# Atlantic States Marine Fisheries Commission

## Winter Flounder Management Board

*August 4, 2026*
*1:30 p.m. – 2:30 p.m.*

## Draft Agenda

The times listed are approximate; the order in which these items will be taken is subject to change; other items may be added as necessary.

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|---|---|---|
| 1. | Welcome/Call to Order *(N. Lengyel Costa*) | 1:30 p.m. |
| 2. | Board Consent<br>• Approval of Agenda<br>• Approval of Proceedings from February 2026 | 1:30 p.m. |
| 3. | Public Comment | 1:35 p.m. |
| 4. | Update on Board Request for Information on Environmental Impacts to Winter Flounder Population Dynamics (*R. Balouskus*) | 1:45 p.m. |
| 5. | Review New England Fishery Management Council's Groundfish Specification Process (*R. Frede/T. Bauer*) | 1:50 p.m. |
| 6. | Technical Committee Report (*R. Balouskus*) **Possible Action**<br>• Potential Impacts of Increasing Bag Limit in Southern New England/ Mid-Atlantic | 2:05 p.m. |
| 7. | Other Business/Adjourn | 2:30 p.m. |

This meeting will be held at The Westin Crystal City (1800 Richmond Highway, Arlington, VA; 703.486.1111) and via webinar; click here for details

# MEETING OVERVIEW

**Winter Flounder Management Board**
**August 4, 2026**
**1:30 p.m. – 2:30 p.m.**

| | | |
|---|---|---|
| Chair: Nicole Lengyel Costa (RI) | Technical Committee Chair: Rich Balouskus (RI) | LEC Representative: Keith Williams |
| Vice Chair: Vacant | Advisory Panel Chair: Bud Brown | Previous Board Meeting: February 3, 2026 |
| Voting Members: ME, NH, MA, RI, CT, NY, NJ, NMFS, USFWS (9 votes) | | |

2. **Board Consent**
   - Approval of Agenda
   - Approval of Proceedings from February 2026

3. **Public Comment –** At the beginning of the meeting public comment will be taken on items not on the agenda. Individuals that wish to speak at this time should use the webinar raise your hand function and the Board Chair will let you know when to speak. For agenda items that have already gone out for public hearing and/or have had a public comment period that has closed, the Board Chair may determine that additional public comment will not provide additional information. In this circumstance, the Board Chair will not allow additional public comment on an issue. For agenda items that the public has not had a chance to provide input, the Board Chair may allow limited opportunity for comment. The Board Chair has the discretion to limit the number of speakers and/or the length of each comment.

**4. Update on Board Request for Information on Environmental Impacts to Winter Flounder Population Dynamics (1:45 – 1:50 p.m.)**

- At their February 2026 meeting, the Board expressed interest in receiving additional information in the future regarding: 1) information on research of environmental drivers that are hypothesized to limit stock rebound and 2) utilization of catch limits in federal waters.
- The TC has prepared a memo which provides an update on these two requests (**Briefing Materials**).

**Presentations**

- Technical Committee update on Board requests by R. Balouskus, Chair

**5. Review New England Fishery Management Council's Groundfish Specification Process (1:50 – 2:05 p.m.)**

- At their February 2026 meeting, the Winter Flounder Management Board requested a staff memo explaining the current specification process for winter flounder.
- Commission and Council staff have prepared a memo which addresses this request, detailing the New England Fishery Management Council's (Council's) specification process (**Supplemental Materials**).

**Presentations**

- Summary of the New England Fishery Management Council's Groundfish Specification Process by R. Frede and T. Bauer

| 6. Technical Committee Report (2:05 – 2:30 p.m.) Possible Action |
|---|
| • At the February 3, 2026 meeting, the Winter Flounder Management Board (Board) tasked the Winter Flounder Technical Committee (TC) with analyzing available data to assess the potential for increasing the daily bag limit in the recreational Southern New England/Mid-Atlantic (SNE/MA) winter flounder fishery.<br>• The TC met via webinar on March 17, May 15, and June 16, 2026 to review and provide input on the Board requests. To address the Board task, the TC 1) discussed potential stock implications and 2) analyzed available Marine Recreational Information Program (MRIP) data, both of which are described in their report (**Briefing Materials**). |
| **Presentations**<br>• Technical Committee Report by R. Balouskus, Chair |
| **Board Actions for Consideration**<br>• Consider Technical Committee Recommendations |

**7. Other Business/Adjourn**

# DRAFT PROCEEDINGS OF THE

# ATLANTIC STATES MARINE FISHERIES COMMISSION

# WINTER FLOUNDER MANAGEMENT BOARD

**The Westin Crystal City**
**Arlington, Virginia**
**Hybrid Meeting**

**February 3, 2026**

These minutes are draft and subject to approval by the Winter Flounder Management Board.
The Board will review the minutes during its next meeting.

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**INDEX OF MOTIONS**

1. **Approval of agenda** by consent (Page 1).

2. **Approval of Proceedings of February 2025** by consent (Page 1).

3. **Move to approve status quo commercial and recreational Southern New England/Mid-Atlantic and Gulf of Maine winter flounder measures for the 2026-2028 fishing years** (Page 11). Motion by Eric Reid; second by Ray Kane. Motion passes by unanimous consent (Page 12).

4. **Move to approve Winter Flounder FMP Review for the 2024 fishing year, state compliance reports, and de minimis status for New Jersey's commercial fishery** (Page 12). Motion by Doug Grout; second by Ray Kane. Motion passes by unanimous consent (Page 12).

5. **Move to elect Nicole Lengyel Costa as Vice Chair of the Winter Flounder Management Board** (Page 13). Motion by Matt Gates; second by Dan McKiernan. Motion passes by unanimous consent (Page 13).

6. **Move to adjourn** by consent (Page 13).

**ATTENDANCE**

**Board Members**

Nichola Meserve, MA, proxy for D. McKiernan (AA)
Sarah Ferrara, MA, proxy for Rep. Peake (LA)
Jason McNamee (AA)
Eric Reid, RI, proxy for Sen. Sosnowski (LA)
Bill Hyatt, CT (GA)
Craig Miner, CT proxy for Rep. Gresko, CT (LA)
Jim Gilmore, NY, proxy for M. Gary (AA)
Emerson Hasbrouck, NY (GA)
Heather Corbett, NJ, proxy for J. Cimino (AA)
Jeff Kaelin, NJ (GA)
John Clark, DE (AA)
Roy Miller, DE (GA)
Craig Pugh, DE, proxy for Rep. Carson (LA)
Michael Luisi, MD, proxy for L. Fegley (AA)
Lewis Gillingham, VA, proxy for J. Green (AA)
Chris Batsavage, NC, proxy for K. Rawls (AA)
Jerry Mannen, NC (GA)
Chad Thomas, NC, proxy for Rep. Wray (LA)
Malcolm Rhodes, SC (GA)
Ben Dyar, SC, proxy for Sen. Cromer (LA)
Spud Woodward, GA (GA)
Erika Burgess, FL, proxy for J. McCawley (AA)
Karyl Brewster-Geisz, NMFS

**(AA = Administrative Appointee; GA = Governor Appointee; LA = Legislative Appointee)**

**Ex-Officio Members**

Corinne Truesdale, Technical Committee Chair
Tracy Pugh, Technical Committee Chair
Rob Beal, Law Enforcement Committee Rep.

**Staff**

Bob Beal
Toni Kerns
Tina Berger
Madeline Musante
Caitlin Starks
Jeff Kipp
Tracy Bauer
James Boyle
Katie Drew
Jainita Patel
Chelsea Tuohy

These minutes are draft and subject to approval by the Winter Flounder Management Board.
The Board will review the minutes during its next meeting.

The Winter Flounder Management Board of the Atlantic States Marine Fisheries Commission convened in the Jefferson Ballroom of the Westin Crystal City Hotel, Arlington, Virginia, via hybrid meeting, in-person and webinar; Tuesday, February 3, 2026, and was called to order at 11:15 a.m. by Chair Bill Hyatt.

**Call to Order**

CHAIR WILLIAM HYATT: Good morning, everybody. This meeting of the Winter Flounder Management Board is called to order. My name is Bill Hyatt; I am the Governor's Appointee from Connecticut and the current Chair of this Board.

**Approval of Agenda**

Everyone has had a chance to review the agenda. Are there any changes? Seeing none; the **agenda is approved** by consent.

**Approval of Proceedings**

Regarding the **proceedings** from January, 2023. On Page four and continuing through Page six is a long presentation that was attributed to me. I did not give that presentation, it was done by Tony Wood. Are there any other corrections needed to the proceedings? Seeing none; the **proceedings as corrected are approved** by consent. Next is Toni.

MS. TONI KERNS: I just want to let everyone know who is online for the Board today, and maybe I'll do a little bit better for this Board meeting than I did last time. I have Steve Train from Maine, I have Representative Gesko from Connecticut, Adam Nowalsky and Heather Corbett from New Jersey, Emerson Hasbrouck from New York, and I think that's everybody. I apologize if I left anybody off.

**Public Comment**

CHAIR HYATT: Thank you, Toni. Next is Public Comment. Is there anybody in the room who wants to comment on anything that is not on the agenda today? Seeing none; anybody online? Okay, no public comment so that brings us to Review of the 2025 Management Track Assessments for Gulf of Maine and Southern New England/Mid-Atlantic Stocks of Winter Flounder. For this we have presentations by Paul Nitschke and Tony Wood. We'll take questions after each of the presentations. Paul, are you ready?

**Review 2025 Management Track Assessments for Gulf of Maine and Southern New England/Mid-Atlantic Stocks of Winter Flounder**

MR. PAUL NITSCHKE: Good morning, my name is Paul Nitschke, from the Population Dynamics Branch. I will be giving a quick overview of the 2025 Management Track Assessment for the Gulf of Maine winter flounder. This was a Level 1 Assessment, so that's a direct delivery to the SSC.

