Ocean health in the Northeast United States from 2005 to 2017

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Abstract

1. People in the Northeast United States have a long history of benefiting from the ocean in many ways, exemplified by the region's important cod and lobster fisheries, coastal tourism and recent expansion of offshore energy. Over the past few decades, the region has become one of the fastest warming spots on the planet, has seen significant growth in coastal populations, and expansion of new sectors into the marine environment, resulting in ecosystem shifts and changes to the supply and distribution of these benefits. With these changes comes a need for measuring ocean health to understand how engagement with the ocean may be affected, and how regional management may need to adapt.

2. To address this need, we tailored the Ocean Health Index framework to the U.S. Northeast region, scoring eight distinct goals for ocean health on a scale of 0 to 100 for 11 sub-regions over 13 years (2005–2017).

3. All goal scores were averaged resulting in an Ocean Health Index score of 83 for the Northeast in 2017. This score fluctuated by 1 point in either direction (82–84) in the previous 12 years.

4. The lowest scoring goals in 2017 also exhibited the highest volatility since 2005, Food Provision (64) and Resource Access Opportunities (71).

5. The region's highest goal scores came from Livelihoods & Economies (99) and Biodiversity (90) and remained stable during the study period.

6. Clean Waters scores had a steady, significant downward trend since 2005, while Resource Access Opportunities and Aquaculture show the largest improvements.

7. This synthesis of over 50 datasets to create annual aggregate scores provides the public, government and non-government agencies with an easily digestible summary of how the region is faring in regards to ocean health. Perhaps even more importantly, this synthesis allows for the tracking of trends over time and the ability to quickly identify and prioritize low-scoring components of ocean health that could benefit from dedicated resources for improvement.
1 | INTRODUCTION

Continued growth of the human population, expansion of ocean uses, and acceleration of climate change all play a role in impacting ocean health at local and global scales. Effective management requires understanding, assessing and planning for these changes while simultaneously protecting ocean resources and allowing for continued access to and use of those resources. Typically, planning efforts bring diverse stakeholders together to identify complementary and conflicting ocean activities and to develop regulatory frameworks and pathways for management of resources and activities. Plan development also allows the setting of social, economic and environmental goals (Fairbanks et al., 2019). Yet, planning processes rarely incorporate monitoring and evaluation mechanisms to track changes after time of implementation (Ferraro & Pattanayak, 2006). Long-term assessments can be used to understand whether a management decision was a success or failure (Sullivan et al., 2018) and guide responsive decision-making for adaptive management (Vugteveen et al., 2015). While plan development is important, tracking changes before, during and after implementation is equally essential for ensuring effective management.

The benefits people derive from ocean systems involve economic, cultural and natural aspects of the ecosystem, and thus assessments of ocean health should integrate social, economic and environmental information. The Ocean Health Index (OHI) was designed to do this, defining a healthy ocean as one that ‘sustainably delivers a range of benefits to people now and in the future’ (Halpern et al., 2012) and drawing on diverse data to holistically assess the status of a range of goals people have for healthy oceans. The framework can be applied at any scale, from local to global, and indeed to date, OHI assessments have been conducted at local (US West Coast—Halpern et al., 2014; British Columbia—O’Hara et al., 2020), national (Elfes et al., 2014; Selig et al., 2015), multi-national (Baltic sea states—Blenckner et al., 2021, Arctic—Burgass et al., 2019) and global scales (Halpern et al., 2012, 2015).

Here we focus on applying the OHI framework to the Northeast region of the United States, where regional coordination around integrating social, economic and environmental information has been occurring in support of ocean planning for over a decade through the Northeast Regional Ocean Council (NROC). NROC, established in 2005, is a state and federal partnership from Maine to Connecticut—one of several Regional Ocean Partnerships in the U.S. that are voluntarily convened by state governors, in collaboration with other governments and stakeholders, to address ocean and coastal issues of common concern. Other regional partners, such as the New England Fishery Management Council and federally recognized tribes, and bordering jurisdictions, such as the State of New York and Provinces of Canada, also participate in NROC ocean planning activities. In 2016, the US Northeast Ocean Plan was completed and established regional priorities for enhancing planning and coordination within existing mandates in ultimate support of the goals of healthy ocean and coastal ecosystems, effective decision-making, and compatibility among ocean uses (Northeast Regional Planning Body, 2016). Examples of priorities identified in the plan include aquaculture, energy and infrastructure, commercial and recreational fishing, marine life and habitat, marine transportation, recreation and cultural resources. In addition to identifying these areas for regional coordination, the plan identified potential monitoring and evaluation tools that could be developed to support and inform decision-making, including this initial OHI assessment.

Recent ecosystem and socio-economic changes in the region make the US Northeast an interesting place to study changes in ocean health. The Gulf of Maine is warming faster than 99% of the global ocean (Pershing et al., 2015), leading to observed changes in the regions iconic lobster fishery as the population shifts northward (Goode et al., 2019; Pinsky et al., 2013). The endangered Northern Right Whale population has gained significant attention in the area due to increased conflicts with humans through ship strikes (Davies & Brillant, 2019). Meanwhile there is expansion in the shellfish (Lapointe et al., 2013; Rickard et al., 2018) and seaweed (Yarish et al., 2017) aquaculture industries, and increasing interest in harnessing offshore wind as an alternative energy source (Firestone et al., 2012; Klain et al., 2017). All of these changes in the US Northeast offer an important opportunity to use OHI to better understand how ocean health has been changing, and plan for how it will continue to change.

Through the regional application of the OHI, we aimed to develop an assessment that helps inform regional planning by addressing the following questions: (a) how has ocean health changed over time in the region? (b) what environmental or management changes may explain those shifts? and (c) where can focused efforts result in significant increases to Ocean Health? In addressing these questions, we hope to inform NROC and other regional decision-makers in their efforts to plan for and manage ocean uses to support and maintain regional ocean health.

8. As managers plan for the future in a changing Northeast marine region, the ability to track annual changes in ocean health and its respective components is key to making decisions that benefit the entire social-ecological system.

