STATE OF CONNECTICUT
DEPARTMENT OF AGRICULTURE
Bureau of Aquaculture & Laboratory Services

Bryan P. Hurlburt
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2021 Statewide Shellfish Disease Update

Shellfish health is a critical factor in maintaining viable wild and cultivated populations, which support a robust aquaculture industry. The Connecticut Department of Agriculture, Bureau of Aquaculture (DABA) has monitored shellfish health since 1997. This report provides recent oyster and hard clam disease data with historic context.

Contents

History of Oyster Diseases in Connecticut

The following important infectious oyster diseases are present in CT: MSX (Multinucleated Sphere Unknown, due to *Haplosporidium nelsoni*), SSO (Seaside Organism, due to *Haplosporidium costale*), Dermo (due to *Perkinsus marinus*), and ROD (*Roseovarius* Oyster Disease, formerly JOD (Juvenile Oyster Disease)) (fig. 1).

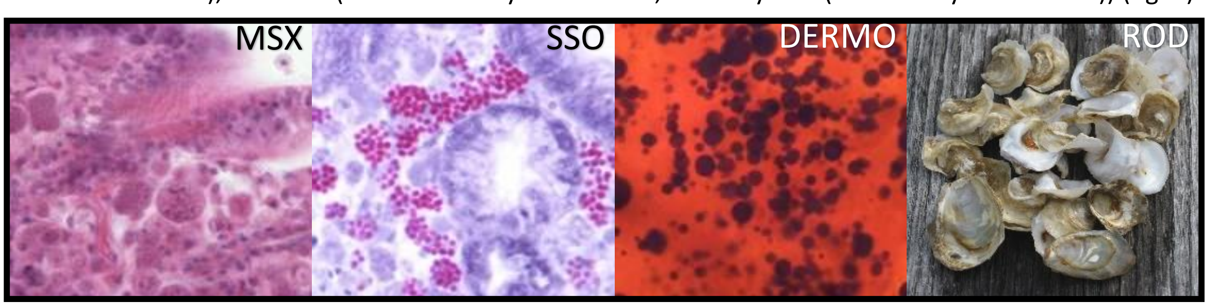

Figure 1. Infectious diseases impacting oyster populations in Connecticut. Left to right: microscopic images of MSX, SSO, and Dermo in oyster tissue, and a photograph of ROD-infected oysters.

P.O. Box 97, Milford, CT 06460

The following information is based on data collected by Dr. Inke Sunila, DABA pathologist from 1997-2016.

MSX disease may occur at epizootic levels in Connecticut waters. A 1997 outbreak in market size oysters caused serious economic damage to the industry. The following year, infection spread to seed oyster beds. Oyster production decreased from more than 500,000 bushels in 1996 to 80,000 bushels in 2000, reflecting high MSX-associated mortalities. MSX-prevalence in Connecticut oysters has been in steady decline as the population gained natural resistance and MSX-resistant strains, including “Clinton” developed by DABA, were introduced. Localized areas in CT may continue to have high MSX prevalence and/or MSX-associated mortalities. In CT, MSX can occur as a co-infection with another haplosporidian parasite, SSO. While SSO has caused high mortalities in Virginia and Maryland, SSO prevalence has remained low in CT and has not been associated with large mortality events.

Dermo spread rapidly, and has largely remained at high prevalences since 1997, throughout statewide oyster populations. However, Dermo is a slow-killing disease. It takes up to three years in Connecticut after initial infection for parasite intensities to approach levels high enough to cause oyster mortality. Oysters are typically marketed when they are three years old. Consequently, Dermo has not caused significant mortalities in Connecticut’s commercial oyster stocks. High oyster mortalities in 1997 and 1998 were due to an MSX outbreak, not Dermo infection. On the other hand, Dermo-associated mortalities have been detected in areas of unusually slow oyster growth or during restoration efforts when oysters are grown indefinitely.

ROD affects hatchery-raised seed on the U.S. east coast from Maine to New York. Oysters experience retarded growth, mortality, unequal shell growth, cupping of the left valve, shell checks and conchiolin rings (“brown rings”) on the internal shell surface. The first CT ROD outbreak occurred in 2000, and it has subsequently caused periodic mortalities. A ROD–resistant oyster strain was derived from the MSX-resistant “Clinton” strain that survived the 2000 ROD outbreak.

History of Hard Clam Diseases in Connecticut

The following information is based on data collected by Dr. Inke Sunila, DABA pathologist from 1997-2016.

Hard clams are impacted by QPX (Quahog Parasite Unknown, due to Labyrinthomorpha). QPX is believed to be an opportunistic parasite that is ubiquitous in high-salinity estuaries, and can be fatal. While QPX has caused disease outbreaks and mortalities in multiple neighboring states, only 6 out of 2,358 hard clams (0.3%) were infected with QPX between 1997 and 2007 in CT (fig. 2). Therefore, QPX is not considered to currently pose a threat to CT’s industry.

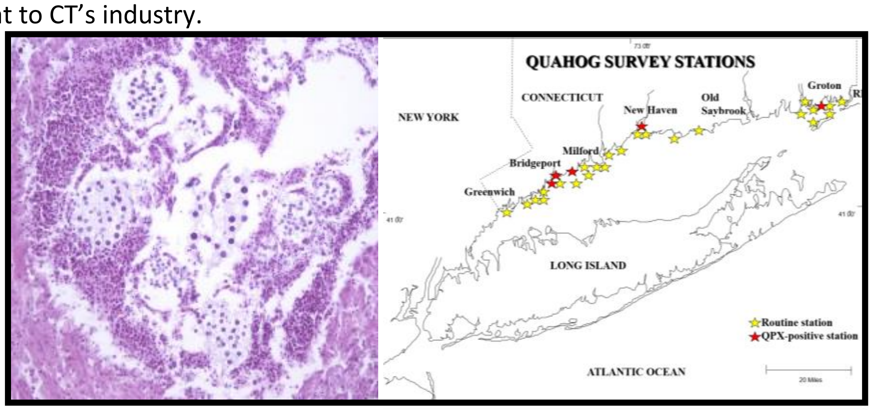

Figure 2. Microscopic images of QPX in hard clams (left). QPX-positive locations relative to routine quahog survey stations (1997-2007) (right). The QPX-positive stations are shown with red stars.

Methodology

Disease Monitoring Methods

The DABA employed a full-time shellfish pathologist, Dr. Inke Sunila, from 1997-2016. She used histology to visually monitor shellfish disease prevalence and intensity throughout Connecticut. Given the historic MSX outbreak, multiple potential oyster pathogens, and widespread absence of hard clam diseases, this work focused largely on oysters. The number of sample sets and routine pathology stations for 1997-2016 data are presented (fig. 3).

Total number of oyster sample sets analyzed for disease surveillance from 1997-2016			
1997	9	2007	17
1998	37	2008	22
1999	30	2009	21
2000	21	2010	12
2001	20	2011	11
2002	20	2012	8
2003	14	2013	9
2004	16	2014	16
2005	12	2015	11
2006	14	2016	11
Each sample set was comprised of ~30 oysters			

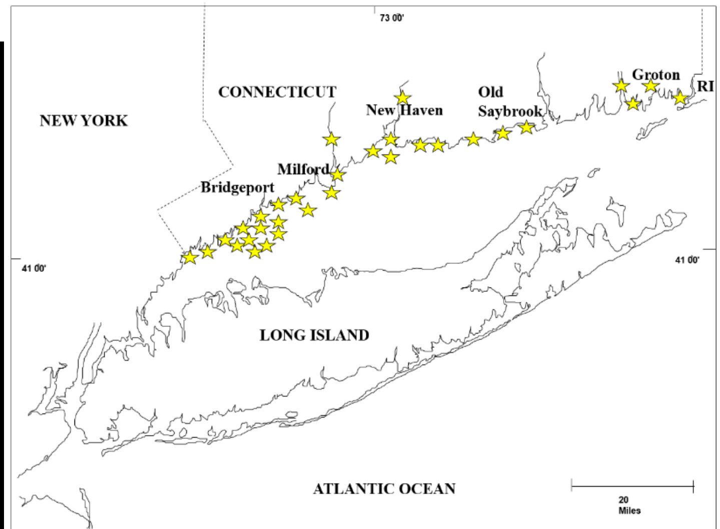

Figure 3. Number of oyster pathology samples analyzed by DABA (left) and routine pathology sampling stations (right) from 1997-2016

In the current absence of a state shellfish pathologist, disease surveillance was conducted by monitoring disease prevalence and intensity using a molecular method, triplex PCR, to detect the DNA of disease-causing organisms in shellfish samples. Roxanna Smolowitz, DVM, at the Aquatic Diagnostic Laboratory at Roger Williams University, led the 2019-2021 disease surveillance project. Funding was provided by the United States Department of Agriculture (USDA) Animal and Plant Health Inspection Service (APHIS).
Wild and hatchery oysters and clams were collected throughout the coastline in 2019-2021 (fig. 4). Given the historic MSX outbreak, multiple potential oyster pathogens, and widespread absence of hard clam diseases, disease monitoring continues to focus largely on oysters.