The last assessment was done in 2022. This assessment is based on the 30 + centimeter survey-area swept. This is an empirical approach, so it is a fairly simple assessment model. The Gulf of Maine stock was historically thought of as the smallest of the three winter flounder stocks. That perhaps has changed with the declines in the Southern New England stock. The catch for the Gulf of Maine stock mostly comes out of Statistical Area 514; Cape Cod Bay, Massachusetts Bay, Stellwagen Bank are important areas for the removals of this stock. Here is the removal time series for the Gulf of Maine stock.

In the early 1980s the recreational component was a significant chunk of the removals. However, that declined fairly quickly into the 1990s. The commercial removals declined more gradual. More recently, the catch is around a few hundred metric tons. However, early on the removals were a few thousand metric tons.

There has been a large change in the catch over the time series. However, that change in the time series doesn't really seem to correspond to response in the surveys. When we look at the surveys, the indices remain relatively flat for the entire time series. Perhaps you could argue the Mass DMF Spring survey has a little bit of a decline, but in general the turns are fairly flat.

In addition, when we look at the size and age structure, there is also not really a big change in the size in age over time. This produced a real conflict when we tried to do the analytical models back at SARC 52. It resulted in a massive retrospective problem in the model, to the point where it wasn't accepted. It didn't get passed through peer review.

Then after that, basically the 30 + area swept estimate was developed as the empirical approach for this stock. This biomass estimate comes directly from survey information. We use three different surveys, because you don't have a single survey that covers the entire stock. We used these three surveys that use Strata sets that don't overlap to cover the stock.

We used the Northeast Fisheries Science Center Bottom Trawl Surveys for the offshore Strata, and some of the inshore Strata in Mass Bay and Cape Cod Bay. We used the Mass DMF Survey for the real shallow Strata in Cape Cod Bay and Mass Bay, and we used the Maine/New Hampshire Survey north of Massachusetts inshore.

We did develop overfishing definitions using a length-based Yield per Recruit Model with this same 30+ centimeter knife edge selectivity. This was a crude proxy for the selectivity so that we could estimate exploitable biomass. Exploitable biomass can then be calculated based on the 30+ centimeter biomass index per tow from each survey, multiplied by this expansion factor, which is the total survey area divided by the tow footprint times q.

Q, you can think of q as the efficiency of the gear between the wingspread. Q, the estimate of exploitable biomass is very sensitive to this assumption of Q. These expansions tend to be very large, because of that huge expansion factor for the entire area. Once you have that estimate you can estimate the exploitation rate, which is simply the catch over the 30+ centimeter biomass estimate.

You can compare that exploitation rate to the overfishing definition from the length-based yield per recruit. This table just shows how large these expansion factors really are. When you look at that total area divided by the footprint from each survey it results in very large multiplying those estimates out. There was an experiment done using a twin trawl, to get at this efficiency estimate. This experiment compared catch rates from the Bigelow here versus a flat vet, which is more efficient for flat fish. Tim Miller and others have developed this relative catch efficiency estimate, taken into account biomass effects and also size effects. Here you can see that beyond 30+ centimeters there isn't really a big size effect. However, there is a big day/night effect.

During the night there really isn't a big difference in efficiency between the two gears, but during the day you can see there is a pretty big difference. With this we can calculate a q for each survey in each year. We basically have been taking the average of all that information and using that for the assumption of the q to estimate the 30+ centimeter biomass.

Now with time we're adding more information to this average and those numbers are starting to, they are not changing as much with more information and you can see this updated estimate didn't change very much from the last assessment. The spring estimate was a 0.71 and the fall estimate was a 0.79.

Here is a plot of basically the results of the 30+ centimeter biomass estimate. On top is the spring survey and on bottom is the fall survey. You can see in the spring that there is a greater proportion of the population in the state surveys. This makes sense, because in the spring the fish are spawning. They tend to move inshore.

It's also perhaps some concerns that we're missing fish in the spring, because there could be fish inside the estuaries that are not covered by the survey. That is one reason we rely more on the fall survey estimates. The other reason is, we do have efficiency experiments with the Bigelow gear, and with a greater chunk of the population being in the offshore survey, we perhaps have a little more confidence in the fall estimates.

Regardless of that, if you look at the estimates between the spring and the fall it produced pretty similar results in total. Here is the plot of the total 30+ biomass estimates over time on top and on the bottom is the exploitation rates. More recently there has been some positive increases in that 30+ biomass estimate, which seems to correspond to the decline in the exploitation rate.

Hopefully there is perhaps some sort of response now under these low exploitation rates, with some positive effects on the biomass. Hopefully the exploitation rates remain low and this is true that these trends will continue in the future. However, I wanted to stress there is still some uncertainty and the dynamics are still hard to explain with this method.

If you look at the time series you see this decline that occurred, which is hard to explain, because under these estimates we're thinking that the exploitation rate is far below the overfishing definition. This is not what we would expect if that were true. But perhaps because the catch continues to go down, the exploitation rates continue to be low.

Maybe there is now a positive response to that. For the stock status the overfished status is unknown, because there is no way of determining that from this method. Overfishing is not occurring. The stock is not in a rebuilding plan, and actually was never declared overfished. The ABCs were calculated using the 75% of the exploitation rate at 40%, multiplied by the 30+ centimeter biomass index from the fall surveys. We use the average of the most recent fall surveys in this estimate. At the last assessment we actually did use some of the spring information, because we were missing information from COVID at that time. In this assessment we went back to using the fall information, since that information is available again. This is the PDT Test Performance Plot that we put together.

Just looking at the OFLs and ABCs over the time series compared to the catch. The updated ABCs and OFLs are very similar to what we had in the last three years. There is hardly any change between the OFLs and ABCs. Maybe a very slight decline, but pretty close to what we had before, so it isn't a big change. I can take any questions if there are any.

CHAIR HYATT: Thank you, Paul. Any questions for Paul regarding the Gulf of Maine assessment? Seeing no questions in the room, any questions from the public? Okay, Eric and then David.

MR. ERIC REID: I'm curious why you don't use NEAMAP Survey data. They are fishing in much shallower water than the Bigelow can get to, and at times that is where those flounders are. That's my question, thank you.

MR. NITCHKE: This assessment is just for the Gulf of Maine and NEAMAP doesn't go into the Gulf of Maine.

CHAIR HYATT: Dave. Okay. Any other questions from the Board? Anything online or from the public? Okay, Tony, why don't you take it away with the Southern New England/Mid-Atlantic stock.

MR. TONY WOOD: This should be a pretty quick summary of the most recent Level 1 assessment or Southern New England winter flounder. This stock was last assessed in 2022. AT that time it was a Level 3. The model has stayed consistent with that last update; it still uses ASAP. Reference points at the time indicated the stock was not overfished, overfishing was not occurring.

It's important to note that during this 2022 assessment we made a pretty big change to the recruitment standard that's used in the projections and reference point calculation. Essentially, we move the goal posts and became not overfished, overfishing not occurring. But our perception of the stock really hasn't changed for quite a while.

For fishery dependent data going into the assessment, commercial landings and discards comes from our old AA Table process and switches to our new Catch Account and Monitoring System. Then recreational information, both landings and discards come from MRIP. Commercial landings in recent years have been very low, the lowest in the time series, lower than even the moratorium years in the late 2000s.

Updated landings were 76 metric tons in 2024, and the lowest in the time series in 2023 at 35 metric tons. Commercial discards have stayed pretty consistent for the past decade or so, but well below the time series average. In 2024 commercial discards were 89 metric tons; 60% of those are from trawl and 40% is scallop dredge. Recreational landings have basically collapsed for this stock. In 2024 recreational landings were 1.9 metric tons, a very slight fraction of the average over the time series, and collapsed when compared to the very early values in the time series. The recreational discards saw a similar trend. In 2024 recreational discards were 1.8 metric tons, well below the time series average of 145 metric tons.

Total catch in 2024 was 169 metric tons. In 2023 and 2024 the total catch was less than 1% of the peak catch in the time series, which we see early on. Catch has declined pretty drastically for this stock. These are just the catch components out of the proportion of percent low. Moving on to the fishery independent information.

We have 11 age indices and then 2 young of the year survey indices. The regional survey indices, which are the Science Center Survey and NEAMAP Spring Survey shows pretty consistent trends with the total catch, starting at a peak, a bit of a bump in the middle of the time series, then a slow decline since then.

For all the state survey indices that go into this stock, pretty general declining trend over time, pretty consistent trend between each of the surveys. Finally, for the two Young of the Year Survey indices, kind of contrast one another. Connecticut shows this decline, from a peak in the late nineties and then the Mass Young of the Year Survey seems to be pretty flat over time.

Then the biological information going into the stock was derived in the benchmark in 2011. These values are retained and have been retained since that time, and were for this assessment update. Getting into the results, 2024 biomass estimates, total biomass at about 4700 metric tons with a spawning stock biomass around 2800 metric tons. F is very low, 0.048

Recruitment has been slowly picking up for the past 7 or so years, 2024 recruitment was 6.2 million fish, still well below the time series average. Recruitment has remained pretty flat since about 2008. Retrospective bias in SSB and F is pretty small for this stock. Retrospective bias in recruitment seems to be increasing. But overall, it's considered a minor retrospective pattern and no adjustments are made.

For reference points we use SPR 40% to calculate F40% as a proxy for Fmsy. That 40% declined a bit since 2022. I believe at that time it was 0.26, now we're at 0.23. We project forward a hundred years at this Fmsy proxy to get our SSBmsy reference point. For this assessment update that was at 3100 metric tons.

Here's just a list of the reference points, and the recurring quantities coming out of the model. F is currently at 21% of the threshold, with SSB at 89% of the target and 179% of the threshold. Our stock status is unchanged, it's not overfished, overfishing is not occurring, and again there is no retrospective adjustment made for this stock. That's all I have.