KEYWORDS
aquaculture, fisheries, Gulf of Maine, marine conservation, ocean health, ocean planning
2 | METHODS

2.1 | Region

The US Northeast assessment was divided into 11 sub-regions, including seven nearshore and four offshore areas that extend out to the United States Exclusive Economic Zone (Figure 1). Nearshore sub-region boundaries extend from the shoreline out three nautical miles, the boundary between state and federal waters. Massachusetts’ state waters were additionally split into North and South sub-regions at the southern end of Cape Cod, a well-recognized biogeographic break between George’s Bank region and the Gulf of Maine (Wilkinson et al., 2009). Sub-regions within Long Island Sound follow state waters boundaries between Connecticut and New York. The offshore sub-regions represent Ecological Production Units (EPUs), which are large, defined bioregions that correspond with important groundfish stocks in the region and support distinct community structures (Gamble et al., 2016). The National Marine Fisheries Service and Northwest Atlantic Fisheries Office use these EPUs in ecosystem planning (Koen-Alonso et al., 2019). In addition to these 11 sub-regions, the entire region was also assessed separately as a single 12th region.

2.2 | Stakeholder engagement

Discussions with stakeholders in the Northeast were held in partnership with NROC, both alongside other NROC meetings and separate from NROC events. Over 100 people across 50 organizations were engaged throughout the assessment process to inform decision-making around selection of sub-regional boundaries, ocean health goals, models and indicators for those goals, and datasets to include to measure the indicators (Table S1). Participants included staff from Federal and State agencies (e.g. Northeast Fisheries Science Center, Environmental Protection Agency, Massachusetts Office for Coastal Zone Management) tribes (e.g. Wampanoag Tribe of Gay Head-Aquinnah, Mohegan Tribe of Indians of Connecticut), academics, and non-governmental organizations (e.g. Surfrider, Conservation Law Foundation). In addition to stakeholder engagement activities and discussions during and associated with NROC meetings, 12 webinars were held across 2 years as the project progressed to provide updates, present draft results for discussion, and to generally allow as much stakeholder input as possible. Seven webinars held in 2018 focused on drafting the goal models, identifying available datasets, and determining what regional priorities should or should not be included. Five additional webinars held in spring 2019 were used to present draft results to stakeholders and receive feedback on the data used and models implemented. These webinars were informal discussions and made publicly available. Primary data for our study were not collected through this process and therefore we did not require ethical approval for working with human participants.

2.3 | Ocean Health Index model

Ocean Health Index assessments are designed to measure how close or far a region is from meeting targets for ocean-specific benefits. These discrete benefits are categorized as goals within the Ocean Health Index model and are scored for every region on a scale from 0 to 100. All Ocean Health Index assessments follow the same structure, briefly outlined below, and detailed in Halpern et al. (2012).

2.3.1 | Present status

Present status for each goal ($g$) was determined by setting goal-specific reference points ($X_{g,\text{Ref}}$) and then using best available data to compare how near or far from the reference point a region currently is.

$$\text{Present status} = \frac{X_{g,\text{gn}}}{X_{g,\text{Ref}}}.$$
2.3.2 | Likely future status

The likely future status of each goal projects the expected status of the goal 5 years into the future in an effort to account for the sustainable delivery of goal benefits into the future. This is calculated by applying a weighted average between the trend in present status over the past five years (T, ranging from −1 to 1), and the balance between pressures (p) and resilience (r) measures that are specific to each goal. The recent status trend is given a higher weight (two-thirds) as it is assumed to be a stronger predictor of future status.

\[
\text{Likely future status} = (1 + 0.67T + 0.33(r - p)) \times \text{Present status.}
\]

2.3.3 | Goal score

The goal score for each region is a simple average of present status and likely future state.

\[
\text{Goal score} = \frac{\text{Present status} + \text{Likely future status}}{2}.
\]

2.3.4 | Index score

Each region in the Northeast receives an Index score which is equal to the unweighted average of all goal scores assessed for that region.

By working with local partners and consulting key marine planning and management documents, OHI assessments are tailored to incorporate locally meaningful information, data, priorities and perspectives (Lowndes et al., 2015). The process involves first establishing goal definitions to ensure that all benefits and services provided by the ocean and important to the region are being represented, and then identifying and using locally available data to measure the status of these goals on a scale of 0–100. Data used in each goal ideally meet each of the following criteria: (a) be spatially comprehensive of entire region, (b) of high enough resolution to capture variation throughout space, (c) provide multiple years of data and (d) publicly accessible for free. The OHI US Northeast assessment incorporated over 50 unique regional datasets that met the majority of these criteria from a diversity of sources and represent social, economic and ecological metrics.

Some datasets did not meet all of these criteria but were still the best available information for the goal. We qualitatively assessed each data layer across three dimensions that affect the ability to calculate meaningful goal scores (spatial, temporal and fit dimensions). For each dimension we measured how well the extent and resolution of the data match the assessment. Each dataset was scored across all dimensions and given a 0.0 (poor), 0.5 (fair) or 1.0 (good) as applicable (see Supporting Information for full details).

2.4 | Goals & sub-goals

Goals from the global Ocean Health Index were cross-walked with ocean planning priorities highlighted in the Northeast Ocean Plan. Stakeholders in the Northeast identified at least two priorities in the Northeast Ocean Plan that did not fit within the approach and philosophy of the Ocean Health Index to measure attributes of the ocean system either because they do not depend on the health of the ecosystem (National Security) or are not currently occurring (Offshore Sand Resources). For this reason, these Plan priorities were not assessed in the Northeast OHI. A total of eight goals were assessed in the OHI Northeast assessment, four of which contain two sub-goals, one that contains three and three which do not contain sub-goals (Table 1). Sub-goals are generally used to either measure distinct aspects of a goal that contribute unequally to the overall scoring of that goal or communicate components of a goal directly that were not appropriate as stand-alone goals. Sub-goals were scored on a scale from 0 to 100 and are then combined either through an equal or weighted average to get the final goal score. Sub-goals for four goals were equally weighted, but for one goal, Food Provision, were weighted unequally because they contribute differently to the overall goal. Each goal and sub-goal was made up of data layer(s) that are scaled between 0 and 1 before being combined either using a simple mean, geometric mean or weighted mean, depending on how the layers depend on each other (see supplement for more details).

2.5 | Setting reference targets

Reference points, or targets, can be set in one of several possible ways (Samhouri et al., 2012) and ideally are quantitative and linked to policy (e.g. The Rhode Island Coastal Resources Management Council has set a goal of designating at least one dedicated public access point for each mile of shoreline; CRMC, 2016) or the capacity of the natural system to sustainably deliver the goal (e.g. sustainable yield from fisheries). Some common ways targets can be set in the Index are by using regional or temporal reference points (e.g. highest observed coastal trash pollution along the East Coast, salt marsh extent pre-1920s), or growth targets (e.g. annual aquaculture growth of 4%). The resolution and type of data underlies all decisions around reference points and may be a limiting factor in what type of target can be used. For the US Northeast assessment, targets for each goal and sub-goal were guided by established policy, or used approaches developed for previous assessments [e.g. US West Coast (Halpern et al., 2014); British Columbia (O’Hara et al., 2020)] and stakeholder engagement (Table 1).

