20	0%	0%	NHF&G
2002	Oyster River	20	0%	0%	NHF&G
1997	Adams Point	50	10%	0%	NHF&G
1998	Adams Point	25	0%	0%	NHF&G
2000	Adams Point	20	0%	0%	NHF&G
2001	Adams Point	20	0%	0%	NHF&G
2002	Adams Point	20	15%	0%	NHF&G
1997	Piscataqua River	50	10%	2%	NHF&G
1998	Piscataqua River	18	0%	0%	NHF&G
2000	Piscataqua River	20	0%	0%	NHF&G
1997	Squamscott River	25	4%	0%	NHF&G
1998	Squamscott River	25	0%	0%	NHF&G

Figure 19: Prevalence of Dermo infection in Great Bay oysters



SHL12. Prevalence of Clam Disease

a. Monitoring Objectives

The objective of this supporting variable is to estimate the prevalence of clam disease (sarcomastic neoplasia). This information is needed to answer the following monitoring question:

- "Has the incidence of shellfish diseases changed significantly over time?"

b. Measurable Goal

This is a supporting variable so no measurable goal has been established. These data will be collected to provide additional information to help interpret the results of other indicators.

c. Data Analysis and Statistical Methods

Clams are considered neoplastic if 100% of the assayed blood cells are neoplastic. Therefore, for each clam flat, the prevalance of clams with 100% neoplastic cells will be reported. This prevalence will be tracked over time. No statistical tests will be applied.

d. Results

Sarcomatous neoplasia (neoplasia) is a lethal form of leukemia in soft-shell clams. In 1986-1987, neoplasia was first discovered in clams from Hampton Harbor. The incidence of neoplasia in clams from flats 1, 2, and 4 were 6%, 27%, and 0% respectively. By 1989, 80% of the clams from flat 2 had neoplastic cells. In 1996 and 1997, 100% of the clams collected from each flat had neoplastic cells (NAESCO, 1998).

In 1999, the screening process was changed. Instead of reporting the percentage of clams with neoplastic cells, Seabrook Station began reporting the percentage of clams where 100% of the cells were neoplastic. The last survey conducted in July 1999 indicated that the percentage of clams with 100% neoplastic cells ranged from 2.4% to 7.0% at all flats except Middle Ground where no clams with 100% neoplastic cells were detected. It is expected that all of the clams with 100% neoplastic cells will die, leading to a mortality rate of up to 7% (NAESCO, 2001).

Some recent anecdotal information on neoplasia prevalence is available from a NHEP-funded project to study the factors leading to juvenile clam mortality in Hampton Harbor. Among other tests, two sets of juvenile clams from the flats were tested for neoplasia in March and July 2002. Neither set of clams tested positive for neoplasia (Beal 2002). However, the clams tested for this study were juvenile clams from specific areas of the flats and so do not constitute a harbor-wide survey.

REFERENCES CITED

Barber BJ, Langan R, and Lowell TL (1997) *Haplosporidium nelsoni* (MSX) epizootic in the Piscataqua River Estuary (Maine/New Hampshire, USA), *J. Parasitol*. **83**(1): 148-150.

Beal BF (2002) Evaluating Factors Contributing to Mortalities of Juveniles of the Soft-shell Clam (*Mya arenaria* L.) in Hampton/Seabrook Harbor, New Hampshire. A final report to the NH Estuaries Project prepared by Dr. Brian Beal of the University of Maine at Machias, Machias, ME. December 27, 2002.

Belding DL (1930) The Soft-Shelled Clam Fishery of Massachusetts. Marine Fisheries Series – No. 1. Commonwealth of Massachusetts, Department of Conservation, Division of Fisheries and Game, Marine Fisheries Section. 1930.

Haskin HH and Ford SE (1982) *Haplosporidium nelsoni* (MSX) on Delaware Bay Seed Oyster Beds: A host-parasite relationship along a salinity gradient, *J. Invertebrate Pathology*, **40**: 388-405.

Hurrell J (2003) North Atlantic Oscillation (NAO) Indices Information. National Center for Atmospheric Research. Available at: http://www.cgd.ucar.edu/~jhurrell/nao.stat.winter.html#winter.

Langan (1997) Assessment of Shellfish Populations in the Great Bay Estuary. A Final Report to the NHEP. December 1997.

Manalo AB, Lindsey BE, and Frick GE (1991) New Hampshire Recreational Oyster Harvesters: Profile perceptions and attitudes, UNH Agricultural Experiment Station Report No. 126. 1991.

NAESCO (2001) 2000 Environmental Monitoring in the Hampton-Seabrook Area: A Characterization of Environmental Conditions During the Operation of the Seabrook Station. Prepared by Normandeau Associates, Bedford NH, for North Atlantic Energy Service Corporation, Seabrook NH. December 2001.