CHAIR HYATT: Thank you, Tony. You did a good job with some rather discouraging information. Are there any questions for Tony? Seeing none; any questions online or from the public? No questions. Thank you, Tony. At this point we'll move into setting the 2026-2028 specifications. Tracey is going to do an overview, then we'll have a review of the Technical Committee recommendations by Richard Balouskus, and review the Advisory Panel Report, which you're going to do, right, Tracey? Okay.

**Set 2026-2028 Specifications**

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MS. TRACEY BAUER: In this presentation I'm going to briefly review the New England Fishery

Management Council Winter Flounder Specifications for fishing year 2026 through 2030. Then I'll give you guys a reminder of the Addendum III specifications process for winter flounder, and then we'll go through the Technical Committee Recommendations, the Advisory Panel Report and then just keep in mind the Board action for this addendum item is to consider setting specifications for fishing year 2026 through 2028.

Starting off with the New England Fishery Management Council specifications for the Gulf of Maine and the Southern New England/Mid Atlantic spawning stocks. Here on the slide, I have it for the current fishing year 2025 to compare to the upcoming years that they set it for, fishing year 2026 through 2030.

The New England Fishery Management Council and NOAA decided to put specifications for the next five years on the books, because there is a possibility that management track assessments will not be able to be conducted as frequently as in years past due to lack of things like staff, time, money; factors such as those.

However, changes can be made in the meantime to these specifications if there is updated information. The sub annual catch limits, ACLs for the fishing years 2026 through 2030 for both stocks have not drastically changed from the recent fishing year. The Gulf of Maine sub-ACL was adjusted up by a few percentage points and it has held constant over the five years.

Then the Southern New England/Mid-Atlantic sub-ACL was adjusted down by about 14%, again, reflecting the results of the 2025 Management Track Stock Assessment you guys just heard about. As part of the specifications the Council also sets the state sub component for the next five years. As a reminder, the state sub component is comprised of both the recreational and commercial catch.

The commercial portion of the state sub component is caught by vessels that do not hold federal multispecies permits and the sub component is an estimate of what the state fisheries will harvest in each year. It is an estimate not an allocation, so there is no accountability measures associated with the state waters sub component, meaning there is no payback if the state water sub component is exceeded.

Moving into what the New England Fishery Management Council set for the state sub component, or estimated for the state sub component. They were both adjusted to reflect the average catch for the years 2022 through 2024. This means for the Gulf of Maine state sub components, there was a 7% decrease from fishing year 2025, and for the Southern New England/Mid-Atlantic state sub component this is just a 2% increase from fishing year 2025.

As a reminder, Addendum III, which was approved back in 2013, revised the state specifications setting process so that recreational and commercial measures could be set for up to three years to better align with the federal specifications process, at that time at least. Commercial measures that are subject to change are trip limits, trigger trip limits, size limits, season and area closures. Then the recreational measures that are subject to change are the size limits, bag limits and season. You'll notice that there is sort of a discrepancy between what the New England Fishery Management Council has set specifications for five years, whereas we can only set specifications for only three years at a time.

We'll just come back in three years and set those, unless there is new information available. Here on the slide, which we can refer back to. However, whenever we need to this is the current commercial winter flounder regulations for both the Gulf of Maine and Southern New England/Mid-Atlantic, and these management measures have not changed since 2014.

In the next slide we have the respective recreational winter flounder regulations, which again have not changed in a while. Again, we can refer back to those if needed. I will hand it over to the Winter Flounder TC Chair, Rich, to cover the summary of our TC call.

**Review Technical Committee Recommendations**

MR. RICHARD BALOUSKUS: Thank you, Tracey. My name is Rich Balouskus, I'm a biologist with the state of Rhode Island and the Chair of the TC. The TC met by webinar on January 6 of this year. As I think Tony put it so well, the 2025 Management Track Stock Assessment really didn't change up the managers perceptions of the two stocks that ASMFC manages.

As a result of that and some further discussion, no changes are recommended to commercial and recreational measures for either Gulf of Maine or the Southern New England/Mid-Atlantic stocks for '26 through '28. As per each stock we had discussions for each. In the Gulf of Maine, the Technical Committee discussed at length Massachusetts conservation equivalency program that was implemented in 2024 and approved by the Winter Flounder Board. This program permitted fishermen to keep back-to-back commercial limits across two days.

Basically, discussion was limited, as only a partial year of data was available to look at. But through what we were able to see in some discussion, the TC is fine-tuning the reporting requirements for Massachusetts, so that we can better understand both this program and how commercial harvesters are using that full 500-pound daily limit on targeted trips. As far as Southern New England/Mid-Atlantic, the commercial and recreational catch remain very low, you know steady low across more than a decade at least.

Maybe that last part is a little strongly worded, but the TC has not received any specific requests or commentary from the Board looking to make specific changes to management measures for the past period of time. Last time the TC met the discussion really strongly revolved around keeping both commercial and recreational specs at status quo, until the planned Research Track Stock Assessment was released.

We really had a strong hope that the inclusion of environmental and climate data into a new research track stock assessment model was going to help to, I guess, provide more insight into both the current state of the stocks and really help inform those projections by the Science Center that we rely on for spec setting. You know sort of help us get at that disconnect between the indices and the catch decline that Paul talked about for the Gulf of Maine. That research track stock assessment is indefinitely paused. We did start it and put in some work, but due in part to staffing and prioritization of other assessments at the Science Center, that assessment is no longer happening, or at least officially paused. Also sort of contributed to the TC effectively defaulting back to status quo for this round of the recommendations.

I think we would really, in the present and the near future be looking to the Board and the AP for tasking or thoughts on future exploration or spec changes. This is the last point I'll make, but it was sort of an extensive conversation that the Technical Committee had. It's sort of about the overall spec setting process that we discussed.

I can really only speak to winter flounder, as it's the only groundfish comanaged by the Commission and the Council, but as far as I know this may also be a potential discussion that other comanaged stocks may come up against. As Tracey mentioned, the Council is now setting five-year specs for winter flounder, and this occurred prior to our Technical Committee meeting.

As Tracey sort of outlined, in the Council spec setting procedure they effectively use a status quo assumption for state waters catch by using those recent averages across the region, and that is true for both commercial and recreational. As we were discussing this, this sort of results in a question of how and when Commission spec changes could or even should take place in relationship to those Council decisions.

Then we also have that three vs. five-year schedule offset on changes. It's just a discussion, you know what we had spent some time on in the TC meeting, and we're looking maybe for some input moving forward from both the Commission and Council, perhaps smooth that out. Obviously, a status quo recommendation from us, it's not a huge sticking point at the moment, but just something we wanted to consider.

That said, even with the Council moving ahead with those status quo assumptions, if the Board tasks the TC with exploring possible changes we'll obviously work with all the parties to figure out how to make this work moving forward. I think that concludes my comments. Yes, thanks, Tracey.

**Review Advisory Panel Report**

MS. BAUER: Thanks, Rich. Moving into the Advisory Panel Meeting summary, which I will be covering. The AP met on January 12 of this past month with four AP members in attendance. At that meeting we came out with a few recommendations. Two advisors supported status quo, commercial and recreational management measures for fishing years 2026 through 2028 for both stocks.

They made the note with this recommendation that they would be able to reevaluate regulations in three years if changes ended up needing to be made. They weren't too concerned about continuing with status quo for now. Specifically for the Southern New England/Mid-Atlantic stock they noted that recreational fishermen, including party boats, specifically are no longer really targeting winter flounder anymore.

Any changes to regulations wouldn't be highly impactful at this time in their estimation. Similarly, AP members noted that bait shops have stopped carrying bait in April, in I think it was New York specifically, and most anglers are not putting their boats into the water until May. Gulf of Maine specifically, Advisors noted it appeared like how I mentioned the biomass estimates have been generally stable over the last ten years. There was some speculation by the AP that this could indicate that the stock had stabilized.

It had matched one of the advisors on the water observation, so they thought based on all these reasons, not many people targeting, biomass estimates in the Gulf of Maine seem to be stable right now. Status quo was the recommendation. Moving on to some general comments and research recommendations by the Advisory Panel at this meeting.

One advisor had noted he has been observing expansion of Gulf of Maine winter flounder size classes, in particular seeing larger fish. The advisor however, noted this may not necessarily indicate that the age structure is also expanding, but could indicate something with their environment is just generally changing, leading to increased growth rates.

After discussing some recent research that there was very low survival of young of year winter flounder. The AP as a whole expressed general frustration with the lack of answers on how to ensure winter flounder survived to maturity and to some the in general the continued low biomass of winter flounder.

Related to this discussion as well, the AP discussed different types of natural mortality that might be impacting winter flounder's ability to recover, including predation impacts. For research recommendations, the AP provided and discussed, first one advisor who is also a member of the Northeast Trawl Advisory Panel noted that there is that recent interest and improvement in the catchability estimates from the Northeast Fisheries Science Center, Northeast Trawl Survey that Paul noted.

He recommended that similar research be conducted for the other state surveys that go into this assessment. The AP also expressed the importance of continued exploration into ecosystem approaches in winter flounder management, to improve the estimates of natural mortality specifically, especially changes through time of natural mortality.

An advisory reiterated his recommendation from the last time the AP met to discuss specs back in January 2023, that managers should reconsider utilizing stock enhancement as a potential path forward for winter flounder. Then lastly, the AP had a short discussion on the potential need for an assessment that focuses on winter flounder in Long Island Sound specifically. That concludes my summary of the Advisory Panel meeting, so move to the Board Action for consideration for this meeting of considering setting specifications for fishing year 2026 through 2028.

CHAIR HYATT: Thank you, Tracey, thank you, Rich. At this point are there any questions for Tracey or Rich? Dan, go ahead.