2.6 | Calculating goal scores

Below are descriptions of how we calculated each goal and sub-goal. For more detailed methods and equations see Supporting Information.

The Biodiversity goal measures the conservation status of all ocean-dependent species and habitats in each region and contains two sub-goals, Species and Habitats. For the species sub-goal we used species risk assessments for 691 species that have been
| Goal                      | Subgoal         | Regions assessed | Reference target(s)                                                                 | Data source(s)                                                                 |
|---------------------------|-----------------|------------------|-------------------------------------------------------------------------------------|--------------------------------------------------------------------------------|
| **Biodiversity**          | Habitats        | All              | • No loss of salt marsh habitats from pre 1920 historical estimates                 | • Northeast Ocean Data Portal (NROC, 2009)                                     |
|                           |                 |                  | • All eelgrass habitats have GOOD water quality condition as established by the EPA | • Environmental Protection Agency’s National Coastal Condition Assessment (US EPA, 2016) |
|                           |                 |                  | • Unvegetated seabed habitats have no disturbance from fishing activity             | • Fishing effects model outputs (NEFMC, 2019)                                   |
|                           | Species         | All              | • All species identified as present in the region are not at risk of extinction and are classified as of Least Concern by IUCN criteria | • Coastal Change Analysis Program (C-CAP) (NOAA, 2016)                          |
| **Clean Waters**          |                 | Nearshore        | • Zero water pollution from pathogens and trash in coastal waters                  | • Beach Advisory and Closing On-line Notification database 2.0 (U.S. Environmental Protection Agency, BEACON 2.0, 2019) |
|                           |                 |                  | • Sediment and water quality levels meet EPA threshold values                      | • International coastal cleanup report (Ocean Conservancy, 2019)                |
|                           |                 |                  |                                                                                   | • Environmental Protection Agency’s National Coastal Condition Assessment (US EPA, 2016) |
| **Food Provision**        | Aquaculture     | Nearshore        | Sustainably farmed seafood production is growing by 4% annually                    | • Put together by hand from available state and agency reports                  |
|                           | Wild-Caught     | All              | All harvested stocks are neither overfished nor underfished but rather fished at maximum sustainable yield | • Seafood Watch sustainability scores                                          |
|                           | Fisheries       |                  |                                                                                   | • NOAA Fisheries Commercial Landings (2019)                                     |
|                           |                 |                  |                                                                                   | • National Marine Fisheries Service stock assessment database (National Marine Fisheries Service, 2018) |
|                           |                 |                  |                                                                                   | • RAM Legacy Stock Assessment Database v4.44 (Ram Legacy Stock Assessment Database, 2018) |
| **Habitat Services**      | Carbon Storage  | Nearshore        | All biogenic habitats that support carbon storage are in good condition            | • Coastal Change Analysis Program (C-CAP) (NOAA, 2016)                          |
|                           | Coastal Protection | Nearshore     | All biogenic habitats that support coastal protection are in good condition         | • Environmental Protection Agency’s National Coastal Condition Assessment (US EPA, 2016) |
|                           |                 |                  |                                                                                   | • Coastal Change Analysis Program (C-CAP) (NOAA, 2016)                          |
|                           |                 |                  |                                                                                   | • Environmental Protection Agency’s National Coastal Condition Assessment (US EPA, 2016) |
| **Livelihoods & Economies** | Economies      | Nearshore        | Annual growth in ocean related sectors’ gross domestic product is at least 3%      | • Ocean Economic Data by Sector & Industry (NOEP, 2018)                         |
|                           | Livelihoods     | Nearshore        | Annual growth for ocean-dependent jobs meets or exceeds national growth & wages grow by 3.5% annually | • Ocean Economic Data by Sector & Industry (NOEP, 2018)                         |
|                           |                 |                  |                                                                                   | • US Quarterly Census of Employment and Wages (BLS, 2016)                        |
| **Resource Access Opportunities** |              | Nearshore        | • The average gas to wage ratio does not increase over time                         | • US Regular gasoline prices (U.S. Energy Information Administration, 2019)      |
|                           |                 |                  | • Each mile of coastline has a public access point                                | • US Quarterly Census of Employment and Wages (BLS, 2016)                        |
|                           |                 |                  | • All fish stocks are sustainably managed (Fish Stock Sustainability Index score = 4) | • Fish Stock Sustainability Index (NOAA Fisheries Stock Sustainability Index, 2019) |
|                           |                 |                  |                                                                                   | • Environmental Sensitivity Index maps (NOAA/ORR, 2017)                         |
| **Sense of Place**        | Fishing Engagement | Nearshore   | Coastal communities have high levels of commercial fishing engagement and recreational fishing reliance | • Fisheries Community Social Vulnerability Index (Jepson & Colburn, 2013)         |
|                           |                 |                  |                                                                                   | • Northeast Ocean Data Portal (NROC, 2009)                                     |

(Continues)
assessed to provide a geographic snapshot of how total marine biodi-

viversity is faring, recognizing that these species are a very small
sample of overall species diversity (Fautin et al., 2010). The target
was to have all species categorized as of Least Concern using the
IUCN Red List criteria. Following previous approaches (Halpern
et al., 2012; O’Hara et al., 2020), we scaled the lower end of the
score to be 0 when 75% of species are extinct, a level comparable to
each of the five documented mass extinctions that would constitute
catastrophic biodiversity loss (Barnosky et al., 2011).

We included the habitat sub-goal as a measure of both ecosys-
tem integrity and a proxy for condition of the broad suite of spe-
cies that have not been mapped and assessed that depend on the
habitats. We assessed the status of three key foundational habitat
groups in the region: salt marsh, eelgrass and unvegetated seabed
habitat. Each of the habitats had different data availability and re-
quired different reference point targets. Salt marsh coverage was
compared to a historical reference point pre-1920s. Eelgrass con-
dition was calculated using EPA water quality sampling data from
within a 10- km radius of known locations of past and present eel-
grass beds as a proxy for health, with a target of ‘good’ status for all
sites. The unvegetated seabed habitat is an aggregate of 18 individ-
ual unvegetated habitats, grouped into a single foundational group
(New England Fishery Management Council, 2019). Unvegetated
seabed habitat condition was calculated from estimates of habitat
disturbance from bottom-tending fishing gears on these habitats,
with a target of no disturbance. These three layers were averaged
to get the Habitats sub-goal score. The final Biodiversity score was
calculated as an equally weighted average of Species and Habitats
sub-goal scores.