Source		**Number of sample sets (percentage of total sample sets)**		
		2019	**2020**	**2021**
Oyster	Hatchery	10 (55.56%)	8 (57.14%)	4 (30.77%)
	Wild	8 (44.44%)	6 (42.86%)	9 (69.23%)
	Mix	0	0	1
Hard Clam	Hatchery	0	1	0
	Wild	0	2	2
Grand Total		**18**	**17**	**16**
Each sample set was comprised of ~30 shellfish				

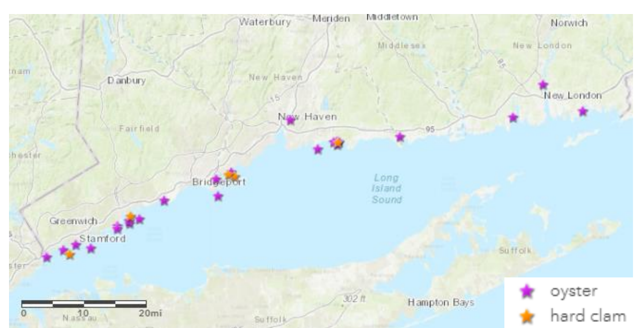

Figure 4. Number of oyster pathology samples analyzed by Roger Williams (left) and pathology sampling stations (right) from 2019-2021

Calculation Methods

Prevalence: percent of animals positive in the population (each sample set was typically 30 shellfish)

Weighed Intensity: total of the scores for each individual animal/total number of animals in the sample set. Weighed intensity is used to report findings from any pathology lab, regardless of the method used to do the evaluation, and provides an overall standardized score to assess the level of infection in each group of oysters by each of the parasites.

Intensity: total of the scores of positive animals/number of positive animals in a sample set. The intensity measurement is an average calculated by including only animals that were positive for the disease (not an overall average of the entire group). Intensity may be important to consider, particularly when mortality is noted on the site even when the overall average for the entire sample set is low. Animals that are badly infected will die even while most animals in the population are not infected or have only low levels of infection. In other words, intensity provides a possible explanation for low level mortality in a group of cultured animals even when weighed intensity is low.

Interpretation

Dermo: Intensity ratings are: 0.5, very light; 1.0, light; 2.0, light to moderate; 3.0, moderate; 4.0, heavy; 5.0, very heavy. Populations with weighed intensities above 2.0 usually show noticeable mortality. Populations with intensities above 2.0 can also show sporadic mortality.

MSX and SSO: Intensity rating are: 1, light; 2.0, moderate; 3.0, severe. Populations with weighed intensities of 2.0 and greater usually show noticeable mortality. Populations with MSX or SSO intensities of 1.5 can show sporadic mortality.

1997-2021 Oyster Disease Trends

The following data are presented as annual statewide averages (figs. 5-8). Results are broken out by town thereafter (see 2019-2021 Oyster Disease Surveillance Results).

Dr. Sunila was involved in a study that compared Dermo, MSX, and SSO disease prevalence by PCR and histology in Norwalk, CT oysters (Russell et al. 2004). An average of the 4 Norwalk oyster samples revealed that the PCR method had an increased detection of 28.33%, 16.67%, and 6.67% for Dermo, MSX, and SSO prevalences, respectively (Russell et al. 2004). Russell et al. (2004) did not report the differences in disease weighed intensity or intensity results comparing PCR and histology; therefore, it is not feasible to normalize the data to make it directly comparable from 1997-2021. However, observed increases in disease statistics in the 2019-2021 data set could be due to increased sensitivity of PCR over histology and/or actual increases in disease prevalence and intensity.

While Dermo has not caused widespread mortality in CT oyster populations, it is clear that average Dermo prevalence has consistently remained high (fig. 5). Populations with a Dermo weighed intensity above 2 can show sporadic mortality, and the statewide 2019 and 2020 averages of 2.2 and 2, respectively, indicate Dermo could be causing localized mortality events (fig. 6). Compared to historic histology data (1997-2016), the PCR Dermo weighed intensity values (2019-2021) are visibly higher.

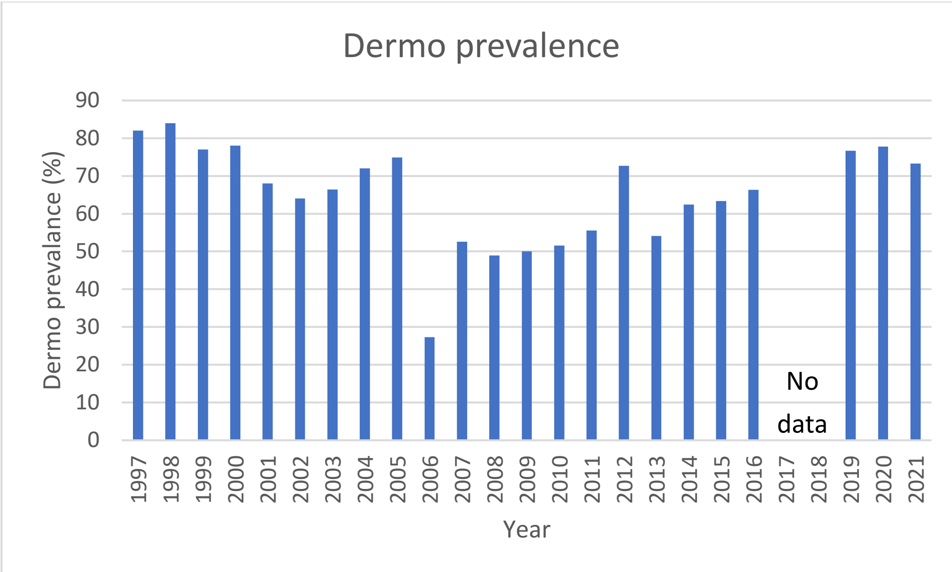

Figure 5. Annual average Dermo prevalence (%) for the entire coastline from 1997-2021. The prevalence indicates the percentage of animals positive in a population. 1997-2016 represents DABA histology data, while 2019-2021 represents Roger Williams PCR data. No data was collected in 2017-2018.

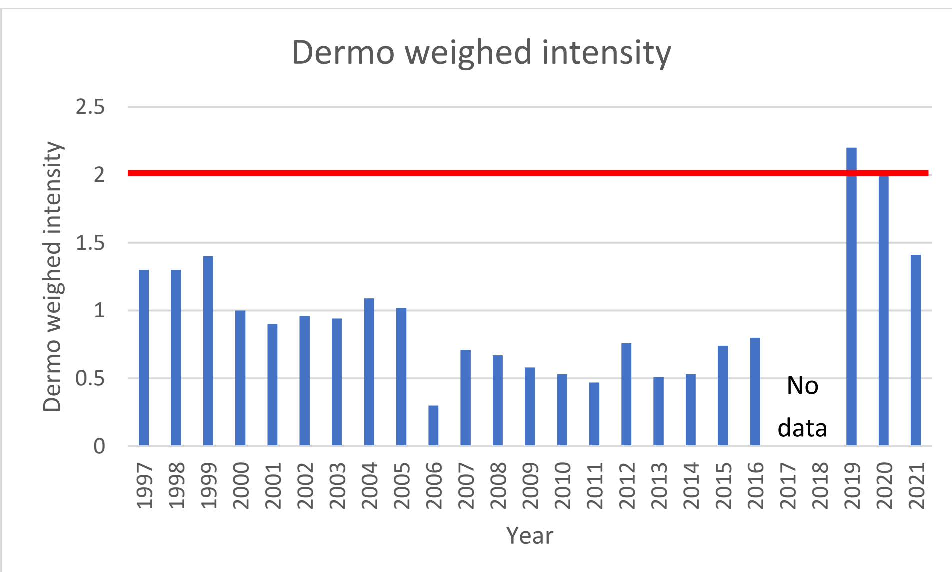

Figure 6. Annual average Dermo weighed intensity for the entire coastline from 1997-2021. The weighed intensity provides an overall standardized score to assess the level of infection in an oyster group by each parasite. For Dermo, populations with weighed intensities above 2.0 usually also show noticeable mortality in the population (shown by the red line). 1997-2016 represents DABA histology data, while 2019-2021 represents Roger Williams PCR data. No data was collected in 2017-2018.

MSX prevalence was the highest in 1997, coinciding with a widespread MSX disease outbreak (fig. 7). MSX continued to decrease and remain at lower prevalences up to 2016 according to histology data (fig. 7). In 2012, the average MSX prevalence in Connecticut was 0, indicating no oysters were infected with MSX (fig. 7). However, 2019-2021 PCR analysis indicates an increase in MSX and SSO prevalences (fig. 7). Histology data from 1997-2016 always reported SSO prevalences as less than 1 (fig. 7). Of note, the 2021 data is skewed because an area of high MSX prevalence was sampled 3 times (fig. 7). Importantly, there has not been an increase in MSX weighed intensity and it has never exceeded 2, which indicates the population, as a whole, is not expected to experience MSX mortality (fig. 8). However, there were widespread mortality events during the epizootic MSX event in 1997, despite the annual weighed intensity remaining below 2 (fig. 8). The average MSX weighed intensities for 2019-2021 remained below the 1997 weighed intensity (fig. 8).