NAESCO (1998) 1996 Environmental Monitoring in the Hampton-Seabrook Area: A Characterization of Environmental Conditions During the Operation of the Seabrook Station. Prepared by Normandeau Associates, Bedford NH, for North Atlantic Energy Service Corporation, Seabrook NH. January 1998.

NHEP (2003) Monitoring Plan, NH Estuaries Project, Portsmouth, NH. March 2003. Available at: http://webster.state.nh.us/nhep/Monitoring/monitoring.htm

NHF&G (2003) Testing of Great Bay Oysters for Two Protozoan Pathogens. A final report to the N.H. Estuaries Project, New Hampshire Fish & Game Department, May 21, 2003.

NHF&G (2002) Shellfish population and bed dimension assessment for the Great Bay Estuary. A final report to the N.H. Estuaries Project, New Hampshire Fish & Game Department, December 31, 2002.

NHF&G (1997) Great Bay Oyster Harvest Survey. A final report to the N.H. Estuaries Project, New Hampshire Fish & Game Department, December 31, 1997.

BIBLIOGRAPHY OF NH SHELLFISH DATA SOURCES

Soft-Shell Clam Data

Beal BF (2002) Evaluating Factors Contributing to Mortalities of Juveniles of the Soft-shell Clam (*Mya arenaria* L.) in Hampton/Seabrook Harbor, New Hampshire. A final report to the NH Estuaries Project prepared by Dr. Brian Beal of the University of Maine at Machias, Machias, ME. December 27, 2002.

Jones and Langan (1996) Assessment of Clam Resources and Sanitary Quality of the Shellfish Growing Waters in Witch Creek, Seavey Creek, and Little Harbor. A final report to the New Hampshire Coastal Program by Drs. Stephen Jones and Richard Langan of the Jackson Estuarine Laboratory, UNH, Durham NH. July 1996.

Langan et al. (1999) Clam Population Assessment in Back Channel, Portsmouth. A final report to the New Hampshire Estuaries Project by Dr. Richard Langan, Dr. Raymond Grizzle, and Gwynne Schnaittacher of the Jackson Estuarine Laboratory, UNH. December 31, 1999.

Langan (1999) Assessment of Clam Populations in the Great Bay Estuary. A final report to the New Hampshire Estuaries Project by Dr. Richard Langan of the Jackson Estuarine Laboratory, UNH. January 1999.

Langan (1997) Assessment of Shellfish Populations in the Great Bay Estuary. A final report to the New Hampshire Estuaries Project by Dr. Richard Langan of the Jackson Estuarine Laboratory, UNH. December 31, 1997.

NAESCO (2002) Seabrook Station 2001 Environmental Monitoring in the Hampton-Seabrook Area: A characterization of environmental conditions during the operation of Seabrook Station. Prepared for North Atlantic Energy Service Corporation, Seabrook NH. Prepared by Normandeau Associates Inc., Bedford NH. August 2002.

NAESCO (2001) Seabrook Station 2000 Environmental Monitoring in the Hampton-Seabrook Area: A characterization of environmental conditions during the operation of Seabrook Station. Prepared for North Atlantic Energy Service Corporation, Seabrook NH. Prepared by Normandeau Associates Inc., Bedford NH. December 2001.

NAESCO (2000) Seabrook Station 1999 Environmental Monitoring in the Hampton-Seabrook Area: A characterization of environmental conditions during the operation of Seabrook Station. Prepared for North Atlantic Energy Service Corporation, Seabrook NH. Prepared by Normandeau Associates Inc., Bedford NH. December 2000.

NAESCO (1999) Seabrook Station 1998 Operational Report. Prepared for North Atlantic Energy Service Corporation, Seabrook NH. Prepared by Normandeau Associates Inc., Bedford NH. October 1999.

NAESCO (1998a) Seabrook Station 1997 Operational Report. Prepared for North Atlantic Energy Service Corporation, Seabrook NH. Prepared by Normandeau Associates Inc., Bedford NH. September 1998.

NAESCO (1998b) Seabrook Station 1996 Environmental Monitoring in the Hampton-Seabrook Area: A characterization of environmental conditions during the operation of Seabrook Station. Prepared for North Atlantic Energy Service Corporation, Seabrook NH. Prepared by Normandeau Associates Inc., Bedford NH. January 1998.

NAESCO (1996) Seabrook Station 1995 Environmental Monitoring in the Hampton-Seabrook Area: A characterization of environmental conditions during the operation of Seabrook Station. Prepared for North Atlantic Energy Service Corporation, Seabrook NH. Prepared by Normandeau Associates Inc., Bedford NH. August 1996.