MR. DANIEL J. McKIERNAN: My question is for Tracey. In the AP conversation, did anyone mention that maybe the two-fish limit discourages participation in the recreational fishery?

MS. BAUER: I think that was touched upon in the AP discussion, where it's like we only have two fish to go for, so why bother going out at all type of sentiments expressed.

MR. McKIERNAN: Yes, thank you. The other thing that strikes me is to me there is a missing part of a story here that when you do this again in three years, maybe you could come forward with a description of the degree of un-utilization of the tows or TACs by the sectors. I'm guessing that in the Gulf of Maine the majority of fish that are being caught is by federally permitted vessels in sectors.

But I think this assessment is kind of ignoring that, and so it would be good to know. I understand we're just managing for the most part the set aside. But the rest of the story, I'm blind to that. It would be useful to understand whether or not we're underutilizing the federally approved quotas, for lack of a better word.

MS. BAUER: Absolutely, I can bring that to the next time we discuss this, for sure.

CHAIR HYATT: David.

MR. DAVID V.D. BORDEN: Just following on Dan's comment. I think it would also be useful in the future to come back with more explicit explanations of what we think the environmental drivers are that are keeping the stock down. I just mention the fact that yes there has been significant environmental changes in the Gulf of Maine.

Stock pre-recruits seem to be fine. You look at those charts. Paul mentioned the fact that they had been remarkably consistent. There has got to be a decoupling in there that explains why we just don't get a rebuilding of it, particularly the Gulf of Maine population. I think it would help all of us to have a discussion of that, why that is taking place.

I know, and this goes back a long time in my history, but at one point we only had two nesting pair of cormorants in the state of Rhode Island on east and west island, and before I retired, we were up to something like 2500 nesting cormorants. Those cormorants were all over the Bay and in packs of 500 fishing in August in a foot and a half of water, where all the juvenile flounder basically reside.

I mean there are probably some correlations here, that the scientific community come back with, and I think that would help us. Maybe there is some strategy that we could put together, in terms of how the cormorants are managed by U.S. Fish and Wildlife Service or whatever, that would address some of these concerns. That's kind of the first step, I think.

MS. BAUER: Yes, and I'll note that in the APs discussion they also discussed factors, when they are having a natural mortality discussion birds come up as well there. But I think that is something we could absolutely put together. Next time maybe a summary of all the recent research going into environmental impacts or something like that. Does that sound like what you're looking for? Okay, thank you.

CHAIR HYATT: Any other questions? Rich, correct me if I'm wrong, but just building on what David just said. My recollection from the Technical Committee is that while they were recommending status quo, the general sentiment went further than that, in that they felt that status quo should be maintained until such time as a research assessment is done, which would address some of the concerns, maybe not the cormorants, but some of the concerns that David brought up. Is my recollection correct, Rich:

MR. BALOUSKUS: Yes, effectively that had been our stance from 2022 through 2025, now operating in a new environment in which we may never be anticipating that is now I guess where David's point comes in, where we may not rely on as much external information and bring some more of that into this ourselves. That was the sentiment of the TC, but obviously facing a different future we're not going to just sit on our hands and do nothing. I think looking at some of those environmental drivers and other things it's going to be our best path forward.

CHAIR HYATT: Any other questions? Anything from online or from the public? Steve Haasz, member of the public online, go ahead.

MR. STEVE HAASZ: I don't understand this. We have no fishery really going on over in New Jersey area. Nobody wants to fish for two fish. I don't understand, why can't we bring it up to like a four or five bag limit, to where we can actually see what is really out there, because nobody is going fishing for two fish.

No party boats or charter boats are even going to think to go out for that, because nobody is going to book the boat. None of the recreational guys, don't want to pay that kind of money to buy baits and all that stuff to go out to do anything. If you're only going for two fish it's too much money.

Give us a little bit of a chance March, April and May, and every year, just to see what happens, whether or not we can get this done or not, just to see what's in the Bays and rivers in New Jersey. We don't really know, because nobody is fishing for them. You guys even say the same thing, you don't know what's going on. I just don't understand where you're coming up with these rules. Why not give us a chance? We've got to fight for something here. Give us a chance to fish for them and see what happens. That's all I've got to say.

CHAIR HYATT: Thank you. Any other comments from the public or online? Nicole.

MS. NICOLE LENGYELL COSTA: This question is for Tracey, just a follow up on the public comment and some other comments that we've heard. Do states still have the option for conservation equivalency, where they could, for example, put in a program to restrain their recreational season but increase their bag limit, and that only goes through ASMFC, you don't have to go through the Council for that.

MS. BAUER: Yes, that is correct. You would have to submit a CE proposal following the guidelines to do something like that. Toni clarifies that we don't need to go to the Council process at all to change any of the recreational measures.

CHAIR HYATT: Dave.

MR. BORDEN: Yes, and just to follow up to that question. What is the timing of the submission to the Commission? I anticipate at some point some state, I mean this issue was raised by a New Jersey AP member, and at some point, the states are going to want to try to submit conservation equivalency proposals, so what is the timeframe they have to do that, the window? Is there one, Toni?

MS. KERNS: For conservation equivalency the guidelines are on the website that it is two months. But I also think that a bunch of individual state conservation equivalency programs may not serve us well, and that if we are interested in changing the recreational measures for these species, that we can task the Technical Committee to evaluate the measures that we have right now and you can give them an idea of what you're looking for, and then they can come back and say, this is what we think would happen to the landings if we made changes on X, Y or Z things.

Then I think what Tracey and I can do is talk with the New England Fishery Management Council staff about the process for specification settings and what happens with the accountability measures if we do exceed the state set-aside for winter flounder for any of the other measures, and what has been going on with the sectors and their landings, and how that impacts what happens when we go beyond what they've set aside for us.

CHAIR HYATT: Are there any other questions or comments before we move along? John.

MR. JOHN MANISCALCO: On the topic of potentially states looking at some alternative measures. New York never adopted the year-round season that most of the other states have. We did this to protect our Bay populations, to prevent people targeting the fish when they were the most vulnerable. We know that there are distinct genetics amongst our Bays. I'm just wondering, would that then be held against New York if other states wish to essentially utilize their longer seasons to potentially pump up the bag limit?

MS. BAUER: Yes, that's is something that the TC could look at if they were tasked to evaluate what sort of impacts shuffling around the bag limit and the season would have. That can definitely be one of the considerations.

CHAIR HYATT: Go ahead, Dan.

MR. McKIERNAN: Consistent with what was just mentioned, it seems to me that the way things are evolving almost all the fish is allocated to the commercial sectors, because the set asides are basically the averages of the previous years and the recreational sector is discouraged from fishing, then they are never going to get a reasonable share, because we'll just be dwindling down to nothing.

I think it would be appropriate if the TC examined, especially in the Southern New England Stock, the potential for going to four fish, that that would be considered risky for the stock, and come back to report on that to this Board, because I think the two-fish limit is basically keeping people home. But as that one gentleman mentioned, maybe a four-fish limit might create some level of interest, especially in Wave 2, which is not a very popular wave to be fishing, but I think that that is what we would gain. We would gain some fishing opportunity in Wave 2 for the recreational sector.

CHAIR HYATT: I don't think we need a motion or anything here, but I think we've got a pretty solid sentiment that we would want the Technical Committee to take a look at various alternatives for using what fish are available to the recreational sector, maybe exploring some shifting, but to take a look at those options and report back to this group at the next meeting. Megan.

MS. MEGAN WARE: Yes, maybe as a part of that, I think it would be helpful for maybe like a staff memo on how the Council specifications are set, because this is a pretty nuance conversation of where these pounds are coming from. The state water set aside is taken off the top, so an increase in that has been mentioned, decrease the federal quota.

There are no accountability measures on the state water set asides so an overage of that is payback by the federal boats. I think this is a pretty dynamic multi rider decision, and I think having some context around that would be really helpful.

CHAIR HYATT: Thank you, Megan, you're correct. State water set aside is the beginning of the process and the end of the process, it could get complicated. Is there anything else? If not, I believe we've got a prepared motion to bring up relative to setting the specifications for '26 to '28.

MS. KERNS: Just as a quick note here. If you are setting specifications for all three years, and then you decide you want to make a change to your recreational measures. Then we would need to do a two-thirds vote, because that is a final action, to change them in the future. You could set all of the specifications except for the recreational measures, because that is what you're asking to explore changes in.

Then do those for '27 and '28. Obviously, '26 you would set your rec measures for, because you can't change those this year. But just so you understand what would need to happen to change them in future years. Does that make sense to everybody?

CHAIR HYATT: If we set the specifications as anticipated, we would need to rescind that with a two-thirds vote and revisit for the recreational part of it, correct?

MS. KERNS: Yes, you don't have to rescind it, but you just do a new vote that is two-thirds.

CHAIR HYATT: Nicole.

MS. COSTA: Yes, just on timeline. When can we expect something back from the TC reasonably?

MS. BAUER: Yes, I would say our August meeting, the summer meeting. I think that seems like a realistic timeline to look into this and get back to you guys.
CHAIR HYATT: Dan.

MR. McKIERNAN: If we were to get a report in August or the decision to maybe increase the bag limit in the recreational sector, would it be able to be done at the November meeting, or do we have to do an addendum?

MS. BAUER: You wouldn't need to do an addendum, because Addendum III allows you to make changes like this. If you guys had a final decision at the August meeting you could make those changes at the August meeting, I believe, unless you think there is something that needs more discussion.

MR. McKIERNAN: That would be ideal, because if recreational fishermen are going to get news of it, it would need to go out in those guides which are usually printed by the first of the year, so that is great, thank you.

CHAIR HYATT: Is there anything else before we bring up a prepared motion and then talk about how to modify that motion? Here we have a motion prepared by staff that follows the recommendations of the Technical Committee and sets these specs for three years, 2026 to '28. I will ask if anybody wants to make this motion or to modify this motion in a manner that better reflects the conversation that we've just had. Eric.

