New York Bight Indicator Report 2023

MOU #AM10560 NYS DEC & SUNY Stony Brook

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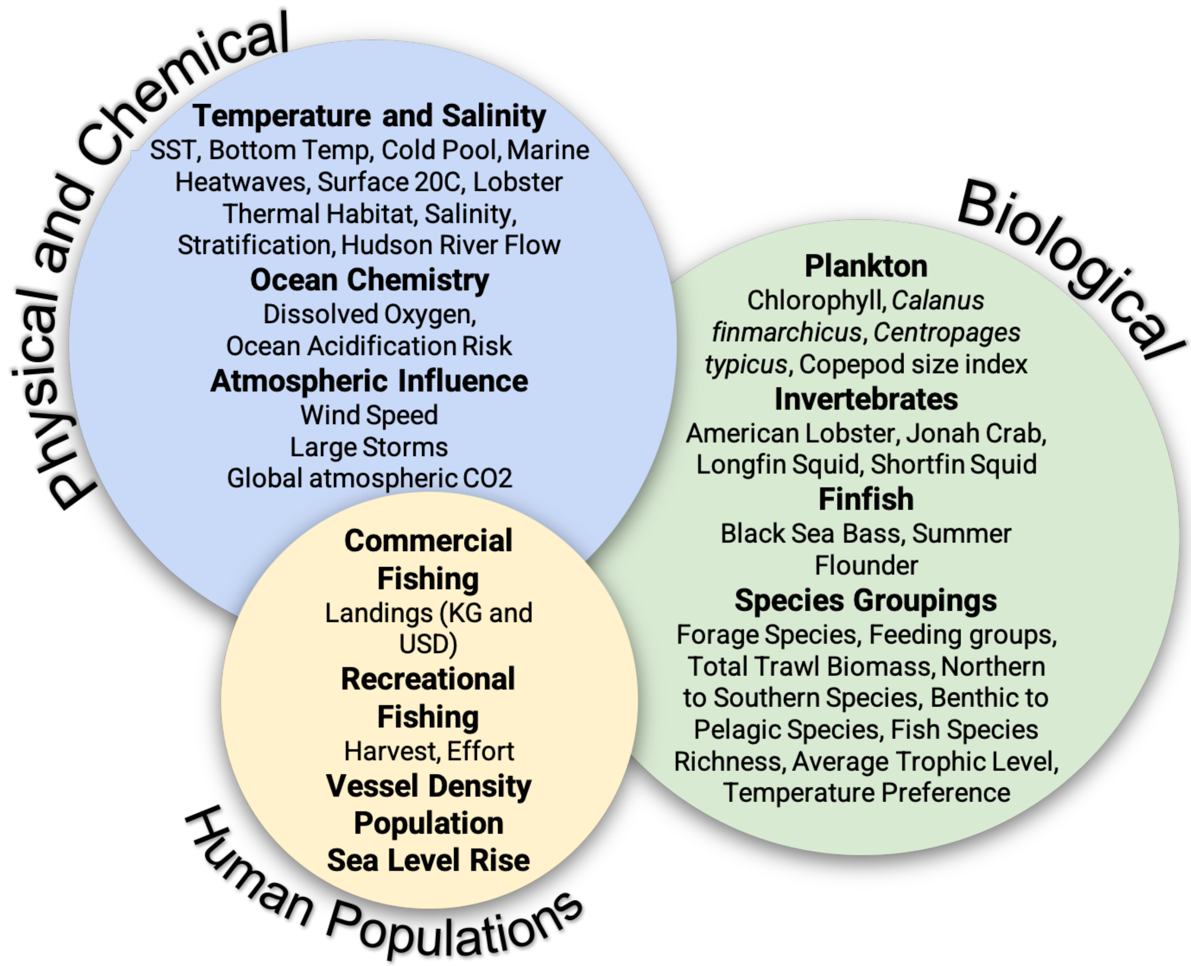

Physical and Chemical
Temperature and Salinity
SST, Bottom Temp, Cold Pool, Marine Heatwaves, Surface 20C, Lobster Thermal Habitat, Salinity, Stratification, Hudson River Flow
Ocean Chemistry
Dissolved Oxygen, Ocean Acidification Risk
Atmospheric Influence
Wind Speed
Large Storms
Global atmospheric CO2
Biological
Plankton
Chlorophyll, *Calanus finmarchicus*, *Centropages typicus*, Copepod size index
Invertebrates
American Lobster, Jonah Crab, Longfin Squid, Shortfin Squid
Finfish
Black Sea Bass, Summer Flounder
Species Groupings
Forage Species, Feeding groups, Total Trawl Biomass, Northern to Southern Species, Benthic to Pelagic Species, Fish Species Richness, Average Trophic Level, Temperature Preference
Human Populations
Commercial Fishing
Landings (KG and USD)
Recreational Fishing
Harvest, Effort
Vessel Density
Population
Sea Level Rise

Part I. Indicator Analysis

1. Indicators at a Glance

Physical and chemical indicators are shown in blue, marine community indicators in green, and human populations indicators in yellow. The long-term trend column indicates an increase or decrease in any significant linear trend over the whole time series of that indicator. The short-term trend shows whether the indicator was increasing or decreasing over the previous three years only. A dotted line indicates no significant trend was present.

	Indicator	Long Term Trend	Short Term Trend	Summary
1	Sea Surface Temperature	↗	⇢	Sea surface temperatures have increased across all seasons. Summer SSTs have plateaued over the last five years.
2	Marine Heatwave Days	↗	↘	Surface and bottom marine heat waves have increased, especially since 2010. In the last three years marine heatwaves have decreased.
3	Bottom Temperature	↗	⇢	Bottom tempearture has increased across all seasons since the 1960s.
4	Cold Pool	↘	⇢	Cold Pool volume has decreased across all summer months since 1993. Glider based indicator shows the smallest volume during the summer of 2022.
5	Bottom DIssolved Oxygen	N/A	⇢	Bottom dissolved oxygen shows no hypoxia risk.
6	Ocean Acidification Risk	N/A	⇢	The region of ocean acidification concern is largest during the summer of 2022.
7	Wind Speed	⇢	⇢	The number of days where wind speeds would trigger a small craft advisory do not show consistent long or short term trends.
8	Stratification	⇢	⇢	Stratification shows no significant long or short term trends in any season.
9	Hudson RIver Flow	↗	⇢	Hudson River flow at Green Island shows an increasing trend. Hudson River flow at the Narrows is too short to determine long term trends.
10	Salinity	↗	⇢	Bottom salinity shows a long term increasing trend during the summer.
11	Global Carbon Dioxide	↗	↗	Global atmospheric carbon dioxide continues to increase.
12	Surface 20°C Isotherm	↗	↗	Surface 20°C isotherm continues to move northward in summer and autumn.
13	Lobster Thermal Habitat	⇢	⇢	No long or short term trends are present in the percentage of New York Bight seafloor thermally inhospitable to lobster.
14	Number of Large Storms	⇢	⇢	No long or short term trends are present in large storm indicators.

	Indicator	Long Term Trend	Short Term Trend	Summary
15	Chlorophyll	→	→	No significant long to short term trends are present in surface chlorophyll.
16	Calnus finmarchicus	→	→	No significant long or short term trends are present in *Calanus finmarchicus* abundance.
17	Centropages Typicus	→	→	No significant long or short term trends are present in *Centropages typicus* abundance.
18	Copepod Size Index	→	→	No significant long or short therm trends are present in copepod size index.
19	American Lobster	↘	→	American Lobster biomass has decreased in the autumn.
20	Jonah Crab	→	→	Jonah Crab biomass has decreased in the spring, but increased in the fall.
21	Longfin Squid	→	→	Longfin Squid biomass has decreased during the spring, but increased during the sutumn.
22	Shortfin Squid	↗	→	Shortfin Squid biomass has increased during the spring.
23	Forage Species Bioimass	→	↗	Forage species biomass has increased in the short term during the sutumn.
24	Aggregate Feeding Groups	→	→	Long term increases are seen in Benthos and Planktivores in the autumn. Long term decreases are seen in Piscivores in the autumn.
25	Total Trawl Biomass	↘	→	Total trawl biomass has decreased during the autumn.
26	Black Sea Bass	↗	↗	Black Sea Bass biomass is increasing in the long term in both the spring and fall, and in the short term in the fall.
27	Summer Flounder	↗	↗	Summer Flounder biomass is increasing in the long term in both the spring and fall, and in the short term in the fall.
28	Ratio Northern to Southern Species	↘	→	The ratio of northern to southern species has decreased in the autumn.
29	Ratio Benthic to Pelagic Species	↘	↘	The ratio of benthic to pelagic species has decreased in the autumn in the long term, and in both the spring and autumn in the short term.
30	Fish Species Richness	↗	↗	Fish species richness has increased in the long term in both the spring and fall, and in the short term in the spring.
31	Average Trophic Level of Fish Communiity	↘	→	The average trophic level of the fish community has decreased in the fall.
32	Temperature Preference of Fish Community	↗	↗	The temperature preference of the fish community has increased in both the long ans short term in both spring and fall seasons.

	Indicator	Long Term Trend	Short Term Trend	Summary
33	Commercial Harvest Tons	↘	→	The commercial harvest has decreased in the long term.
34	Commercial Harvest USD	↗	→	The commercial landings value has increased over time.
35	Recreational Harvest	↘	→	Recreational harvest has decreased in the long term, while the number of fish released has increased.
36	Recreational Effort	↗	→	Recreational effort has increased in the long term.
37	Vessel Density	↗	→	The number of TEUs at the port of New York and New Jersey have increased.
38	Human Population	↗	↘	The population of Long Island has increase in the long term, but has fallen recently from a peak in 2020.
39	Sea Level Rise	↗	→	Sea level continues to rise along both the western and eastern coasts of Long Island.

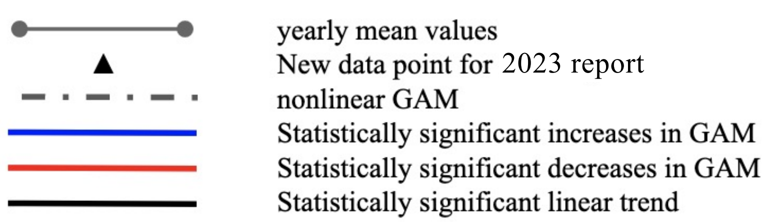
2. Executive Summary

The New York Bight continues to warm both at the surface and the bottom, and throughout all seasons. An increase in marine heatwaves in the surface and subsurface, a decrease in the size of the cold pool, and a major shift in the 20°C isotherm are reflected in the indicators for marine organisms. The temperature preference of the fish community continues to increase, with the most recent data from fall 2022 showing the highest temperature recorded, indicating that the fish assemblage is composed of more warm water species than ever before. Warmer water species, such as black sea bass, continue to increase in abundance. In addition to affecting the fish assemblage, the smaller and/or warmer cold pool could lead to changes in ocean acidification in the NYB, affecting marine calcifiers. We continue to develop our indicators of physiochemical conditions relevant to marine organisms by building the time series from NYB sampling with gliders, ships, and in the future, bottom moorings. Our sampling on the RV Seawolf has allowed for analysis of two important zooplankton species – *Calanus finmarchicus* and *Centropages typicus* – at seasonal temporal resolution. Seasonal trends in lower trophic level organisms will allow us to better link physical and chemical indicators with changes in the abundance of marine organisms. Although the human population of Long Island is slightly down from a peak in 2020, the marine community in the NYB is still strongly linked to human communities. Recreational effort has remained high, but over time more fish have been released alive and fewer harvested. The NYB supports important commercial fisheries, with the value of landings staying strong, although slightly lower than its 2015 peak. In addition to fishing, the NYB is an important thoroughfare for marine commerce, with cargo twenty-foot equivalent units (TEUs; denoting a standard cargo container) increasing overtime, potentially creating a higher risk of vessel strikes for marine mammals.

3. Report Structure

This report is separated into two parts. Part I lists all indicators separated into three subsections, physical and chemical indicators, marine community indicators, and human populations indicators. Part II describes indicators in development. There are several improvements to our indicator analysis which are reflected in this report:

1. Bottom temperature will now be reported seasonally.
2. We are considering the need to change the baseline that defines a marine heatwave. A small discussion box is present in the marine heatwaves section.
3. In addition to cold pool volume calculated from reanalysis data, we use data from our Stony Brook gliders to calculate cold pool area along a repeat section. This will provide us with a near real-time high resolution look at cold pool extent.
4. We now calculate the mean wind speed indicator as the number of days that winds would initiate a small craft advisory.
5. Bottom and surface salinity will be reported seasonally.
6. Stratification will be reported seasonally.
7. A new current meter was deployed by the PORTS program in April 2023 at the Verrazano Narrows allowing for an approximation of volume transport between Brooklyn and Staten Island. We use this data for a more direct measure of the Hudson River input into the NYB.
8. The number of large storms indicator has been completed and is reported for the first time in this 2023 report.
9. Vessel density is reported as total twenty-foot equivalent units (TEUs) passing through the port of New York/New Jersey. We use this as a proxy for cargo ship traffic.
10. NOAA tide gauges from the eastern and western shores of Long Island are used to determine relative sea level rise.



4. Physical and Chemical Indicators

Summary

Temperatures continue to rise within the New York Bight, both at the sea surface and bottom, and across all seasons. Mean summer surface temperatures have plateaued the last five years but it is unlikely that this represents an ongoing cessation of warming, but rather a temporary pause. Marine heatwave days also reflect this warming, with an increase in both surface and bottom heatwaves. As temperatures warm the cold pool is shrinking as indicated by the decrease in volume across summer months. An increase in warm core Gulf Stream rings impinging on the shelf (Gawarkiewicz et al., 2022; Silver et al., 2023) could be the cause of this increase and may have implications for the shelf ecosystem in terms of ring transport of heat, nutrients and marine organisms. The cold pool was especially small during the summer of 2022 as evidenced by glider data. Bottle data collected by Stony Brook's RV Seawolf from the summer of 2022 also shows an anomalously large region of ocean acidification concern associated with the 1.7 (Ω) aragonite contour. A decrease in the size of the cold pool affects summer ocean acidification and could have implications for calcifying organisms.

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yearly mean values
▲ New data point for 2023 report
nonlinear GAM
Statistically significant increases in GAM
Statistically significant decreases in GAM
Statistically significant linear trend

	Indicator	Long Term Trend	Short Term Trend	Summary
1	Sea Surface Temperature	↗	⋯⋯▸	Sea surface temperatures have increased across all seasons. Summer SSTs have plateaued over the last five years.

Seasonal Mean Sea Surface Temperature

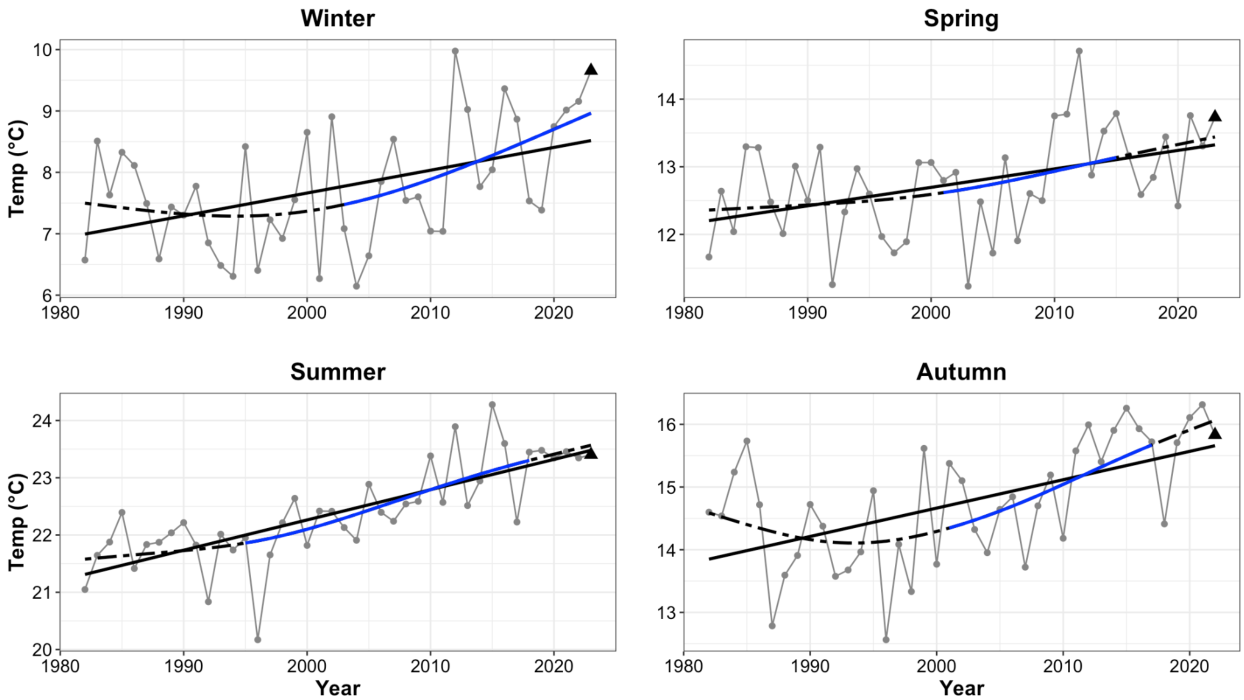


Figure 1. Seasonal mean sea surface temperature from satellite OISST. Surface temperatures are rising across all seasons. Summer surface temperatures have stayed relatively constant since 2018.

	Indicator	Long Term Trend	Short Term Trend	Summary
2	Marine Heatwave Days	↗	↘	Surface and bottom marine heat waves have increased, especially since 2010. In the last three years marine heatwaves have decreased.

Marine Heatwave Days

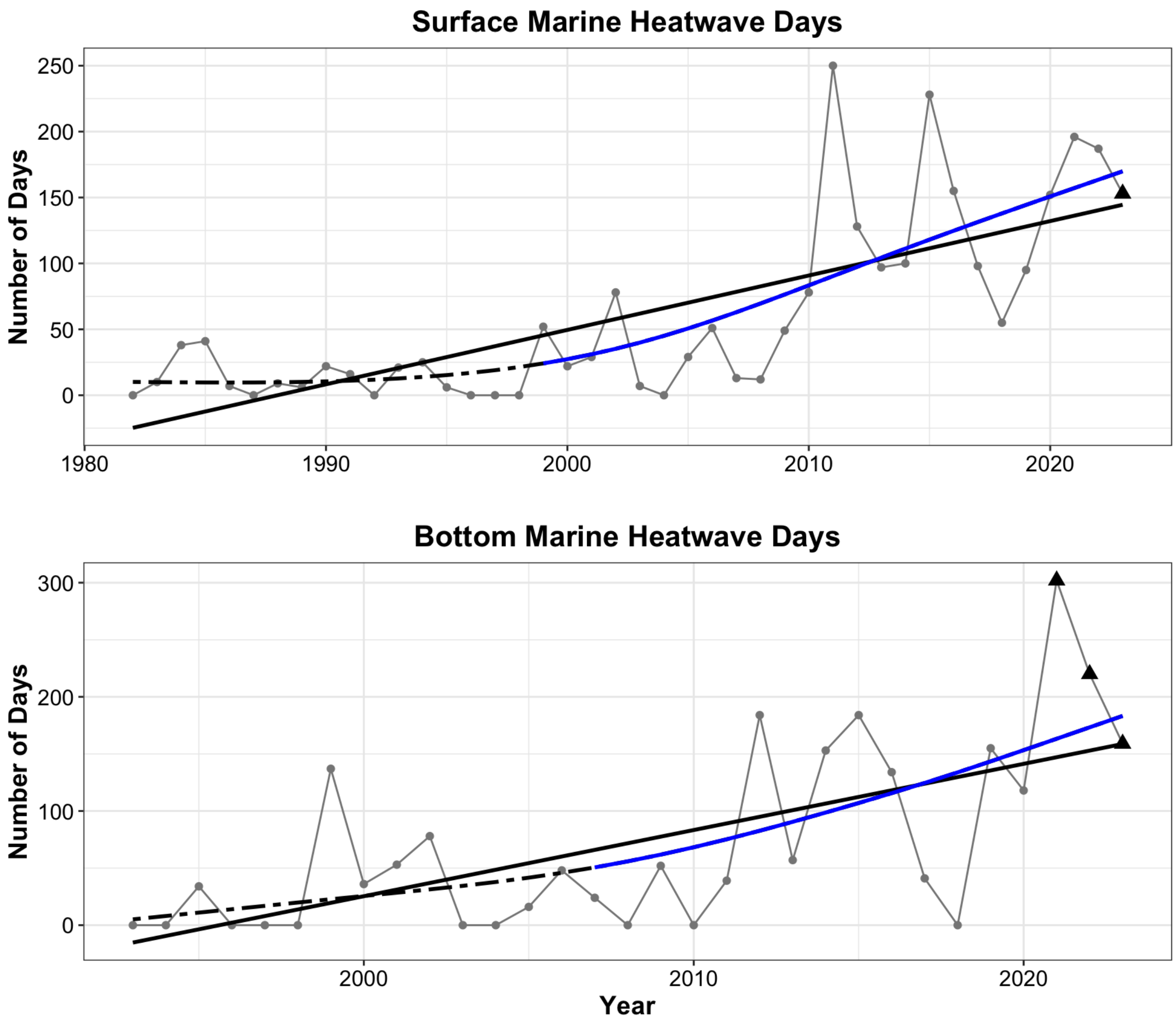
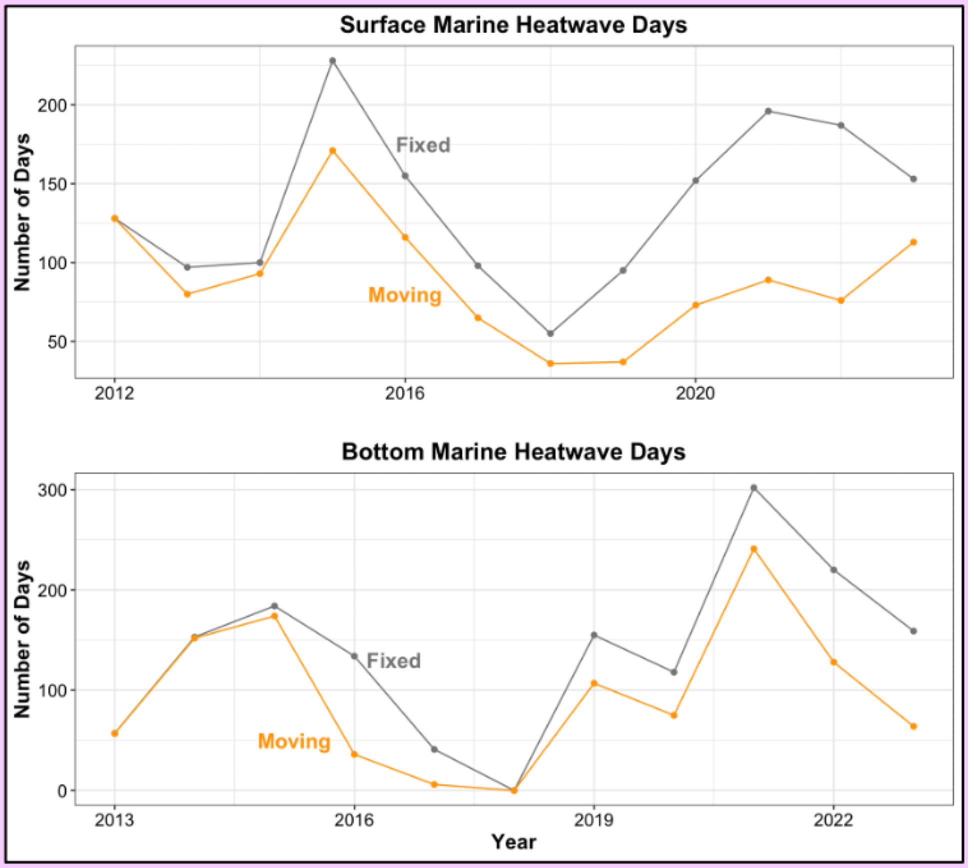


Figure 2. Surface (top) and bottom (bottom) marine heatwave days per year. Marine heatwaves days have rapidly increased, especially since 2010. Although marine heatwave days have increased at both the surface and the bottom they are not exactly the same. For example surface marine heatwave days were highest in 2011, while bottom marine heatwave days were highest in 2021.

A Marine Heatwave Controversy



Within the community that studies marine heatwaves, a debate has erupted concerning how these extreme events are defined. Broadly, a marine heatwave occurs when the ocean temperature is significantly above normal for some time of the year. At the center of the controversy is the definition of 'normal' (Amaya et al., 2023). Is normal some fixed time period in the past (surface 1982-2021, bottom 1993-2012; black lines)? Or should this baseline time period shift to account for widely increasing temperatures as climate change progresses (shifting one year later annually; orange lines)? The answer to this question is still unresolved. For the MHWs calculated in NYB with both methods, the trend remains the same. However, recent surface marine heatwaves are more severe when the historical time period is used as the baseline.

	Indicator	Long Term Trend	Short Term Trend	Summary
3	Bottom Temperature			Bottom tempearture has increased across all seasons since the 1960s.