The Clean Waters goal measures the amount of pollution that is
present in US Northeast Waters by assessing the status of four dif-
f erent components that significantly contribute to the pollution of
coastal waters: pathogens, trash, water quality and sediment quality.
The proportional amount of a region’s swim season with beaches
closed due to the presence of pathogens was used as a proxy for
pathogen pollution, with a target of no closures. The amount of trash
collected (pounds per person) during a nationwide coastal clean-up
was used as a proxy for coastal and ocean pollution from trash, with
a target of zero pounds per person. The water and sediment quality
indices from the EPA were also included as the final two layers for
Clean Waters. Water quality is a composite indicator that combines
measurements of five components (dissolved inorganic nitrogen,
dissolved inorganic phosphorous, chlorophyll a, water clarity and
dissolved oxygen). Sediment quality is a composite indicator that
measures sediment contaminant concentrations and sediment toxic-
ity (US EPA, 2016). The target for both of these components was to
have all sample sites in a region designated ‘good’ status by the EPA.
The status of this goal is calculated as the geometric mean of the four
data layers included, as described elsewhere (Halpern et al., 2012).

The Food Provision goal measures the amount of sustainable
seafood produced and is comprised of two sub-goals, Wild-Caught
Fisheries and Aquaculture.

The Wild-Caught Fisheries sub-goal uses information on stock
status and landings to measure how well the region is maximizing
catch of sustainable wild caught seafood. Sustainability of a stock is
measured on a 0 to 1 scale using assessments of biomass availability
and, where possible, estimates of fishing effort. The amount of bio-
mass in the water (B) compared to the amount of biomass that can be
harvested at maximum sustainable yield ($B_{MSY}$) provides a metric for
knowing whether a single stock is fully exploited ($0.8 < B/B_{MSY} < 1.2$),
overfished ($B/B_{MSY} < 0.8$) or underfished ($B/B_{MSY} > 1.2$). For each
stock, the $B/B_{MSY}$ value is converted into a 0 to 1 score ($B'$) according
to these three thresholds (see Supporting Information Methods for
more details). Wild caught fisheries harvests must remain below lev-
els that would compromise the resource and its future harvest, but
the amount of seafood harvested should be maximized within the
bounds of sustainability, that is, neither overfished ($B/B_{MSY} < 0.8$)
nor underfished ($B/B_{MSY} > 1.2$) but rather fished close to maximum
sustainable yield ($0.8 < B/B_{MSY} < 1.2$).

An additional metric, $F'$, is calculated for stocks where a fish-
ing mortality rate ($F/F_{MSY}$) is available. This allows scores to reflect
whether management actions have been taken to reduce fishing

| TABLE 1 (Continued) |
|---------------------|
| **Goal**            | **Subgoal**         | **Regions assessed** | **Reference target(s)**                                                                 | **Data source(s)**                                                                 |
| Iconic Species      | Nearshore           | All iconic species have a conservation status of Least Concern | • Sought input from experts in the region to develop this list   |
|                     |                     |                     | • Northeast Ocean Data Portal (NROC, 2009)                                                    |
|                     |                     |                     | • IUCN Red List (IUCN, 2018)                                                                     |
|                     |                     |                     | • NatureServe (2019)                                                                              |
|                     |                     |                     | • USGS Protected Areas Database v2.0 (USGS, 2018)                                                 |
|                     |                     |                     | • USGS Protected Areas Database v2.0 (USGS, 2018)                                                 |
|                     |                     |                     | • Ocean Economic Data by Sector & Industry (NOEP, 2018)                                           |
|                     |                     |                     | • Beach Advisory and Closing On-line Notification database 2.0 (EPA, 2019)                     |
|                     |                     |                     | • Environmental Sensitivity Index maps (NOAA/ORR, 2017)                                           |
|                     |                     |                     | • NatureServe (2019)                                                                              |
|                     |                     |                     | • IUCN Red List (IUCN, 2018)                                                                     |
|                     |                     |                     | • Sea Data查询系统 (Ocean Data Query system)                                                    |
|                     |                     |                     | • NOAA FishWatch (NOAA, 2019)                                                                    |
|                     |                     |                     | • FISHERIES (FISHERIES, 2019)                                                                    |
|                     |                     |                     | • Aquaculture (Aquaculture, 2019)                                                                  |
|                     |                     |                     | • NatureServe (2019)                                                                              |
|                     |                     |                     | • IUCN Red List (IUCN, 2018)                                                                     |
|                     |                     |                     | • NatureServe (2019)                                                                              |
|                     |                     |                     | • IUCN Red List (IUCN, 2018)                                                                     |
|                     |                     |                     | • NatureServe (2019)                                                                              |
|                     |                     |                     | • IUCN Red List (IUCN, 2018)                                                                     |
|                     |                     |                     | • NatureServe (2019)                                                                              |
|                     |                     |                     | • IUCN Red List (IUCN, 2018)                                                                     |
|                     |                     |                     | • NatureServe (2019)                                                                              |
|                     |                     |                     | • IUCN Red List (IUCN, 2018)                                                                     |
|                     |                     |                     | • NatureServe (2019)                                                                              |
|                     |                     |                     | • IUCN Red List (IUCN, 2018)                                                                     |
|                     |                     |                     | • NatureServe (2019)                                                                              |
|                     |                     |                     | • IUCN Red List (IUCN, 2018)                                                                     |

(Continued)
pressure, in particular for stocks that are overfished. As such, if a stock is overfished \( \frac{B}{B_{\text{MSY}}} < 0.8 \) but \( F/F_{\text{MSY}} \) is reduced to account for rebuilding, \( F' \) is set to 1 and the stock can receive the highest score of 1. When both \( B/B_{\text{MSY}} \) and \( F/F_{\text{MSY}} \) are available, the stock score is equal to the product of \( F' \) and \( B' \). If only \( B/B_{\text{MSY}} \) is available, the stock score is equal to \( B' \). The target is to have all stocks receive a score of 1 by being fully exploited.

