Gulf of Maine Research Institute

University of New Hampshire

U.S. National Science Foundation

ICES CIEM #ICESASC2025

Diverged in a warming sea

Intra-annual variation in marine fish distributions within a rapidly warming marine ecosystem

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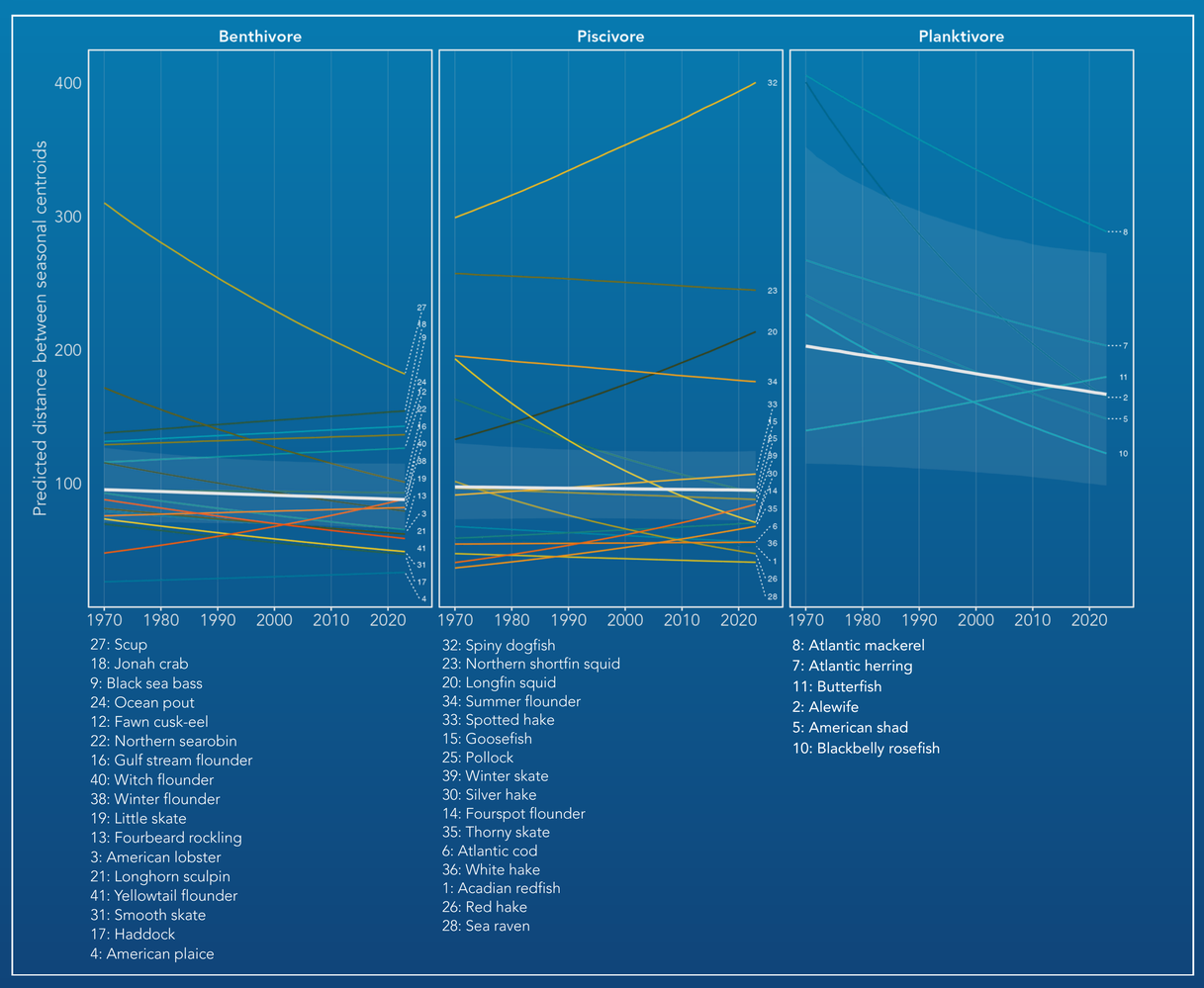
Background

Ocean warming varies not only across regions but also seasonally, driving shifts in species distribution and abundance within the year. These intra-annual shifts affect trophic dynamics, predator–prey connections, seasonal management effectiveness, and resource availability for dependent communities. Analysis of NOAA bottom trawl surveys (1970–2023) revealed patterns of seasonal distribution change across the Northeast U.S. Shelf.