Bottom Temperature

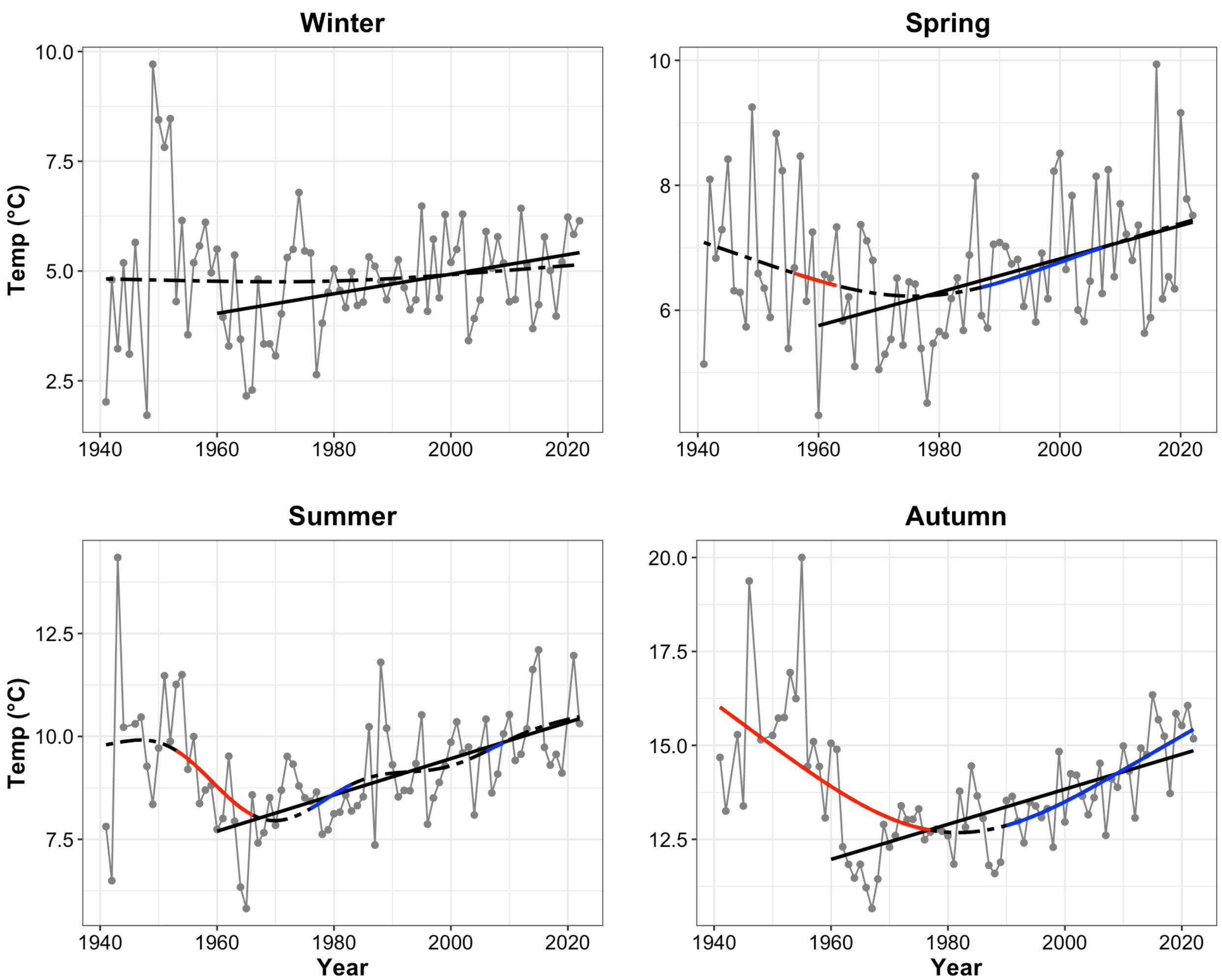
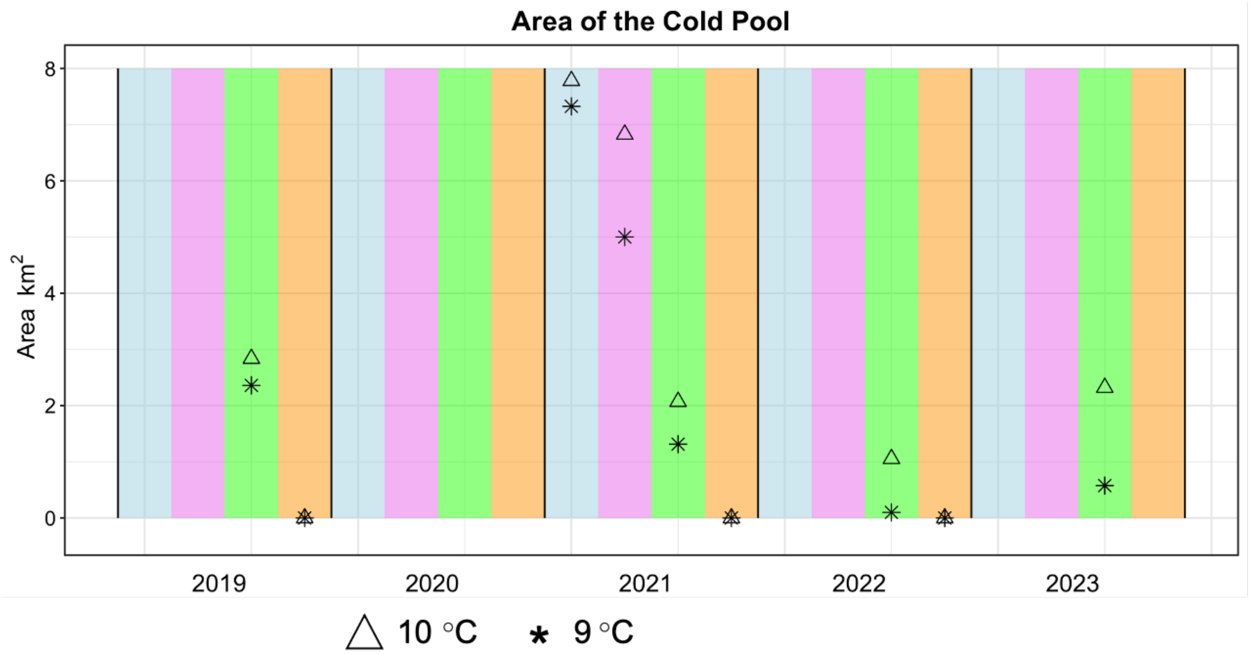


Figure 3. Mean bottom temperature from in-situ measurements. Bottom temperature has been increasing since the 1960s across all seasons. The warmer temperatures in the 1940s are likely due to a combination of reduced data availability, data from older Mechanical Bathythermograph (MBT) instruments, and a warmer phase of the Atlantic Meridional Variability.

	Indicator	Long Term Trend	Short Term Trend	Summary
4	Cold Pool	↘	⇢	Cold Pool volume has decreased across all summer months since 1993. Glider based indicator shows the smallest volume during the summer of 2022.

Cold Pool Volume in NYB



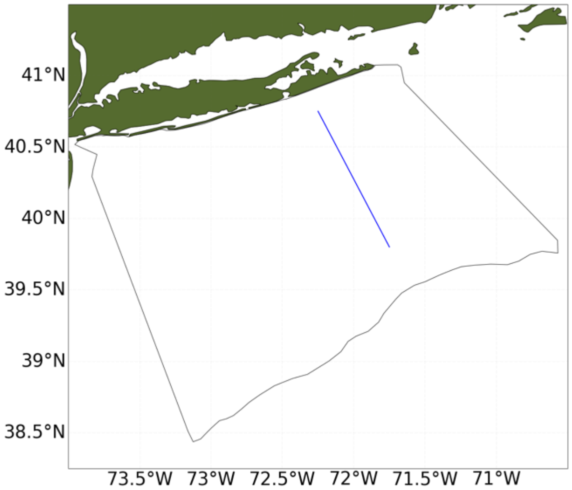


Figure 4. Seasonal cold pool area within the NYB from Stony Brook glider deployments across section 1 shown as blue line in map at left. Colored shading indicates season: blue is winter, pink is spring, green is summer, orange is fall. Triangles represent the cold pool area when the 10°C definition is used. The asterisks represent the cold pool area when the 9°C definition is used. The cold pool was very small during summer of 2022.

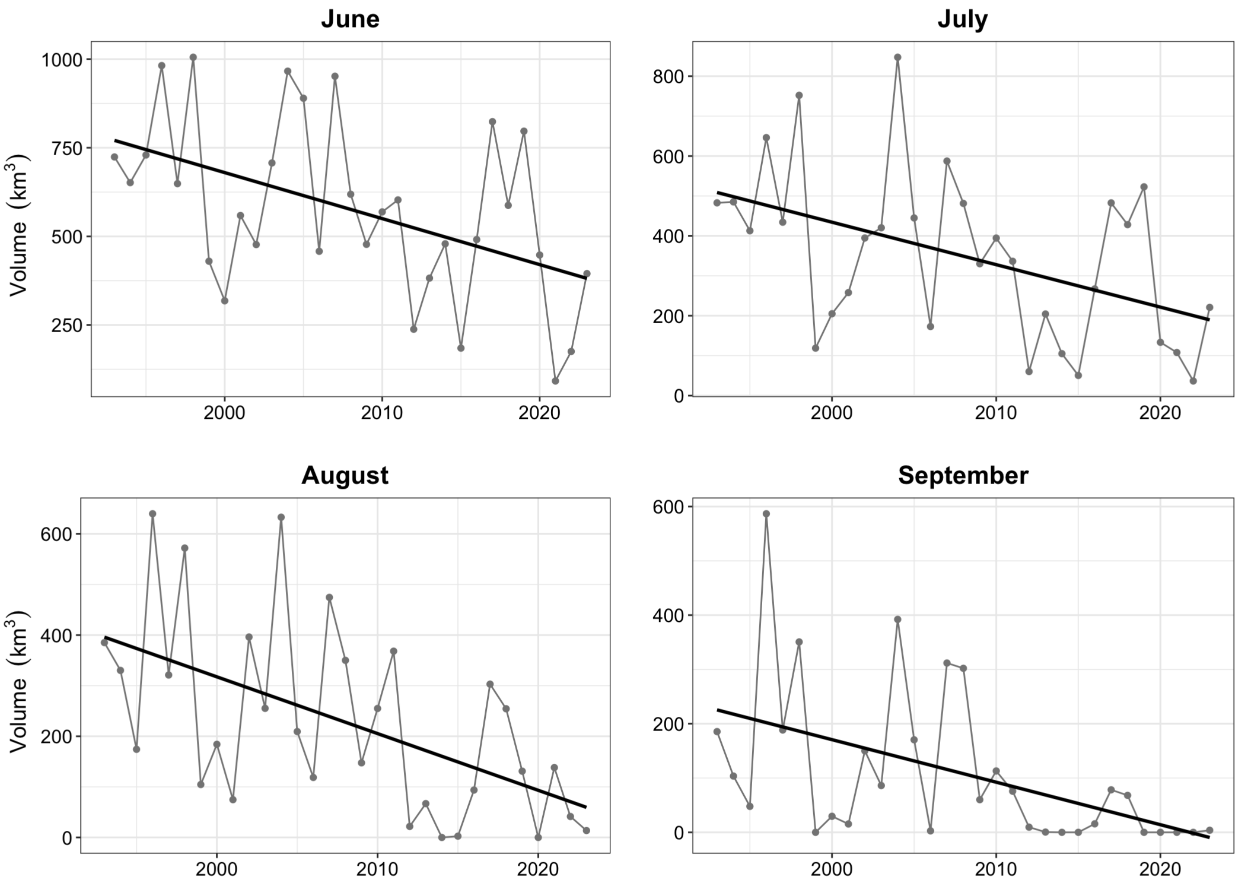


Figure 5. Cold Pool volume in the New York Bight calculated using GLORYS12 reanalysis and analysis data. Plots show trends in summer to fall months, with June, July, August, and September all displaying significant decreasing trends. Since 2012, the cold pool as defined by the 10°C isotherm has often not been detected in the NYB in September. This agrees with the cold pool estimates from glider data where the cold pool was not detected in fall glider deployments.

	Indicator	Long Term Trend	Short Term Trend	Summary
5	Bottom DIssolved Oxygen	N/A	··········►	Bottom dissolved oxygen shows no hypoxia risk.

Bottom Dissolved Oxygen

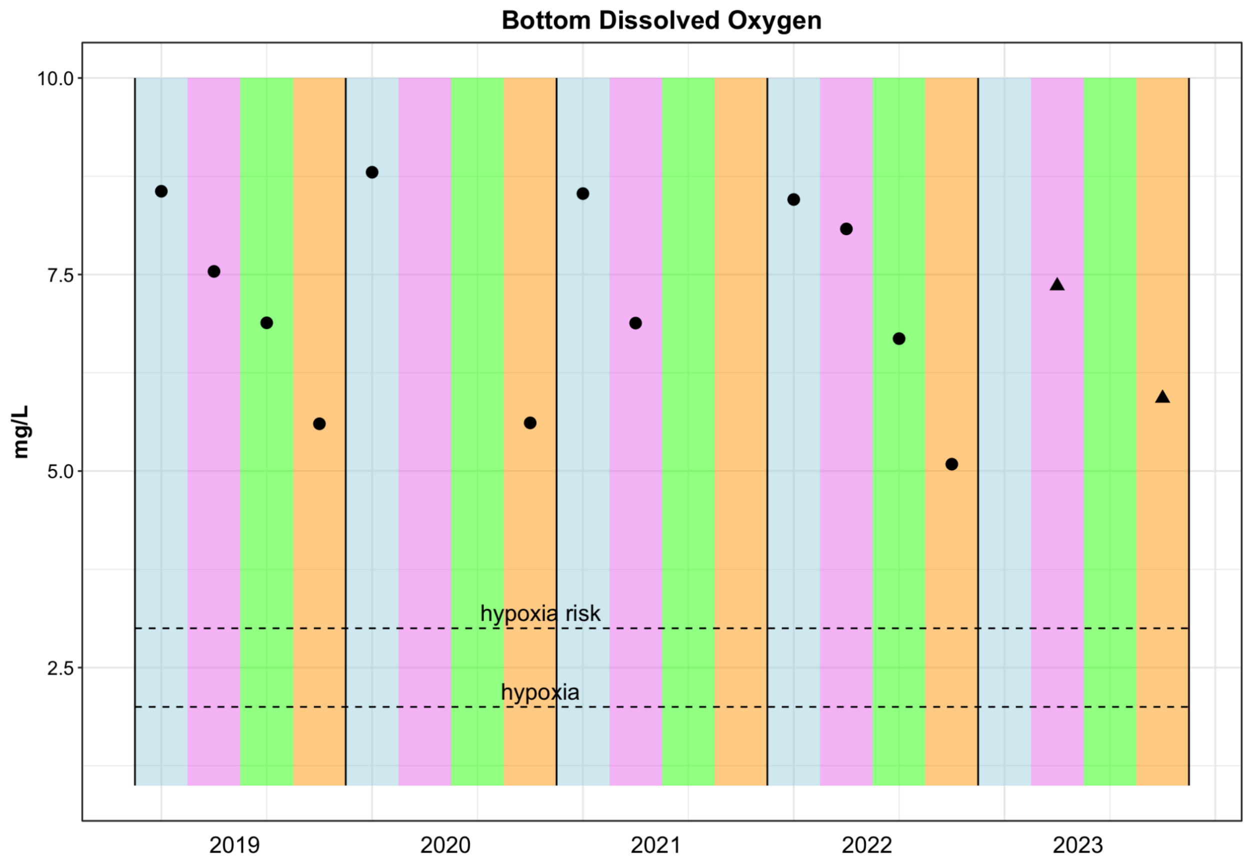
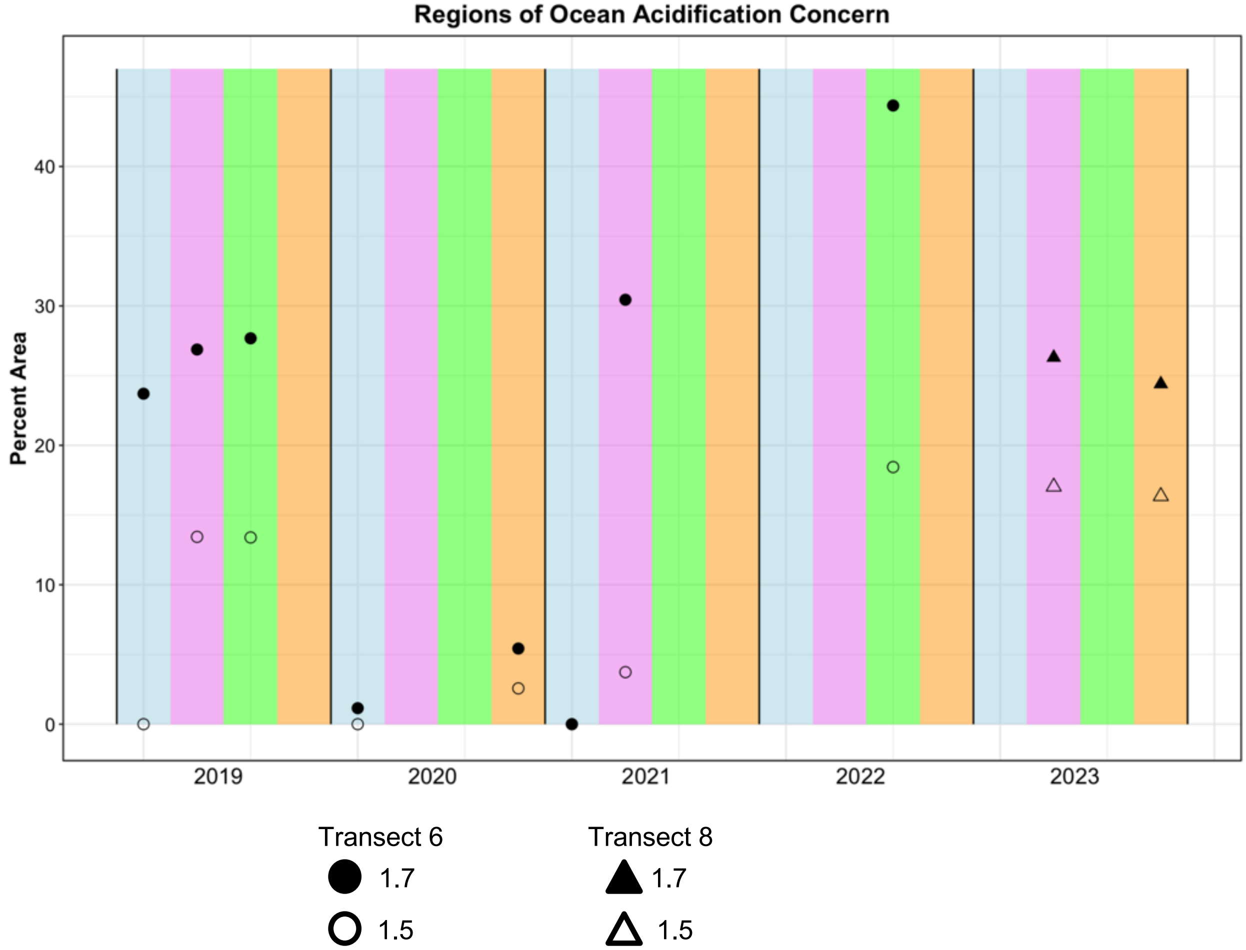


Figure 6. Bottom dissolved oxygen from CTD casts conducted on the RV Seawolf. Colored shading indicates season: blue is winter, pink is spring, green is summer, orange is fall. Dissolved oxygen is highest in winter and decreases as the year progresses. No hypoxia risk was detected. The seasons with no values are years when shipboard sampling was not conducted.

	Indicator	Long Term Trend	Short Term Trend	Summary
6	Ocean Acidification Risk	N/A	⋯⋯⋯▸	The region of ocean acidification concern is largest during the summer of 2022.

Ocean Acidification Risk



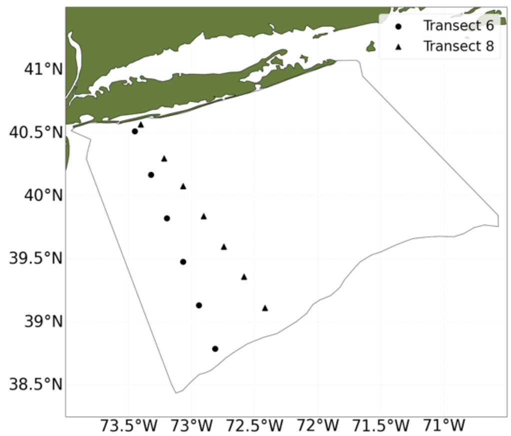
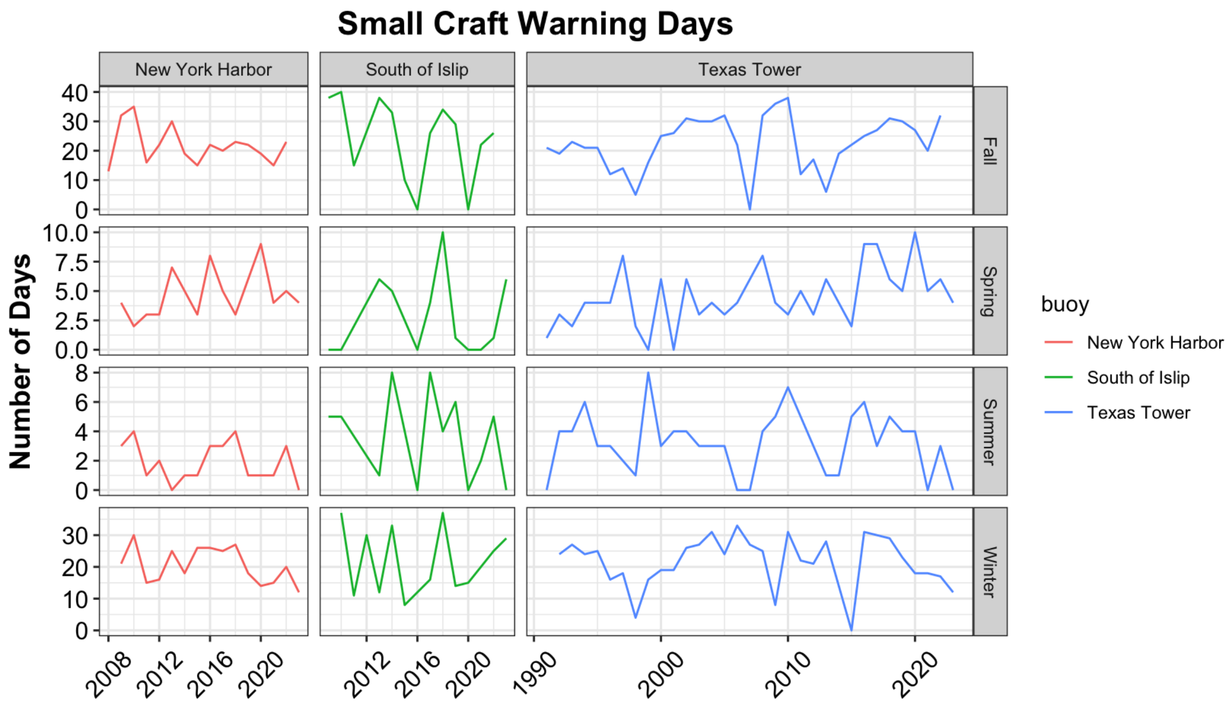


Figure 7. Regions of ocean acidification concern associated with an aragonite saturation state of 1.7 (closed circles and triangles) and 1.5 (open circles and triangles). Colored shading indicates season: blue is winter, pink is spring, green is summer, orange is fall. The summer of 2022 showed the highest percent area lower than 1.7. Values lower than 1.7 indicate regions where acidification which may be detrimental to the growth of longfin squid. During the 2023 cruises transect 6 was replaced by transect 8 (map inset at left).

	Indicator	Long Term Trend	Short Term Trend	Summary
7	Wind Speed	············▸	············▸	The number of days where wind speeds would trigger a small craft advisory do not show consistent long or short term trends.

Wind Speed



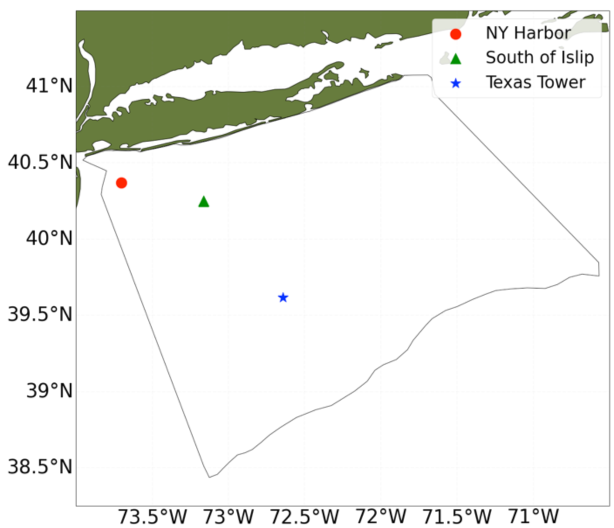


Figure 8. Number of days where wind speeds would trigger a small craft warning (sustained winds between 18 and 33 knots) by buoy and season. The red line shows the New York Harbor Buoy, the green line a buoy South of Islip, and the blue line the Texas Tower buoy further offshore (see map at left).