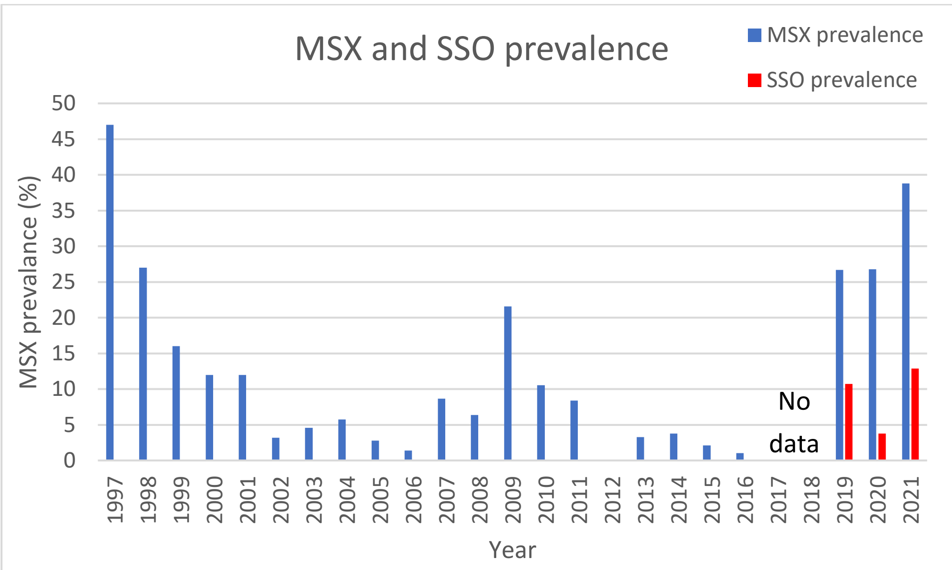

Figure 7. Annual average MSX (blue) and SSO (red) prevalences (%) for the entire coastline from 1997-2021. The prevalence indicates the percentage of animals positive in a population. SSO prevalences are graphed, but are not readily visible, for 1997-2016 because they were always below 1. 1997-2016 represents DABA histology data, while 2019-2021 represents Roger Williams PCR data. No data was collected in 2017-2018.

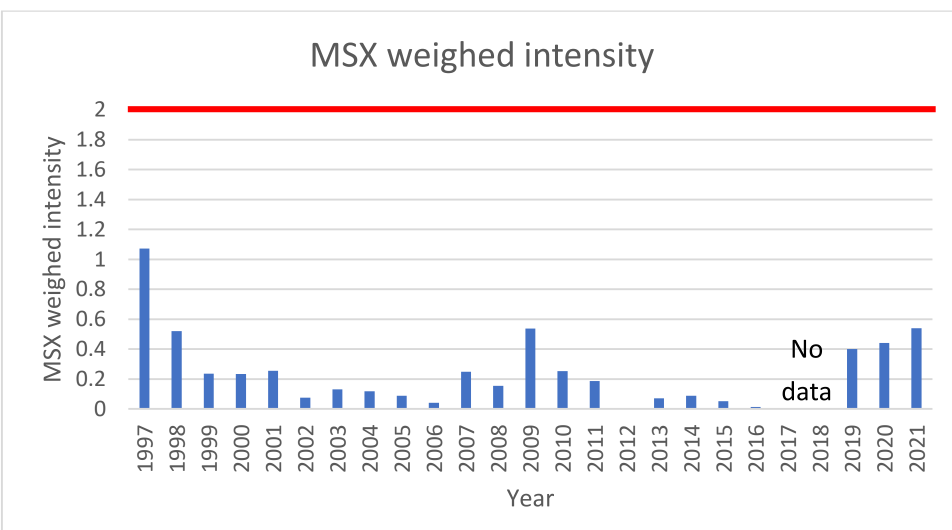

Figure 8. Annual average MSX weighed intensity for the entire coastline from 1997-2021. The weighed intensity provides an overall standardized score to assess the level of infection in an oyster group by each parasite. For MSX, weighed intensity of 2.0 and greater can experience noticeable mortality in the population (shown by the red line). 1997-2016 represents DABA histology data, while 2019-2021 represents Roger Williams PCR data. No data was collected in 2017-2018.

2019-2021 Oyster Disease Surveillance Results

The following tables and graphs are provided to give an overall summary of the 2019-2021 oyster disease surveillance results for Connecticut. Please note that individual sites or farms are not identified in the graphs; if you have specific questions about results for your site, please contact DABA.

The entire data set, comprised of 46 oyster sample sets, for 2019-2021 was analyzed to develop a 3-year disease summary (table 1). There was high data variability for both Dermo and MSX prevalence, ranging from 0 to 100% (table 1). The Dermo prevalence median and 75% of 93.3 and 100, respectively, indicate the population is skewing towards high prevalence (table 1). Dermo weighed intensity and Dermo intensity median values of 2.12 and 2.19, respectively, indicate portions of the population could be experiencing Dermo mortality. MSX prevalence and weighed intensity indicate that while MSX is present, it is not expected to currently cause widespread mortality events. However, the sample sets above the 75% for MSX intensity (1.5) could be experiencing sporadic mortality events (table 1). Dermo was not detected in 1 sample set (2.2%), and MSX was not detected in 7 sample sets (15.2%) (table 1). ROD was not detected in a single oyster from 2019-2021 (table 1), which coincides with typically low ROD rates reported in DABA histology data.

<table>
<tr><th>Disease</th><th>Average /Mean</th><th>Standard deviation</th><th>Min</th><th>Max</th><th>Number of non-detect sample sets</th><th>Median</th><th>25%</th><th>75%</th></tr>
<tr><td>Dermo Prevalence</td><td>78.11</td><td>32.59</td><td>0</td><td>100</td><td rowspan="3">1</td><td>93.3</td><td>65.03</td><td>100</td></tr>
<tr><td>Dermo Weighed intensity</td><td>1.90</td><td>1.07</td><td>0</td><td>3.6</td><td>2.12</td><td>1</td><td>2.80</td></tr>
<tr><td>Dermo Intensity</td><td>2.20</td><td>0.83</td><td>0</td><td>3.71</td><td>2.19</td><td>1.62</td><td>2.80</td></tr>
<tr><td>MSX Prevalence</td><td>30.43</td><td>27.19</td><td>0</td><td>100</td><td rowspan="3">7</td><td>26.7</td><td>6.70</td><td>46.68</td></tr>
<tr><td>MSX Weighed intensity</td><td>0.45</td><td>0.46</td><td>0</td><td>1.93</td><td>0.37</td><td>0.13</td><td>0.60</td></tr>
<tr><td>MSX Intensity</td><td>1.15</td><td>0.64</td><td>0</td><td>3</td><td>1.12</td><td>1</td><td>1.5</td></tr>
<tr><td>ROD prevalence</td><td>0</td><td>0</td><td>0</td><td>0</td><td>46</td><td>0</td><td>0</td><td>0</td></tr>
</table>

Table 1. Descriptive statistics of Dermo and MSX prevalence, weighed intensity, and intensity across 2019-2021. The mean or average is defined as the central value of a data set and is calculated by dividing the sum of all values by the number of samples. The standard deviation is used to quantify the variation in a data set. The minimum is the smallest value in the data set. The maximum is the largest value in the data set. The disease was not detected in a sample set (~30 oysters) listed in the non-detect sample sets column. The median is defined as the "middle" value of a data set and can be a better way of representing data with skewed (high and low) values. Data is generally divided into 25%, 50%, and 75%, such that values lower than the 25 quartile fall below this point, and values lower than the 75 quartile fall below this point.

While there are areas with lower Dermo prevalence, most areas sampled along the coastline had high Dermo prevalence (fig. 9). There are no visible trends in Dermo prevalence or weighed intensity across the 3 years or across the coastline (figs. 9-10). A Dermo weighed intensity of 2 indicates that populations could experience mortality events. There was a decreasing trend from 2019 to 2021 in sample sets exceeding the Dermo weighed intensity of 2; however, not every location was sampled every year, making it difficult to compare disease prevalences and intensities without bias. Sample sets exceeding a weighed intensity of 2 decreased from 12 in 2019 and 9 in 2020 to 4 in 2021 (fig. 10).