NAESCO (1995) Seabrook Station 1994 Environmental Monitoring in the Hampton-Seabrook Area: A characterization of environmental conditions during the operation of Seabrook Station. Prepared for North Atlantic Energy Service Corporation, Seabrook NH. Prepared by Normandeau Associates Inc., Bedford NH. October 1995.

NAESCO (1994) Seabrook Station 1993 Operational Report. Prepared for North Atlantic Energy Service Corporation, Seabrook NH. Prepared by Normandeau Associates Inc., Bedford NH. 1994.

NAESCO (1993) Seabrook Station 1992 Operational Report. Prepared for North Atlantic Energy Service Corporation, Seabrook NH. Prepared by Normandeau Associates Inc., Bedford NH. 1993.

NAESCO (1992) Seabrook Station 1991 Operational Report. Prepared for North Atlantic Energy Service Corporation, Seabrook NH. Prepared by Normandeau Associates Inc., Bedford NH. 1992.

NAI (1991) Seabrook Environmental Studies, 1990: A characterization of environmental conditions in the Hampton-Seabrook area during the operation of Seabrook Station. Technical Report XXII-II. Prepared for Public Service Company of New Hampshire, Yankee Division, Seabrook Station, Seabrook NH. Prepared by Normandeau Associates Inc, Bedford NH. November 1991.

NHF&G (2000) Clam Survey – Middle Ground, Seabrook. Inter-Department Communication from Bruce Smith to John Nelson, NH Fish and Game Department, Region 3, Durham, NH. June 7, 2000.

NHF&G (1999) Recreational Soft-Shell Clam Harvest Survey. A final report to the N.H. Estuaries Project, New Hampshire Fish & Game Department, December 31, 1999.

NHF&G (1998) Recreational Soft-Shell Clam Harvest Survey. A final report to the N.H. Estuaries Project, New Hampshire Fish & Game Department, December 31, 1998.

Sher (2003) Hampton-Seabrook clam flat acreage from 2002 aerial photographs. Personal communication, Ron Sher, Florida Power and Light. September 2003.

Sher (2002) Hampton-Seabrook clam flat acreage from 1977-1995 aerial photographs. Personal communication, Ron Sher, North Atlantic Energy Service Corporation. August 2002.

Oyster Data

Barber BJ, Langan R, and Lowell TL (1997) *Haplosporidium nelsoni* (MSX) epizootic in the Piscataqua River Estuary (Maine/New Hampshire, USA), *J. Parasitol*. **83**(1): 148-150.

Langan (1997) Assessment of Shellfish Populations in the Great Bay Estuary. A final report to the New Hampshire Estuaries Project by Dr. Richard Langan of the Jackson Estuarine Laboratory, UNH. December 31, 1997.

NHF&G (2002a) Testing of Great Bay Oysters for Two Protozoan Pathogens. A final report to the N.H. Estuaries Project, New Hampshire Fish & Game Department, March 30, 2002.

NHF&G (2003) Testing of Great Bay Oysters for Two Protozoan Pathogens. A final report to the N.H. Estuaries Project, New Hampshire Fish & Game Department, May 21, 2003.

NHF&G (2002b) Preliminary Review of Oyster Data - 2002. Inter-Department Communication from Bruce Smith to John Nelson, NH Fish and Game Department, Region 3, Durham, NH. December 20, 2002.

NHF&G (2002c) Shellfish population and bed dimension assessment for the Great Bay Estuary. A final report to the N.H. Estuaries Project, New Hampshire Fish & Game Department, December 31, 2002.

NHF&G (2001a) Preliminary Review of Oyster Data - 2001. Inter-Department Communication from Bruce Smith to John Nelson, NH Fish and Game Department, Region 3, Durham, NH. December 13, 2001.

NHF&G (2001b) Corrected Tables for Oyster Update Memo of 7/12/99. Inter-Department Communication from Bruce Smith to John Nelson, NH Fish and Game Department, Region 3, Durham, NH. September 25, 2001.

NHF&G (2001c) Review of Oyster Data 91-00. Inter-Department Communication from Bruce Smith to John Nelson, NH Fish and Game Department, Region 3, Durham, NH. September 24, 2001.

NHF&G (2001d) Oyster Resource Update – 2000. Inter-Department Communication from Bruce Smith to John Nelson, NH Fish and Game Department, Region 3, Durham, NH. April 26, 2001.

NHF&G (2000) Oyster Resource Update. Inter-Department Communication from Bruce Smith to John Nelson, NH Fish and Game Department, Region 3, Durham, NH. October 10, 2000.

NHF&G (1999) Oyster Resource Update. Inter-Department Communication from Bruce Smith to John Nelson, NH Fish and Game Department, Region 3, Durham, NH. July 12, 1999.

NHF&G (1997) Great Bay Oyster Harvest Survey. A final report to the N.H. Estuaries Project, New Hampshire Fish & Game Department, December 31, 1997.