	Indicator	Long Term Trend	Short Term Trend	Summary
8	Stratification	···········►	···········►	Stratification shows no significant long or short term trends in any season.

Stratification

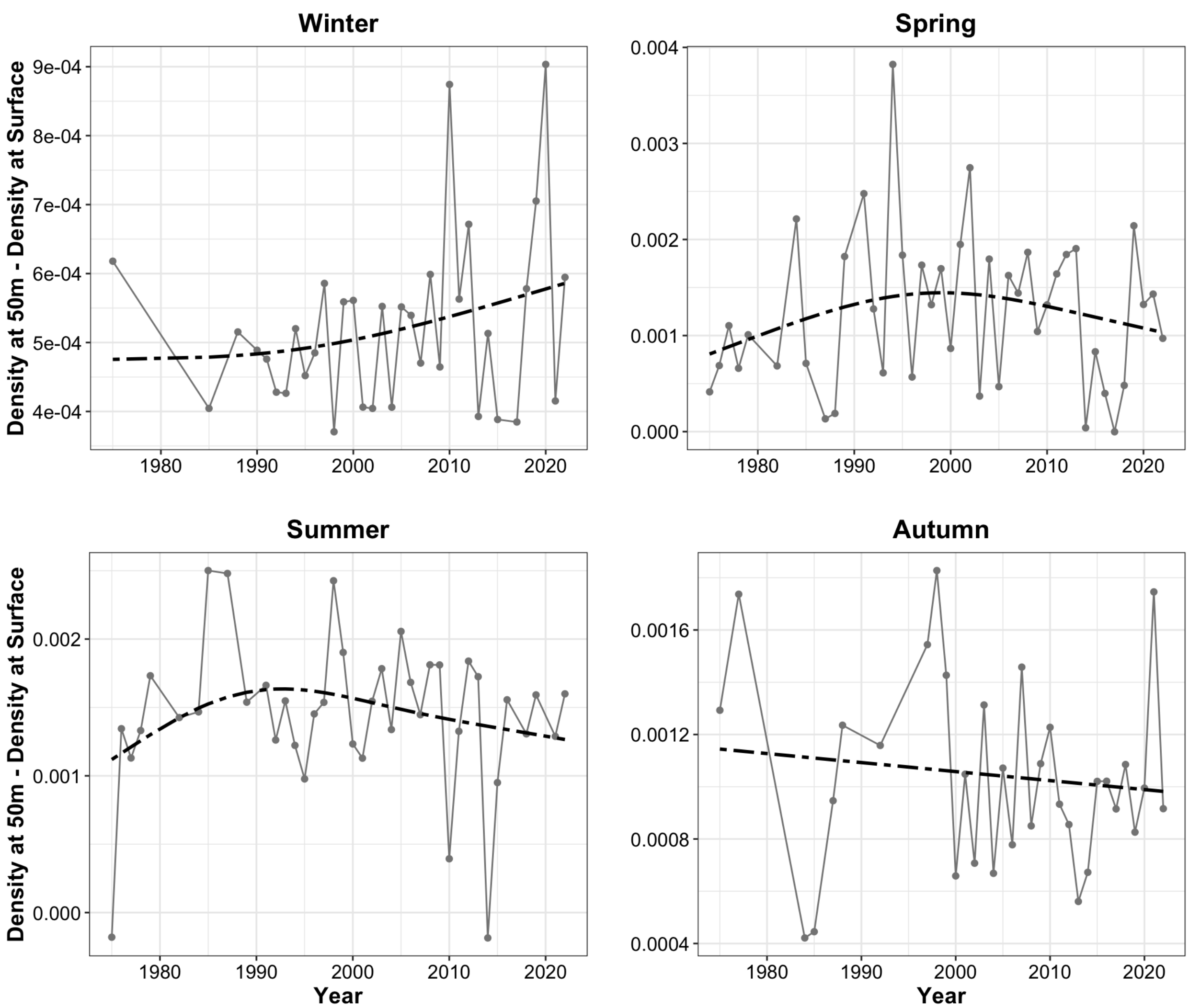


Figure 9. Stratification from in-situ measurements. Stratification is highest in the spring and summer and lowest in the winter when the water column is well mixed. No significant trends in stratification are seen in any season. However, from 2014-2018 the stratification index was lower than average in spring.

	Indicator	Long Term Trend	Short Term Trend	Summary
9	Hudson RIver Flow	↗	⇢	Hudson River flow at Green Island shows an increasing trend. Hudson River flow at the Narrows is too short to determine long term trends.

Hudson River Flow

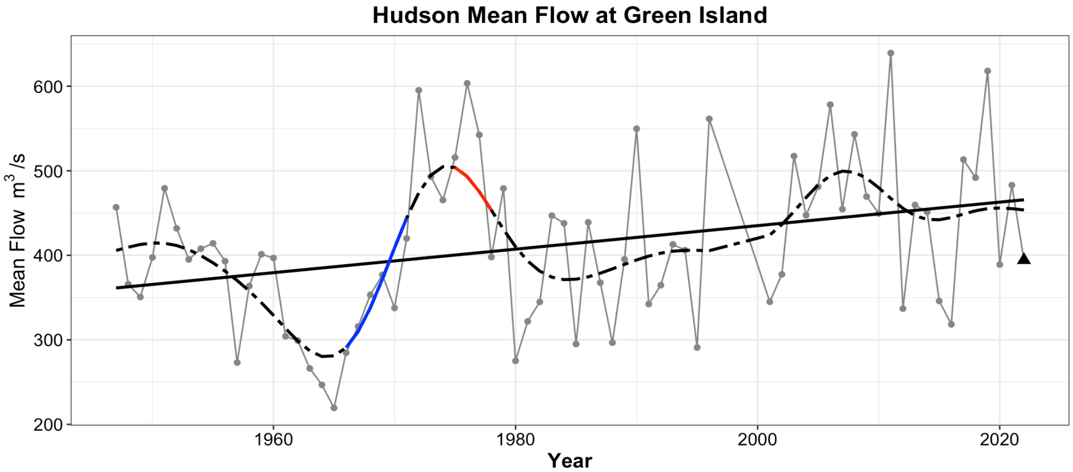


Figure 10. Yearly mean Hudson River flowrate in m^3/s at the Green Island USGS river gauge.

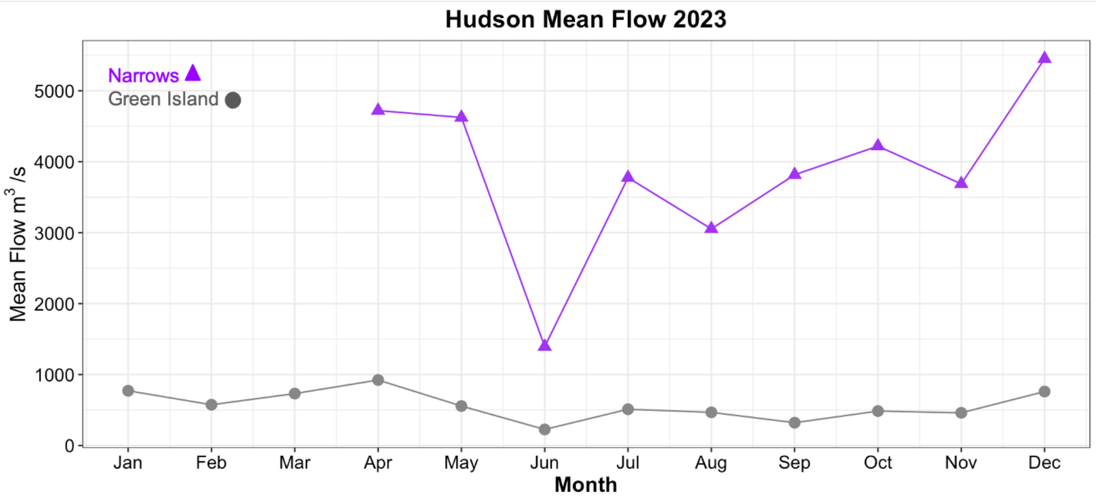


Figure 11. Monthly Hudson River flow in m^3/s during 2023. The grey line shows measurements from the USGS river gauge at Green Island. The purple line shows current meter data from the Narrows Station of the NY/NJ PORTS project. In the future we will evaluate using this station to monitor Hudson River flow.

	Indicator	Long Term Trend	Short Term Trend	Summary
10	Salinity	↗	⇢	Bottom salinity shows a long term increasing trend during the summer.

Salinity

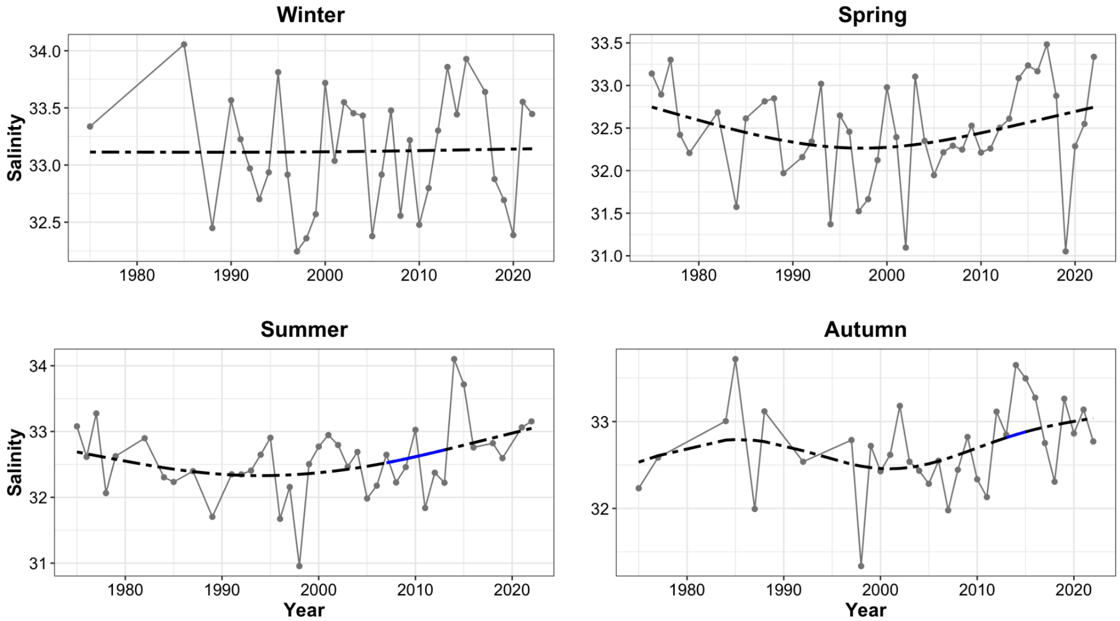


Figure 12. Yearly mean sea surface salinity by season from in-situ measurements.

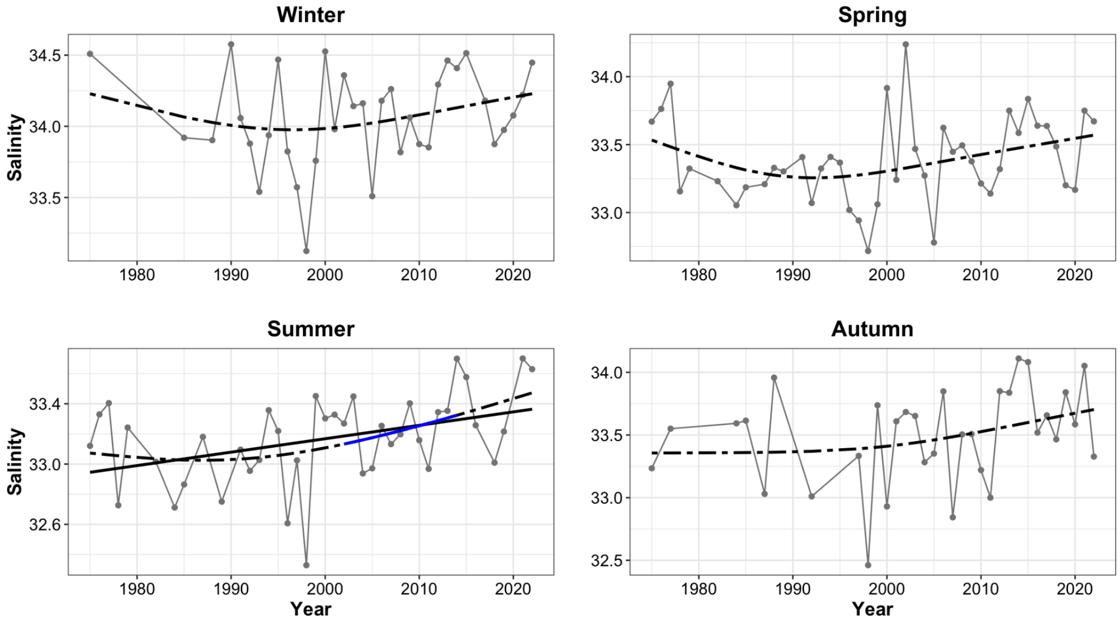


Figure 13. Yearly mean bottom salinity by season from in-situ measurements. Salinity has increased significantly during the summer, possibly due to increased Gulf Stream influence.

	Indicator	Long Term Trend	Short Term Trend	Summary
11	Global Carbon Dioxide	↗	↗	Global atmospheric carbon dioxide continues to increase.

Global Carbon Dioxide

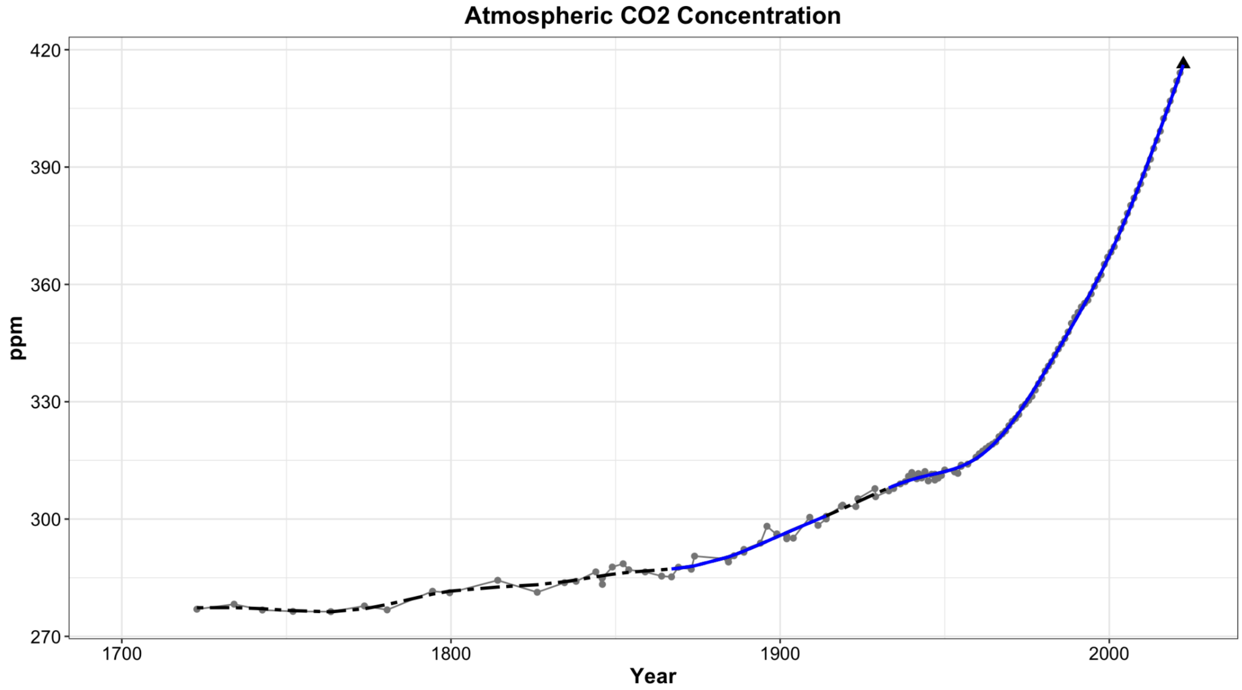


Figure 14. Global mean atmospheric CO_2. Atmospheric carbon dioxide continues to increase.

	Indicator	Long Term Trend	Short Term Trend	Summary
12	Surface 20°C Isotherm	↗	↗	Surface 20°C isotherm continues to move northward in summer and autumn.

Location of Surface 20°C Isotherm

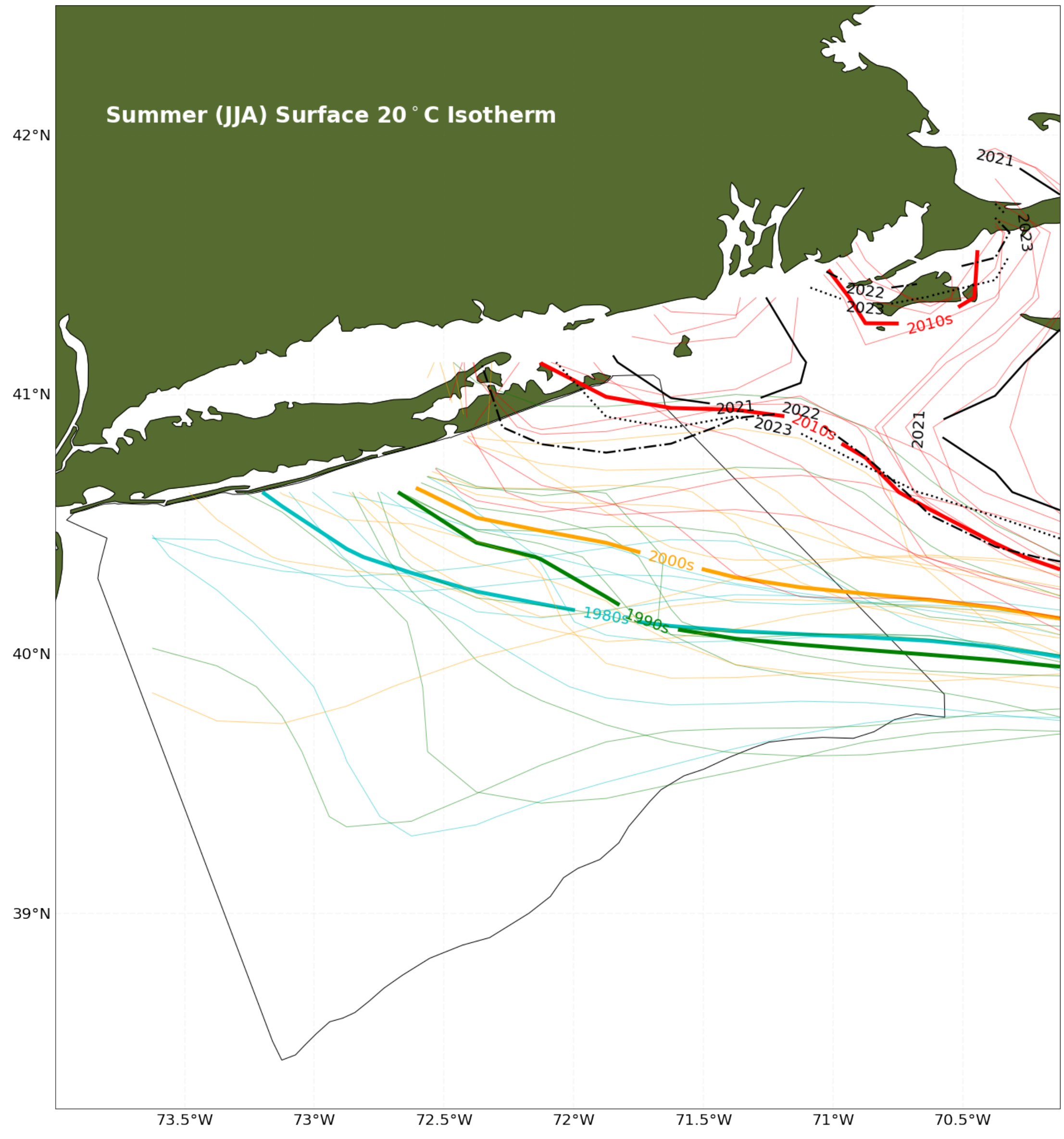


Figure 15. Summer (June, July, August) surface 20°C isotherm location. The thick blue line shows the mean position during the 1980s, the green line during the 1990s, the orange line during the 2000s and the red line during the 2010s. Thin colored lines show individual years during

those decades. The solid black line shows the 20°C isotherm during 2021, the dashed line during 2022, and the dotted line 2023. Northwestward movement of the 20°C isotherm in summer is consistent with the warming trend in this region.

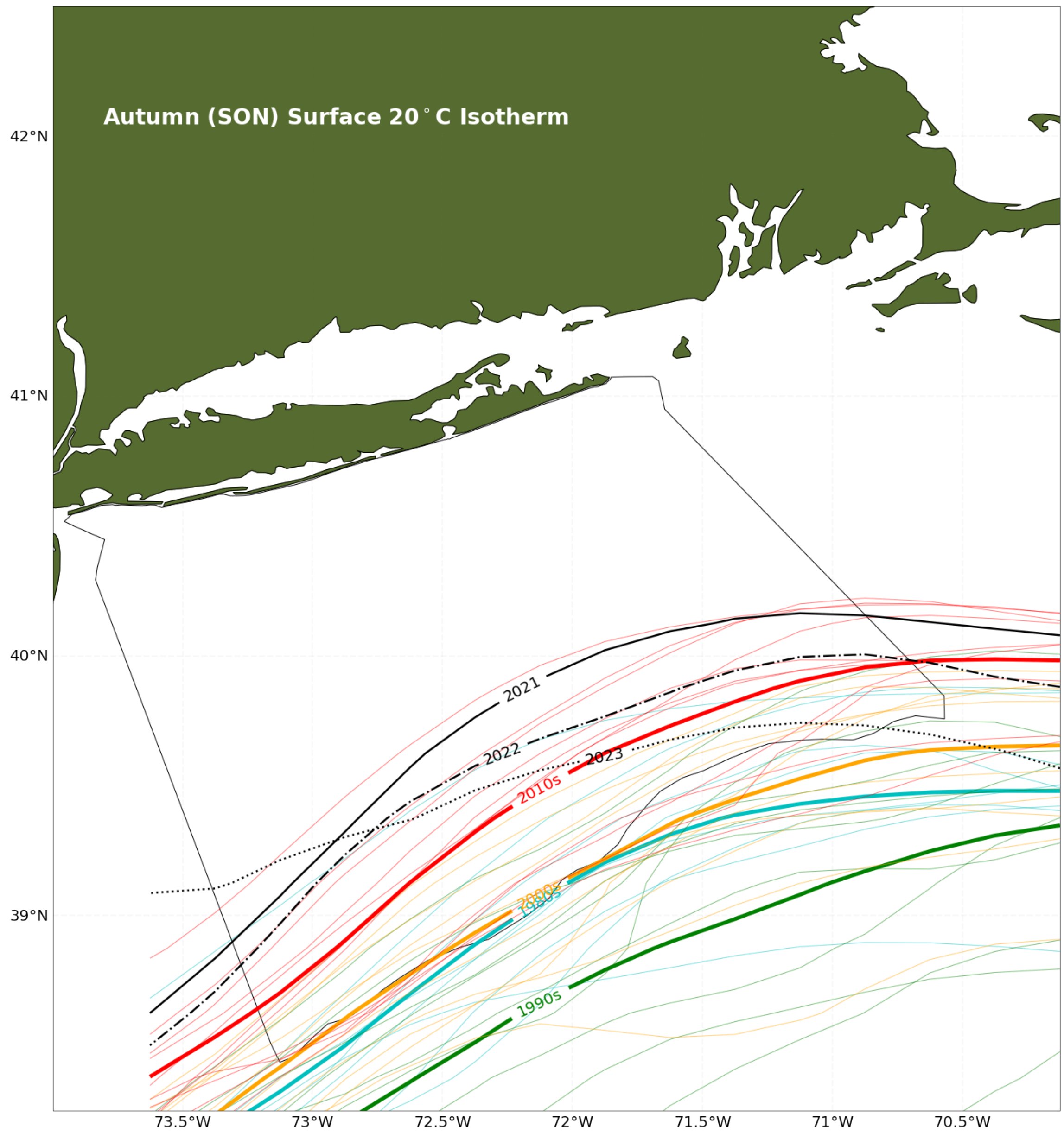


Figure 16. Autumn (September, October, November) surface 20°C isotherm. The thick blue line shows the mean position during the 1980s, the green line during the 1990s, the orange line during the 2000s and the red line during the 2010s. Thin colored lines show individual years during those decades. The solid black line shows the 20°C isotherm during 2021, the dashed line during 2022, and the dotted line 2023. Northward movement of the 20°C isotherm in autumn is consistent with the warming trend in this region.

	Indicator	Long Term Trend	Short Term Trend	Summary
13	Lobster Thermal Habitat	············►	············►	No long or short term trends are present in the percentage of New York Bight seafloor thermally inhospitable to lobster.

