Marine Species Distribution

Identification

1. Indicator Description

This indicator examines the changes in the distribution of fish and invertebrate species in North American oceans from 1968 to 2015. Marine animals are sensitive to the physical conditions of their environment, including water temperature. Changes in the temperature of ocean water could result in animals moving to areas of the ocean beyond their historical ranges. This indicator uses data from large fish-sampling surveys to determine the average geographic position (i.e., latitude, longitude, and depth) for the entire population of one or more species. In general, deeper or more northerly waters tend to be colder. Movement of individual species, or groups of species, to these areas may be a natural outcome of fish seeking cooler water. Such shifts have implications for interspecies competition, the economics of fishing, and overall ocean ecosystem health.

Components of this indicator include:

- The annual average change in the latitude and depth of the center of distribution for 105 North American marine species from 1982 to 2015 (Figure 1).
- Year-to-year movement of three selected species in the Northeast from 1968 to 2015 (Figure 2).
- Year-to-year movement of three selected species in the eastern Bering Sea from 1982 to 2015 (Figure 3).

2. Revision History

August 2016: Indicator published.

Data Sources

3. Data Sources

This indicator is based on data from research trawl surveys conducted by the National Oceanic and Atmospheric Administration's (NOAA's) National Marine Fisheries Service (NMFS). Survey results have been processed and managed by the Pinsky Lab of Rutgers University and published in various peer-reviewed studies, including Pinsky et al. (2013) and the U.S. Global Change Research Program's National Climate Assessment (Melillo et al., 2014). Mike Kolian of EPA developed this indicator in collaboration with Roger Griffis of NOAA and Malin Pinsky of Rutgers University.

4. Data Availability

All data for this indicator are available from the OceanAdapt website at: http://oceanadapt.rutgers.edu. This website provides query tools and data descriptions. It is maintained by the Rutgers University

School of Environmental and Biological Sciences. At the time of publication, data were available through 2015 for both survey regions used for this indicator and for all of the species except Alaska pollock. Thus, Figure 3 shows data through 2014 for Alaska pollock, based on an earlier OceanAdapt query.

Methodology

5. Data Collection

This indicator is based on data collected through research trawl surveys that NMFS conducts annually along various parts of the U.S. continental shelf. These bottom trawl surveys involve dragging a large net at a set depth behind a research vessel for a set time and distance. The trawl haul is brought aboard the vessel, where scientists sort the catch by species and record their size and abundance. They may also record additional information such as sex, maturity, and evidence of disease. Species recorded include fish (particularly fish that live near the ocean floor), shellfish, and other invertebrates such as sea stars, anemones, and ascidians (sea squirts).

NMFS conducts systematic trawl surveys on a regular basis to provide information for use in fisheries management. In the Northeast, for example, NMFS conducts 300 half-hour trawl sets at random sites in both spring and fall.

The length of trawl survey records varies by region. Some of the first NOAA survey trawling vessels in the Northeast were in use as early as 1948 (the Albatross III) and 1950 (the Delaware). Regular collection of surveys began in the 1960s in the Northeast, the late 1970s along the West Coast, and the 1980s in coastal Alaska and the Gulf of Mexico.

For more information about NMFS bottom trawl surveys, see: http://oceanadapt.rutgers.edu/blog/bottom-trawl-survey and: www.nefsc.noaa.gov/femad/ecosurvey/mainpage/why_nefsc_surveys.htm. Pinsky et al. (2013) and the references therein describe sampling methods in additional detail.

6. Indicator Derivation

This indicator focuses on the center of biomass for each species, which is the biomass centroid of the population distribution at any point in time. The centroid is a common way to characterize the general location of a population. The centroid for a particular species represents the point (latitude, longitude, and depth) that is in the geographic center of the total “weight” of the entire population of that species. For example, the latitude of a species’ centroid means that half of the total biomass (or weight) of that species was caught north of that latitude, while half was caught south of that latitude. As a result, if a population were to shift generally northward, the biomass centroid would be expected to shift northward as well. Tracking the depth of the centroid is also useful, as it also indicates whether marine species are shifting to deeper and presumably cooler waters.