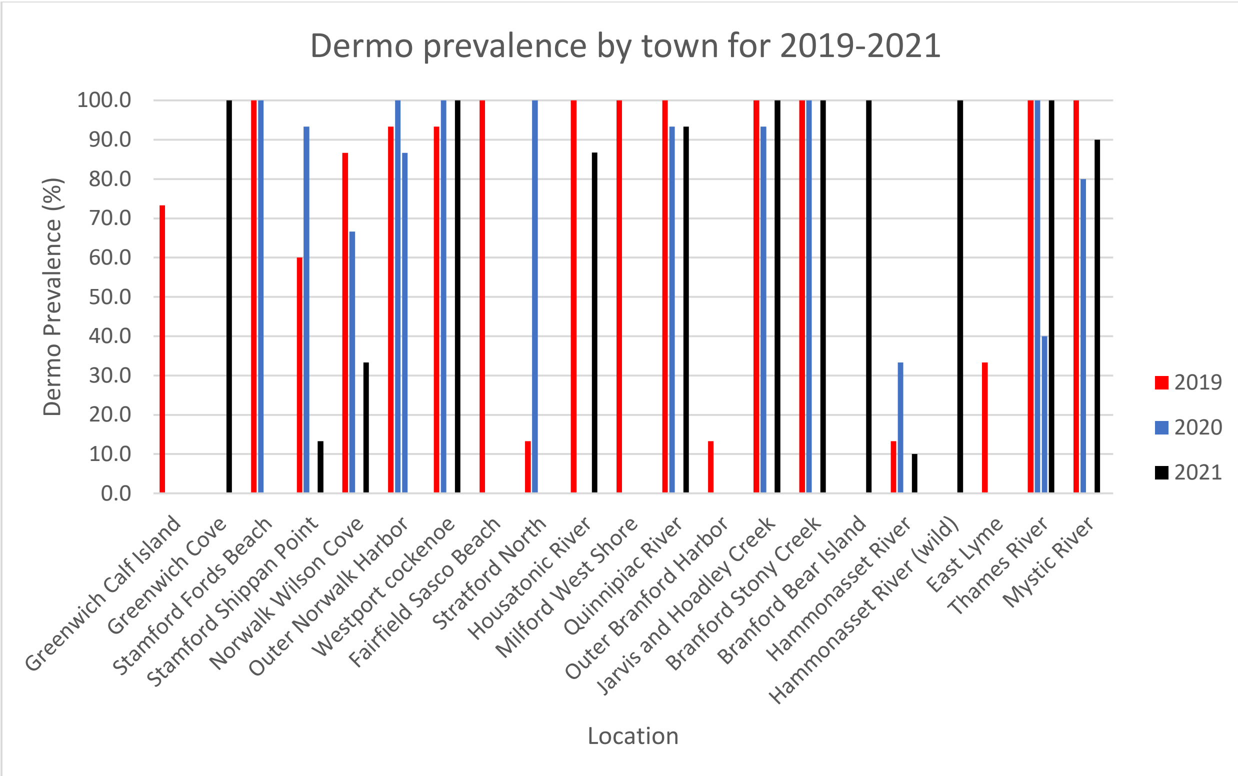

Figure 9. Dermo prevalence (%) for each sampling location. The prevalence indicates the percentage of animals positive in a population. 2019 (red), 2020 (blue), and 2021 (black) data are shown. Not every location was sampled every year. The only location without Dermo detection was one Hammonasset River sample set in 2021.

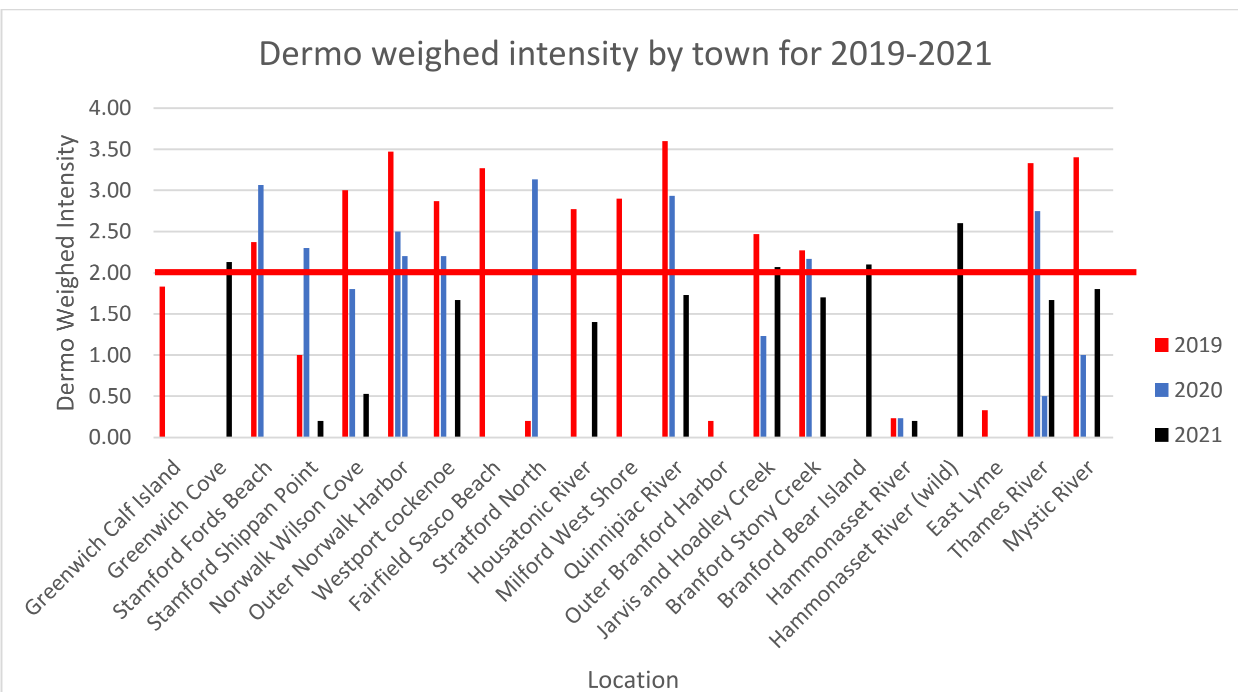

Figure 10. Dermo weighed intensity for each sampling location. The weighed intensity provides an overall standardized score to assess the level of infection in an oyster group by each parasite. For Dermo, populations with weighed intensities above 2.0 usually show noticeable mortality in the population (shown by the red line). 2019 (red), 2020 (blue), and 2021 (black) data are shown. Not every location was sampled every year. The only location without Dermo detection was one Hammonasset River sample set in 2021.

There were areas of high MSX prevalence, notably the Hammonasset River across all 3 years, but overall prevalence was much lower than Dermo (fig. 11). MSX weighed intensities of 2 or greater indicate a population could experience mortality events. MSX weighed intensities across the coastline remained below 2 (fig. 12). However, MSX weighed intensities for the Hammonasset River remained elevated and near 2 for all 3 years (fig. 12).

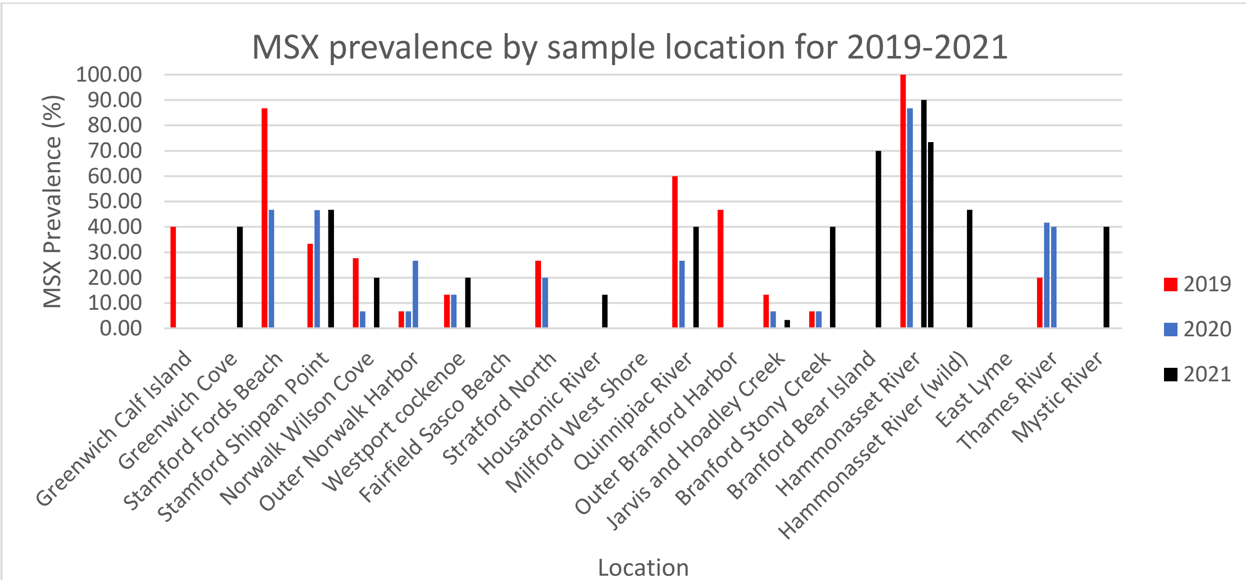

Figure 11. MSX prevalence (%) for each sampling location. The prevalence indicates the percentage of animals positive in a population. 2019 (red), 2020 (blue), and 2021 (black) data are shown. Not every location was sampled every year. MSX was not detected in the Thames River in 2021, Mystic River in 2020 and 2019, Fairfield Sasco Beach in 2019, Housatonic River in 2019, Milford West Shore in 2019, and East Lyme in 2019.