Lobster Thermal Habitat

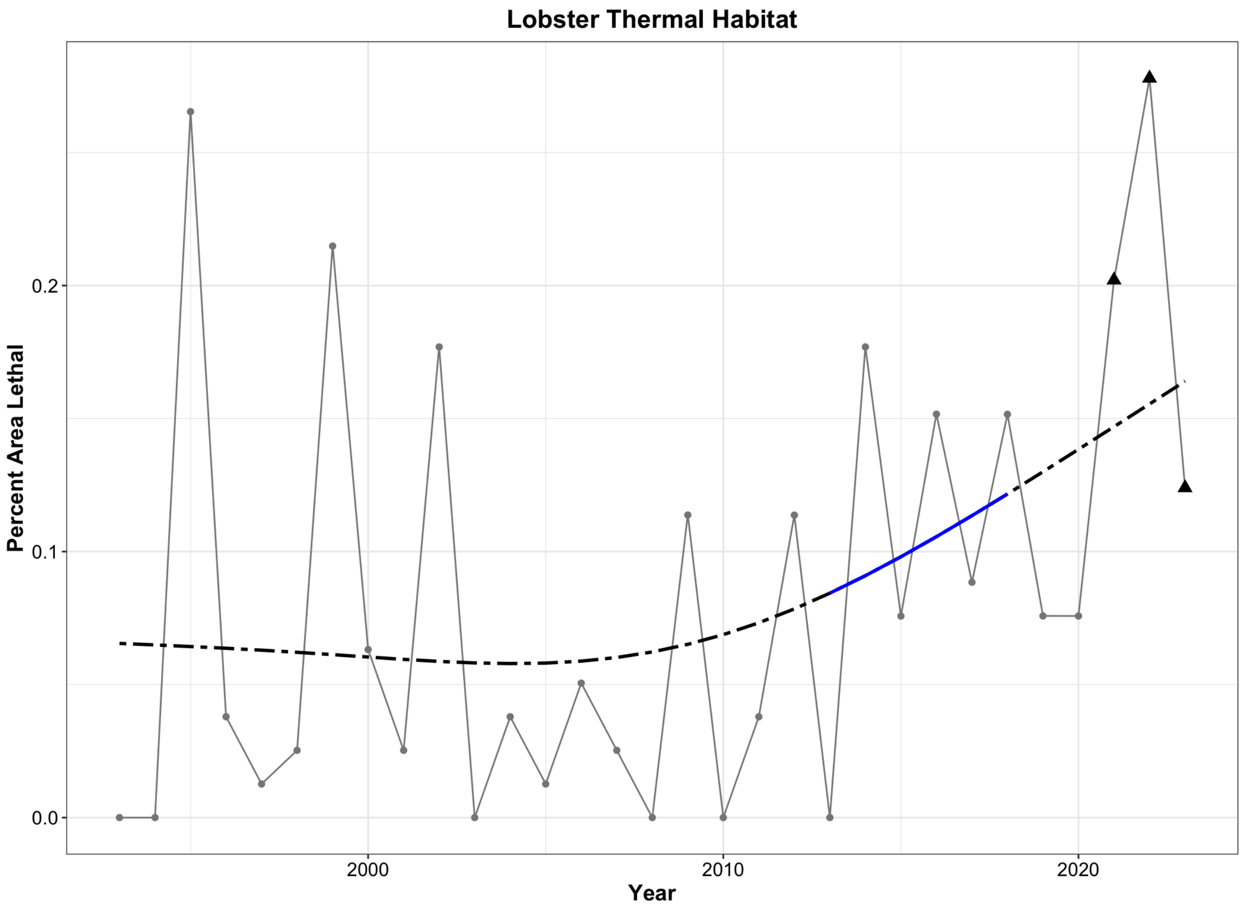
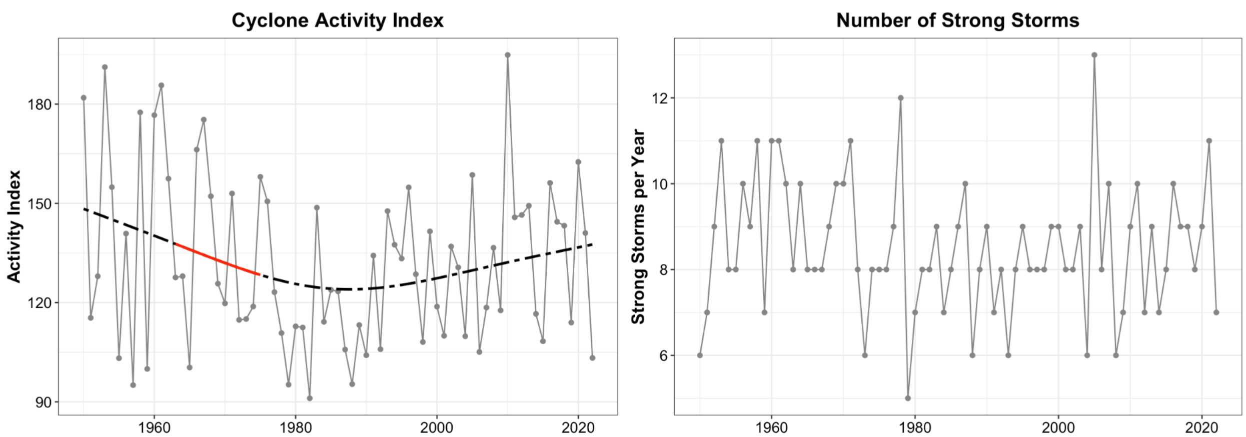


Figure 17. Yearly values for the percentage of the NYB that contains bottom temperatures greater than 20°C (the upper lethal temperature for lobster). The percent lethal area is consistently below 1%.

	Indicator	Long Term Trend	Short Term Trend	Summary
14	Number of Large Storms	┈┈┈►	┈┈┈►	No long or short term trends are present in large storm indicators.

Number of Large Storms



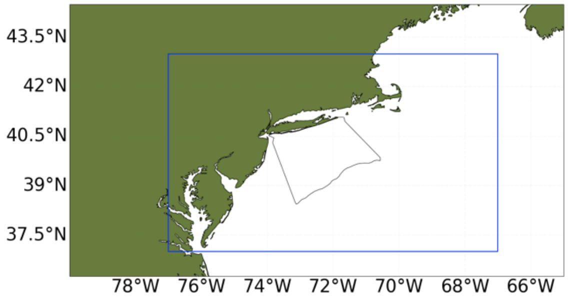
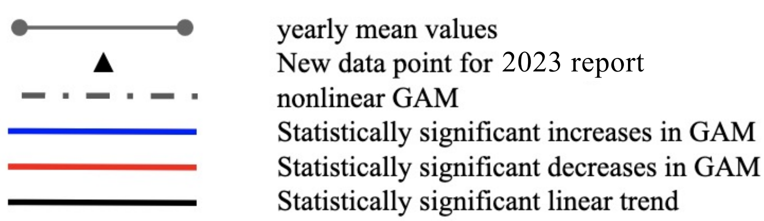


Figure 18. ***Top Left*** The cyclone activity index for the New York Bight and surrounding region (from 77°W to 67°W longitude and 37°N to 43°N latitude, blue box in map at left; NYB in black line) defined as the number of storms per year times the mean intensity of those storms (Wang et al., 2006). ***Top Right*** The number of strong storms defined as the number of cyclones per year within the NYB and surrounding region with a high intensity based on the local pressure gradient. Because the location of the storm is determined by its centroid, and damaging winds, rain, and flooding can also be found outside of the centroid, we use an area larger than the NYB when calculating this indicator.

5. Marine Community

Summary

Due to ship and staffing challenges the 2023 Spring NOAA NEFSC (Northeast Fisheries Science Center) bottom trawl survey was cut short and data for New York Bight Region was not obtained. Our biological indicators have a new data point for Fall 2022 but not for Spring 2023. Monthly mean chlorophyll is now reported from data from the MODIS Terra satellite mission, which better captures the spring bloom. A glider based subsurface chlorophyll maximum indicator, which will help draw a more complete picture of primary production within the NYB, is under development and will be included in subsequent reports (see 2023 Annual Report for more detail). Seawolf sampling has allowed for a finer scale seasonal analysis of zooplankton abundances, with the spring of 2021 standing out as a time of increased *Calanus finmarchicus* and *Centropages typicus*. While *Calanus finmarchicus* abundance remains high in the spring of 2022, *Centropages typicus* abundance greatly decreases. Warming waters are having an impact on marine life, with 2023 showing the highest autumn levels of black sea bass biomass since the start of the NOAA trawl, as well as the highest autumn temperature preference of the fish community in fall 2022.



	Indicator	Long Term Trend	Short Term Trend	Summary
15	Chlorophyll	··········►	··········►	No significant long to short term trends are present in surface chlorophyll.

Monthly Mean Surface Chlorophyll

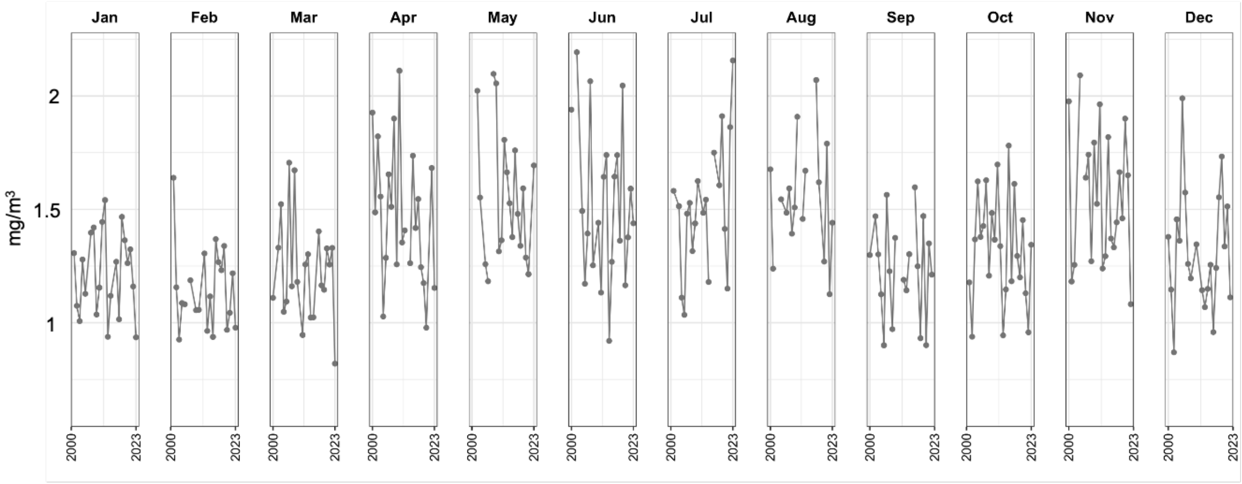


Figure 19. Monthly mean surface chlorophyll from satellite observations, starting with January on the left through December on the far right.

	Indicator	Long Term Trend	Short Term Trend	Summary
16	Calnus finmarchicus	···········►	···········►	No significant long or short term trends are present in *Calanus finmarchicus* abundance.

Calanus finmarchicus abundance

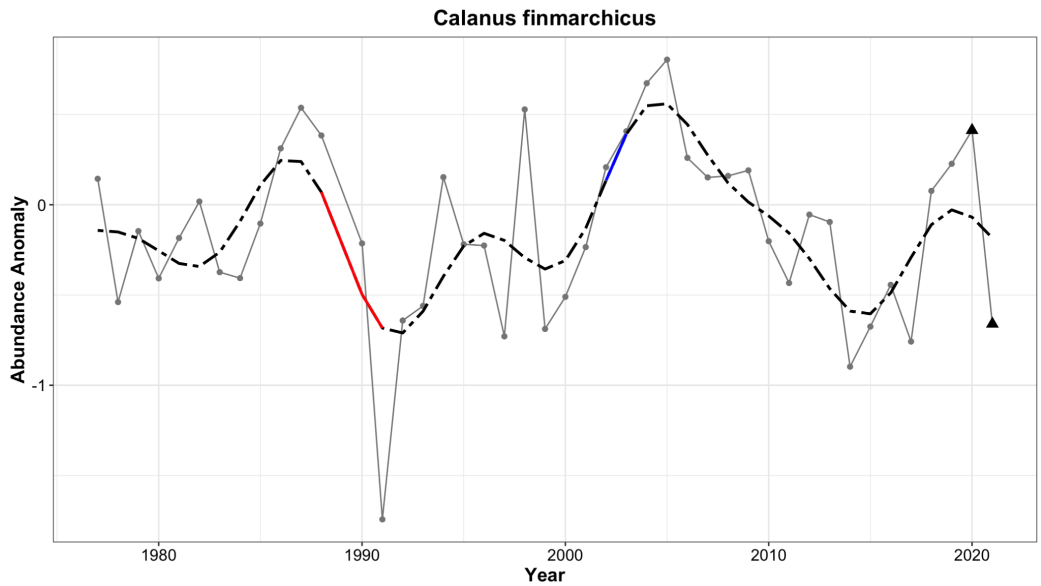


Figure 20. *Calanus finmarchicus* abundance anomaly in the NYB from NOAA ECOMON data.

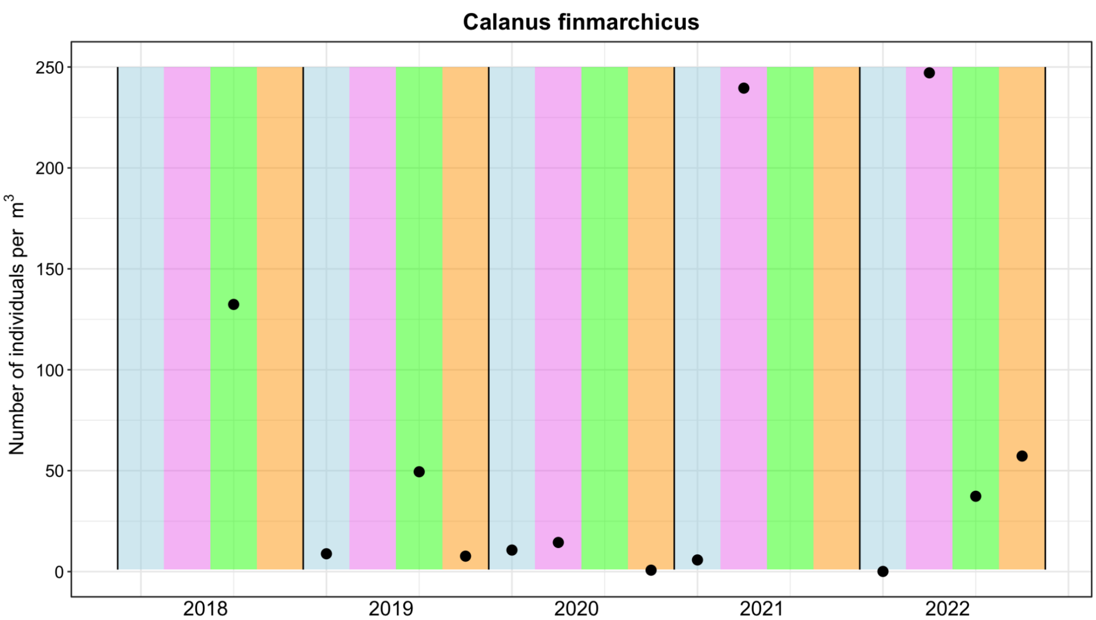


Figure 21. *Calanus finmarchicus* density in number of individuals per m^3 from seasonal RV Seawolf sampling. Colored shading indicates season: blue is winter, pink is spring, green is summer, orange is fall.

	Indicator	Long Term Trend	Short Term Trend	Summary
17	Centropages typicus	···········▸	···········▸	No significant long or short term trends are present in *Centropages typicus* abundance.

Centropages typicus abundance

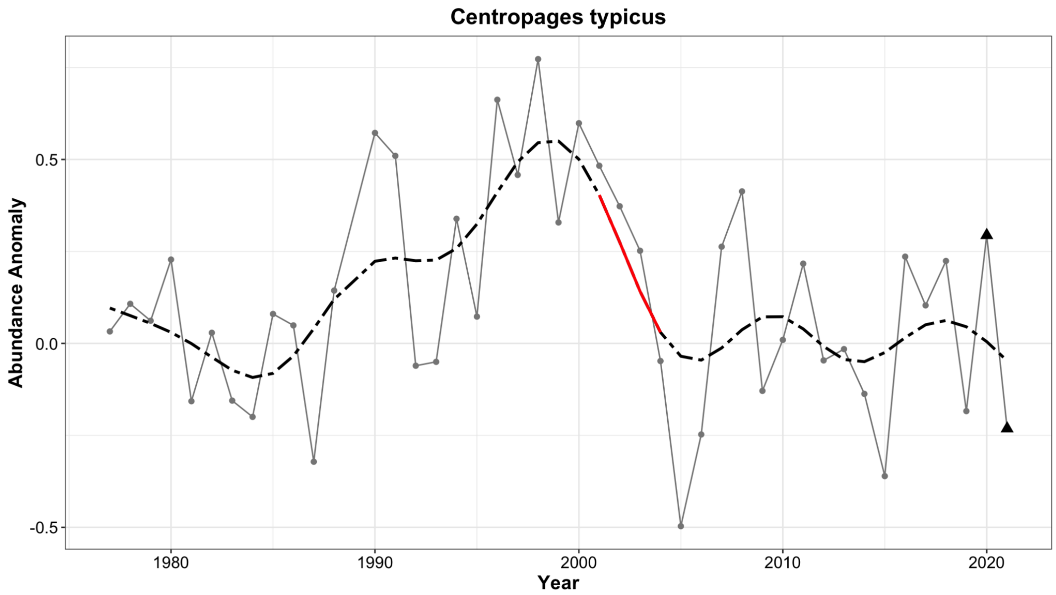


Figure 22. *Centropages typicus* abundance anomaly in the NYB from NOAA ECOMON data.

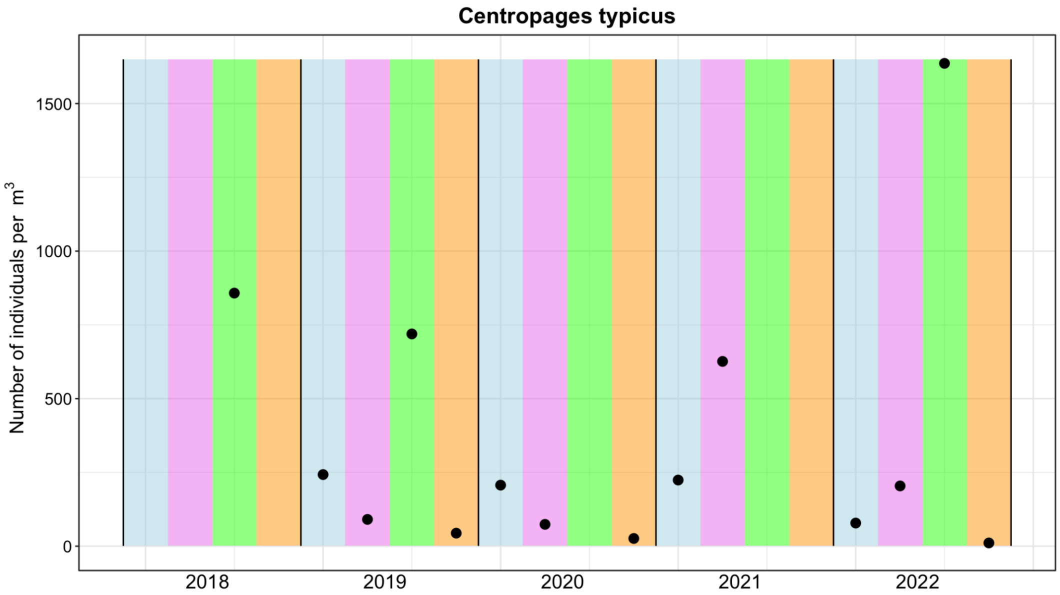


Figure 23. *Centropages typicus* density in number of individuals per m^3 from seasonal Seawolf sampling. Colored shading indicates season: blue is winter, pink is spring, green is summer, orange is fall.

	Indicator	Long Term Trend	Short Term Trend	Summary
18	Copepod Size Index	·············▸	·············▸	No significant long or short therm trends are present in copepod size index.

Copepod Size Index

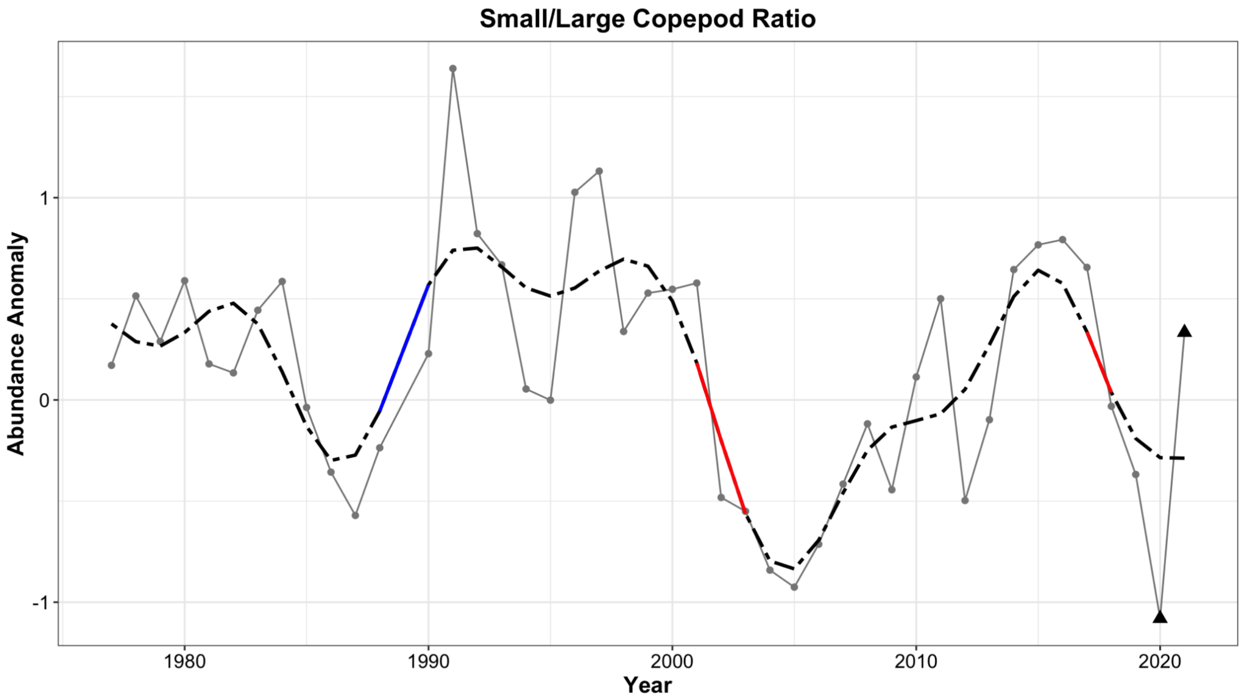


Figure 24. Small to large copepod ratio in the NYB calculated from NOAA ECOMON data.

Commercially Important Invertebrates

	Indicator	Long Term Trend	Short Term Trend	Summary
19	American Lobster			American Lobster biomass has decreased in the autumn.

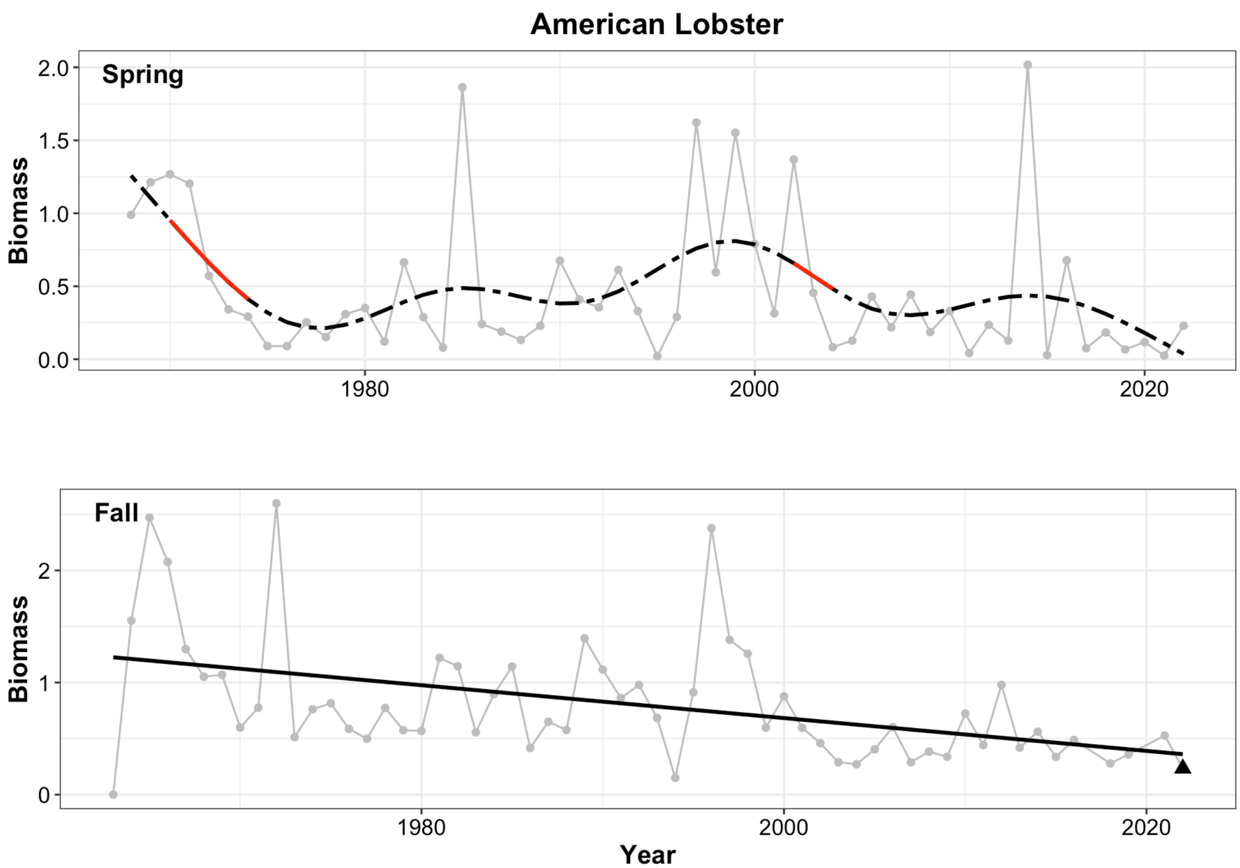


Figure 25. American lobster biomass in NYB during the spring (top) and fall (bottom) NOAA bottom trawl survey.