Spatial landings data for all 53 assessed stocks across 42 species were used to weight the contribution of each stock’s score to the overall sub-goal score. Although only 42 out of the 137 commercially fished species are assessed, this represents more than 90% of total reported landings for each year in the assessment.

The \textit{Aquaculture} sub-goal measures annual production of farmed species (clams, mussels, oysters, scallops, Atlantic salmon and trout) and incorporates sustainability weights, on a scale from 0 (least sustainable) to 1 (most sustainable), derived from Seafood Watch criteria for aquaculture (Monterey Bay Aquarium Seafood Watch Program, 2019). Species-specific annual production (pounds produced) was multiplied by sustainability scores so that a more sustainably grown species (e.g. oysters) would contribute more to total aggregate production than the same annual production of a less sustainable species (e.g. Atlantic salmon). Total annual production across all species was compared to the previous year’s production to calculate annual growth rates. With limited information about regional targets for aquaculture production in the Northeast, a total annual aquaculture production growth rate of 4% was used. This target was informed by historical growth trends across all species throughout the United States. Although the region also houses a few seaweed farms, they are not yet producing at a commercial level, so we did not include them. However, the industry as a whole is expected to grow and we foresee inclusion of many more farms and higher levels of production in the future, in which case seaweed grown for human consumption can and should be incorporated into the Food Provision score. The Food Provision score was calculated using a production weighted average of the Fisheries and Aquaculture sub-goals.

The \textit{Habitat Services} goal is comprised of two sub-goals, \textit{Coastal Protection} and \textit{Carbon Storage}. Coastal protection measures the amount of protection provided by marine and coastal habitats to coastal areas that people value. Healthy habitats can increase protection from storm surge, flooding and sea level rise (Narayan et al., 2017). Carbon storage measured the health or extent of habitats serving as carbon sinks. In the Northeast US, both of these sub-goals include salt marsh and eelgrass habitats. The salt marsh layer was scaled from 0 to 1 for each region using a historical pre-1920s reference point on the spatial extent of the habitat. The eelgrass layer was scaled from 0 to 1 using EPA water quality sampling data from within a 10-km radius of known locations of past and present eelgrass beds as a proxy for eelgrass health, with a target of all sites being designated ‘good’. Salt marsh has been shown to be four times as protective as eelgrass against coastal storm surge (Sharp et al., 2018). This difference was accounted for by weighting the salt marsh layer four times as much as the eelgrass layer for Coastal Protection. Carbon Storage scores were calculated by taking a simple, unweighted average of the eelgrass and salt marsh layers. The two sub-goals were equally weighted to get the Habitat Services goal score.

The \textit{Livelihoods & Economies} goal measures the number and quality of jobs and total Gross Domestic Product (GDP) produced across coastal and ocean industries as separate sub-goals, \textit{Livelihoods} and \textit{Economies}. The livelihoods sub-goal measures growth in jobs and average wages with a target of job growth meeting or exceeding national job growth, and for wages to grow by 3.5% annually, equal to the Nominal Wage Growth Target as set by the Federal Reserve (EPI, 2020). The Economies sub-goal measures GDP growth and has a target of a 3% annual growth rate, in line with a well-recognized target of national growth between 2% and 4% annually (Fautin et al., 2010). The two sub-goals were equally weighted to get the Livelihoods & Economies goal score.

\textbf{Resource Access Opportunities} measures the public’s ability to access coastal and ocean resources through three distinct but related components: economic, physical and natural resource access. Economic access represents the ability for people to access the ocean via a gas powered boat and was measured using the ratio of gas prices to median wages every year. As this ratio increases, access becomes restricted due to increasing costs. The target for economic access is to maintain a constant ratio each year, similar to the US West Coast Ocean Health Index (Halpern et al., 2014), but applied annually rather than compare to a 5-year average. A score of 100 was achieved when there was no change, or a negative change, indicating increased economic access. Thus, the reference point resets each year to the previous year’s ratio. A doubling of the ratio in a year results in a score of 0, as this would quickly and dramatically reduce economic access by half. Physical coastal access is measured by comparing the number of access points per mile to a regionally established target of one point per mile (CRMC, 2016). Natural resource access is the physical availability of a resource for extraction, such as fish. This layer is derived from fish stock sustainability data that combine information from stock assessments to measure stock sustainability on a 0 to 4 scale. We used 4, the highest possible (most sustainable) score, as the target since sustainability indicates the level of physically available biomass is at least 80% of what is needed for maximum sustainable yield \( B_{\text{MSY}} \). Since these three components of access are dependent on each other for complete resource access, a geometric mean was calculated for the final score for Resource Access Opportunities.

The \textit{Sense of Place} goal attempts to measure aspects of the coastal and marine system that people value as part of their cultural identity. This definition includes people living near the ocean and those who live far from it but still derive a sense of identity or value from the ocean ecosystem. While quantifying cultural identity is difficult, it is a critical aspect of the suite of benefits people receive from the ocean (Cheng et al., 2003). We included three sub-goals that represent different aspects of Sense of Place: \textit{Iconic Species}, \textit{Lasting Special Places} and \textit{Fishing Engagement}. Iconic species
measures the conservation status of 29 birds, crustaceans, fish, and mammals identified by stakeholders as iconic to the US Northeast. The target for all iconic species is to have a status of Least Concern. Lasting Special Places measures the amount of protected area within 1 km of the coast inland and 3 km offshore for each region. The total proportion of protected area for land and ocean was compared to the Aichi target of 17% land protection and 10% marine protection (CBD, 2011). The Fishing Engagement sub-goal attempts to measure the importance of fishing to coastal communities. This sub-goal is made up of two layers: commercial fishing engagement and recreational fishing reliance. Coastal communities are scored annually on a scale of 0 to 4 for both of these indicators. Commercial fishing engagement measures the presence of commercial fishing through fishing activity as shown through permits and vessel landings. Recreational fishing reliance measured the presence of recreational fishing in relation to the population of a community (Jepson & Colburn, 2013). Only coastal communities were included and their scores were scaled from 0 to 1 using a spatial reference point of 110% greater than the regional high across the data time series which covers 2009 to 2016. This reference point was chosen under the assumption that there is room to increase fishing engagement for both of these layers. The Sense of Place goal scored highest when marine species valued by the community had a conservation status of least concern, when there were areas identified as special that were protected, and when there was engagement in fishing. These three sub-goals were equally weighted to calculate the final Sense of Place goal score.