Forage fish (mainly planktivores) showed decreasing distances between spring and fall biomass centers, with spring centers moving northward into the Gulf of Maine.

In contrast, benthivores and piscivores shifted distributions with little net change in seasonal distances, potentially reducing overlap with planktivores and triggering cascading ecological and fishery impacts.

Modeling changes in seasonal distance



To quantify intra-annual changes in seasonal distance and evaluate emergent patterns across guilds, the distance between biomass-weighted spring and fall centroids for 41 commercially relevant species was calculated. These values were modeled across years using a hierarchical Bayesian framework, accounting for survey timing and nesting species within feeding guilds to capture species-specific trends while sharing information across similar species.

The shaded white areas represent the 95% Bayesian credible interval (BCI) around the mean for each guild, while the colored lines represent the predicted values in the distance between the spring and fall centers by species. Species are listed in the order they appear within each group, from the largest initial distance between seasonal centroids to the smallest.

Categorizing seasonal trends

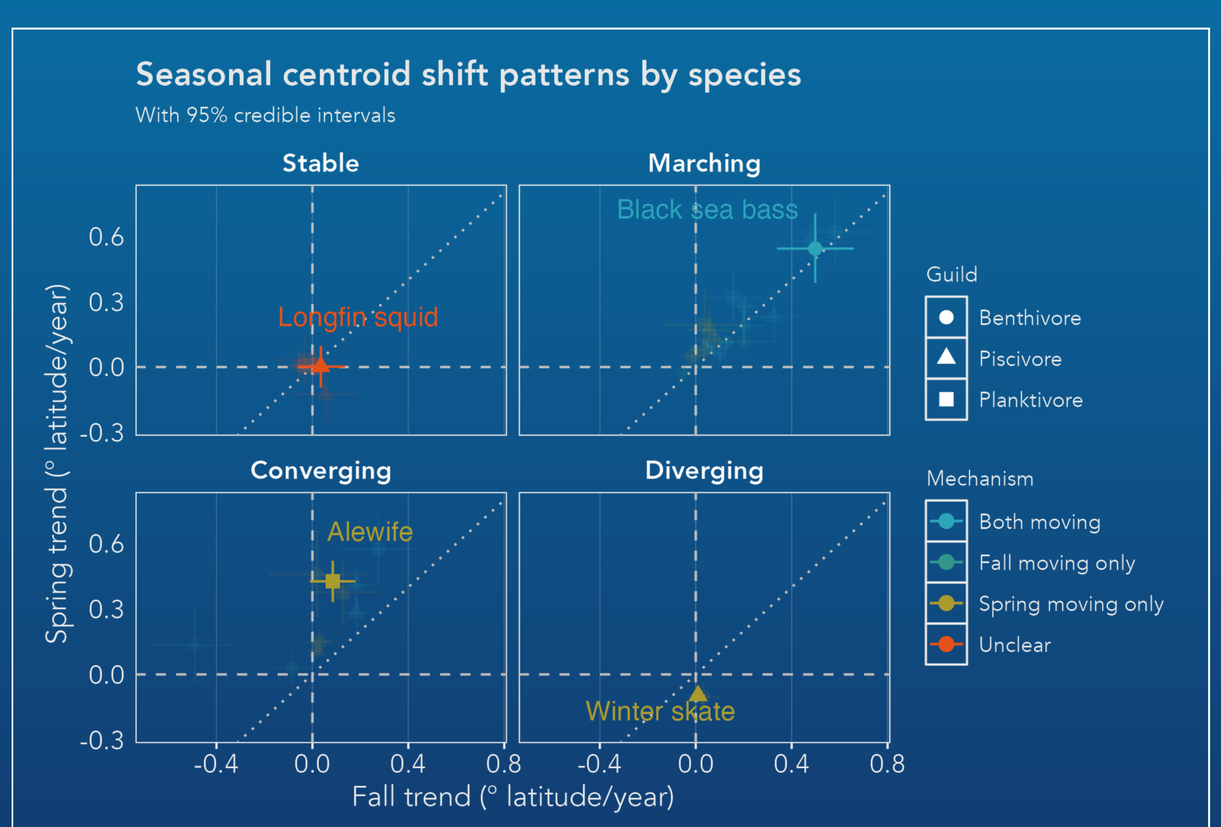
Mechanisms behind observed changes in seasonal distance can vary across species, driven by differing patterns of spring and fall shifts.