	Indicator	Long Term Trend	Short Term Trend	Summary
20	Jonah Crab	············►	············►	Jonah Crab biomass has decreased in the spring, but increased in the fall.

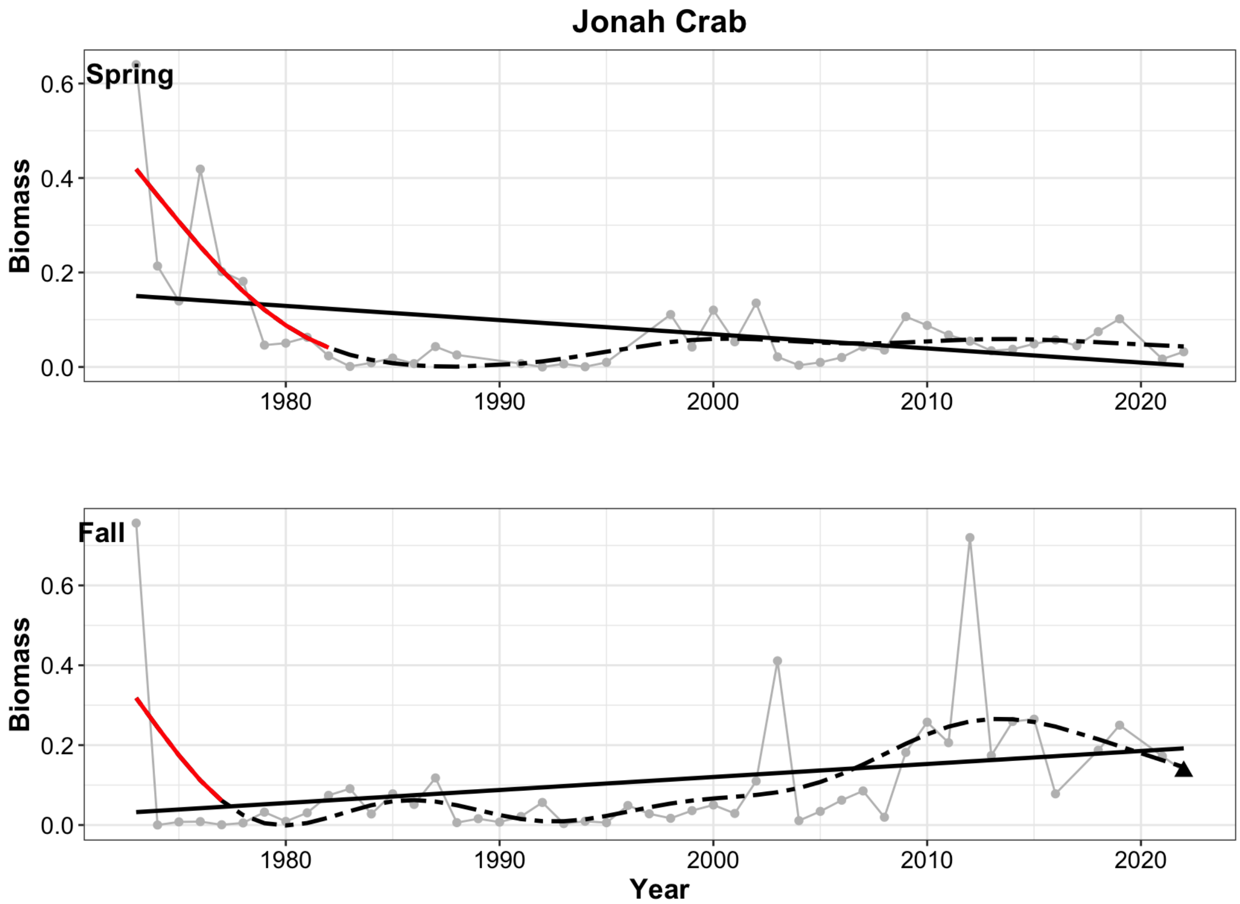


Figure 26. Jonah crab biomass in NYB during the spring (top) and fall (bottom) NOAA NEFSC bottom trawl survey.

	Indicator	Long Term Trend	Short Term Trend	Summary
21	Longfin Squid	·············▸	·············▸	Longfin Squid biomass has decreased during the spring, but increased during the sutumn.

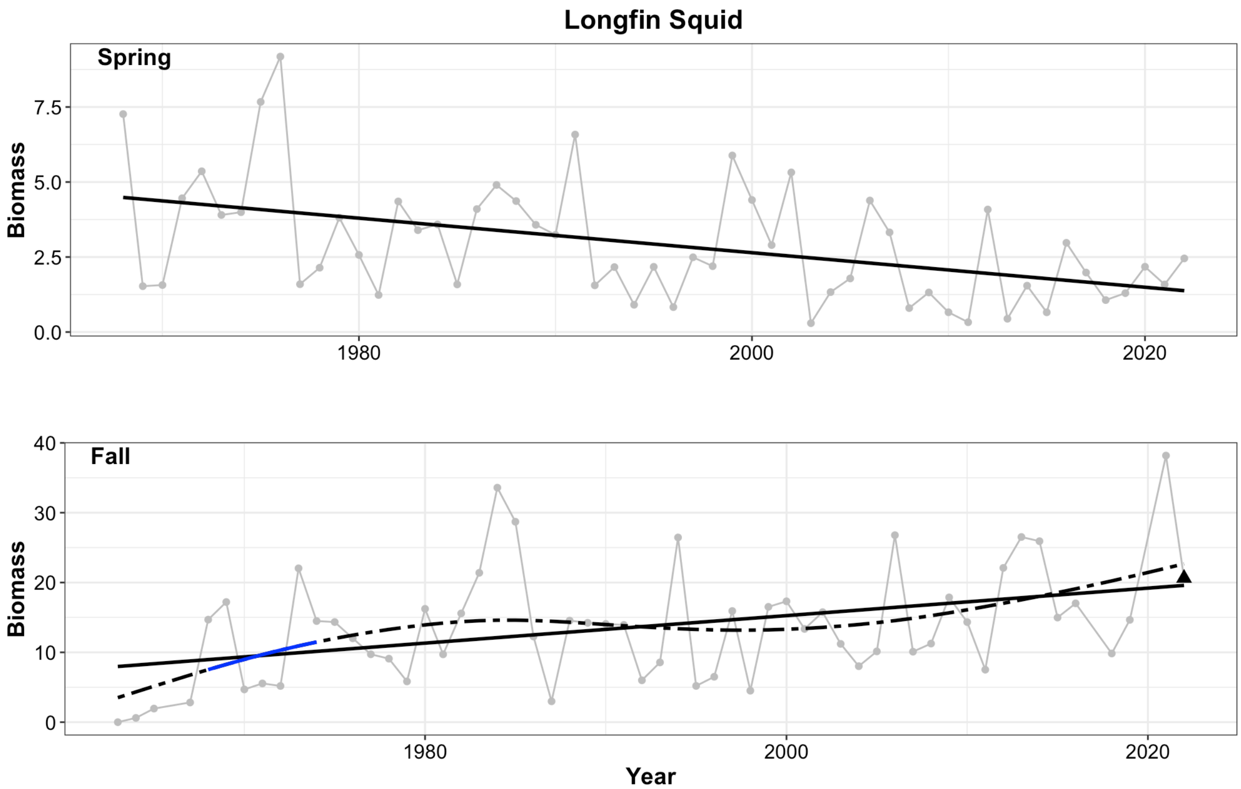


Figure 27. Longfin squid biomass in NYB during the spring (top) and fall (bottom) NOAA NEFSC bottom trawl survey.

	Indicator	Long Term Trend	Short Term Trend	Summary
22	Shortfin Squid	↗	⋯⋯▸	Shortfin Squid biomass has increased during the spring.

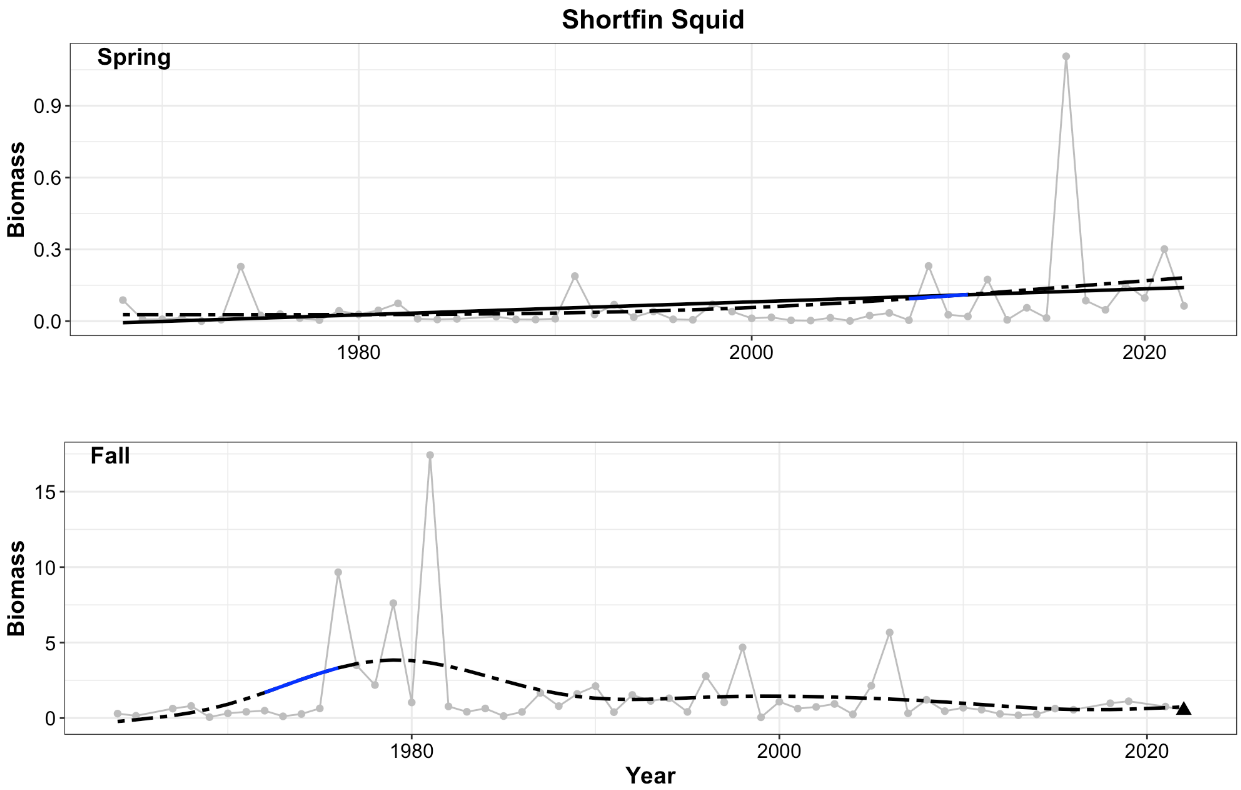


Figure 28. Shortfin squid biomass in NYB during the spring (top) and fall (bottom) NOAA NEFSC bottom trawl survey.

	Indicator	Long Term Trend	Short Term Trend	Summary
23	Forage Species Bioimass	··········▸	↗	Forage species biomass has increased in the short term during the sutumn.

Forage Species Biomass

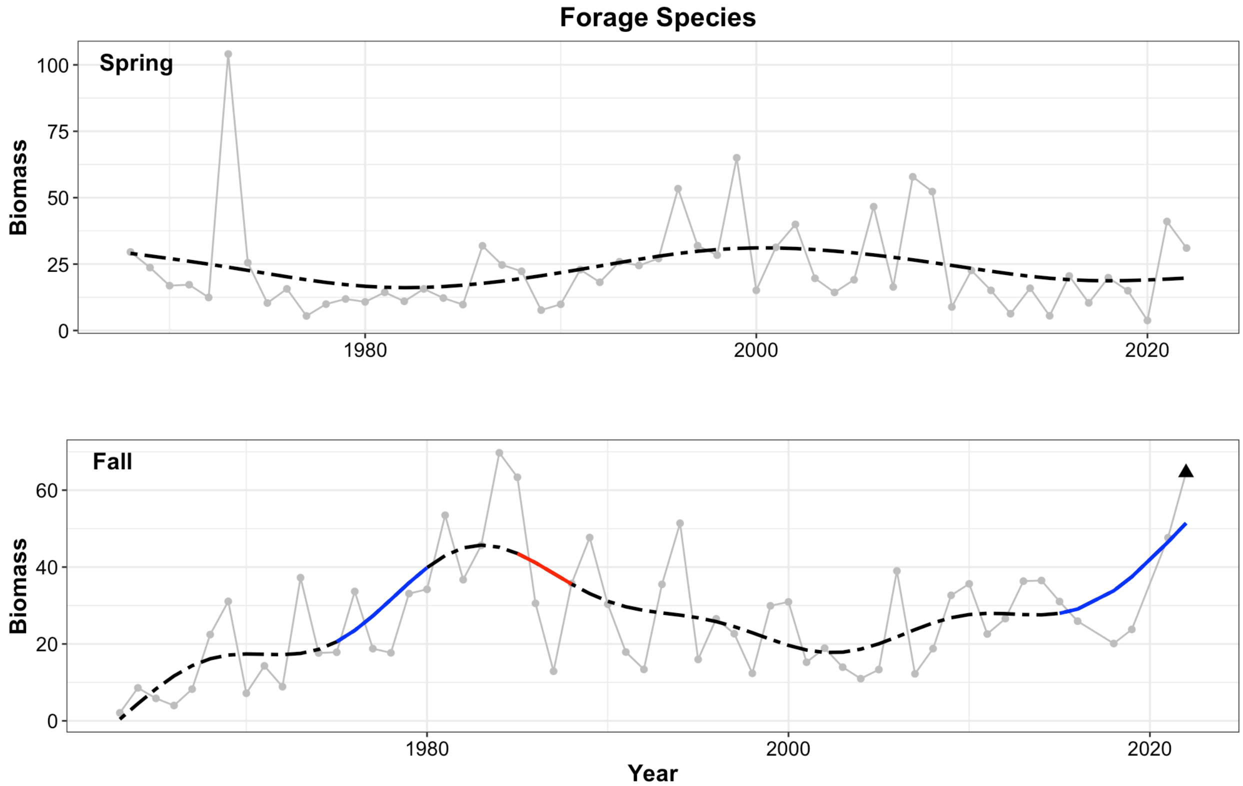


Figure 29. Forage species biomass in the NYB during the spring (top) and fall (bottom) NOAA NEFSC bottom trawl survey.

	Indicator	Long Term Trend	Short Term Trend	Summary
24	Aggregate Feeding Groups	············▸	············▸	Long term increases are seen in Benthos and Planktivores in the autumn. Long term decreases are seen in Piscivores in the autumn.

Aggregate Feeding Groups

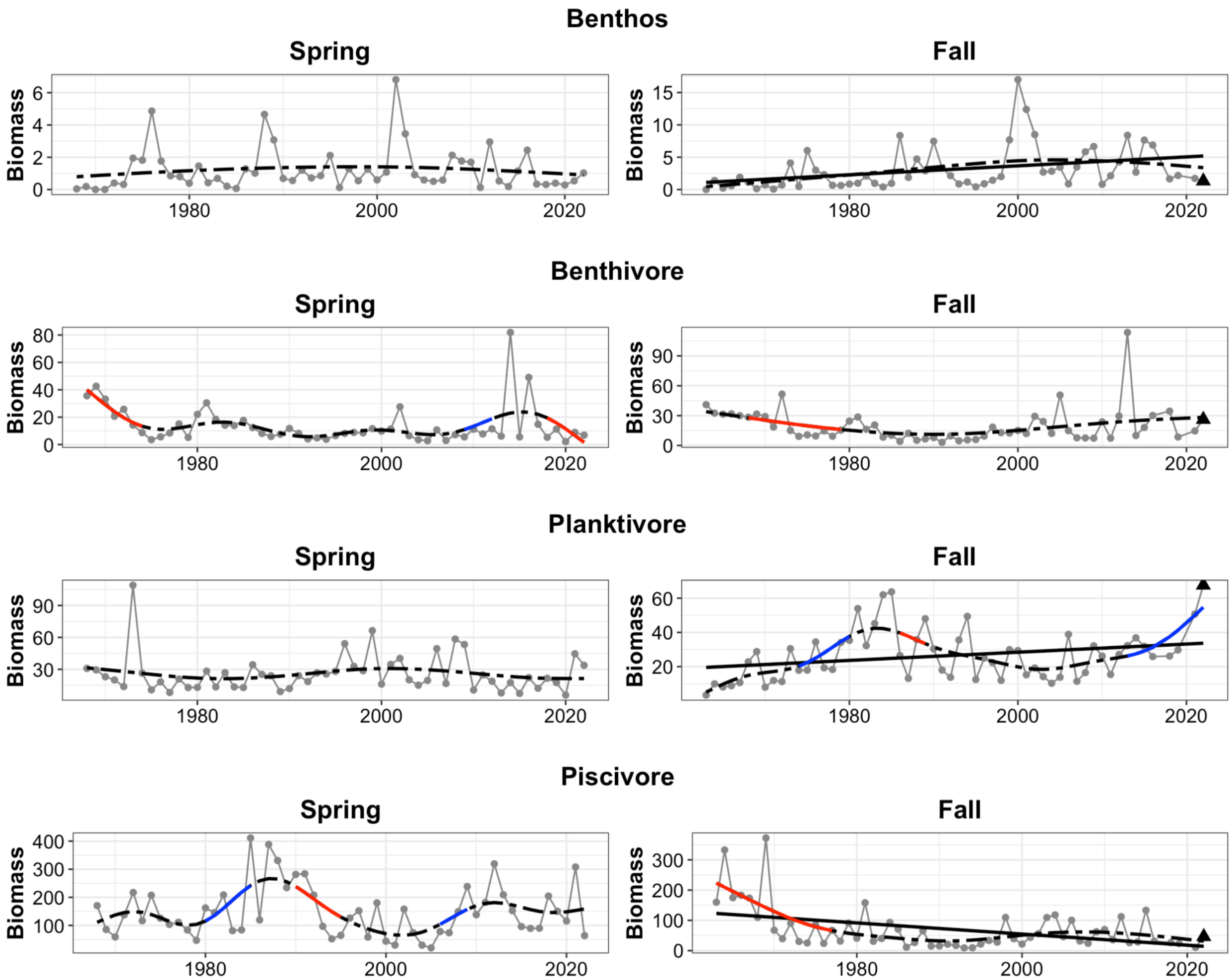


Figure 30. Spring (left) and fall (right) biomass are shown for benthos (top), benthivores (second from top), planktivores (second from bottom), and piscivores (bottom) in the NOAA NEFSC bottom trawl survey.

	Indicator	Long Term Trend	Short Term Trend	Summary
25	Total Trawl Biomass			Total trawl biomass has decreased during the autumn.

Total Trawl Biomass

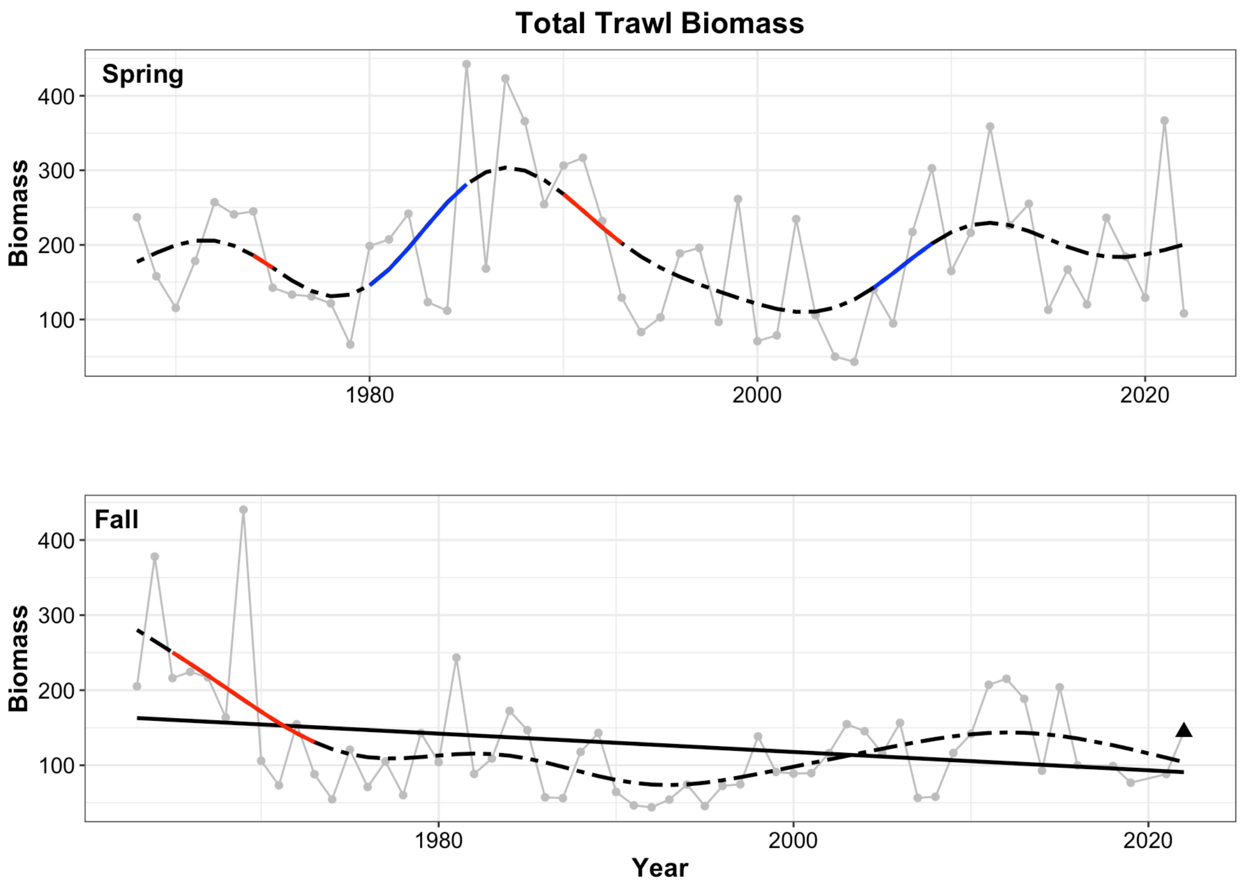


Figure 31. Total trawl biomass in NYB during the spring (top) and fall (bottom) NOAA NEFSC bottom trawl survey.

Ratio of northern to southern species, finfish, and macroinvertebrates

	Indicator	Long Term Trend	Short Term Trend	Summary
26	Black Sea Bass	↗	↗	Black Sea Bass biomass is increasing in the long term in both the spring and fall, and in the short term in the fall.

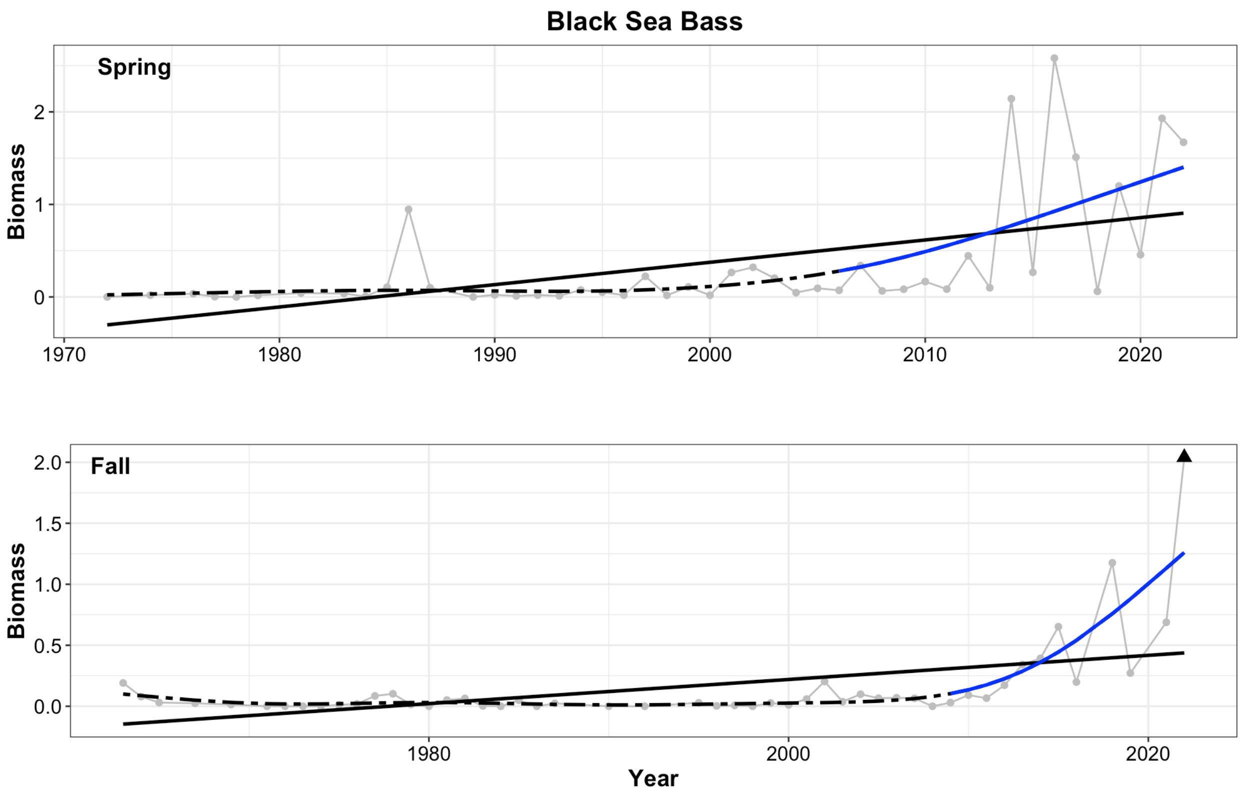


Figure 32. Black sea biomass in the NYB during the spring (top) and fall (bottom) NOAA NEFSC bottom trawl survey.