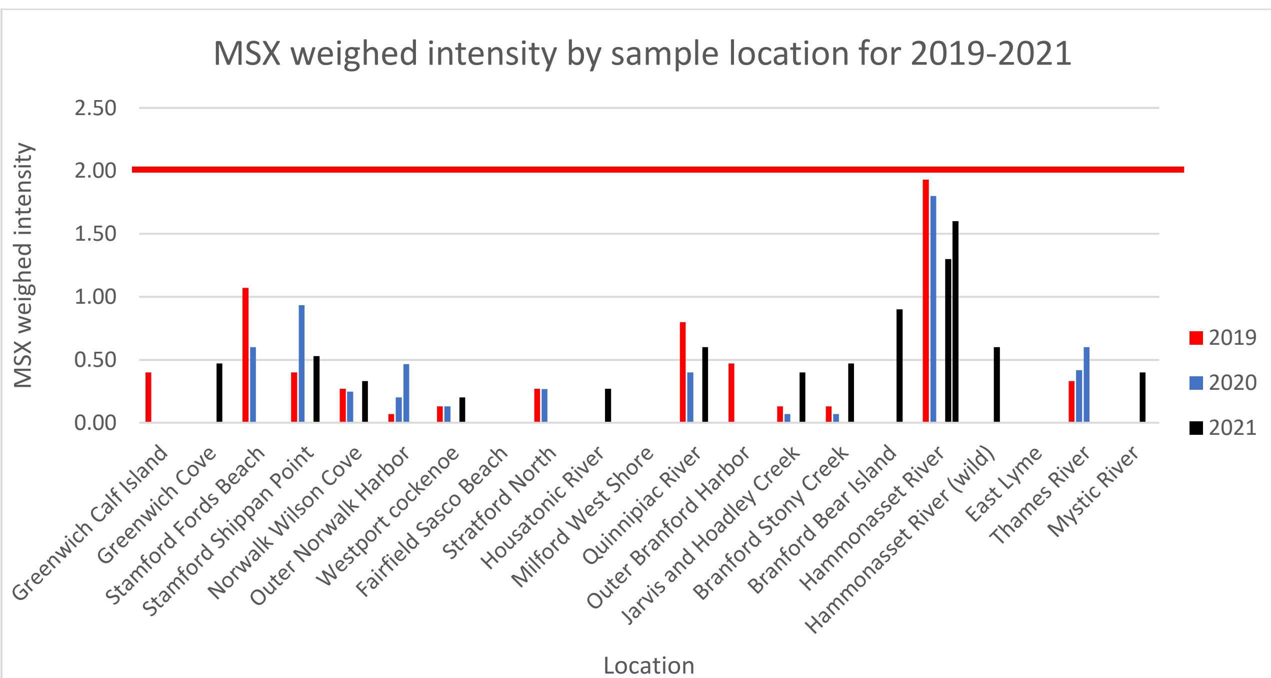

Figure 12. MSX weighed intensity for each sampling location. The weighed intensity provides an overall standardized score to assess the level of infection in an oyster group by each parasite. For MSX, weighed intensity of 2.0 and greater can experience noticeable mortality in the population (shown by the red line). Not every location was sampled every year. MSX was not detected in the Thames River in 2021, Mystic River in 2020 and 2019, Fairfield Sasco Beach in 2019, Housatonic River in 2019, Milford West Shore in 2019, and East Lyme in 2019.

2019-2021 Wild & Hatchery Oyster Comparative Results

The entire data set, comprised of 23 wild and 22 hatchery sourced oyster sample sets, for 2019-2021 was analyzed to develop a 3-year disease summary (table 2). Statistical analysis determined that wild oysters had significantly higher rates of Dermo prevalence and Dermo weighed intensity (table 2). The average (91.6%) and median (100%) Dermo prevalences for wild oysters were much higher than for hatchery oysters (63.03% and 76.65%, respectively) (table 2). The average and median Dermo weighed intensity for wild oysters both exceeded the weighed intensity of 2, indicating that portions of the population could be experiencing mortality events (table 2). Comparatively, the average and median Dermo weighed intensities for hatchery oysters remained below 2; however, the 75% of 2.6 indicates that a portion of the hatchery populations could be experiencing mortality events (table 2). Furthermore, the average and median Dermo intensities for both wild and hatchery oysters exceeded 2, suggesting Dermo intensity is high for both and could be causing localized mortality events (table 2). MSX prevalence, weighed intensity and intensity were higher for hatchery than wild oysters, but they were not significantly different (table 2). Wild oysters did not exceed weighed intensities of 2 or intensities of 1.5, which indicate the population is not expected to experience mortality events (table 2). However, the hatchery oyster intensity 75% of 1.8 indicates a portion of the population could be experiencing MSX mortality events (table 2).

	Average/ Mean	Min	Max	Number of non-detect sample sets	Median	25%	75%	Significance
WILD Dermo Prevalence	91.6	13.3	100	0	100	93.3	100	Significantly higher
HATCHERY Dermo Prevalence	63.03	0	100	1	76.65	28.3	94.98	
WILD Dermo Weighed intensity	2.2	0.2	3.3	0	2.21	1.67	2.9	Significantly higher
HATCHERY Dermo Weighed intensity	1.57	0	3.5	1	1.8	0.2	2.6	
WILD Dermo Intensity	2.34	1.32	3.6	1	2.2	1.67	3.07	Not significantly different
HATCHERY Dermo Intensity	2.06	0	3.71	0	2.19	1.25	2.75	
WILD MSX Prevalence	22.1	0	70	3	20	6.7	40	Not significantly different
HATCHERY MSX Prevalence	38.64	0	100	4	40	6.67	53.35	
WILD MSX Weighed intensity	0.3	0	0.9	3	0.27	0.13	0.42	Not significantly different
HATCHERY MSX Weighed intensity	0.6	0	1.93	4	0.44	0.17	0.97	
WILD MSX Intensity	1.09	0	2	3	1	1	1.33	Not significantly different
HATCHERY MSX Intensity	1.22	0	3	4	1.17	1	1.8	

Table 2. Descriptive Statistics of Dermo and MSX prevalence, weighed intensity, and intensity comparing wild and hatchery sample sets across 2019-2021. The mean or average is defined as the central value of a data set and is calculated by dividing the sum of all values by the number of samples. The standard deviation is used to quantify the variation in a data set. The minimum is the smallest value in the data set. The maximum is the largest value in the data set. The disease was not detected in a sample set (~30 oysters) listed in the non-detect sample sets column. The median is defined as the "middle" value of a data set and can be a better way of representing data with skewed (high and low) values. Data is generally divided into 25%, 50%, and 75%, such that values lower than the 25 quartile fall below this point, and values lower than the 75 quartile fall below this point.

Dermo prevalence (fig. 13) and weighed intensity (fig. 14) are shown comparing wild and hatchery oysters for 2019-2021. Dermo prevalence and weighed intensity were significantly higher for wild oysters (table 2). While 9 hatchery oyster sample sets were below the weighed intensity of 2, only 4 wild oyster sample sets were below 2 (fig. 14). There are no consistent trends for Dermo prevalence or weighed intensity across the coast.

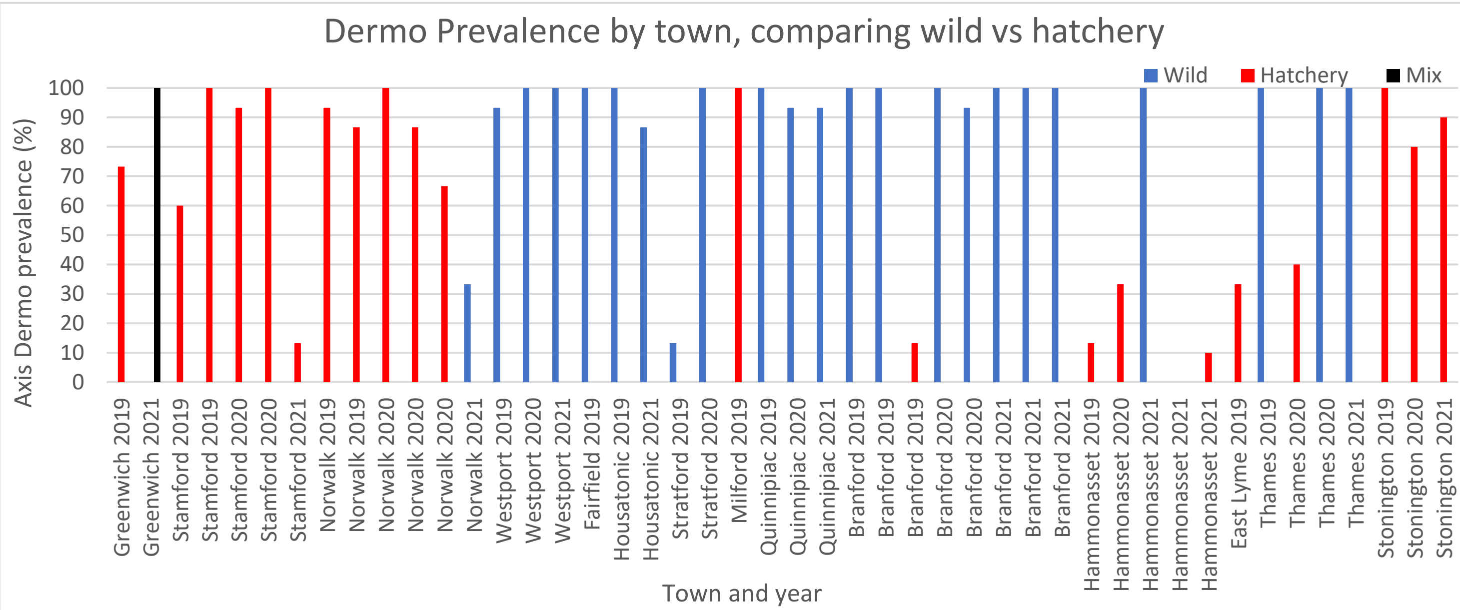

Figure 13. Dermo prevalence (%) for each sampling location. The prevalence indicates the percentage of animals positive in a population. Wild (blue), hatchery (red), and a mix of both (black) oysters are shown. The only location without Dermo detection was one Hammonasset River sample set in 2021.