To quantify and categorize these relationships, biomass-weighted latitude was modeled as a function of year, season, and their interaction. From the fitted linear regression models, parameter estimates and BCIs were extracted and used as the statistical criteria for defining the movement categories described below:

Category	Definition	Statistical criteria	Interpretation
Stable	No significant trend in either season.	95% Bayesian credible intervals (BCIs) for both spring and fall slopes include zero.	No directional shift; seasonal distributions remain consistent over time.
Marching	Both seasons shift at similar rates.	BCIs for both spring and fall slopes exclude zero; BCI for distance (fall – spring) includes zero.	Parallel seasonal shifts, likely reflecting shared environmental forcing.
Converging	The distance between seasons is narrowing over time.	BCI for distance (fall – spring) excludes zero; estimated distance change is negative.	Spring and fall distributions are becoming more similar, decreasing "seasonality."
Diverging	The distance between seasons is widening over time.	BCI for distance (fall – spring) excludes zero; estimated distance change is *positive*.	Spring and fall distributions are growing more distinct, increasing "seasonality."

Seasonal centroid shift patterns by species

With 95% credible intervals



Each point represents the posterior median shift rate in spring (x-axis) and fall (y-axis) for a particular species. Colors denote the inferred mechanism: unclear shifts, both moving, fall moving only and spring moving only. Species that shift faster in spring than fall appear below the 1:1 line (converging), while those shifting faster in the fall than in the spring appear above (diverging).

Four species have been highlighted as examples of different movement categories, mechanisms of movement, and feeding guilds.

Results and implications

Across the three feeding guilds, planktivores appear to have the strongest negative trend, suggesting that the spring and fall centers of biomass are converging on each other and the mean distance between seasonal centers is decreasing over time. The predicted mean seasonal distance for piscivores and benthivores appears stable, but may mask underlying species-specific trends. By modeling the mechanisms of seasonal distance patterns, seasonal trends and interactions elucidated patterns, or categories, of species distribution change. Benthivorous black sea bass is an example of a species that is *marching,* with both seasonal centers shifting at parallel rates. Conversely, alewife, an anadromous planktivore, is shifting north in the spring at a faster rate than the fall, resulting in a *converging* distribution and decreased seasonal distance.

Any potential mismatch in intra-annual species distribution shifts across species may have significant ecological, socioeconomic, and cultural impacts. Many predatory species rely on key forage species, such as alewife, and may be forced to feed on more abundant but less nutrient-dense prey species or spend more energy to find food. Seasonally managed commercial fisheries may have to adjust harvest windows in order to compensate for temporal shifts in distribution and abundance. And lastly, many anadromous species, like American shad and alewife have become cultural icons for their historic spawning runs. Many river towns host large festivals to celebrate the runs, and with climate change disrupting the distribution, abundance, and timing of these runs, these cultural institutions may be at risk.

Questions? Message me on Whova or email me at **clovas@gmri.org**

National Science Foundation Award No. 20232536

This research has been adapted for use in U.S. schools! To learn more about this predator-prey curriculum and others, visit **teach.gmri.org**