	Indicator	Long Term Trend	Short Term Trend	Summary
27	Summer Flounder	↗	↗	Summer Flounder biomass is increasing in the long term in both the spring and fall, and in the short term in the fall.

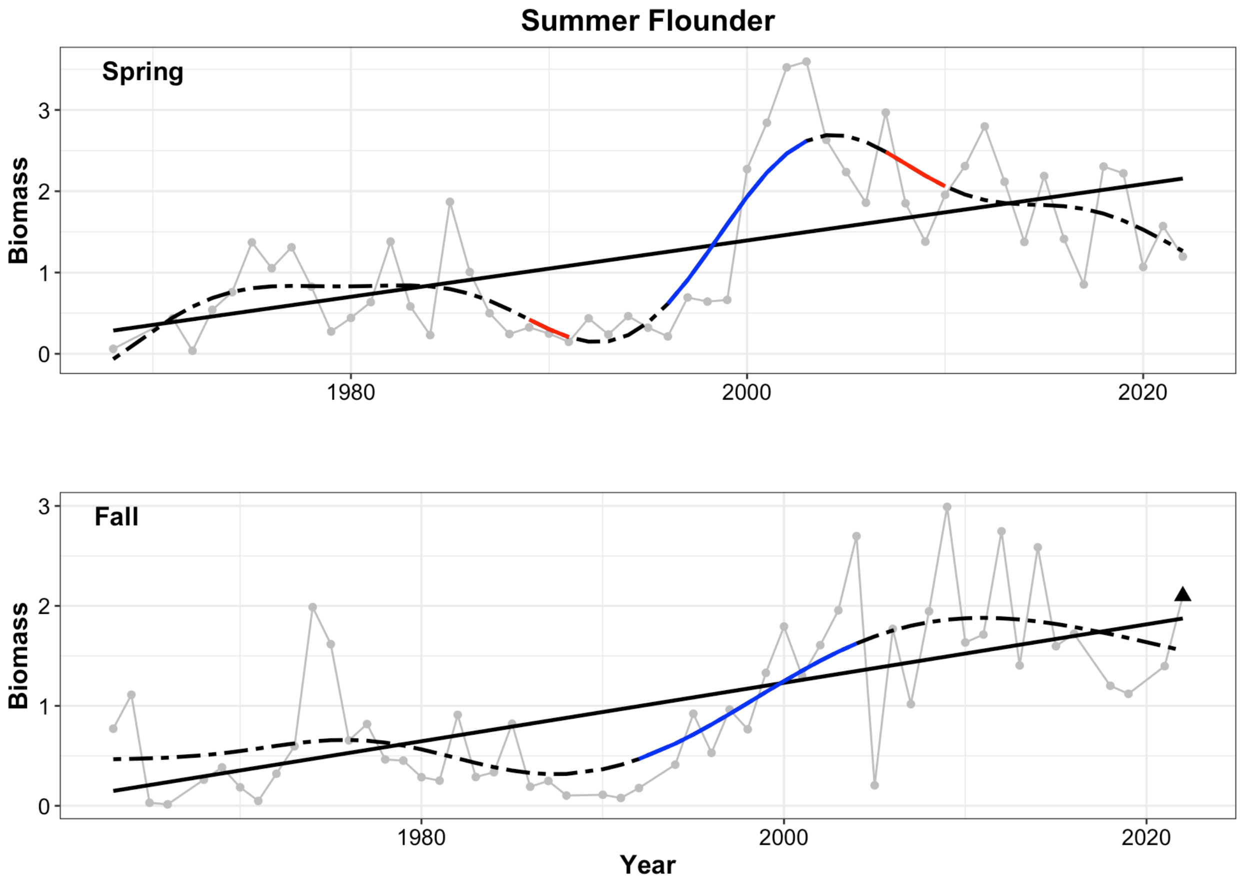


Figure 33. Summer flounder biomass in the NYB during the spring (top) and fall (bottom) NOAA NEFSC bottom trawl survey.

	Indicator	Long Term Trend	Short Term Trend	Summary
28	Ratio Northern to Southern Species	↘	⋯⋯▸	The ratio of northern to southern species has decreased in the autumn.

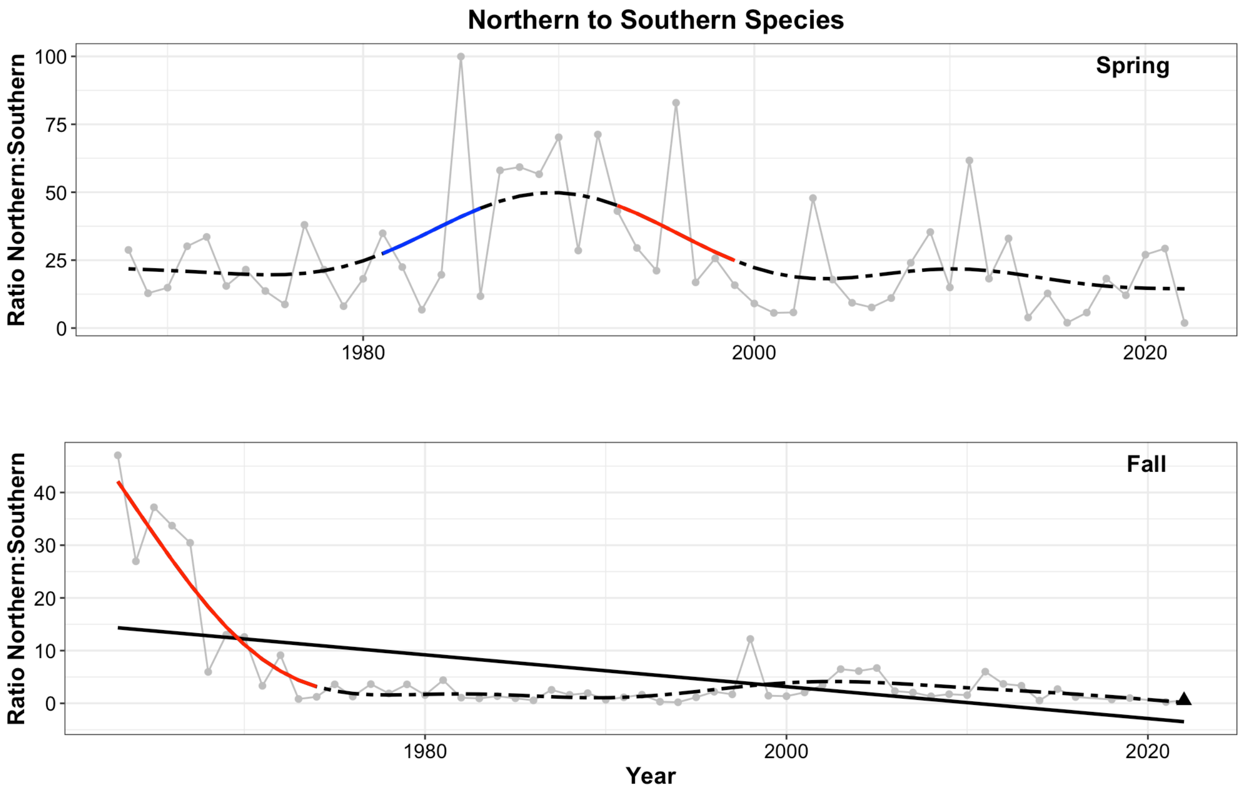


Figure 34. Ratio of northern to southern species in NYB during the spring (top) and fall (bottom) NOAA NEFSC bottom trawl survey.

Ratio of Benthic to Pelagic Species

	Indicator	Long Term Trend	Short Term Trend	Summary
29	Ratio Benthic to Pelagic Species	↘	↘	The ratio of benthic to pelagic species has decreased in the autumn in the long term, and in both the spring and autumn in the short term.

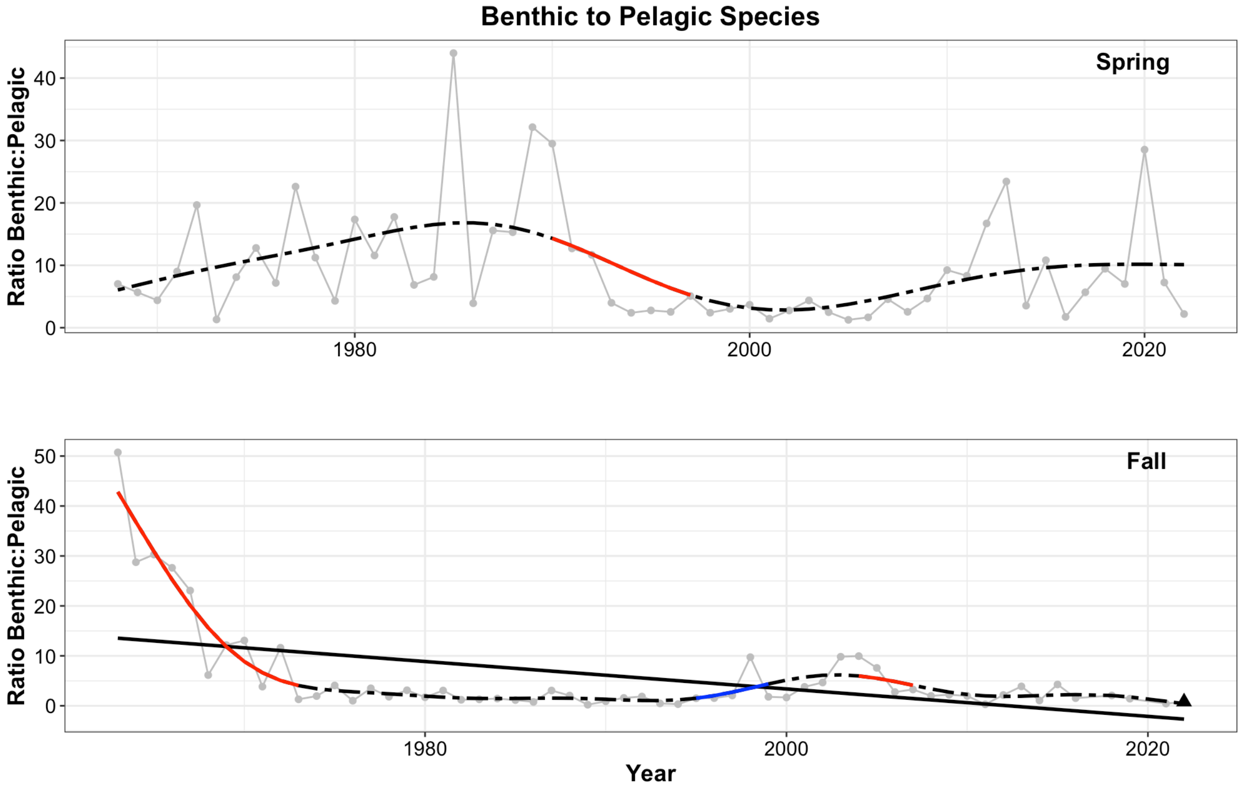


Figure 35. Ratio of benthic to pelagic species in NYB during the spring (top) and fall (bottom) NOAA NEFSC bottom trawl survey.

	Indicator	Long Term Trend	Short Term Trend	Summary
30	Fish Species Richness	↗	↗	Fish species richness has increased in the long term in both the spring and fall, and in the short term in the spring.

Fish Species Richness

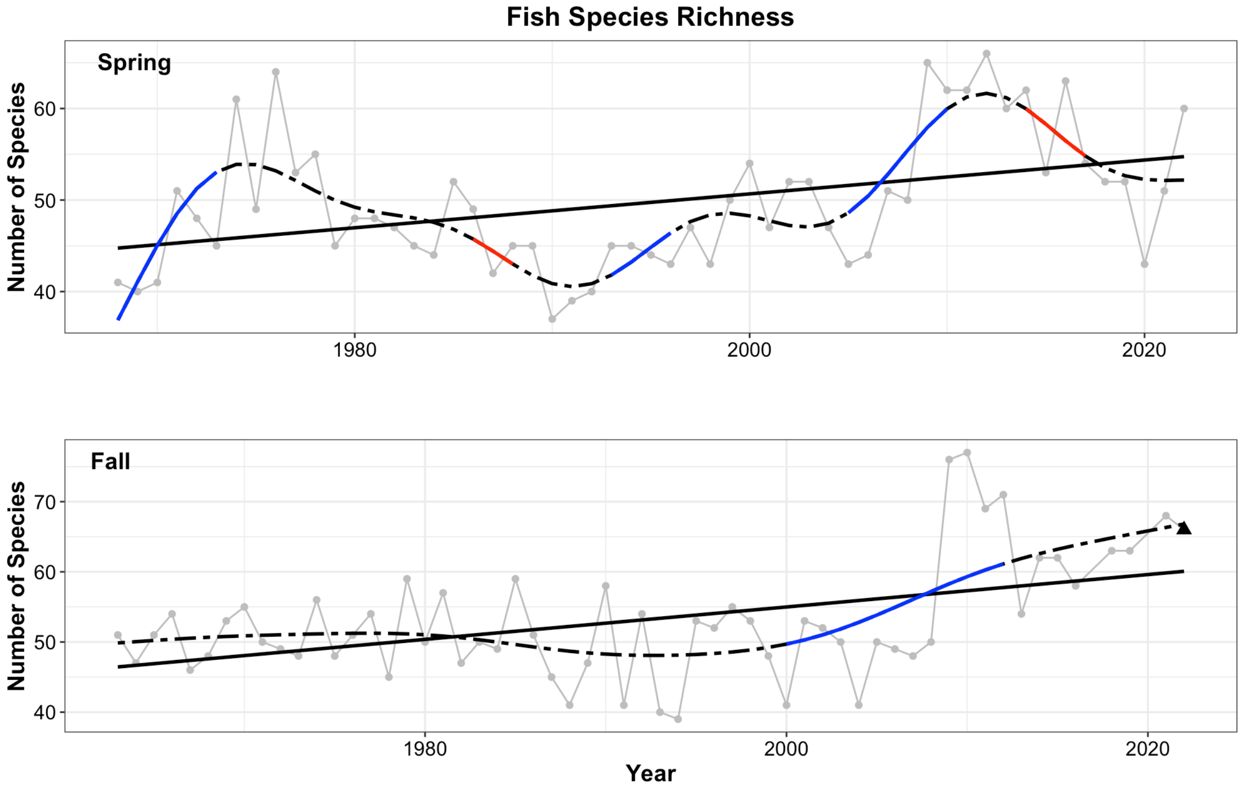


Figure 36. Fish species richness in the NYB during the spring (top) and fall (bottom) NOAA bottom trawl survey.

	Indicator	Long Term Trend	Short Term Trend	Summary
31	Average Trophic Level of Fish Communiity	↘	⇢	The average trophic level of the fish community has decreased in the fall.

Average Trophic Level of the Fish Community

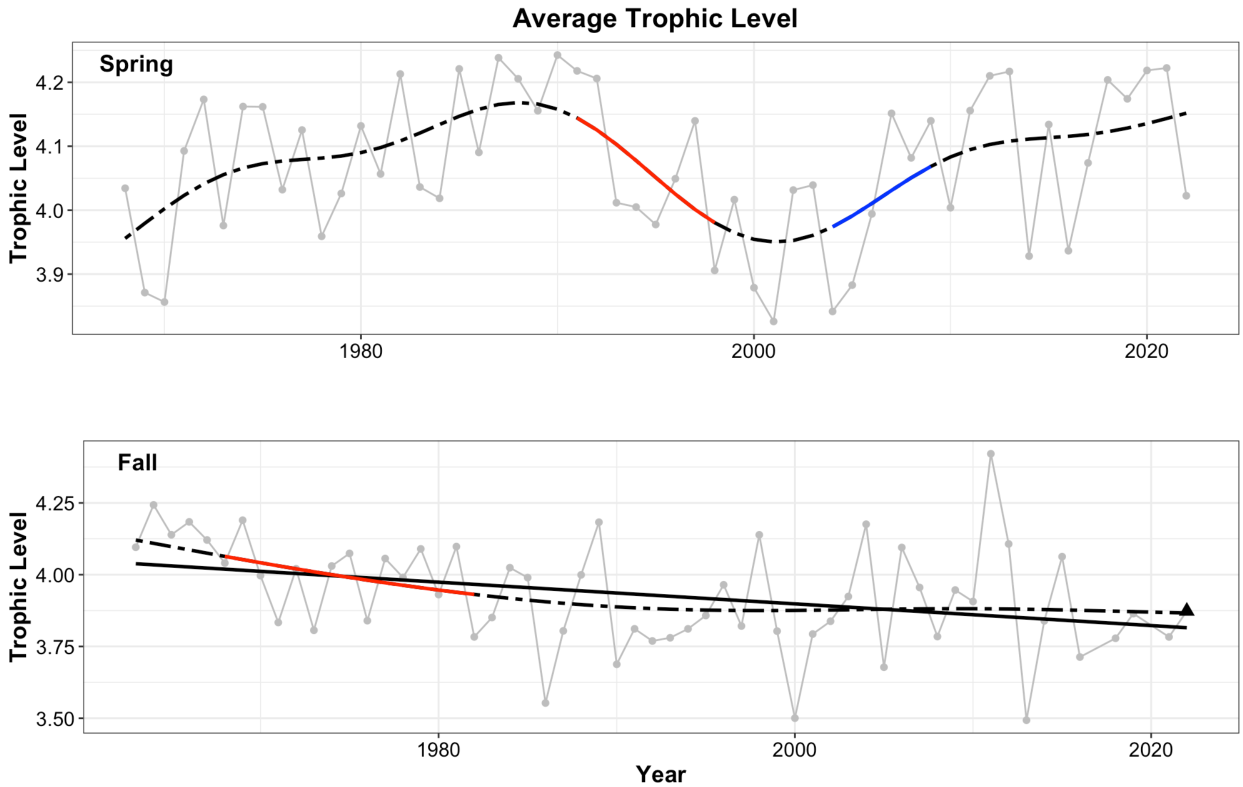


Figure 37. The average trophic level of the fish community in the NYB during the spring (top) and fall (bottom) NOAA NEFSC bottom trawl survey.

	Indicator	Long Term Trend	Short Term Trend	Summary
32	Temperature Preference of Fish Community	↗	↗	The temperature preference of the fish community has increased in both the long ans short term in both spring and fall seasons.

Temperature preference of the fish community

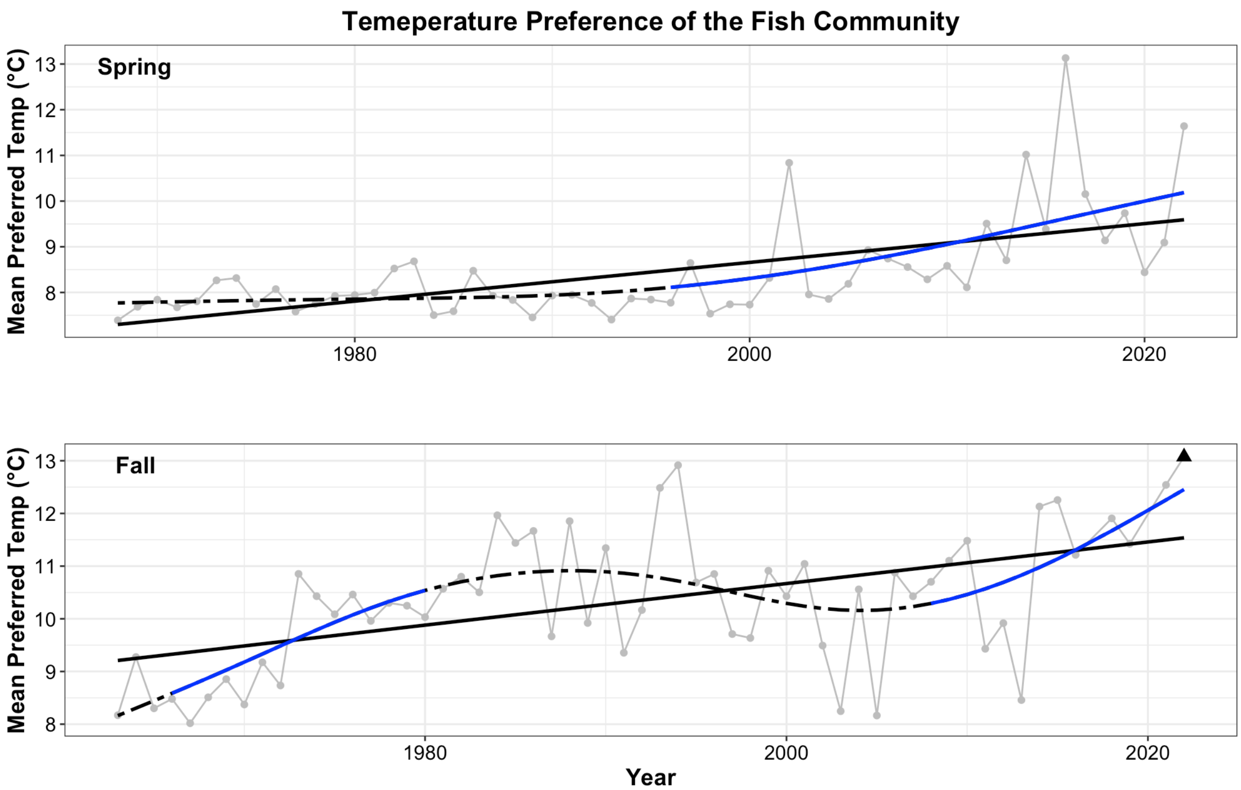


Figure 38. The temperature preference of the fish community in the NYB during the spring (top) and fall (bottom) NOAA NEFSC bottom trawl survey.

6. Human Populations

Summary

The population of Long Island, while increasing over the long term, has decreased slightly from a peak in 2020. This population is vulnerable to sea level rise, which is evident from tide gauge records at both the eastern and western edges of the island. Recreational fishing has increased, but many fishers may be releasing their catch as this increase in effort is coupled with a decrease in recreational fish harvest and an increase in fish released alive. Short term trends in recreational fishing are difficult to determine as portions of the Marine Recreational Information Program were suspended in 2020 and 2021 due to the COVID19 pandemic, and data from those years may be incomplete.

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yearly mean values
New data point for 2023 report
nonlinear GAM
Statistically significant increases in GAM
Statistically significant decreases in GAM
Statistically significant linear trend

	Indicator	Long Term Trend	Short Term Trend	Summary
33	Commercial Harvest Tons	↘	⋯▸	The commercial harvest has decreased in the long term.

Commercial Fisheries Landings

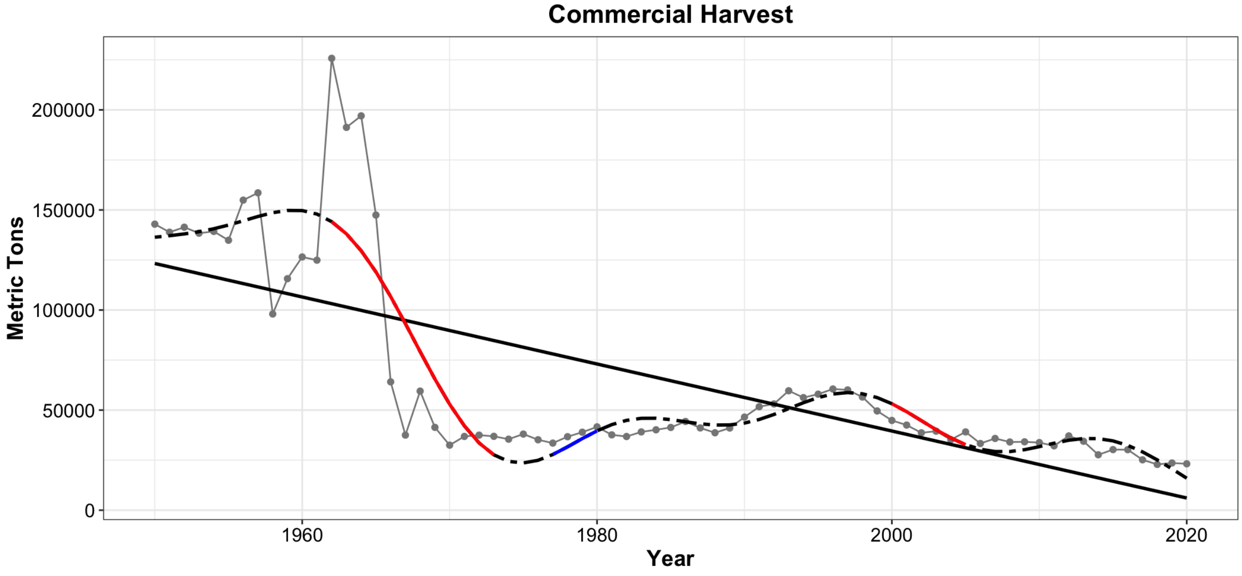

Figure 39. Commercial harvest in the NYB in metric tons.