The analyses presented in this indicator focus on two areas: the Northeast and the eastern Bering Sea. Although data have also been collected from the Southeast, the Gulf of Mexico, the West Coast, and other parts of Alaska, these regions were excluded for one or both of the following reasons:

- Data for several of these areas were too sparse to support meaningful long-term trend analysis. Some of these areas have only been sampled every few years—not annually—or have not had consistent survey methods in use over the course of several decades.

- Some of these regions—for example, the Gulf of Mexico—have coastlines that would prevent marine species from moving northward in response to warming waters. Such physical barriers mean that the data from these regions cannot be used to test the hypothesis that coastal species are moving northward in response to warming water.

Northeast data come from spring surveys, which have historically been more complete than fall surveys. Northeast time series in this indicator start in 1968, which is when spring surveys in the Northeast became systematized. Data from the eastern Bering Sea come from summer surveys that have been conducted consistently since 1982.

Figure 1. Change in Latitude and Depth of Marine Species, 1982–2015

Figure 1 shows the latitude and depth of the average center of biomass for each year, averaged across all 105 Northeast and eastern Bering Sea species that had sufficient data available (i.e., species that were routinely caught in sufficiently large numbers to estimate a centroid). Both metrics are based on an unweighted average of all species. Thus, no adjustments are made for population differences across species. Although Northeast species have survey records from the 1960s onward, Figure 1 begins in 1982, based on eastern Bering Sea data availability. EPA converted northward distance from latitude to miles using a conversion factor of 69 miles per degree. Although the length of a degree of latitude is fairly standard worldwide (unlike longitude, which shrinks as one moves poleward), there are slight differences because the Earth is not a perfect sphere. Many sources, however, use 69 as a reasonable approximation for unit conversion. Both parts of Figure 1 show cumulative change since the first year of data, with the first year shown as zero on the y-axis.

Figures 2 and 3. Average Location of Three Fish and Shellfish Species in the Northeast, 1968–2015, and the Bering Sea, 1982–2015

Figures 2 and 3 show the position of the biomass centroid for three species in each region of interest. Each species was selected for some or all of the following reasons, based on recommendations from NOAA experts:

- These species represent a variety of habitats and taxonomic groups, including two benthic invertebrates (lobster and snow crab).

- These species are thought to be minimally impacted by factors such as overfishing and associated population rebound effect, which may influence their population centers.

- These species are present throughout the region in consistently large numbers across the time period.

- These species have been highlighted in other peer-reviewed studies using survey data that examine distribution shifts.

- Several of these species are important for commercial, sport, and/or subsistence fisheries. For example, Alaska pollock is one of the nation's largest commercial fisheries; Pacific halibut is a large commercial and sport fishery; and American lobster is a large fishery and an iconic part of the culture and cuisine of New England.

The maps in Figures 2 and 3 show the annual position of each species using the latitude and longitude calculations provided by the data source. Individual years are identified by the saturation of the color scale indicated in the legend. Lighter colors represent an earlier point in the time series, whereas darker colors represent later years. The depth component to this indicator is not depicted on either map. The small graphs to the right of each map show each species' northward/southward movement in miles, using the same distance conversion and cumulative position approach as Figure 1.

7. Quality Assurance and Quality Control

NOAA scientists and other experts have performed several statistical analyses to ensure that potential error and variability are adequately addressed. These analyses and results are described in Pinsky et al. (2013). For more information about methods to ensure data quality in NMFS's bottom trawl surveys, see: http://oceanadapt.rutgers.edu/blog/bottom-trawl-survey and: www.nefsc.noaa.gov/femad/ecosurvey/mainpage/why_nefsc_surveys.htm.

Analysis

8. Comparability Over Time and Space

Trawl surveys have been conducted since at least the 1950s in some regions, but the data used in this indicator begin in 1968 for the Northeast and 1982 for the eastern Bering Sea. These start dates ensure comparable data collection over the entire period of study, including sufficient sample sizes and consistent methods, survey design, and frequency. To ensure that the time series in Figure 1 are comparable over time and space, this figure begins in 1982, and it uses a consistent set of 105 widely measured species.