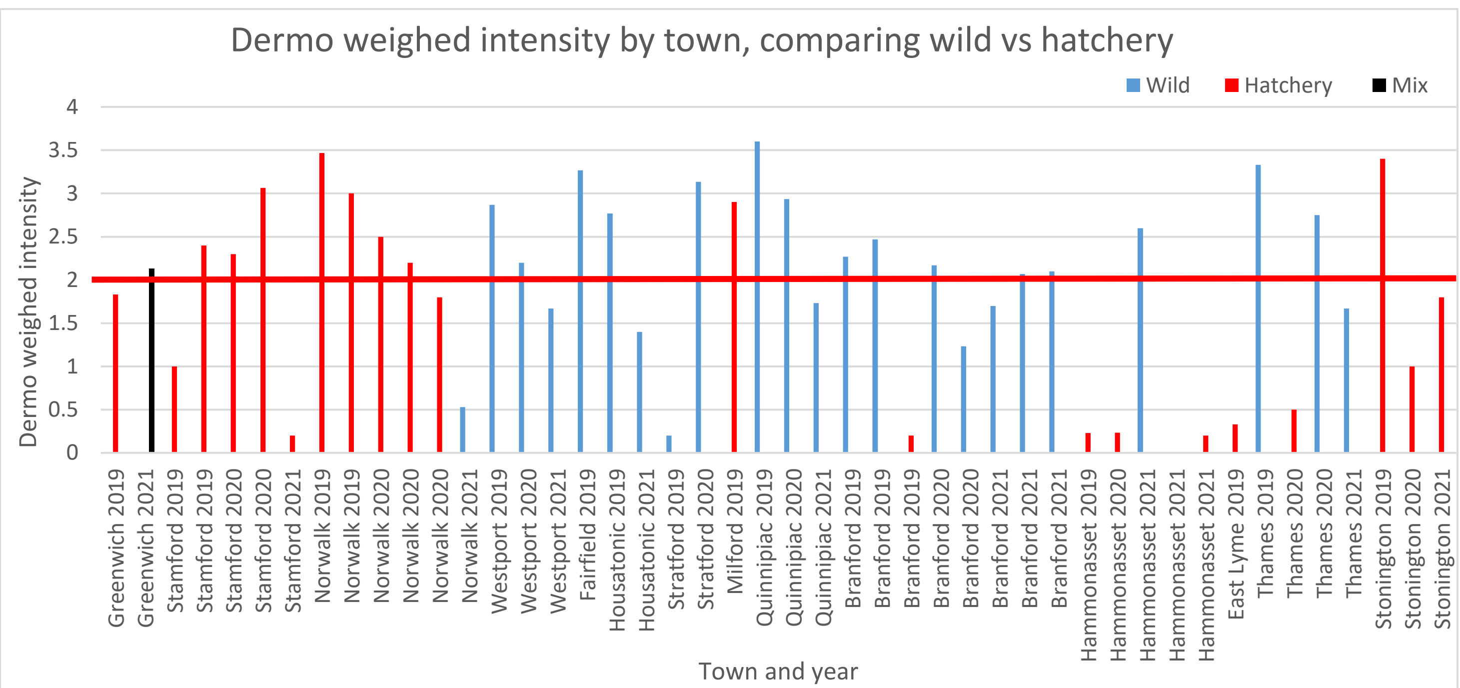

Figure 14. Dermo weighed intensity for each sampling location. The weighed intensity provides an overall standardized score to assess the level of infection in an oyster group by each parasite. For Dermo, populations with weighed intensities above 2.0 usually show noticeable mortality in the population (shown by the red line). Wild (blue), hatchery (red), and a mix of both (black) oysters are shown. The only location without Dermo detection was one Hammonasset River sample set in 2021.

MSX prevalence and weighed intensity were slightly, but not significantly, higher for hatchery oysters than wild oysters (table 2). There are no trends in MSX prevalence or weighed intensity among towns or years, but the hatchery oysters on the Hammonasset River have some of the highest prevalences and weighed intensities recorded in 2019-2021 (figs. 15-16). In 2021, 2 hatchery and 1 wild oyster sample sets were collected from the Hammonasset River, and the wild oyster had notably lower MSX prevalence and weighed intensity (figs. 15-16).

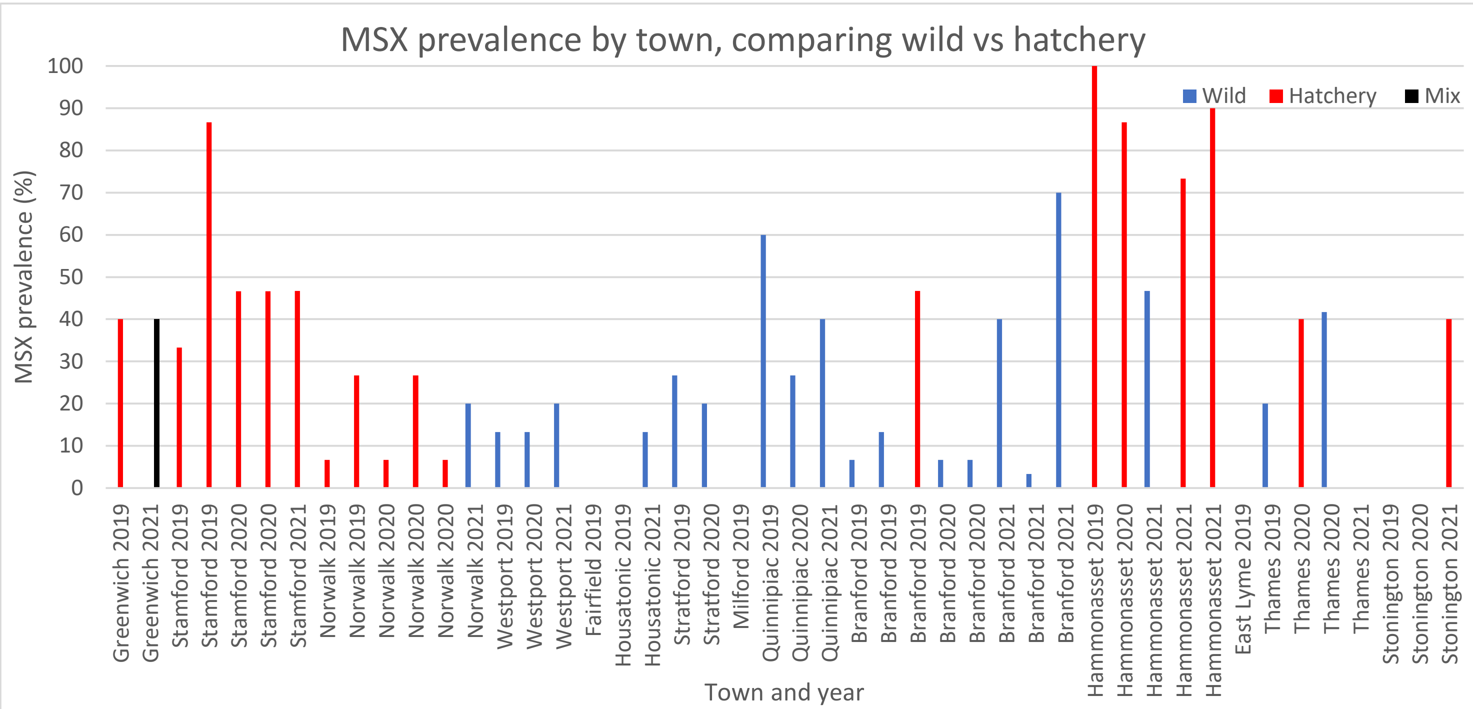

Figure 15. MSX prevalence (%) for each sampling location. The prevalence indicates the percentage of animals positive in a population. Wild (blue), hatchery (red), and a mix of both (black) oysters are shown. MSX was not detected in the Thames River in 2021, Mystic River in 2020 and 2019, Fairfield Sasco Beach in 2019, Housatonic River in 2019, Milford West Shore in 2019, and East Lyme in 2019.