	Indicator	Long Term Trend	Short Term Trend	Summary
34	Commercial Harvest USD			The commercial landings value has increased over time.

Commercial Landings Value

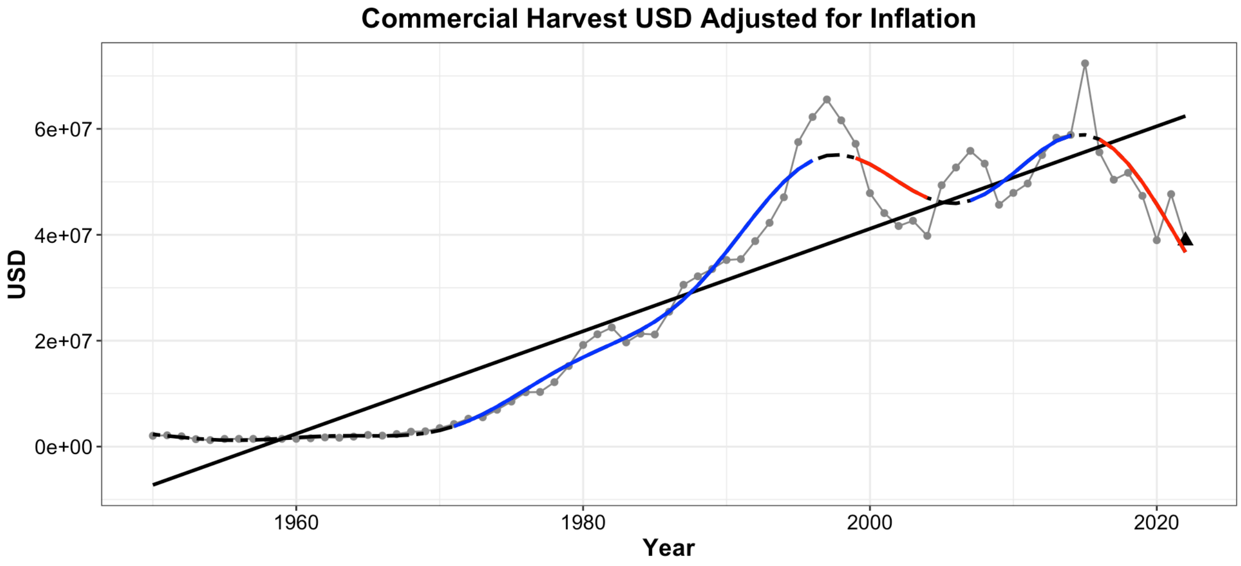

Figure 40. Commercial harvest from NYB in US dollars accounting for inflation.

	Indicator	Long Term Trend	Short Term Trend	Summary
35	Recreational Harvest			Recreational harvest has decreased in the long term, while the number of fish released has increased.

Recreational Harvest

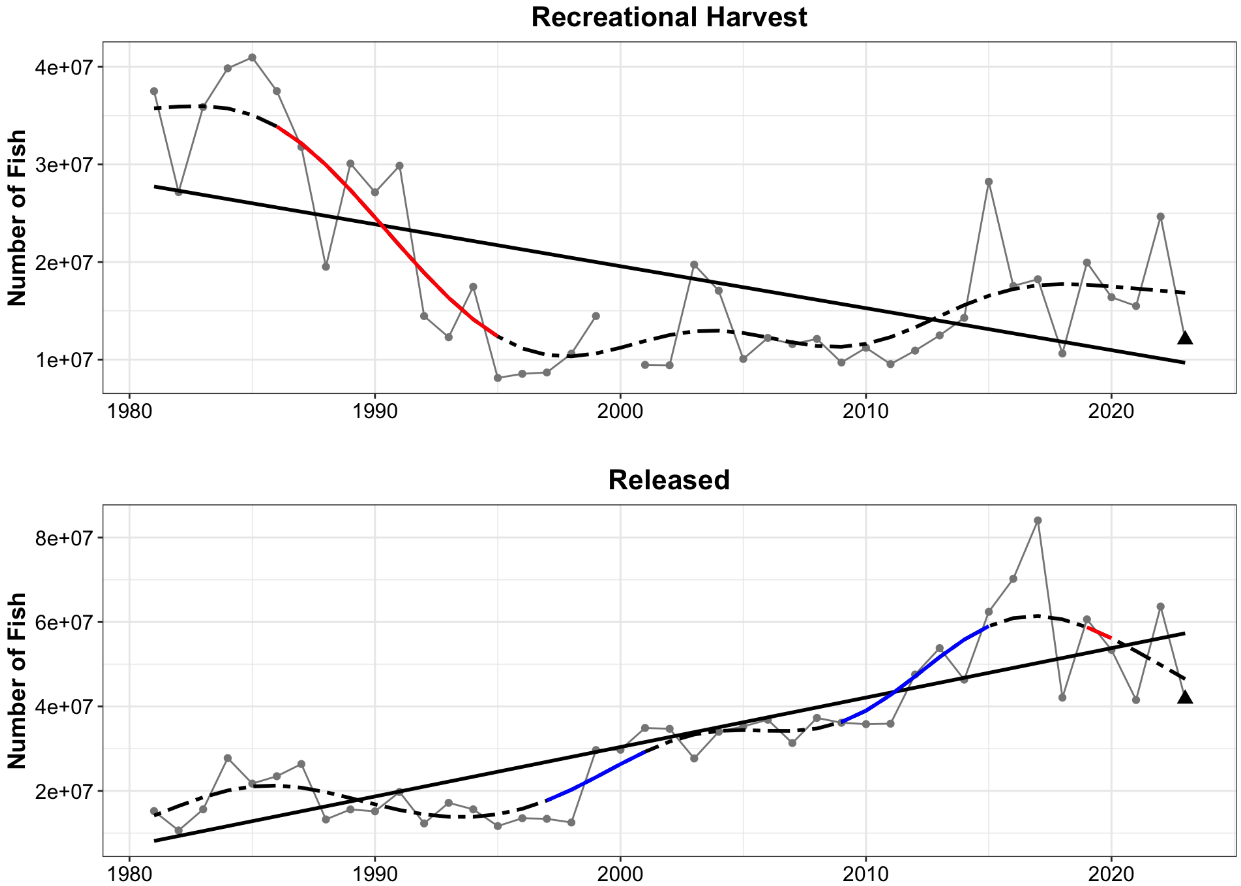

Figure 41. ***Top*** Recreational harvest shows a linear decrease since the 1980s. ***Bottom*** The number of fish released has increased since the 1980s. The Marine Recreational Information Program that monitors recreational fishing was partially suspended in 2020 and 2021 due to the COVID19 pandemic, data from these years may be incomplete. Only data that meet the most stringent data quality standards are included.

	Indicator	Long Term Trend	Short Term Trend	Summary
36	Recreational Effort	↗	⇢	Recreational effort has increased in the long term.

Recreational Effort

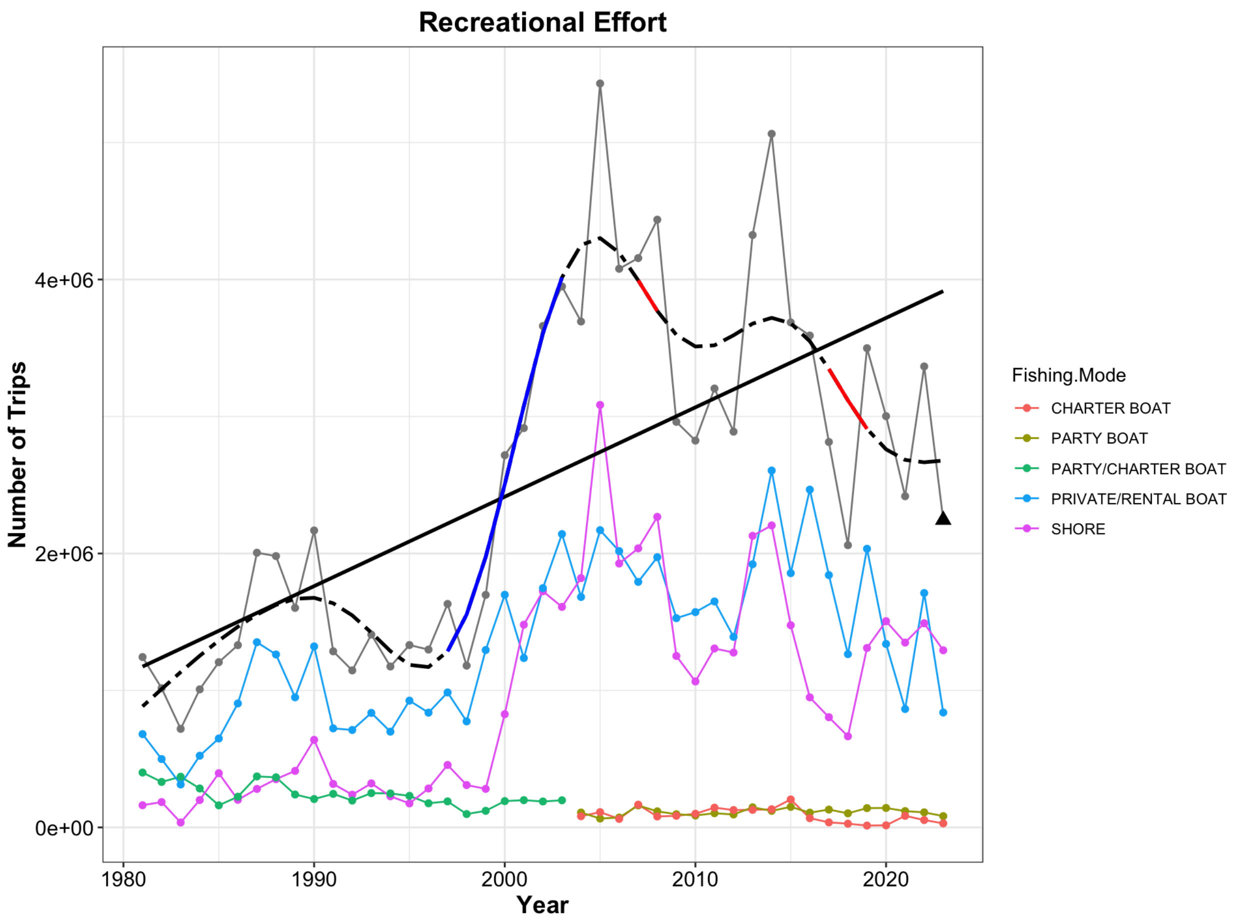

Figure 42. Total recreational effort in number of trips per year is shown in the grey line. This is broken down based on the type of recreational trip: purple indicates fishing from shore, blue indicates private/rental boats, and green indicates party/charter boats. From 2004 onward the party and charter boats have been separated into party boat (brown) and charter boat (red). Recreational effort shows a linear increase over the whole time series. During 2020 and 2021 portions of the Marine Recreational Information Program were suspended due to the COVID19 pandemic and data from these years is likely incomplete.

	Indicator	Long Term Trend	Short Term Trend	Summary
37	Vessel Density	↗	⇢	The number of TEUs at the port of New York and New Jersey have increased.

Vessel Density

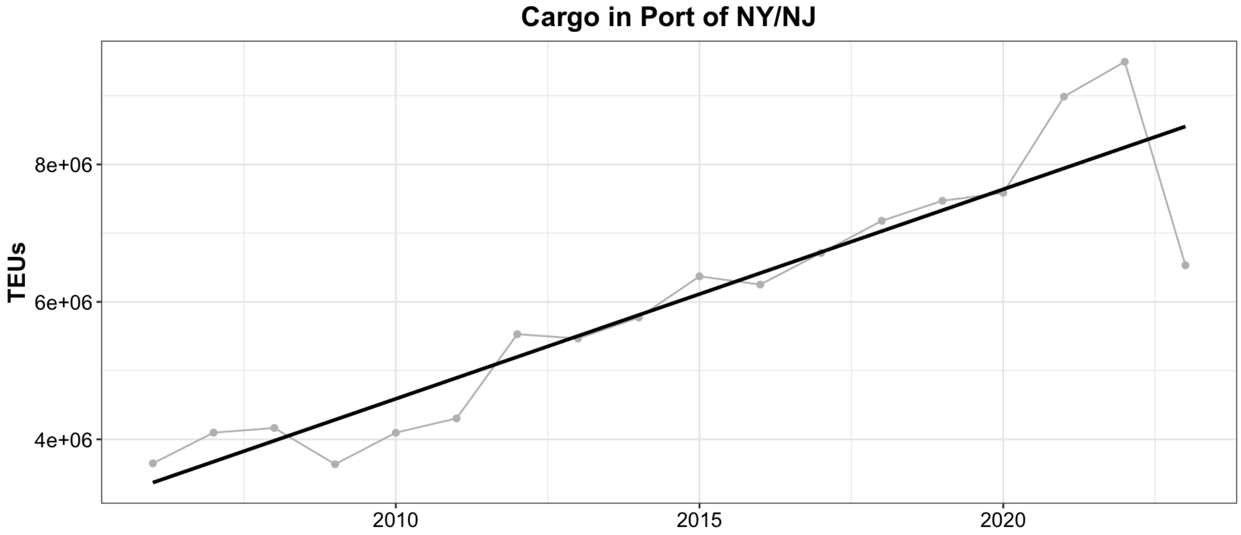

Figure 43. Cargo in the port of New York and New Jersey defined as the number of twenty-foot equivalent units (TEUs). This unit represents the size of a standard cargo container. Data for 2023 were only available through October and are incomplete.

	Indicator	Long Term Trend	Short Term Trend	Summary
38	Human Population	↗	↘	The population of Long Island has increase in the long term, but has fallen recently from a peak in 2020.

Human Population of Long Island

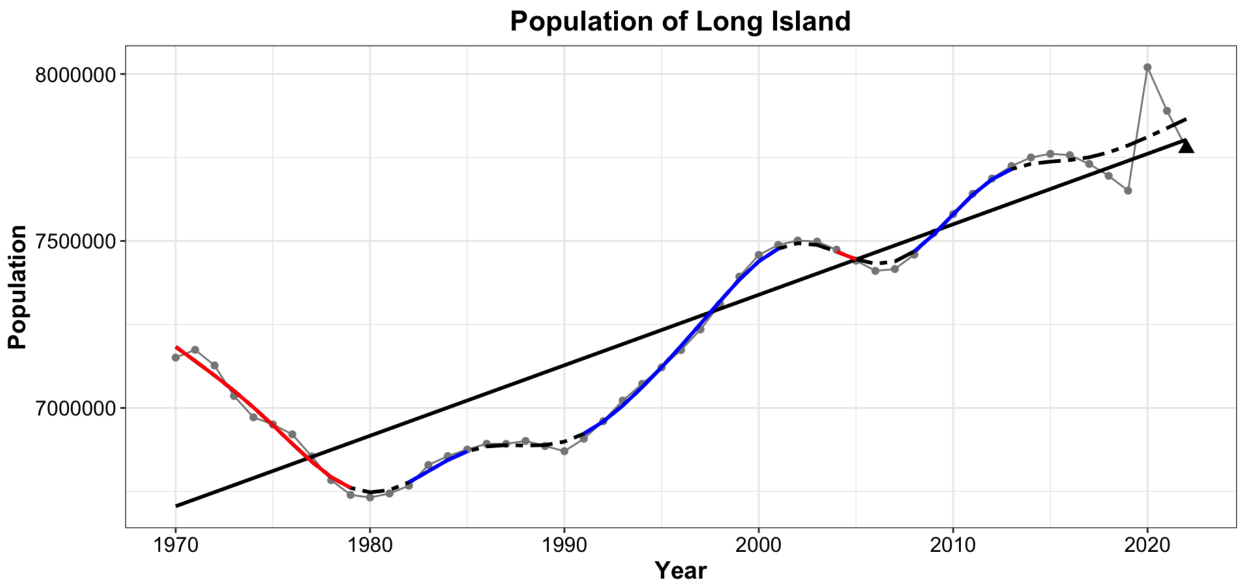

Figure 44. The combined population of the four New York State counties that make up Long Island: Kings, Queens, Nassau, and Suffolk. These counties were selected to represent those communities most impacted by changes in ocean conditions. Population has been on the rise since the 1980s, peaked in 2020 and then has declined in recent years.

	Indicator	Long Term Trend	Short Term Trend	Summary
39	Sea Level Rise			Sea level continues to rise along both the western and eastern coasts of Long Island.

Sea Level Rise Risk for Long Island Communities

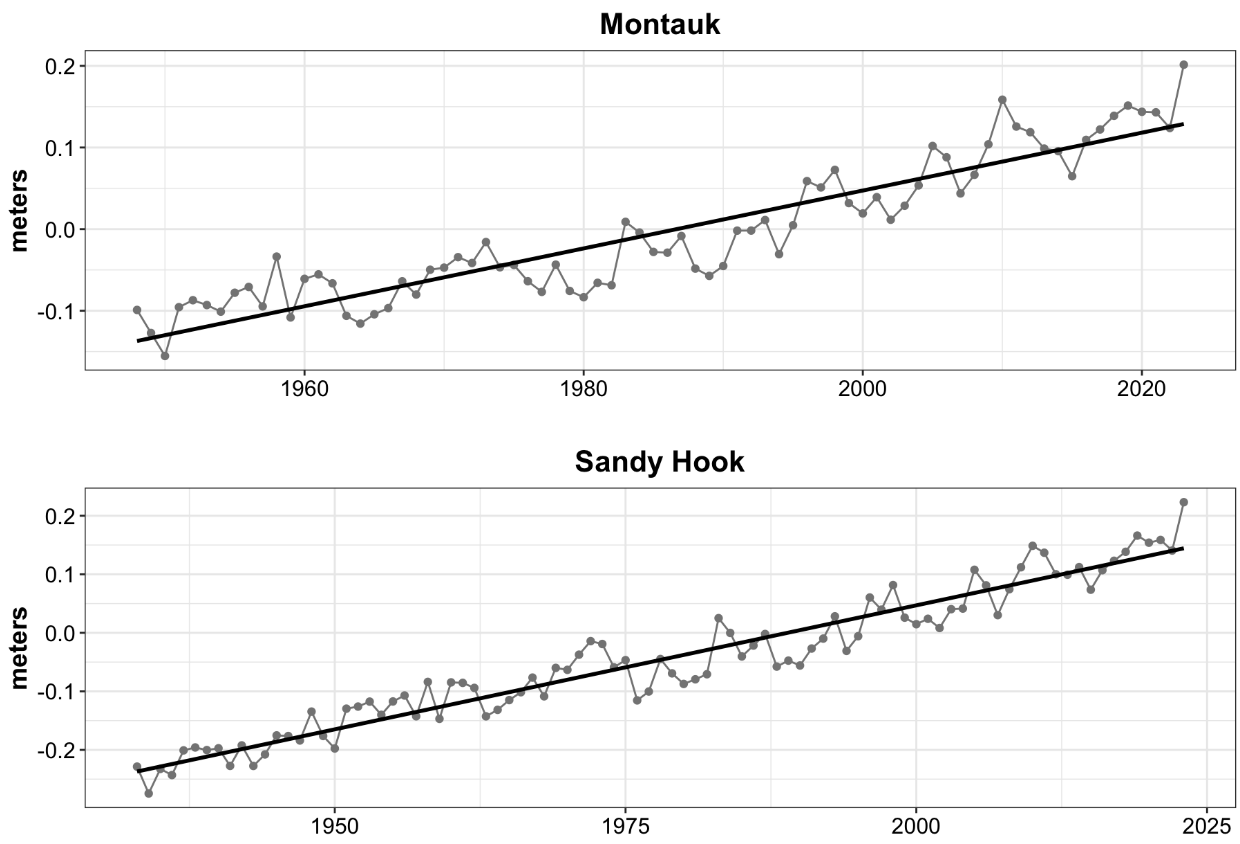

Figure 45. Trends in relative sea level with seasonal cycle removed. Relative sea level is related to the rise and fall of sea level as well as the rise and fall of land that the measurement is referenced to locally. The top plot shows relative sea level at the Montauk tide gauge on the most eastern tip of Long Island. The bottom plot shows relative sea level at the Sandy Hook tide gauge in northern New Jersey near the western tip of Long Island. Relative sea level is increasing at both locations. The NYB is located in a known hot-spot of rapid sea level rise (Sallenger et al., 2012). Sea level rise in the NYB is comparatively faster than global average sea level rise (about 4mm/yr for the NYB compared to about 1.3mm/yr – 1.9mm/yr for the global average for the 20th century (IPCC, 2023)).

Part II. Ongoing Indicator Development

Whale Body Condition

Body condition of upper trophic level species can provide an indicator of ecosystem health of the New York Bight as these species integrate across multiple trophic levels and across long time frames (Bossart, 2011; Hazen et al., 2019; Moore, 2008). Baleen whales are capital breeders that separate their breeding and feeding grounds, acquiring and storing energy while on the foraging grounds, and relying on that stored energy for the remainder of the year. Thus, the body condition of baleen whales reflects their energy stores. Changes in baleen whale body condition through time, and between foraging areas, can provide information not only about whale health, but also about changes to resource availability (prey), and anthropogenic stressors (Bossart, 2011; Bradford et al., 2012; Christiansen et al., 2020; Lemos et al., 2022). We are developing an indicator of baleen whale body condition in the NYB by integrating Unoccupied Aerial Systems (UAS), or drone, measurements with a scalable three-dimensional (3D) model to estimate baleen whale body volume, which provides a holistic means of assessing body volume (Hirtle et al., 2022). We are conducting field studies to quantify the body condition of humpback whales foraging in New York waters to detect and examine interannual changes in body condition. Further, we are using this indicator to make comparisons of body condition of humpback whales foraging in New York waters with those in different foraging areas across the North Atlantic.

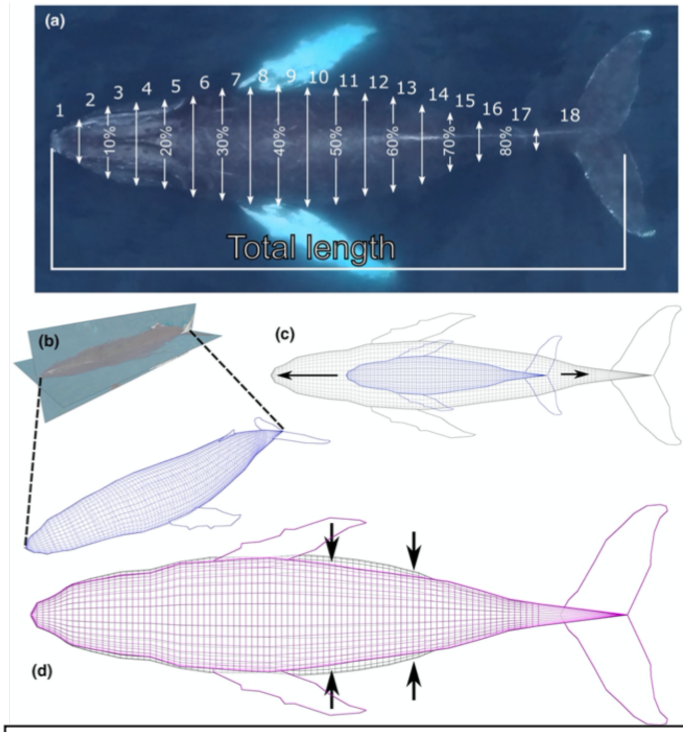

Figure 1: A workflow diagram of the model scaling process used to generate estimates of body volume, from Hirtle et al. (2022). (a) Width measurements (white arrows) and total length measurements are derived from Unoccupied Aerial System (UAS) images. Numbers between width measurements indicate percent total length from rostrum to fluke notch. Integers 1–18 indicate three-dimensional (3D) body segments corresponding to regions between width measurements. (b) The base 3D model is constructed using dorsal and lateral images. (c) The base model (blue) is scaled to length, conserving model proportions. (d) The model is scaled laterally and dorsoventrally to match corresponding width measurements and height-width ratios, resulting in the final model (purple). Black arrows indicate regions of greatest change relative to the base model.