9. Data Limitations

Factors that may impact the confidence, application, or conclusions drawn from this indicator are as follows:

1. Water temperature is not the only factor that can cause marine animal populations to shift. Other factors could include interactions with other species, harvesting, ocean circulation patterns, habitat change, and species' ability to disperse and adapt. As a result, species might have moved northward for reasons other than, or in addition to, changes associated with climate.

2. This indicator does not show how responses to climate change vary among different types or groups of marine species. For example, there are likely to be large differences among species, which have varying abilities to adapt to temperature changes. Some species could have moved significantly in one direction while others moved in the opposite direction or did not have a discernible change.

3. Some data variations are caused by differences between surveys, such as variation in start and end locations of the surveys. Such differences, however, are not expected to unduly influence the results of this analysis.

4. By focusing on the center of biomass for each species, this indicator does not characterize the complete range that each individual species inhabits and how the shape of that range may be changing. For example, northward movement of the centroid for American lobster does not reveal whether the northern range of the lobster is expanding, the southern edge is contracting, both, or neither.

5. The biomass centroid metric relies not only population, but also on the weight of individuals. Thus, if a fish population were to benefit from large feedstocks in one area, but suffer from a lack of food in another, the biomass centroid could shift in the "healthy" direction regardless of a change in population.

6. NMFS follows general boundaries for conducting its surveys. If populations of one or more species were to move outside of the study area, this would affect the location of the biomass centroid in a way that the indicator would not detect accurately.

10. Sources of Uncertainty

The sources of uncertainty in this indicator have been analyzed, quantified, and accounted for to the extent possible. The statistical significance of the trends suggests that the conclusions drawn from this indicator are robust.

One potential source of uncertainty in these data is uneven geographic sampling among surveys. Basic information on analytical methods can be found in Pinsky et al. (2013), including methods that have been used to account for variability in survey collection data.

11. Sources of Variability

Rare or difficult-to-observe marine species could lead to increased variability. Figure 1 addresses this concern by focusing on 105 widely observed species, while Figures 2 and 3 address this concern by focusing on a smaller set of relatively common species.

12. Statistical/Trend Analysis

Pinsky et al. (2013) document the statistical significance of distribution shifts for each species. Using annual data points, EPA applied an ordinary least-squares regression to determine long-term trends in movement for all species in Figure 1 and for each individual species in Figures 2 and 3. Table TD-1 shows the slope and statistical significance of each trend. Northward and downward movement of the combined set of 105 species in Figure 1 was highly significant, as was the northward movement of all three highlighted Northeast species and one of the three highlighted Bering Sea species (Pacific halibut). Regression slopes were multiplied by the length of the period of record to estimate the total movement described in the "Key Points" section of this indicator. EPA used Sen slope analysis to verify the apparent trends; the Sen slope results were nearly identical to the least-squares regression results.

Table TD-1. Linear Regression of Annual Centers of Biomass

Species	Common name	Timeframe	Variable	Slope (per year)	P-value	Significant to a 95% level?
All 105 species		1982–2015	Latitude (miles)	0.294	< 0.001	yes
All 105 species		1982–2015	Depth (feet)	0.602	< 0.001	yes
Homarus americanus	American lobster	1968–2015	Latitude (miles)	2.42	< 0.001	yes
Centropristis striata	Black sea bass	1968–2015	Latitude (miles)	3.09	< 0.001	yes
Urophycis chuss	Red hake	1968–2015	Latitude (miles)	2.07	< 0.001	yes
Theragra chalcogramma	Alaska pollock	1982–2014	Latitude (miles)	0.398	0.14	no
Hippoglossus stenolepis	Pacific halibut	1982–2015	Latitude (miles)	0.615	< 0.001	yes
Chionoecetes opilio	Snow crab	1982–2015	Latitude (miles)	0.307	0.29	no

References

Melillo, J.M., T.C. Richmond, and G.W. Yohe (eds.). 2014. Climate change impacts in the United States: The third National Climate Assessment. U.S. Global Change Research Program. http://nca2014.globalchange.gov.

Pinsky, M.L., B. Worm, M.J. Fogarty, J.L. Sarmiento, and S.A. Levin. 2013. Marine taxa track local climate velocities. Science 341(6151):1239–1242.