The Tourism & Recreation goal aims to capture the number of people visiting coastal and marine areas and attractions and the quality of their experience. Although coastal tourism industries can be important contributors to coastal economies, the Tourism and Recreation goal was assessed separately from its economic benefits, which are reported in the Livelihoods & Economies goal. We included three components for this goal: tourism growth (measured by job growth in the tourism sector), the proportion of the swim season with beach closures, and access points along the coast. Job growth in the tourism sector is used as a proxy measure, one that mirrors tourism participation trends in the region. If tourism jobs grow, we assume that is a direct result of increased participation in tourism. Annual growth was compared to the average of the previous 3 years. Any increase was awarded a score of 100, while a decrease, indicating a decline in tourism, resulted in a lower score, with a 25% loss as the lowest possible score (0). The beach closure layer was calculated in a similar manner as Clean Waters where the layer was scaled from 0 to 1 based on the average proportion of a swim season that a region’s beaches are closed, with a target of no closures. The main difference here is all beach closures were included regardless of reasoning. Coastal access was assessed in the same manner as Resource Access Opportunities with the target of at least one point of access per mile of coastline. These three layers together provide a comprehensive picture of Tourism & Recreation in the US Northeast and thus a geometric mean was applied to the three layers to get the final goal score.

2.7 | Pressures

Anthropogenic stressors to marine ecosystems are represented as pressures within the Ocean Health Index. Alone and cumulatively, pressures can diminish both the quality and magnitude of benefits received from the ocean. In the same manner as other OHI assessments, we quantified and incorporated these pressures and their level of impact and sensitivity on each goal separately. There are six categories of pressures in the assessment: (a) climate change (sea level rise, sea surface temperature, ocean acidification), (b) water pollution (sediment quality, water quality, trash), (c) habitat alteration (trawling, coastal hardening, aquaculture farms, coastal trampling), (d) fishing pressure, (e) aquatic species pollution (aquaculture farm disease spread, aquaculture escapes, pathogens, invasive species) and (f) social pressures. In total there were sixteen pressure layers across these six categories. Each layer was scaled from 0 (no impact) to 1 (highest impact) and assigned an impact sensitivity rank between 1 and 3 specific to each relevant goal. (Tables S1 and S2).

2.8 | Resilience

The resilience dimension measures an ecosystem’s ability to cope with and return to a stable state following acute or chronic pressures and is comprised of three components: ecological integrity, social resilience and regulatory resilience. There are a total of seven resilience layers: one ecological, one societal and five regulatory. Regulatory layers consist of (a) climate change resilience, (b) water pollution resilience, (c) habitat alteration resilience, (d) fishing resilience, (e) aquatic species pollution resilience (Table S4).

Resilience metrics were selected to directly counter pressure metrics outlined above, representing how the human and natural system act to counter the negative impacts caused by stressors. Resilience layers were only included in calculating goal or sub-goal scores when the pressure they counteract is present for that goal or sub-goal. For example, the water pollution pressure pathogen layer only affected the Resource Access Opportunities, Clean Waters, Lasting Special Places and Tourism & Recreation goals, and so the water pollution resilience layer only applied to those goals and sub-goals. Ecological integrity is measured by species’ statuses used in the Biodiversity goal’s Species sub-goal.

Social resilience represents a region’s ability to implement measures safeguarding ocean health. We used data from national assessments aimed at estimating various aspects of societal health. These assessments include measurements of regional opportunities based on health, education, economy and communities, coastal fishing vulnerability and resilience, whether or not states have certain policies in place for sustained economic growth, and if voting for environmentally driven politicians is a priority for regional communities. These four data layers were averaged with an equal weighting for the social resilience layer.

We were able to account for additional aspects of regulatory resilience compared to past OHI assessments by accounting for
three components of regulatory resilience (presence of regulations, enforcement and compliance). This was uniquely possible for this regional assessment because of the breadth and quality of data available in the Northeast region that meet the Index’s requirements. We used 17 different data sources to measure the three components of each of the five regulatory resilience layers (see Supporting Information for details). The components were then averaged resulting in one score for each of the five layers. This new method enabled us to equally weight each of the three components of regulatory resilience, and give a region a higher resilience score if it not only implements policies to combat stressors but also follows through with enforcing and ensuring compliance with those policies.

3 | RESULTS

3.1 | US Northeast overall

The US Northeast region received an Ocean Health Index score of 83 out of 100 for 2017, the most recent year of the assessment (Figure 2). Highest scoring goals were Livelihoods & Economies (99) and Biodiversity (90), and the lowest scoring goals were Food Provision (64) and Resource Access Opportunities (71).

The US Northeast Index score changed very little over time, ranging between 82 and 84 (Figure 2; Table 2). Some goals showed substantial variation in scores over time (Table 2; Figure 3), particularly Food Provision (standard variation, $\sigma = 6.62$) and Resource Access Opportunities (standard variation, $\sigma = 4.59$). The other six goals had a narrower range of scores, varying by no more than 6 points across the time series (range of standard variation, $\sigma = 0.469$–1.8). Linear regression of scores over time (Table 2) showed that three goals had downward trends, Clean Waters (slope = −0.35), Sense of Place (slope = −0.06) and Food Provision (slope = −0.42). The remaining goals had slightly positive increases in scores since 2005, with Habitat Services showing the largest, yet still relatively low, gain (slope = 0.12).

3.2 | Trends by sub-regions

By evaluating annual goal scores over time (Figure 4) and absolute changes from 2005 to 2017 (Figure 5) we can see three general trends across goals and regions; (a) high scoring (75 and above) with low volatility, (b) scores varying widely between regions and maintaining low volatility and (c) goals scoring lower with high volatility. No region ever scored below 35 for any goal.

3.2.1 | High scores, low volatility

The highest scoring goals across most regions were Biodiversity and Livelihoods & Economies, with very little change since 2005. Biodiversity scores maintained a steady or growing trend across all regions with scores spread from 75 (Rhode Island) to 97 (Offshore) and no region saw a decrease in their Biodiversity score since 2005 (Figure 5). Livelihoods & Economies scores were above 80, and often much higher, for nearly the entire time series, with a couple of exceptions (New Hampshire from 2005 to 2008 and Massachusetts-South from 2011 to 2013). Most regions show a dip in scores in 2009, the largest of which is by 13 points in Rhode Island; nearly all recovered by 2010. New Hampshire increased from 55 in 2005 to 99 in 2011 and then remained above 95. This is due to a 25% decrease in GDP in New Hampshire in 2008. Since the underlying layers for Livelihoods & Economies rely on growth comparisons to the previous 3 years, all values from 2005 to 2007 are gap filled from the 2008 score. Southern Massachusetts had a significant drop from 99 in 2009 to 43 in 2011, then back to 99 in 2014. This region experienced a high level of job, wage and GDP loss in the Living Resources (i.e. Fisheries and Aquaculture) sector during this time.