MR. REID: Yes, Mr. Chair, I'll make this motion. **I move to approve status quo commercial and recreational Southern New England/Mid-Atlantic and Gulf of Maine winter flounder measures for the 2026 through 2028 fishing years.**

CHAIR HYATT: Second by Ray. Motion by Eric, second by Ray.

MR. REID: Given the discussion, did you hear what Megan Ware said about having to engage the New England Council? That is not a small topic, because of the way the tonnage is allocated. Whether or not we have a report for our August meeting or not, I think it's going to take a lot longer time than that to get this where everybody is comfortable with it. I have no problem with the three years, and if in fact we want to change it with a two-thirds vote, I don't think that is any problem either. I would just as soon leave this motion the way that it is and move forward.

CHAIR HYATT: Ray, do you have anything to add? Nothing to add.

MR. RAYMOND W. KANE: I thought I heard Tracey say that she and Toni would talk to the Council, thank you.

CHAIR HYATT: Thank you, Ray. Any further discussion? Are there any concerns with this motion? Any abstentions? If not, **motion passes by consent**. Thank you. Next item to consider is the Fishery Management Plan Review and State Compliance for the 2024 Fishing Year. Tracey.

## Consider FMP Review and State Compliance for the 2024 Fishing Year

MS. BAUER: Yes, I think I can go through this very quickly. I will skip the monitoring requirements; they remain unchanged except for the review of what is in the FMP. There is one de minimis request, and then I'll go through the PRT discussion and recommendations. One de minimis request. New Jersey continues to request de minimis status for their commercial fishery. Then moving on to the PRT recommendation. The PRT found no inconsistencies between state compliance reports and the requirements of the winter flounder FMP, and there are a few questions that the PRT recommends be added to the compliance reports.

Essentially, these questions are just to help the PRT in the future track if and like whether overages are occurring on commercial trips, next are found in the FMP review if you want to review them more closely. But basically, they just give information or allow the PRT to look at information about how many trips are landing at the trip limit, below the trip limit and over the trip limit, and if there is ay overage how much that overage is.

If there are no trips, commercial trips that are exceeding the trip limit then you can put that in too. But this was just something that the PRT thought would be helpful as a reference in future years. Just briefly, Rich already went through Massachusetts' CE Plan. The Massachusetts compliance report provided some initial information on the period that has been active thus far, just in 2024, which was September 20 through the end of the year, 2024.

If you go to the next slide the PRTs discussion recommendation, they had recognized that this compliance report had only contained information for a very small portion of the year, so there is interest to see how it will perform in the first full year. There was some conversation by the PRT that generally for all CE programs it might be useful in the future to consider types of socioeconomic data that could be gathered to evaluate performance.

In this case for Massachusetts program some of the justifications for the program in Massachusetts proposal was for socioeconomic reasons, so monitoring this information potentially, or consideration of monitoring this information in the future could help, you know the state and the PRT determine if the program is meeting the goals and objectives of that program.

Lastly, the PRT just noted the change in the requirements to seal each day's catch with a DMF issued tag, changing it to require each day's catch to be clearly segregated and accurately labeled. The Board action for consideration is to approve the Winter Flounder FMP Review and de minimis status for New Jersey's commercial fishery.

CHAIR HYATT: Is there anybody who would like to make this motion to read into the record? Doug.

MR. DOUGLAS E. GROUT**: I move to approve the Winter Flounder FMP Review for the 2024 fishing year, state compliance reports and de minimis status for New Jersey's commercial fishery.**

CHAIR HYATT: Thanks Doug and second. Second by Ray. Any discussion or any questions for Tracey on the report that she gave? Seeing none; is there any concern with this motion? Any abstentions? **It passes by consent.** Go ahead, Tracey.

MS. BAUER: Before we move on from this topic, I just want to make sure that the Board doesn't have any concerns or objections to adding those questions to the future compliance reports. If there are no concerns with that, then that will be in the next template that I send out this year.

CHIAR HYATT: No concerns, so, so noted. Last item on our agenda is election of a Vice-Chair. I believe that we've got a motion and a nomination. Matt.

MR. MATTHEW GATES: It is my pleasure to **nominate Nicole Costa from out neighboring state to the east, Rhode Island.**

CHAIR HYATT: Thank you, Matt, second Dan. Are there any other nominations? Okay, Nicole, **congratulations**.

At this point, is there any other business to come before the Board? Seeing none; we are **adjourned.** Thank you.

(Whereupon the meeting adjourned at 12:20 p.m. on Tuesday, February 3, 2026)

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# Atlantic States Marine Fisheries Commission

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## MEMORANDUM

**TO:** **Winter Flounder Management Board**

**FROM:** **Winter Flounder Technical Committee**

**DATE:** **July 20, 2026**

**SUBJECT:** **Update on Board Requests**

At its February 2026 meeting, the Winter Flounder Management Board (Board) expressed interest in receiving additional information in the future regarding several topics. This memo provides an update for the Board from the Technical Committee (TC) on 1) information on research of environmental drivers that are hypothesized to limit stock rebound and 2) utilization of catch limits in federal waters.

### *1. Research on Environmental Drivers Limiting Winter Flounder Stock Rebound*

In February 2026, there was a request from the Board for information on the environmental drivers limiting the rebuilding of the winter flounder stock to be provided at a future meeting. Predation, specifically from cormorants, was mentioned as a topic of particular concern. Although there are no peer-reviewed papers specifically addressing winter flounder predation by cormorants, the TC was able to locate several existing datasets, and conducted a preliminary analysis which is provided below.

More broadly, the Winter Flounder Research Track Working Group had prioritized further analysis and compilation of information on environmental drivers on the winter flounder population. Population projections within the current ASAP model framework have been found to be sensitive to the recruitment period chosen, as well as the temporal period selected from which recruitment estimates are drawn. In addition, recruitment and natural mortality are both likely to be dependent on environmental conditions, which cannot be explored within the ASAP framework. Although the Northeast Fisheries Science Center (NEFSC) winter flounder research track stock assessment is currently paused, investigations of environmental covariates within a state-space model framework (e.g., WHAM) are ongoing, including graduate work at University of Maine.

A Master's thesis regarding the characterization of environmental impacts on winter flounder stock dynamics in US waters was recently completed (Appendix 1; Barron 2025). Topics covered in this thesis include a literature review of ecosystem and climate influences on winter flounder stock dynamics, an evaluation of shifts in winter flounder stock dynamics, and modeling of climate and ecosystem drivers of the winter flounder population.

M26-66

Since there are one or more peer review publications in progress based on this thesis, the TC will come back to the Board at a future meeting with a presentation summarizing the literature review and other results of this research.

***Double-Crested Cormorants***

The coastal colonial waterbird nesting survey was initiated in Rhode Island in 1976 and in Massachusetts in 1984. The survey has been conducted annually in RI with a partial survey conducted in 2021 and no survey in 2023. The MA survey has been conducted sporadically: 1984, 1994-95, 2006-08, 2013, 2018, and 2024. Fixed stations are surveyed once annually. For this analysis, all RI stations are used and only MA stations adjacent to the SNE/MA winter flounder stock bounds are used (e.g., Buzzards Bay, south side of Cape Cod, Martha's Vineyard, Nantucket). The first nesting pair was not observed until 1982. Only one single station (of 46 sampled) in the MA coastal colonial waterbird nesting survey had double-crested cormorants present in the 1984 survey. The cormorant nesting population increased steadily through the 1980s until the mid-1990's when the population appears to have plateaued (perhaps reaching ecosystem carrying capacity; Figure 1).

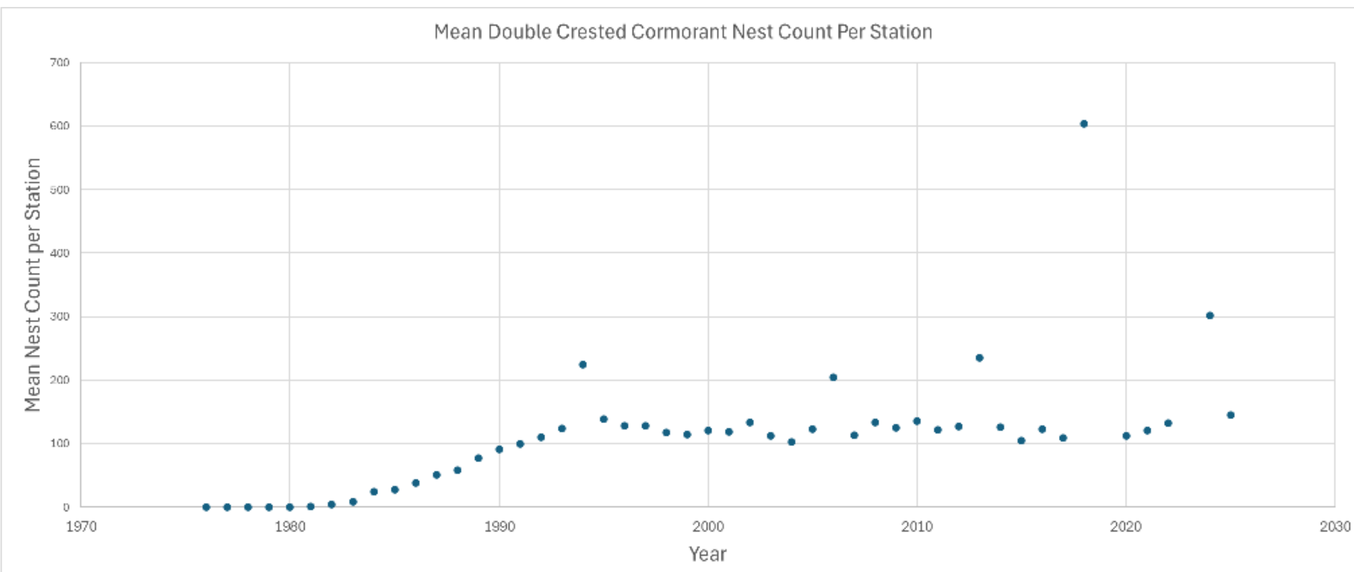


***Figure 1. Mean double-crested cormorant nest count data 1976-2025 for Massachusetts and Rhode Island combined. Number of stations sampled per year are variable.***

In 1995, from April through August, the State of Rhode Island conducted a stomach content analysis on double-crested cormorants at two locations within Narragansett Bay (Hope Island and Sakonnet Point). Sixty-seven (67) cormorants were collected during this project. Thirteen of the 67 cormorants (19.4%) had winter flounder in their stomachs. When present, winter flounder comprised between 16 and 100% of the mass of the cormorant stomach contents. Across all cormorants sampled, cunner comprised the greatest mass of all prey, winter flounder were second most among identifiable prey species.