A large proportion of the whales we observe foraging in the NYB are juveniles (Stepanuk et al., 2021), making it important to use a body condition metric that accounts for changes in body volume relative to body size. We are therefore using the approach of Christiansen et al. (2020), which uses the significant linear log-log relationship between body volume and body length (whales with a longer body length inherently have a larger body volume). The body condition index of individual whales is calculated as the residual of this log-log relationship. Positive (negative) values of this index reflect better (worse) body condition than the average whale of the size body length. However, developing reliable values of this metric requires a large sample size so as to have sufficient data to establish a strong relationship between body volume and body length as calculated residuals are strongly dependent on this relationship. We are therefore building up our dataset of baleen whale morphometrics so as to rigorously assess the relationships between body volume and body length. Further, to put the body condition of humpback whales in the NYB in a broader context, we are comparing body condition of humpbacks foraging in the NYB with that of whales in other foraging grounds across the North Atlantic (Napoli et al., in review), the idea being that condition of whales in NYB is an integrated indicator of health in lower trophic levels and anthropogenic stress on these predators.

Odontocete Strandings

We examined trends in odontocete species strandings in New York from 1996-2022. Odontocetes are suitable study species for examining changes to the distribution of cetacean strandings through time as they are typically resident or weakly migratory and thus analyses are not complicated by migratory patterns, and because odontocetes are well represented in the strandings data. We followed the methods outlined in Thorne et al. (2022) to examine temporal trends in the species composition of odontocetes stranding in New York specifically. Briefly, we obtained Level A data from the National Marine Mammal Stranding Database, collated by the National Marine Fisheries Service. Level A data includes basic information such as species ID, location, and condition of the stranded information. We classified odontocete species as warm water, cool water, cosmopolitan, and Arctic as in Thorne et al. (2022). Warm and cool water species made up the vast majority of odontocete strandings during the study period (99%) and we therefore examined changes to the proportion of strandings made up of warm water and cold water species, respectively, using linear models. We found significant increases in the proportion of warm water species through time, and significant decreases in the proportion of cold water species. These trends were primarily driven by increases in the number of bottlenose dolphin (*Tursiops truncatus*) and common dolphin (*Delphinus delphis*) strandings (warm water species).

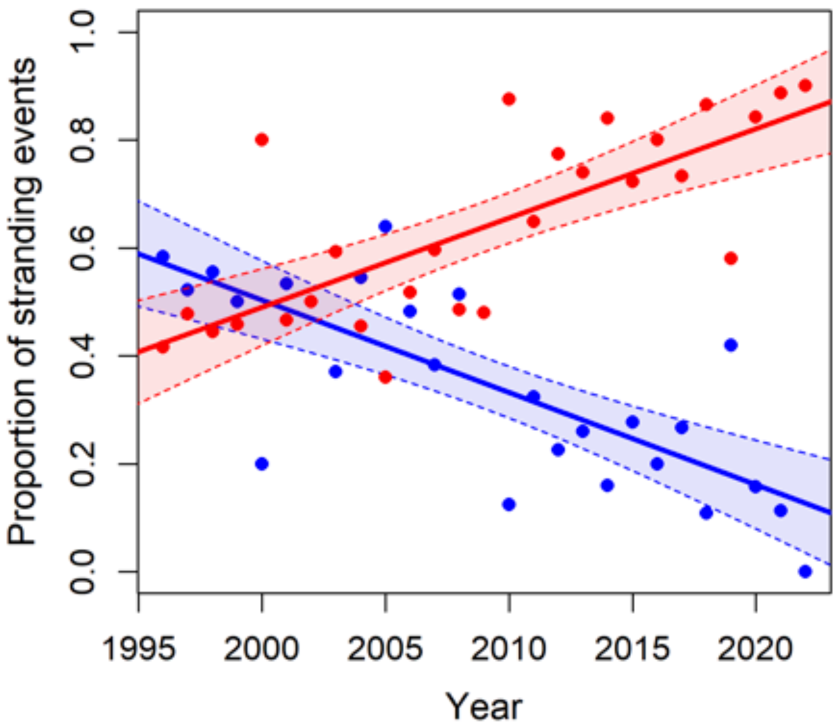

Figure 2. Proportion of strandings that were warm (red) or cold (blue) water species.

Abundance and distribution of seabirds in the New York Bight

New York waters provide important habitat for a wide array of seabird species, including protected species like the federally endangered Roseate Tern (*Sterna dougallii*). Upcoming wind development in offshore waters of the New York Bight have raised concerns regarding the potential impacts on wildlife populations, particularly for seabirds. Collisions with moving turbine blades can cause mortality in seabirds, but wind farms can also have important sub-lethal effects, creating barriers to movement and causing birds to be displaced from important foraging areas. Thus, providing baseline data on the habitat use of seabirds in the New York Bight (NYB) prior to offshore wind development is important to understanding the impacts of this development. We are conducting line transect surveys of seabirds to quantify the abundance and distribution of seabirds in the NYB seasonally. These surveys were initiated in 2022, and we will be developing indicators of seabird abundance and species composition as these surveys generate sufficient data to do so.

NASC

The Nautical Area Scattering Coefficient (NASC) is the amount of backscatter in a defined 3D box within the water column. It is used as a proxy for biomass with units of meters squared per nautical miles squared (m^2nmi^{-2}). In preliminary Figure 3 below we show NASC at four different frequencies. We expect 38 and 70 kHz to reflect fish and squid biomass and 120 and 200 kHz to reflect zooplankton biomass. Because it is not useful to compare units of NASC across the different frequencies (i.e. 100 units of NASC at 38kHz and 100 units of NASC at 200 kHz does not mean those are the same biomass) each frequency will be treated as its own "indicator." As a simplistic example, if 38 kHz NASC goes up, there are likely more fish.

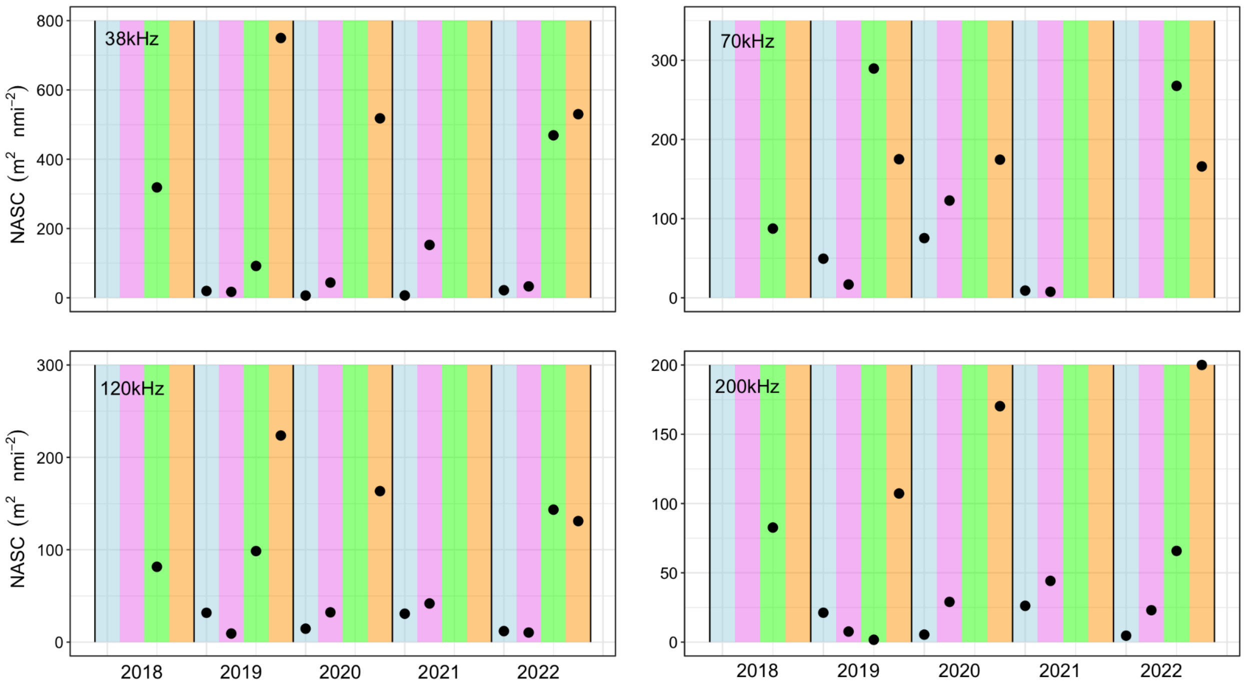

Figure 3. Seasonal trends in NASC (m^2 nmi^{-2}) were estimated using the stratified means at each frequency using an algorithm adapted from Jolly & Hampton (1990). The background colors represent winter (blue), spring (pink), summer (green), and fall (orange) seasons. Note that the y-axes at each frequency are not the same since NASC values are not directly comparable across frequencies.

Subsurface Chlorophyll

We continue to develop a better indicator of primary production within the NYB. For the 2023, and all previous reports, we have examined surface chlorophyll based on satellite observations. Surface chlorophyll is not a direct measurement of primary production and has long been a problematic way to characterize the energy available at the base of the food chain to all higher trophic levels. Many assumptions go into the relationship between surface chlorophyll and net primary productivity, but one major assumption is that the surface chlorophyll is a good proxy for production of the entire water column. Glider data clearly shows that the maximum chlorophyll often occurs below the surface in an area that is undetectable to satellites. In subsequent indicator reports, we will characterize the amount of chlorophyll in the subsurface and compare to satellite measurements.

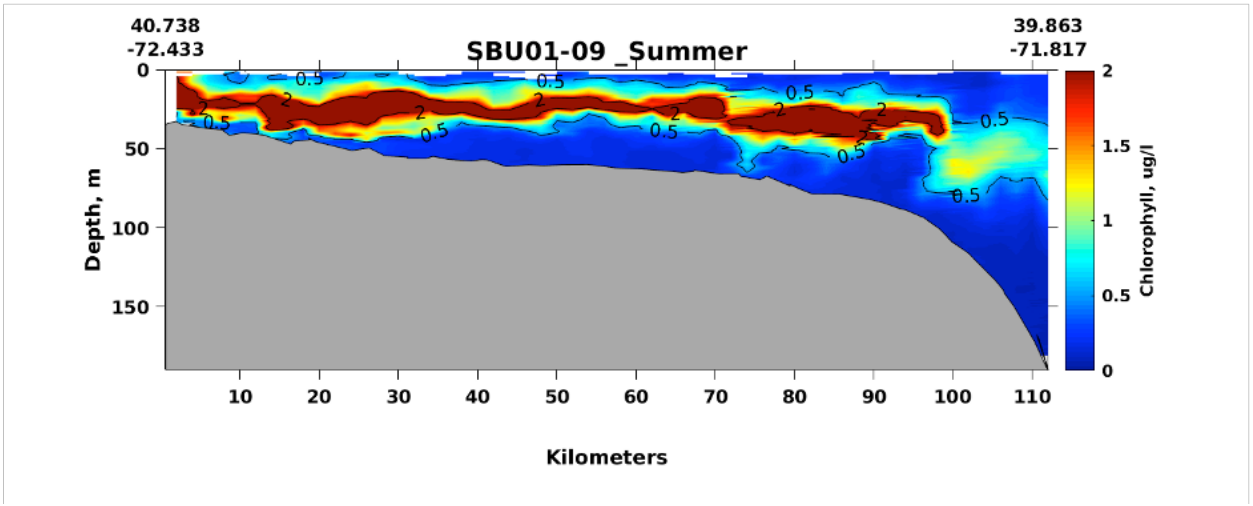

Figure 4. Subsurface chlorophyll during the August 2023 glider deployment. Higher concentrations of chlorophyll, shown in red, are located in the subsurface with a maximum at around 25m depth. The surface ocean shown comparatively low chlorophyll concentration.

Data Sources and Code availability

All code are available at: https://github.com/Nyelab/NYB_Indicators_Calculations

	Indicator	Data Source
1	Sea Surface Temperature	OISST (Huang et al., 2020)
2	Marine Heatwaves	
	a. surface	OISST (Huang et al., 2020)
	b. bottom	GLORYS12 Reanalysis, GLORYS12 physics analysis and forecast (Lellouche et al., 2021)
3	Bottom Temperature	WODB XBT and CTD (Boyer et al., 2018), **Seawolf sampling**
4	Cold Pool	**SBU Glider deployments**, GLORYS12 Reanalysis, GLORYS12 physics analysis and forecast (Lellouche et al., 2021)
5	Bottom Dissolved Oxygen	**Seawolf sampling**
6	Ocean Acidificatiion Risk	**Seawolf Sampling**
7	Mean Wind Speed	Natiional Data Buoy Center (1971)
8	Stratification	WODB CTD (Boyer et al., 2018), **Seawolf sampling**
9	Hudson River Flow	River Gauge (U.S. Geological Survey, 2016), NOAA Tides and Currents (2023)
10	Salinity	WODB XBT and CTD (Boyer et al., 2018), **Seawolf sampling**
11	Global Carbon Dioxide	Keeling et al. (2001) and Macfarling Meure et al. (2006)
12	Location of Surface 20C Isotherm	OISST (Huang et al., 2020)
13	Lobster Thermal Habitat	GLORYS12 Reanalysis, GLORYS12 physics analysis and forecast (Lellouche et al., 2021)
14	Number of Large Storms	Crawford et al. (2020)
15	Surface Chlorophyll	MODIS-Terra Ocean Color (NASA Goddard Space Flight Center, 2014)
16	Calanus finmarchicus	EcoMon Program, **Seawolf Sampling**
17	Centropages typicus	EcoMon Program, **Seawolf Sampling**
18	Small/Large Copepod Ratio	EcoMon Program, **Seawolf Sampling**
19	American Lobster	Bottom Trawl Survey (Northeast Fisheries Science Center, 2023)
20	Jonah Crab	Bottom Trawl Survey (Northeast Fisheries Science Center, 2023)
21	Longfin Squid	Bottom Trawl Survey (Northeast Fisheries Science Center, 2023)
22	Shortfin Squid	Bottom Trawl Survey (Northeast Fisheries Science Center, 2023)
23	Forage Species Biomass	Bottom Trawl Survey (Northeast Fisheries Science Center, 2023)
24	Aggregate Feeding Groups	Bottom Trawl Survey (Northeast Fisheries Science Center, 2023)
25	Total Trawl Biomass	Bottom Trawl Survey (Northeast Fisheries Science Center, 2023)
26	Black Sea Bass	Bottom Trawl Survey (Northeast Fisheries Science Center, 2023)
27	Summer Flounder	Bottom Trawl Survey (Northeast Fisheries Science Center, 2023)
28	Northern to Southern Species Ratio	Bottom Trawl Survey (Northeast Fisheries Science Center, 2023)
29	Benthic to Pelagic Species Ratio	Bottom Trawl Survey (Northeast Fisheries Science Center, 2023)
30	Fish Species Richness	Bottom Trawl Survey (Northeast Fisheries Science Center, 2023)
31	Average Trophic Level of Fish Community	Bottom Trawl Survey (Northeast Fisheries Science Center, 2023)
32	Temperature Preference of Fish Community	Bottom Trawl Survey (Northeast Fisheries Science Center, 2023)
33	Commercial Harvest	NOAA Fisheries Office of Science and Technology, Commercial Landings Query
34	Commercial Landings Value (USD)	NOAA Fisheries Office of Science and Technology, Commercial Landings Query
35	Recreational Harvest	Marine Recreational Information Program
36	Recreational Effort	Marine Recreational Information Program
37	Vessel Density	Port of New York and New Jersey (2023)
38	Human Population of Long Island	U.S. Census Bureau (2023)
39	Sea Level Rise Risk	NOAA Tides and Currents (2023)

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References

Amaya, D. J., Jacox, M. G., Fewings, M. R., Saba, V. S., Stuecker, M. F., Rykaczewski, R. R., Ross, A. C., Stock, C. A., Capotondi, A., Petrik, C. M., Bograd, S. J., Alexander, M. A., Cheng, W., Hermann, A. J., Kearney, K. A., & Powell, B. S. (2023). Marine heatwaves need clear definitions so coastal communities can adapt. *Nature*, 616(7955), 29–32. https://doi.org/10.1038/d41586-023-00924-2

Bossart, G. D. (2011). Marine Mammals as Sentinel Species for Oceans and Human Health. *Veterinary Pathology*, *48*(3), 676–690. https://doi.org/10.1177/0300985810388525

Boyer, T.P., Baranova, O.K., Coleman, C., Garcia, H.E., Grodsky, A., Locarnini, R.A., Mishonov, A.V., Paver, C.R., Reagan, J.R., Seidov, D., Smolyar, I.V., Weathers, K., and Zweng, M.M. (2018) World Ocean Database 2018. A.V. Mishonov, Technical Ed., NOAA Atlas NESDIS 87. https://www.ncei.noaa.gov/sites/default/files/2020-04/wod_intro_0.pdf

Bradford, A. L., Weller, D. W., Punt, A. E., Ivashchenko, Y. V., Burdin, A. M., VanBlaricom, G. R., & Brownell, R. L. (2012). Leaner leviathans: Body condition variation in a critically endangered whale population. *Journal of Mammalogy*, *93*(1), 251–266. https://doi.org/10.1644/11-MAMM-A-091.1

Christiansen, F., Dawson, S., Durban, J., Fearnbach, H., Miller, C., Bejder, L., Uhart, M., Sironi, M., Corkeron, P., Rayment, W., Leunissen, E., Haria, E., Ward, R., Warick, H., Kerr, I., Lynn, M., Pettis, H., & Moore, M. (2020). Population comparison of right whale body condition reveals poor state of the North Atlantic right whale. *Marine Ecology Progress Series*, *640*, 1–16. https://doi.org/10.3354/meps13299

Crawford, A., Barber, D., Dahl-Jensen, D., Stroeve, J. C., Serreze, M. C., Sommer, N. (2020). *Northern Hemisphere Extratropical Cyclone Tracks from ERA-5* [Data set]. CanWIN. https://doi.org/10.34992/ebnw-s681

Ecosystem Monitoring program for the Northeast U.S. continental shelf. Archived by National Aeronautics and Space Administration, U.S. Government, OB.DAAC. https://doi.org/10.5067/SeaBASS/ECOMON/DATA001.

Gawarkiewicz, G., Fratantoni, P., Bahr, F., & Ellertson, A. (2022). Increasing frequency of mid depth Salinity Maximum Intrusions in the Middle Atlantic Bight. *Journal of Geophysical Research: Oceans*, 127, e2021JC018233. https://doi.org/10.1029/2021JC018233

Hazen, E. L., Abrahms, B., Brodie, S., Carroll, G., Jacox, M. G., Savoca, M. S., Scales, K. L., Sydeman, W. J., & Bograd, S. J. (2019). Marine top predators as climate and ecosystem sentinels. *Frontiers in Ecology and the Environment*, *17*(10), 565–574. https://doi.org/10.1002/fee.2125

Hirtle, N. O., Stepanuk, J. E. F., Heywood, E. I., Christiansen, F., & Thorne, L. H. (2022). Integrating 3D models with morphometric measurements to improve volumetric estimates in marine mammals. *Methods in Ecology and Evolution*, *13*(11), 2478–2490.

Huang, B., Liu, C., Banzon, V., Freeman, E., Graham, G., Hankins, B., Smith, T., and Zhang, H.-M. (2020) Improvements of the Daily Optimum Interpolation Sea Surface Temperature (DOISST) Version 2.1. *Journal of Climate* 34:2923-2939. doi: 10.1175/JCLI-D-20-0166.1

IPCC, 2023: Summary for Policymakers. In: *Climate Change 2023: Synthesis Report.*Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, pp. 1-34, doi: 10.59327/IPCC/AR6-9789291691647.001

Jolly, G. M., & Hampton, I. (1990). A Stratified Random Transect Design for Acoustic Surveys of Fish Stocks. *Canadian Journal of Fisheries and Aquatic Sciences*, *47*(7), 1282–1291. https://doi.org/10.1139/f90-147

Keeling, C.D., Piper, S.C., Bacastow, R.B., Wahlen, M., Whorf, T.P., Heimann, M., & Meijer, H.A. (2001). Exchanges of atmospheric CO_2 and $^{13}CO_2$ with the terrestrial biosphere and oceans from 1978 to 2000. I. *Global aspects, SIO Reference Series*, No. 01-06, Scripps Institution of Oceanography, San Diego, 88 pages.

Lemos, L. S., Olsen, A., Smith, A., Burnett, J. D., Chandler, T. E., Larson, S., Hunt, K. E., & Torres, L. G. (2022). Stressed and slim or relaxed and chubby? A simultaneous assessment of gray whale body condition and hormone variability. *Marine Mammal Science*, *38*(2), 801–811. https://doi.org/10.1111/mms.12877

Lellouche, J.-M., Greiner, E., Bourdalle-Badie, R., Garric, G., Melet, A., Drevillon, M., Bricaud, C., Hamon, M., Le Galloudec, O., Regnier, C., Candela, T., Testut, C.-E., Gasparin, F., Ruggiero, G., Benkrian, M., Drillet, Y., & Le Traon, P.-Y. (2021) The Copernicus Global 1/12°Oceanic and Sea Ice GLORYS12 Reanalysis. *Frontiers in Earth Science* 9:698876. doi: 10.3389/feart.2021.698876

Macfarling Meure, C., Etheridge, D., Trudinger, C., Steele, P., Langenfelds, R., van Ommen, T., Smith, A., & Elkins., J. (2006) Law Dome CO2, CH4 and N2O ice core records extended to 2000 years BP. *Geophysical Research Letters* 33:L14810. doi:10.1029/2006GL026152.

Moore, S. E. (2008). Marine mammals as ecosystem sentinels. *Journal of Mammalogy*, *89*(3), 534–540. https://doi.org/10.1644/07-MAMM-S-312R1.1

Napoli, C., Hirtle, N., Stepanuk, S., Christiansen, F., Heywood, E. I., Grove, T., Stoller, A., Dodds, R., Glarou, M., Rasmussen, M., Lonati, F. L., Davies, K. T. A., Videsen, S., Simon, M., Boye, T. K., Zoidis, A., Todd, S. K., & Thorne, L. H. (in review). Drone measurements reveal differences in humpback whale body condition and mass across North Atlantic foraging grounds. *Frontiers in Marine Science*.

NASA Goddard Space Flight Center, Ocean Ecology Laboratory, Ocean Biology Processing Group; (2014): MODIS-Terra Ocean Color Data; NASA Goddard Space Flight Center, Ocean Ecology Laboratory, Ocean Biology Processing Group. http://dx.doi.org/10.5067/TERRA/MODIS_OC.2014.0

NOAA Fisheries Office of Science and Technology, Commercial Landings Query, Available at: www.fisheries.noaa.gov/foss.

NOAA Tides and Currents (2023). New York/New Jersey Harbor PORTS n03020 The Narrows. https://tidesandcurrents.noaa.gov/ports/ports.html?id=n03020&mode=show_all

NOAA Tides and Currents (2023). 8531680 Sandy Hook, NJ. https://tidesandcurrents.noaa.gov/stationhome.html?id=8531680

NOAA Tides and Currents (2023). 8510560 Montauk, NY. https://tidesandcurrents.noaa.gov/stationhome.html?id=8510560

Northeast Fisheries Science Center (2023). Fall and Spring Bottom Trawl Surveys.

https://www.fisheries.noaa.gov

Port of New York and New Jersey (2023). Facts and Figures, Monthly Cargo Volumes. https://www.panynj.gov/port/en/our-port/facts-and-figures.html

Sallenger, A., Doran, K. & Howd, P. Hotspot of accelerated sea-level rise on the Atlantic coast of North America. *Nature Climate Change* 2, 884–888 (2012). https://doi.org/10.1038/nclimate1597

Silver, A., Gangopadhyay, A., Gawarkiewicz, G., Fratantoni, P., & Clark, J. (2023). Increased gulf stream warm core ring formations contributes to an observed increase in salinity maximum intrusions on the Northeast Shelf. *Scientific Reports* 13, 7538. https://doi.org/10.1038/s41598-023-34494-0

Stepanuk, J., Heywood, E., Lopez, J., DiGiovanni Jr, R., & Thorne, L. (2021). Age-specific behavior and habitat use in humpback whales: Implications for vessel strike. *Marine Ecology Progress Series*, *663*, 209–222. https://doi.org/10.3354/meps13638

Thorne, L. H., Heywood, E. I., & Hirtle, N. O. (2022). Rapid restructuring of the odontocete community in an ocean warming hotspot. *Global Change Biology*, *28*(22), 6524–6540. https://doi.org/10.1111/gcb.16382

U.S. Census Bureau. (2023). Annual Population Estimates for New York State and Counties: Beginning 1970. https://data.ny.gov/Government-Finance/Annual-Population-Estimates-for-New-York-State-and/krt9-ym2k

US DOC/NOAA/NWS/NDBC > National Data Buoy Center (1971). Meteorological and oceanographic data collected from the National Data Buoy Center Coastal-Marine Automated Network (C-MAN) and moored (weather) buoys. [Stations 44065, 44025, and 44066]. NOAA National Data Buoy Center. Dataset. https://www.ndbc.noaa.gov/.

U.S. Geological Survey. (2016). National Water Information System data available on the World Wide Web (USGS Water Data for the Nation), https://waterdata.usgs.gov/ny/nwis/rt.

Wang, X. L., Swail, V.R., & Zwiers, F.W. (2006). Climatology and Changes of Extratropical Cyclone Activity: Comparison of ERA-40 with NCEP–NCAR Reanalysis for 1958–2001. *Journal of Climate* 19, 3145–3166. https://doi.org/10.1175/JCLI3781.1.