Tourism & Recreation also demonstrated low volatility over time but had a larger spread in regional scores than the previously discussed goals (21 points between the lowest and highest scores). Tourism & Recreation scores were based on growth in tourism jobs, beach closures and coastal access. Every region had increasing jobs in the tourism sector and relatively low proportions of beach closures throughout the 13 years. The primary driver in varied scores for this goal was coastal access. Maine, the lowest scoring region for Tourism & Recreation, has only 39% of their coast with an access point every mile, followed by Massachusetts North (43%) and South (44%). On the other hand, Rhode Island has 90% of its coastline accessible. These regional differences in coastal access, combined with
the fact that the underlying data for access lacks annual resolution, can explain the patterns we see in Tourism & Recreation.

3.2.2 | Varying scores, low volatility

Scores for the Sense of Place and Habitat Resources goals had the largest and most consistent spread across regions across the entire time period (40 points for Habitat Services, and 30 points for Sense of Place). Sense of Place scores ranged widely across regions, with Connecticut at the low end (53 in 2017) and New Hampshire and Massachusetts at the high end (81 and 82, respectively). This goal has three sub-goals, Iconic Species, Lasting Special Places and Fishing Engagement. All sub-goals showed variation, but the largest score spread in sub-goals is from Lasting Special Places (Figure S2). The high scoring regions have all met their targets for Lasting Special Places, meaning they have at least 10% of offshore marine area protected and 17% of coastal area within 1 km of the shore protected. The rest of the regions have Lasting Special Places scores below 70 and Connecticut is much lower at 40, indicating these regions are much further from reaching this target. All three sub-goals showed little change over 13 years. The amount of area protected did not change at all over the 13 years for marine areas, and only increased by 3% at most for inland areas. The conservation status of Iconic Species was also unchanged but the third sub-goal, levels of Fishing Engagement, did show interannual variation across most regions.

The large difference in Habitat Services goal scores between Maine on the upper end (99) and New York on the lower end (59) can be explained by examining the underlying data for each of the marine habitats in these regions. Maine’s habitats are meeting the goal targets with no loss of salt marsh, high water quality near eelgrass beds, and improving seabed habitats under reduced fishing.
3.2.3 | Low scores, high volatility

Food Provision and Resource Access Opportunities scored the lowest and showed the most volatility for each region since 2005. Food Provision scores varied widely, with a general downwards trend (Figure 5), with the exception of Connecticut which maintained a high score from 2008 onwards due to strong growth in aquaculture production (Figure S4). Both George’s Bank and Gulf of Maine scores decreased by more than 20 points from 2005 (75 and 81, respectively) to 2017 (51 and 60). Regions showed high annual volatility in scores for Resource Access Opportunities, with a 13 point increase from 2011 to 2012 for five regions. All regions’ scores increased 4 to 6 points in Resource Access Opportunities since 2005.

4 | DISCUSSION

This retrospective assessment of ocean health in the US Northeast provides a comprehensive view of how ocean health changed over recent time, in turn allowing exploration of what might explain any observed changes and where policy and management efforts could focus to improve ocean health in the region. We found that overall ocean health for the whole US Northeast region has remained high, with few goals showing substantial changes since 2005, the start of our assessment. The trends in goal score volatility reveal what aspects of ocean health we can expect to change quickly, and why, and where we should expect slower responses to either ecosystem or policy changes.

Some shifts in goal scores were primarily driven by changes in the underlying ecosystem. For example, the Gulf of Maine American lobster stock has increased in abundance in recent years (Pinsky et al., 2013). This stock, which made up the majority of tonnage in the Northeast during the latter half of the study period, was most recently assessed in 2015, and 2009 before that (ASMFC, 2009, 2015). Lobster were found to be underfished in 2015, with a B/B_{MSY} of 2.32, but much less so in 2009 (B/B_{MSY} 1.62). Because the target for Wild-Caught Fisheries is to maximize the harvest of sustainable stocks, when stocks are underfished (B/B_{MSY} > 1.2) the score is penalized since more biomass could be taken out of the water sustainably. This unique characteristic of the Wild-Caught fisheries model means that low scores can be a result of either fishing too much, or not fishing enough. This sub-goal tracks changes in stock status and can dramatically increase or decrease when a stock is reassessed and is found to be under- or overfished, or experiencing under- or over-fishing. Since the Wild-Caught Fisheries sub-goal score contributes most to the Food Provision score (82% in 2017), these changes drive Food Provision goal scores.

In other cases, goal score changes reflected impacts from policy. For example, although the Livelihoods & Economies goal showed little change across the 13-year time period for most regions, with scores at or above 90, there were notable exceptions in New Hampshire and Massachusetts-South. The large decline in this goal for Massachusetts-South in 2010 and 2011 can be attributed to a decrease in the number of jobs, median wage and GDP in the living vulnerability (Figure S3). On the other hand, New York has lost 50% of historical salt marsh habitat and experienced high, but decreasing, impacts to seabed habitats from fishing. Water quality sampling in and around Long Island Sound shows low and unchanging water quality, negatively impacting the health of existing eelgrass habitat.
resources and transportation sectors. In 2010, NOAA implemented a catch-share management strategy in the groundfish sector. This led to consolidation of fleets and a decrease in the number of fishers and a more dramatic loss in gross domestic product from southern Massachusetts fishing communities during this period (Brinson & Thunberg, 2013).

In many cases understanding volatility in ocean health goals is more important than trends, as short term changes can drive people’s perceptions of ocean health. Several key results emerged from our analyses on goal volatility. First, some goals are highly sensitive to economic conditions. For example, because our analysis spanned the Great Recession of 2009, both the Livelihoods & Economies and Resource Access Opportunities goals, which are driven in particular by economic variables, showed large dips during this period. Five of the eight regions where Livelihoods & Economies were assessed had a decrease in scores in 2009, increasing the following year. The other three regions (NH, CT and MA-South) maintained small but growing GDP from ocean sectors that year, buffering against a drop in scores until later years. Resource Access Opportunities scores in the region were similarly strongly influenced by changes in economic access, which was also volatile. The fluctuations in economic access are tied to trends in gas prices and median wages, both of which were quite variable over the study period.