***Table 1. Top ten greatest mass prey species from double-crested cormorant stomach contents collected from Narragansett Bay, Rhode Island 1995. Mass represents the total grams of each prey species sampled from all 67 cormorants collected. Percentage of total mass shows the relative percentage of mass of prey species among all collected cormorants.***

| **Species** | **Mass (g)** | **Percentage of Total Mass** |
|---|---|---|
| Cunner | 1153.2 | 18.9 |
| Unidentified | 1100.7 | 18.1 |
| Winter Flounder | 623.6 | 10.2 |
| Northern Searobin | 559.5 | 9.2 |
| Common Mummichog | 491.8 | 8.1 |
| Butterfish | 466.4 | 7.7 |
| Oyster Toadfish | 465.4 | 7.6 |
| Tautog | 283.8 | 4.7 |
| Grubby Sculpin | 206 | 3.4 |
| Scup | 164.8 | 2.7 |

### *2. Commercial Utilization*

The TC compiled information on the utilization of catch limits for the SNE/MA and GOM stocks between 2011 and 2025, which in the future will be updated for Board discussions of specifications.

Commercial utilization of winter flounder was extracted from the commercial summary table (sector and common pool) catch monitoring database hosted by NOAA GARFO (https://apps-garfo.fisheries.noaa.gov/quota-monitoring/groundfish/MultiMonReports.html). Commercial utilization of SNE/MA winter flounder by the federal groundfish fleet has steadily declined from 2018 through 2025 (Figure 2). Commercial utilization of GOM winter flounder by the federal groundfish fleet has generally varied without much trend (Figure 3).

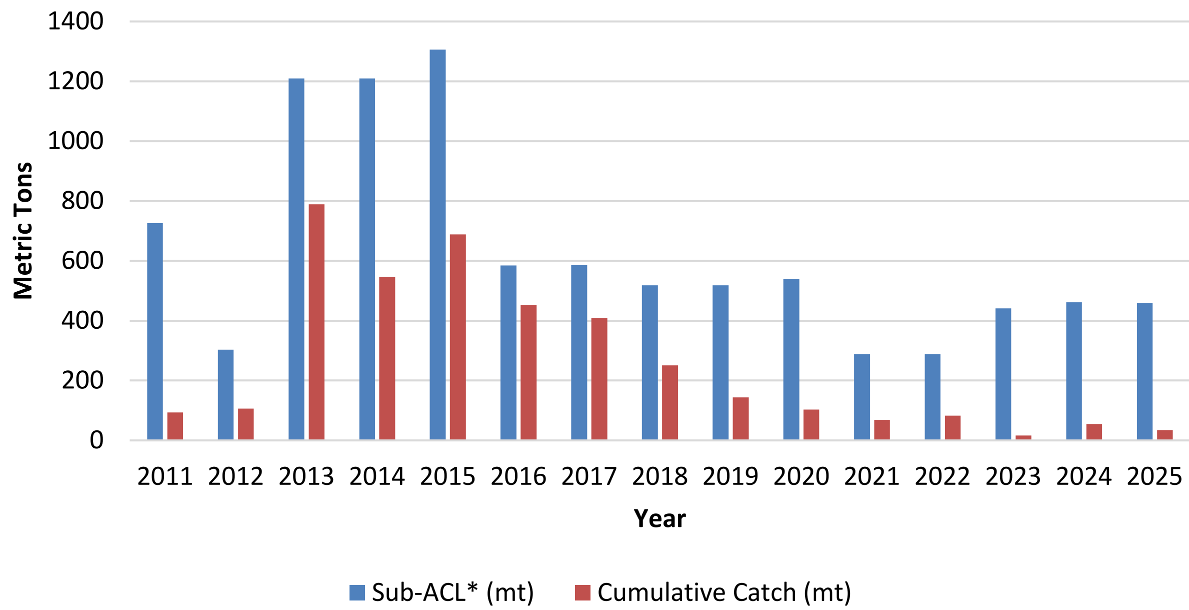


***Figure 2. Comparison of cumulative catch vs. the groundfish sub-ACL by year for SNE/MA winter flounder in metric tons. In years where utilization rates are high, the red cumulative catch bars are close in height to the blue sub-ACL bars. In years where utilization rates are low the red bars are small compared to the blue bars.***

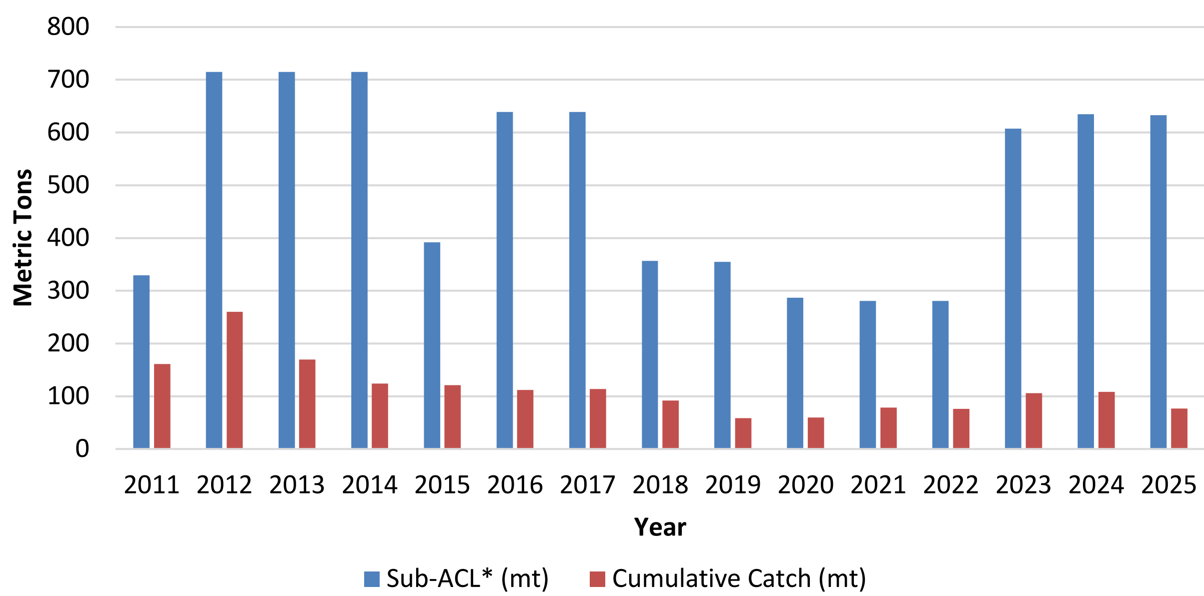


***Figure 3. Comparison of cumulative catch vs. the groundfish sub-ACL by year for GOM winter flounder in metric tons. In years where utilization rates are high, the red cumulative catch bars are close in height to the blue sub-ACL bars. In years where utilization rates are low the red bars are small compared to the blue bars.***

12-2025

# Characterizing the Impacts of Climate Change on Winter Flounder Stock Dynamics in US Waters

Julia K. Barron

**CHARACTERIZING THE IMPACTS OF CLIMATE CHANGE ON WINTER FLOUNDER STOCK DYNAMICS IN US WATERS**

By

Julia Barron

B.A. Smith College, 2020

A THESIS

Submitted in Partial Fulfillment of the

Requirements for the Degree of

Master of Science

(in Marine Biology)

The Graduate School

The University of Maine

December 2025

Advisory Committee:

Lisa Kerr, Professor of Marine Sciences, Advisor

Michelle Staudinger, Professor of Marine Sciences

Steven Cadrin, University of Massachusetts Dartmouth-SMAST

## UNIVERSITY OF MAINE GRADUATE SCHOOL LAND ACKNOWLEDGMENT

The University of Maine recognizes that it is located on Marsh Island in the homeland of Penobscot people, where issues of water and territorial rights, and encroachment upon sacred sites, are ongoing. Penobscot homeland is connected to the other Wabanaki Tribal Nations— the Passamaquoddy, Maliseet, and Micmac—through kinship, alliances, and diplomacy. The University also recognizes that the Penobscot Nation and the other Wabanaki Tribal Nations are distinct, sovereign, legal and political entities with their own powers of self-governance and self determination.

# CHARACTERIZING THE IMPACTS OF CLIMATE CHANGE ON WINTER FLOUNDER STOCK DYNAMICS IN US WATERS

By Julia Barron

Thesis Advisor: Dr. Lisa Kerr

An Abstract of the Thesis Presented
In Partial Fulfillment of the Requirements for the
Master of Science
(in Marine Biology)
December 2025

Over the last 40 years, the Northwest Atlantic region has warmed at an accelerated rate, impacting marine fish communities and the fisheries that depend on them. Winter flounder, *Pseudopleuronectes americanus*, is a demersal flatfish species managed as three stock units in U.S. waters (Georges Bank, Gulf of Maine, Southern New England/Mid-Atlantic). In the 1980s, winter flounder stocks were severely overfished. Groundfish species like winter flounder are sensitive to environmental change, and despite little fishing pressure, the stocks have not recovered to their historical abundance levels. Thus, characterizing the impact of climate change on stock dynamics is critical for accurate stock assessment and effective fisheries management of winter flounder.