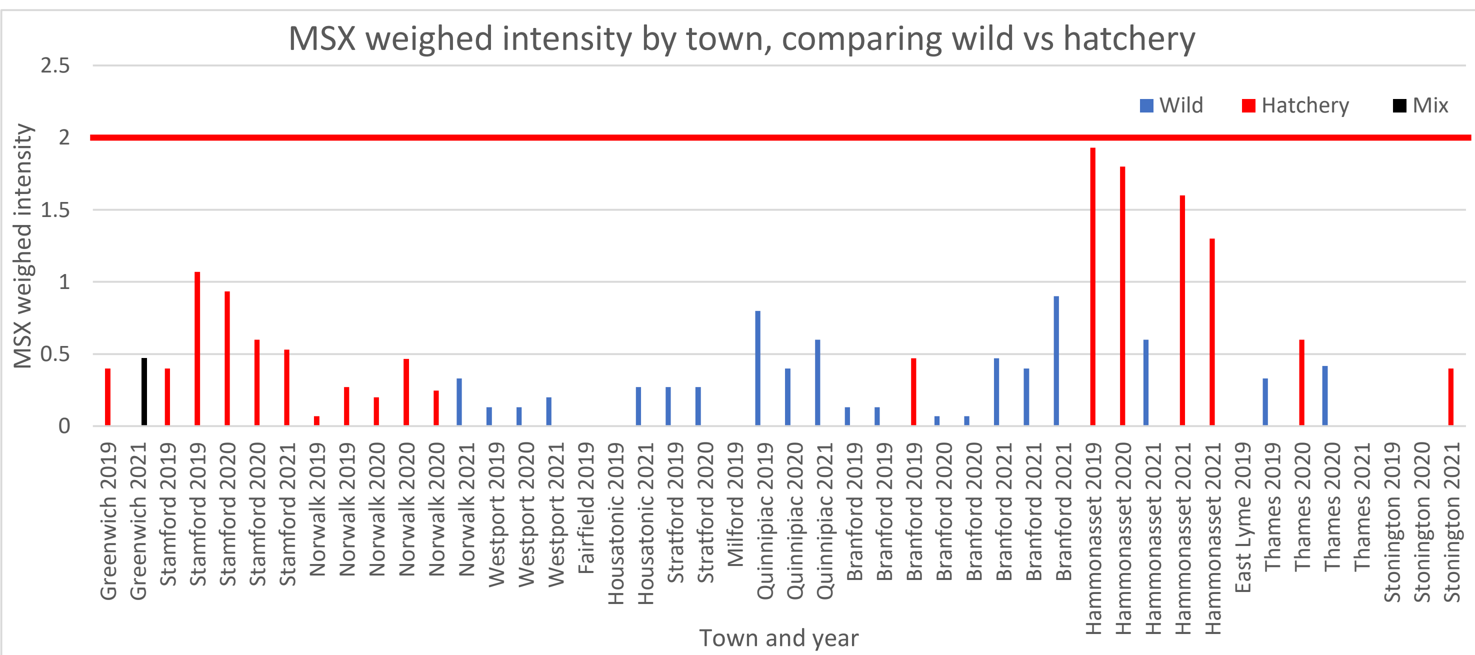

Figure 16. MSX weighed intensity for each sampling location. The weighed intensity provides an overall standardized score to assess the level of infection in an oyster group by each parasite. For MSX, weighed intensity of 2.0 and greater can experience noticeable mortality in the population (shown by the red line). Wild (blue), hatchery (red), and a mix of both (black) oysters are shown. MSX was not detected in the Thames River in 2021, Mystic River in 2020 and 2019, Fairfield Sasco Beach in 2019, Housatonic River in 2019, Milford West Shore in 2019, and East Lyme in 2019.

2020-2021 Hard Clam Disease Surveillance Results

Hard clam sample sets submitted to Roger Williams were tested for Quahog Parasite Unknown (QPX), neoplasia (abnormal tissue growth causing tumor formation), and other potential pathogens (table 3). All clams were negative for QPX (table 3), which is consistent with previous DABA histology findings. No significant cause of mortality was found in 2020-2021 with PCR analysis.

1 case of hemocytic neoplasia (HN) was detected in 2020 from a New Jersey hatchery-source clam sample set (table 3). HN is an emerging infectious disease that only impacts hard clams, and typically impacts hatchery hard clams.

Year	Town	Wild or Hatchery	Results
2020	Branford	Hatchery (New Jersey)	Hemocytic neoplasia (HN) detected in 1.7% of clams. The clam displayed moderate-severe HN.
2020	Milford	Wild	No disease concerns
2020	Greenwich	Wild	No disease concerns
2021	Westport	Wild	No disease concerns
2021	Milford	Wild	No disease concerns
Each sample set contained 30 or 60 hard clams			

Table 3. 2020-2021 hard clam disease surveillance sample sets and relevant results.

Discussion

Weighed intensity is the most important finding to be considered when assessing the disease burden and implications for the statewide health of Connecticut shellfish. However, disease prevalence indicates the overall proportion of the population that has the disease, and intensity is a useful parameter to assess low level disease mortality events.

Oyster Disease Discussion

The 2019-2021 Dermo prevalence trends suggest that Dermo is widespread throughout the coastline, and weighed intensities suggest there could be mortality events attributed to Dermo. 54% of oyster sample sets exceeded the Dermo weighed intensity of 2. Wild oysters had a significantly higher Dermo prevalence and weighed intensity for the 2019-2021 data set. Only 1 sample set (2.2%) was negative for Dermo between 2019-2021. While Dermo weighed intensities above 2 in the northeast region generally cause noticeable mortality, this level of infection has not historically caused significant mortalities in the Connecticut commercial oyster stocks. Shellfish harvesters have not indicated a high level of mortality associated with this moderate to high disease prevalence. Growers who are experiencing noticeable or significant mortality on their farm should report this finding to DABA and seek additional guidance from the consulting pathologist. Based on these high rates of Dermo infection in both wild and hatchery oysters, it is prudent to continue harvesting oysters at 3 years of age, in accordance with state size regulations, to prevent Dermo mortality events. Oysters should not be grown indefinitely. Our findings correspond with modeling by Ben-Horin et al. (2018), who demonstrated that sufficient aquaculture harvest is an effective management strategy for Dermo because it helps to dilute parasite prevalence and reduces disease burden on wild oyster populations.

From 2019-2021, 0% of oyster sample sets exceeded the MSX weighed intensity of 2, suggesting MSX is not causing widespread mortalities. From 2019-2021, 15.22% of sample sets were negative for MSX. However, 26% of sample sets exceeded an MSX intensity of 1.5, which could indicate localized mortality events are occurring in groups with advanced disease progression. For example, the Hammonasset River had higher MSX prevalence, weighed intensities, and intensities for all 3 years than other areas surveyed in Connecticut. Hatchery populations had higher MSX prevalence, weighed intensity, and intensity; however, the overall differences between the two populations were not significant. Given the widespread MSX epizootic mass mortality events during the late 1990's in CT, growers should remain vigilant to the potential for MSX-related mortality events. MSX may be causing low levels of background mortalities in CT populations. Growers who are experiencing noticeable or significant mortality on their farm should report this finding to DABA and seek additional guidance from the consulting pathologist.

SSO can occur as a co-infection with MSX, but has not been associated with high mortality events in CT. 1997-2016 histology data indicated prevalences <1%; however, PCR detection suggests a higher infection rate for 2019-2021. Currently, SSO is still not believed to be a major cause of oyster mortality events. Continued vigilance is important to understand if disease prevalence is increasing or if the more sensitive PCR method is detecting SSO that is not typically detectable by histology. Of note, SSO prevalence was reported at a maximum of 100% for 1 sample set, despite low MSX prevalence at that location (6.7%). Intensities of 1 have routinely been reported for 2019-2021 data. An intensity of 1.5 or greater for MSX or SSO has been associated with mortality events in the northeast.

ROD was not detected in any oyster sample sets from 2019-2021. Connecticut oysters developed natural resistance to ROD during a 2000 outbreak, and mortality events periodically occurred historically. Currently, ROD is not impacting wild or hatchery oyster populations.

Under normal circumstances for the New England area, 67.39% of sample sets analyzed by PCR for 2019-2021 were predicted to experience Dermo, MSX, or multiple disease mortality events (table 4). Sample sets listed as multiple disease mortality events exceeded the standards outlined above for both of the respective diseases listed. The intensity of the mortality events would be related to the weighed intensity and intensity for each respective area; therefore, some areas could experience larger mortality events than others. 47.82% of the anticipated mortality events were attributed to Dermo (table 4). While it appears that the overall expected mortality rate for Dermo is decreasing from 2019-2021, not all locations were sampled every year. For example, Calf Island, Greenwich; Fords Beach, Stamford; Outer Norwalk Harbor; Sasco Beach, Fairfield; and West Shore, Milford were not sampled in 2021 and all were listed as locations of expected Dermo mortality in 2019 (table 4). The Hammonasset River was the only location with expected MSX mortality (table 4). The Thames River (2019), Stamford Shippan Point (2020), Branford Bear Island (2021), and Norwalk Wilson Cove (2021) all had expected Dermo and MSX mortality (table 4). Branford Stony Creek (2019) was the only location with an expected Dermo and SSO mortality (table 4). In 2019, Branford Stony Creek had an SSO prevalence of 100% and weighed intensity and intensity of 1. However, SSO mortality was not predicted for Branford Stony Creek in 2020 or 2021. High prevalence of multiple diseases in an area could have compounding effects, as oysters could be infected with more than one disease.