Second, some goals showed little volatility because either the underlying system has inherent inertia or because significant lags in data collection or monitoring delay detection of changes.

For example, goals that used species status as an indicator of health (Biodiversity and Sense of Place: Iconic Species sub-goal) relied upon assessment data that are either infrequently gathered or that take years to decades to manifest given the lifespan of many marine species. For goals that measured habitat presence and health (Habitat sub-goal and Habitat Services), results of restoration activities may not be detectable for years or decades, and thus not captured in our 13-year time series, leading to consistent patterns of no change.

4.1 Where is there potential for improving ocean health in the US Northeast?

Although the overall Northeast region score is high, the Index allows us to detect and prioritize goals that need improving. Given the overall low scores for Food Provision and Resource Access Opportunities goals, concerted management efforts aimed at improving these goals have the potential to significantly increase the overall ocean health outlook across regions. Actions could include improving coastal access, especially in Maine and Massachusetts, increasing sustainable aquaculture production, and encouraging continued or increased fishing of under-fished species. Additionally, there is room for improvement for several other goals by better meeting marine protected area targets, restoring eelgrass bed and salt marsh habitats, and improving water quality along the coast.
One of the greatest needs is to refine targets for all aspects of ocean health throughout the region. In this assessment, targets for each goal were developed under the constraints of currently available data. Although appropriate for the region, the targets could be improved by formally bringing together regional experts to evaluate and form targets. By establishing more focused targets, specific goals for ocean health would be better represented in the OHI. We recognize there is inherent difficulty in achieving this task across a large region, such as the US Northeast, which is made up of diverse stakeholders and policy makers from local to federal government levels, but there currently exists a regional planning process that could be leveraged to achieve such a task. Even with agreed-upon targets, if consistent data collection and monitoring are missing, then any progress towards targets will be difficult to measure.

Many of the underlying datasets used in this assessment were of appropriate spatial and temporal resolution to allow a year-to-year picture of ocean health, but not all. Most notably, health and locations of past and present eelgrass beds, coastal access and marine debris pollution are key data gaps for the US Northeast. Rather than removing these layers from the Index, we relied on the best available data to act as proxies. For example, a high resolution assessment of eelgrass condition does not exist for the Northeast. Some locations in the Northeast, such as New Hampshire’s Great Bay National Estuarine Research Reserve, have been monitoring eelgrass health consistently for multiple years. But these data could not appropriately be extrapolated to the entire region. We ultimately chose to use the NCCA’s Water Quality Index (WQI) data as a proxy of eelgrass health since it monitors water clarity and nutrient pollution, both of which are drivers of eelgrass condition (Short & Wyllie-Echeverria, 1996; Waycott et al., 2009). This data layer also required temporal gap filling since it contained multi-year gaps due to the nature of the assessment, which is done every 5 years by the EPA. The fact that it is a proxy dataset that required significant temporal gap filling begs careful consideration of the goals where this data layer is used (Clean Waters, Habitat Services and Habitats Sub-goal). The data quality analysis (Figure 6) can be used to quickly identify goal layers which are of lesser quality.

The inclusion of proxy and gap filled data are necessary steps towards a more complete and immediate understanding of ocean health. Data availability, accuracy and appropriateness is a spectrum and any useful Index should be able to include imperfect data in the absence of perfect data. Utilizing the best data available, while acknowledging the shortcomings of any data product is crucial to making timely and informed management decisions. The results of both the OHI assessment and the data quality analysis can help users understand and evaluate the potential trade-offs when including imperfect data, as well as guide future data collection and monitoring efforts in the Northeast.

When developing an Ocean Health Index assessment, it is important to prioritize datasets that have high geographic and temporal resolution that allow for quick response to changes. When selecting datasets for an assessment, the focus should be on quality over quantity. Each goal needs at least one dataset but if the...
quality of that dataset is low, often times multiple datasets will be combined to develop a comprehensive view of the goal. One of the biggest challenges for indicators is that the best-available science and the underlying data to inform indicators often changes over time. The Ocean Health Index is designed to be flexible and updatable with improved information, such that new data can be incorporated when available and the Index can be expanded to incorporate new ocean uses or priorities into the assessment as they become relevant. In the Northeast, this could include new activities such as offshore wind and offshore aquaculture. Indeed, this repeatability also significantly lowers the bar to repeat assessments even when no changes in underlying science or data have occurred (Lowndes et al., 2017).

Moving forward, the US Northeast Ocean Health Index assessment can be used to not only examine historical changes, but can also be used to evaluate how ocean health might change in the future under different scenarios by simulating changes before actions are taken. For example, on 5 June 2020, the United States federal government announced their intention to remove protection of the Northeast Canyons and Seamounts Marine National Monument (Proclamation No. 9496), an area of nearly 5,000 square miles. If this were to happen, it would reduce the total marine area protected in the Northeast by 5% (22% to 17%). This effect would be seen within the Index by decreasing resilience for several goals and ultimately decreasing goal scores. One might also expect the Lasting Special Places sub-goal status to decline, but because the target is already achieved and exceeded by a lot (target is 10% protection) it would not impact the goal status unless further protections are removed. This further supports the need for explicit, agreed-upon regional targets for goals that people in the Northeast value, such as the protection of Lasting Special Places. Additionally, the opening of this area for commercial fishing could impact Food Provision goal scores in either direction depending on what stocks are fished, and increased fishing activity could potentially negatively impact seabed habitats and marine biodiversity in the region. The impact of this decision can be measured across many different components of the Index. If the US Northeast Ocean Health Index assessment continues in the future, it has substantial potential to support and guide decision-making, and ultimately to help the US Northeast achieve ocean health goals.

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CONFLICT OF INTEREST
The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

AUTHORS’ CONTRIBUTIONS
B.H., C.S. and J.M. conceptualized and designed the study; J.M. and C.S. led and coordinated the data collection and analysis; J.M. and J.V. analysed the data; E.S. and N.N. provided guidance on data collection, analysis and stakeholder engagement. All authors contributed to the writing and editing of the manuscript and approved its submission.

DATA AVAILABILITY STATEMENT
The full US Northeast Ocean Health Index assessment data are archived and publicly available on Zenodo https://zenodo.org/record/4721453 (Montgomery et al., 2021). The results are also displayed on an interactive dashboard: https://ohi-northeast.shinyapps.io/ne-dashboard/.

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**Supporting Information**

Additional supporting information may be found online in the Supporting Information section.

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