By reviewing the best available science on ecosystem influences on winter flounder stock dynamics, I identified key environmental drivers described as affecting winter flounder distribution, recruitment, growth, and natural mortality in previous studies. Environmental drivers such as surface and bottom temperatures, salinity, and the frequency of warm-core rings were identified in the scientific literature as affecting the dynamics of winter flounder in one or more stock areas. Due to the varied timing and spatial scale of these studies, it is important to revisit these relationships to determine their stability and whether new relationships emerged.

Large-scale ecosystem changes or regime shifts in the Northeast US shelf ecosystem can drive temporal shifts in fish population dynamics, specifically impacting stock productivity. To identify temporal non-stationarity in winter flounder stock dynamics, I conducted a changepoint analysis of three stock responses: recruitment, growth, and distribution. The scales at which these changepoints are evident (i.e., across all stocks or in individual stocks) can inform further steps in understanding the environmental drivers of non-stationarity in stock trends.

I used generalized additive models to characterize relationships between the previously identified environmental drivers and winter flounder stock dynamic indices. This analysis revealed strong correlations between winter flounder stock dynamics and ecosystem drivers, contributing to a comprehensive understanding of how this species responds to environmental change. This research aims to inform improved winter flounder stock assessment and management through examination and characterization of climate influences at the stock scale.

**DEDICATION**

To my parents, whose unconditional and unwavering support throughout my educational career has brought me to where I am today. Thank you for instilling in me the love of learning and giving me the perseverance to continue learning every day.

## ACKNOWLEDGEMENTS

Thank you to my husband, Sean, who moved with me to Maine so that I could achieve this advanced degree. I would not be half the person I am today without his love, support, and encouragement. Thank you to the Kerr Lab for their cheers of support throughout this process, as well as the countless hours they contributed to reading and reviewing my thesis. I would like to highlight the constant help and assistance from lab manager Jamie Behan, who was invaluable in my learning and understanding of the statistical analyses conducted in this thesis. I would also like to thank the members of the paused winter flounder NOAA Working Group Research Track, who contributed to the making of the ecosystem profile, assisted me with data acquisition, and provided invaluable feedback throughout all stages of my research. Lastly, I would like to extend my deepest gratitude to my committee members for their constant support and time spent reviewing my thesis.

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# CHAPTER 1

## Introduction

The Northeast U.S. continental shelf ecosystem supports abundant and diverse living marine resources that many coastal communities in New England rely upon. Within the last 40 years, the Northwest Atlantic has warmed at an unprecedented rate, significantly impacting marine fishery resources and communities (Townsend et al. 2023, Pershing et al. 2015). Winter flounder (*Pseudopleuronectes americanus*) is an important fishery resource in the Northwest Atlantic that has been significantly affected by climate change. Winter flounder is a demersal flatfish species managed as three stock units in US waters: the Gulf of Maine (GOM), Georges Bank (GB), and Southern New England/Mid-Atlantic (SNE/MA) stocks. In the 1980s, winter flounder stocks were severely overfished and are now dimly representative of what once was a thriving commercial fishery resource. Although recent stock assessments (NOAA 2022) indicate no overfishing currently occurs on these stocks, the resource has yet to return to its historic abundance.

The most recent status determinations for winter flounder stocks are as follows: the Georges Bank stock is not overfished, is still rebuilding, and is not subject to overfishing (NOAA 2025). The Southern New England/Mid-Atlantic stock is not overfished, is not subject to overfishing, and has rebuilt to the target population level due to the revision of biological reference points (NOAA 2025). The Gulf of Maine stock is not subject to overfishing, and the overfished status is unknown because the population size could not be estimated due to highly uncertain assessment results (NOAA 2025). NOAA initiated a research track stock assessment for winter flounder stocks in U.S. waters in 2023; however, this process has been temporarily paused due to capacity issues.

**Problem Statement**

Winter flounder have historically been a highly valued fishery resource with cultural and economic significance to the Northeast US. The fishery resource is targeted by the groundfish fishery as part of a multi-species complex. The magnitude to which climate and ecosystem drivers have been influencing winter flounder population dynamics and, therefore, affecting sustainable yield are unknown.

The Northeast US continental shelf region has undergone large-scale changes primarily due to global warming within the past half-century. Like many species in the groundfish complex, winter flounder are sensitive to environmental change. Due to their dependence on both estuarine and demersal waters, they can be particularly susceptible to climate change and other anthropogenic impacts on these varied habitats. A vulnerability assessment of species along the Northeast U.S. Shelf to climate change ranked winter flounder as having a “very high” vulnerability score with “high” biological sensitivity and “very high” climate exposure (Hare et al. 2016). Hare et al. (2016) suggested that the impacts of climate change are expected to negatively impact winter flounder, particularly at the southern extent of their range. This vulnerability assessment provides useful context for understanding climate change impacts on winter flounder, but it is based on expert opinion and the data available at the time of publication. Understanding the influence of ecosystem and climate drivers of winter flounder population dynamics is essential to the accurate assessment of these stocks and the effectiveness of their management.

Stock assessments are a crucial aspect of the fishery management process, providing estimates of current stock biomass and status (i.e., overfished and overfishing status) that inform harvest advice.  Most stock assessments do not explicitly include climate and ecosystem impacts on population dynamics, leading to model misspecification. The failure to account for these impacts can lead to inaccurate assessments and impact the advice given by managers, resulting in ineffective management and the potential for overfishing (Kerr et al. 2022). Given the multiple sources of uncertainty inherent in the assessment process, evaluations for climate-vulnerable species, such as winter flounder, should incorporate ecological and environmental context to enhance understanding and management of the stock. For many groundfish stocks, the impacts of climate change are thought to play a significant role in preventing the rebuilding of these fishery resources (Wiedenmann and Jensen 2018). The lack of rebuilding of winter flounder stocks to historic levels has severely reduced the targeting of winter flounder by the groundfish fishery, affecting the industry and its stakeholders.

**Research Goals and Objectives of Thesis**

The goal of this thesis was to characterize how climate change is influencing winter flounder stock dynamics and to provide recommendations on how to integrate this information to improve the assessment and management of this important groundfish species. The core research questions included:

1) What are the key climate and environmental drivers influencing the dynamics of winter flounder stocks in the US?

2) How are these drivers impacting fish productivity and distribution?

3) How can we use this information to inform improved stock assessment accuracy and management effectiveness?

These questions were addressed through the research activities described in three chapters. Chapter 2 synthesizes the best available science on the influences of climate and ecosystem change on winter flounder population dynamics and provides ecosystem context for the species that can inform climate-integrated management of this fishery resource. This ecosystem profile was developed through a systematic literature review and synthesizing knowledge of experts on winter flounder through NOAA's Winter Flounder Research Track Stock Assessment process. In Chapter 3, evidence of regime shifts in the population dynamics (i.e., recruitment, growth, and distribution) of winter flounder stocks in US waters was tested. Breakpoint analysis was used to identify evidence for regime shift dynamics within and across all three winter flounder stocks. Chapter 4 quantified the relationships between winter flounder population dynamics and the important climate drivers identified in Chapter 2. Generalized additive models (GAMs) were used to evaluate the relationship between stock dynamic processes (i.e., recruitment, growth, and distribution) and environmental drivers.

This work applied a framework developed through the Northeast Climate Integrated Modeling Initiative (NCLIM) that outlines a structured approach for climate information to be integrated into fisheries stock assessment (Fig. 1.1, Kerr et al. In Review). This approach has been applied to multiple groundfish in the region, including American plaice, Atlantic cod, and yellowtail flounder, in the context of research track stock assessments. The results of this work have the potential to inform the stock assessment through 1) providing an ecosystem context to understanding data, 2) improving modeling assumptions, and 3) providing guidance on aspects of stock dynamics that should be considered time-varying or informed by an environmental driver in the context of the stock assessment model. Overall, this research promotes the framework that a deeper understanding of environmental effects from both a literature and stakeholder perspective can benefit stock assessment and management and help us better predict how winter flounder stocks will adapt in the future.

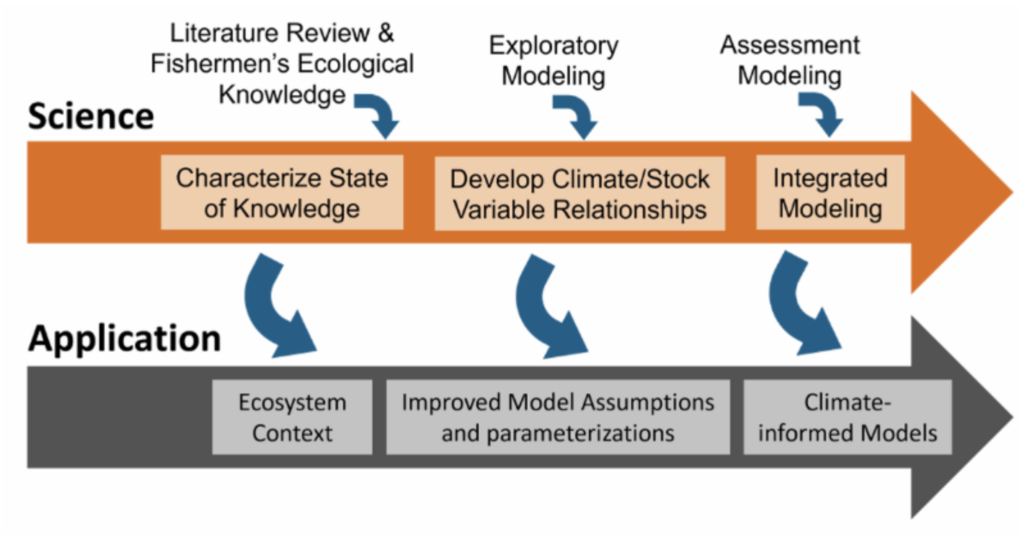



Figure 1.1. NCLIM Stock Assessment Framework. Visualization of the framework by NCLIM to integrate ecosystem and climate knowledge into the stock assessment process, Excerpt from Kerr et al. (In Review).