Type of expected mortality	2019	2020	2021	Total
Expected Dermo mortality	11 (61.11%)	8 (57.14%)	3 (20%)	**22 (47.82%)**
	Calf Island, Greenwich; Fords Beach, Stamford; Outer Norwalk Harbor; Wilson Cove, Norwalk; Westport Cockenoe; Sasco Beach, Fairfield; Housatonic River; West Shore, Milford; Quinnipiac River; Jarvis Creek, Branford; Mystic River, Stonington	Fords Beach, Stamford; Outer Norwalk Harbor; Wilson Cove, Norwalk (2 sample sets); Westport Cockenoe; Stratford North; Quinnipiac River; Stony Creek, Branford	Mystic River, Stonington; Hammonasset River (wild); Greenwich Cove	
Expected MSX mortality	1 (5.56%)	1 (7.14%)	2 (13.33%)	**4 (8.7%)**
	Hammonasset River	Hammonasset River	Hammonasset River (2 sample sets)	
Expected Dermo and MSX mortality	1 (5.56%)	1 (7.14%)	2 (13.33%)	**4 (8.7%)**
	Thames River	Stamford Shippan Point	Bear Island, Branford; Wilson Cove, Norwalk	
Expected Dermo and SSO mortality	1 (5.56%)	0	0	**1 (2.17%)**
	Stony Creek, Branford			
Total	**2019: 14 (77.78%)**	**2020: 10 (71.43%)**	**2021: 7 (46.67%)**	**31 (67.39%)**

Table 4. 2019-2021 expected Dermo, MSX, or multiple disease mortality events based upon pathology report results. Sample sets listed as multiple disease mortality events exceeded the standards outlined above for both of the respective diseases listed. The number and location(s) of expected mortality events for each disease are presented, along with the percentage of sample sets with expected mortality out of the total number of sample sets analyzed. The number of sample sets with expected mortality are totaled on the right by disease type. The number of sample sets with expected mortality per year are totaled on the bottom. The number of sample sets with expected mortality for 2019-2021 are totaled in the bottom right (highlighted in blue).

Hard Clam Disease Discussion

QPX was not detected in the limited number of sample sets analyzed in 2020-2021. Additionally, historic records show that QPX has rarely been detected in Connecticut and is not having large impacts on hard clam populations. The detection of 1 hard clam with the new infectious disease, hemocytic neoplasia (HN), in 2020 highlights the need for continued vigilance and adaptation to prevent emerging disease outbreaks. The presence of a new disease in Long Island Sound underscores the importance of routine disease surveillance in Connecticut and acquiring health reports before shellfish are imported.

HN is a relatively new disease and is consequently not well understood, but it is caused by cells that invade hard clam tissues, causing hemocytes to become non-functional (Roger Williams University 2021). Therefore, HN is an infectious disease that can be transmitted between hard clam populations (Smolowitz 2021). Some areas are already experiencing mass hard clam mortality events due to HN, such as in Wellfleet, MA; however, this disease is predominately believed to impact hatchery hard clams and it is unknown how far the infectious cells can be transported (Smolowitz 2021). HN was first detected in cultured hard clams in Wellfleet Bay starting in 2009, and has subsequently spread throughout the harbor (Smolowitz 2021). Hard clams that are collected on the surface tend to be positive and have a more advanced stage of HN than clams that are in the sediment (Smolowitz 2021). This form of neoplasia is related to neoplastic diseases in other bivalves, but is distinct (Smolowitz 2021). There is no treatment, but clams with low infection levels are able to survive and produce disease-resistant offspring, which is occurring in Wellfleet, MA (Smolowitz 2021).

Conclusions

The overall good health report for Connecticut oysters and clams is a reason to celebrate the successes of past research and disease management by DABA and partner agencies, in collaboration with harvesters. However, it is not a reason to become negligent of critical disease management protocols. While mass mortality events have not been reported to DABA, the predicted mortality of oysters in 67.39% of sample sets analyzed in 2019-2021 raises serious concerns. Many shellfish diseases, including Dermo and MSX, are warm water pathogens that are suppressed by cold winters. Under climate change, warmer water temperatures and less severe winters are predicted to increase disease prevalence and stress shellfish populations, making them more susceptible to diseases (e.g. Burge et al. 2014). The high prevalence and weighed intensity of Dermo rates, and significantly higher rates in wild oysters, raises concerns about potential future outbreaks. Harvesting oysters at age 3 has been a successful Dermo management protocol for decades. Indefinite growth of oysters in CT could contribute to a Dermo outbreak, particularly given the high prevalence documented from 1997-2021. While MSX prevalence and weighed intensity are lower than Dermo throughout CT, certain areas, like the Hammonasset River, are likely experiencing MSX mortalities. Given the severe impacts of the MSX outbreak in 1997, vigilance and continued MSX monitoring are important. Although SSO has not caused mass mortality events in CT, the prevalence increased in 2019-2021 using PCR detection compared to histology, and 1 area in 2019 had expected SSO mortality. ROD previously caused oyster mortalities in CT, but was not detected in 2019-2021. While QPX was not detected in CT hard clams in 2020-2021, 1 clam from a NJ hatchery source had moderate-severe hemocytic neoplasia, a relatively new infectious disease that only impacts hard clams. The high disease prevalences documented in CT oyster populations and potential for emerging diseases highlight the need for continued disease screening prior to importing shellfish into CT. Continued annual surveillance will be critical to understand changes in disease patterns and preventing future outbreaks.

Guidelines for Oyster Disease Management in Connecticut

Harvesters should notify DABA of any unusual mortality events. Additional information about shellfish disease management and downloadable fact sheets are available on the DABA website: https://portal.ct.gov/DOAG/Aquaculture1/Aquaculture/Oyster--Clam-Diseases

Dermo

- Oysters should continue to be marketed at 3 years old. Dermo-associated mortalities occur in areas where oysters are grown indefinitely or areas of unusually slow growth.
- Infected oyster grounds should be kept in operation as an active part of the transplantation programs.
- Since both seed and adult oysters can be infected without significant mortalities in market oysters, transplantation can occur from seedbed to grow-out areas.
- When relying on hatchery-raised seed, use Dermo-resistant strains.

Multinucleated Sphere Unknown (MSX)

- MSX does not lower oysters' market value, and infected oysters remain in good condition very close to death. Oysters should be marketed before infection lowers their condition index and advanced disease progression causes an unpleasant appearance.
- Transplanting oysters from restricted relay areas to MSX infected conditionally approved or approved areas for purification can proceed as before. Maintaining oysters in infected areas between mid-June to the end of November should not exceed three weeks. For example, oysters transplanted in November should be collected in the first week of July the next year.
- Oysters should not be transplanted from infected areas to uninfected areas, and infected areas should not be used as intermediate growing areas in transplantation programs.
- Do not harvest part of the infected lot (10% area) for a period of three years. After three spawning periods, these oysters can be harvested and marketed. These oysters will be the parents of MSX resistant oysters.
- Extend the growth season in seed areas.
- Culling oysters from an infected area should be done directly above the lease area, not on the way to the next harvest area or on the way back to the dock.

Roseovarius Oyster Disease (ROD)

- Decrease density of oyster seed in the nursery system.
- Increase flow rate in the oyster nursery system.
- Avoid infection window by deploying seed early so that it exceeds 25mm by the end of July.
- Use ROD-resistant oyster seed.

Guidelines for Hard Clam Disease Management in Connecticut

Harvesters should notify DABA of any unusual mortality events. Additional information about shellfish disease management and downloadable fact sheets are available on the DABA website: https://portal.ct.gov/DOAG/Aquaculture1/Aquaculture/Oyster--Clam-Diseases

Quahog Parasite Unknown (QPX)

- QPX-positive beds should be kept operational and as an active part of the transplantation programs.
- Clam seed imported from southern states is more susceptible to QPX than local or northern clam seed.
- Keep predator nets, cages, etc. clean of fouling. Major outbreaks have been linked to restricted water flow.

Hemocytic neoplasia (HN)

- HN is believed to mainly infect hatchery hard clams at this time. If possible, only use wild hard clam seed from Long Island Sound.
- When importing hatchery hard clam seed, shellfish growers must have the seed assessed for diseases, including HN. Do not import seed that tests positive for HN. HN is an infectious disease.
- Hard clam mortality events should be reported to DABA to coordinate disease testing. If a bed tests positive for HN, harvesters should limit the movement of their hard clams to prevent disease transmission.
- Hard clams that are sitting on the surface (not in the sediment), should be tested for HN, and should be removed from beds to prevent the disease from spreading.

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