# CHAPTER 2

# PROFILE OF ECOSYSTEM AND CLIMATE INFLUENCES ON STOCK DYNAMICS OF WINTER FLOUNDER

## Introduction

Winter flounder (*Pseudopleuronectes americanus*) are a demersal flatfish species commonly distributed in New England and Eastern Canadian waters (NOAA 2023). Winter flounder have been an intensely studied species both in the field and in the lab, in part because they are readily sampled in nearshore habitats and can be successfully reared under controlled conditions. Decades of research interest in this species led to the establishment of a regional scientific conference in 1986 devoted to winter flounder, which later evolved into the Flatfish Biology Conference, focused on advancing scientific understanding of flatfish species (NOAA 2024). Research on winter flounder has also advanced ecosystem approaches to fisheries science and management. For example, the initial Atlantic States Marine Fisheries Commission (ASMFC) management plan for winter flounder, which explicitly considered habitat (ASMFC 1992), was the basis of the US federal mandate to conserve essential fish habitat.

Winter flounder are currently managed as part of the Northeast Multispecies (groundfish) Fishery Management Plan developed by the New England Fisheries Management Council (NEFMC) and the ASMFC. Three stocks are defined for this groundfish species in U.S. waters: 1) Gulf of Maine (GOM), 2) Georges Bank (GB), and 3) Southern New England/Mid-Atlantic (SNE/MA; Fig. 2.1). Canada manages three additional stocks: Western Scotian Shelf (NAFO Div. 4X), Eastern Scotian Shelf (NAFO Div. 4VW), and the Southern Gulf of St. Lawrence (NAFO Div.4T, DFO). The U.S. three-stock management approach was initiated in 1996 to align with the most current understanding of winter flounder stock structure (NEFSC 1996). Prior to 1996, winter flounder were managed as four stock units in U.S. waters, as Southern New England and Mid-Atlantic were separate stocks (DeCelles and Cadrin 2011).

A vulnerability assessment of species along the Northeast U.S. Shelf to large-scale climate change ranked winter flounder as having a vulnerability score of “very high” with high biological sensitivity and very high climate exposure (Table 1, Hare et al. 2016). The effect of climate change was expected to be negative for winter flounder, particularly at the southern extent of their range (Hare et al. 2016). The vulnerability assessment provides valuable context for understanding the impacts of climate change on winter flounder, but it is based on expert opinion and the data available at the time of publication.

Table 2.1. Winter Flounder Vulnerability Analysis. Climate vulnerability analysis for winter flounder depicting the expert's scores for biological sensitivity and climate exposure. Excerpt from Hare et al. (2016).

Overall Vulnerability Rank = Very High

Biological Sensitivity = High
Climate Exposure = Very High
Data Quality = 92% of scores ≥ 2

| | *Pseudopleuronectes americanus* | Expert Scores | Data Quality | Expert Scores Plots (Portion by Category) |
|---|---|---|---|---|
| Sensitivity attributes | Stock Status | 3.4 | 3.0 | |
| | Other Stressors | 2.4 | 2.6 | |
| | Population Growth Rate | 2.2 | 2.7 | |
| | Spawning Cycle | 2.6 | 2.7 | |
| | Complexity in Reproduction | 2.4 | 2.8 | |
| | Early Life History Requirements | 3.2 | 2.9 | |
| | Sensitivity to Ocean Acidification | 1.4 | 2.4 | |
| | Prey Specialization | 1.3 | 3.0 | |
| | Habitat Specialization | 1.8 | 3.0 | |
| | Sensitivity to Temperature | 2.1 | 3.0 | |
| | Adult Mobility | 1.9 | 2.9 | |
| | Dispersal & Early Life History | 2.7 | 2.8 | |
| | Sensitivity Score | High | | |
| Exposure variables | Sea Surface Temperature | 4.0 | 3.0 | |
| | Variability in Sea Surface Temperature | 1.0 | 3.0 | |
| | Salinity | 1.4 | 3.0 | |
| | Variability Salinity | 1.2 | 3.0 | |
| | Air Temperature | 4.0 | 3.0 | |
| | Variability Air Temperature | 1.0 | 3.0 | |
| | Precipitation | 1.2 | 3.0 | |
| | Variability in Precipitation | 1.3 | 3.0 | |
| | Ocean Acidification | 4.0 | 2.0 | |
| | Variability in Ocean Acidification | 1.0 | 2.2 | |
| | Currents | 2.0 | 1.0 | |
| | Sea Level Rise | 2.2 | 1.5 | |
| | Exposure Score | Very High | | |
| Overall Vulnerability Rank | | Very High | | |

Low
Moderate
High
Very High

The goal of this chapter is to synthesize the best available science on the influence of climate and ecosystem change on winter flounder population dynamics and provide an ecosystem context for the species that can inform climate-integrated management of the fishery. This review was conducted in coordination with NOAA's Winter Flounder Research Track Stock Assessment process to address Term of Reference 1 (TOR 1): "Identify relevant ecosystem and climate influences on the stock. Characterize the uncertainty in the relevant sources of data and their link to stock dynamics. Consider findings, as appropriate, in addressing other TORs. Report how the findings were considered under impacted TORs." Because of the individualized nature of winter flounder stocks in terms of their genetics, distribution, vital rates, morphology, and behavior (DeCelles and Cadrin 2011), this literature review compiles the best available science regarding winter flounder dynamics, including habitat/distribution, recruitment, growth, and natural mortality, and their response to environmental change on a stock-by-stock basis (Kittel 2025).

**Methods**

A broad review of the scientific literature was conducted to develop an ecosystem profile of winter flounder, based on the best available science, identifying climate and ecosystem influences on winter flounder stock dynamics. Keywords searched for in Google Scholar in this review included: "winter flounder", "climate change", "ecosystem", "population", "stock", and "dynamics". Applicable literature was then sorted by stock area, date of publication (search was for any year of publication after 1900), and life history trait studied using the following terms: "habitat", "distribution", "recruitment", "growth", "natural mortality", "Gulf of Maine", "Georges Bank", and "Southern New England/Mid-Atlantic." In addition to this systematic approach to review, a portion of the literature was identified through contributions from NOAA's Winter Flounder Research Track Working Group members, who recommended key studies and seminal works considered essential to understanding winter flounder stock dynamics and ecology. The profile was then organized by each aspect of stock dynamics (i.e., distribution and habitat use, spawning phenology and recruitment, growth and maturity, and natural mortality) with a general description at the beginning of each section followed by stock-specific content where applicable.

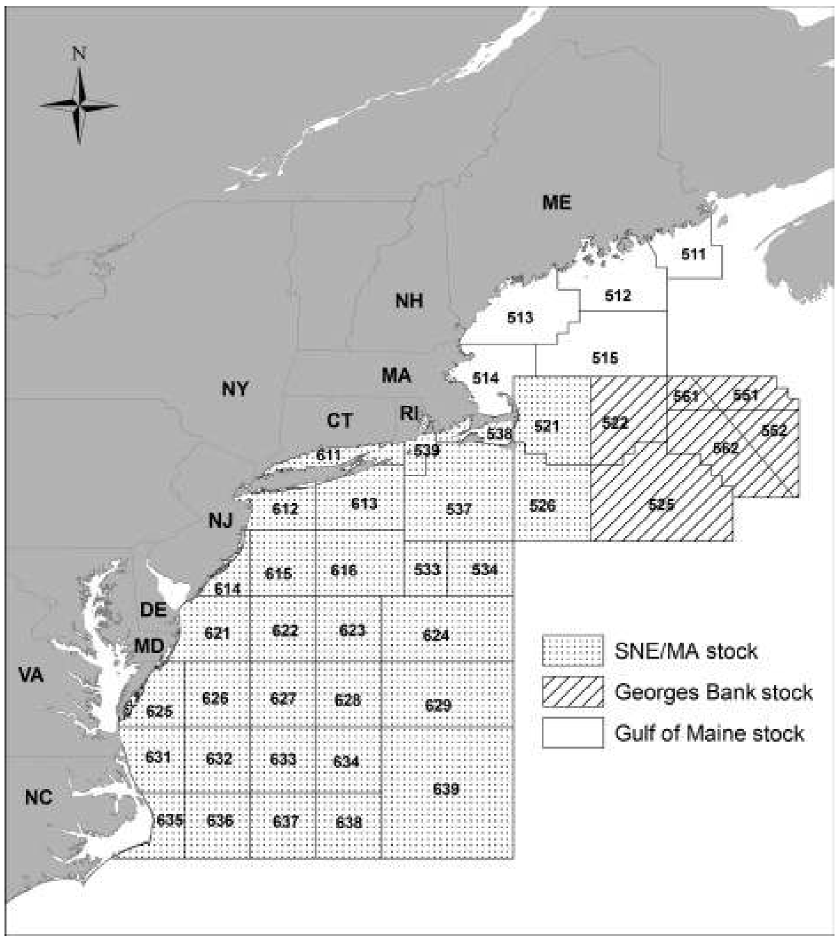


Figure 2.1. Spatial Definition of Winter Flounder Stocks. Spatial definition of the three stocks of winter flounder off the northeast US and southern Canada: Southern New England/Mid-Atlantic (SNE/MA), Georges Bank, and Gulf of Maine. Excerpt from DeCelles and Cadrin (2011)

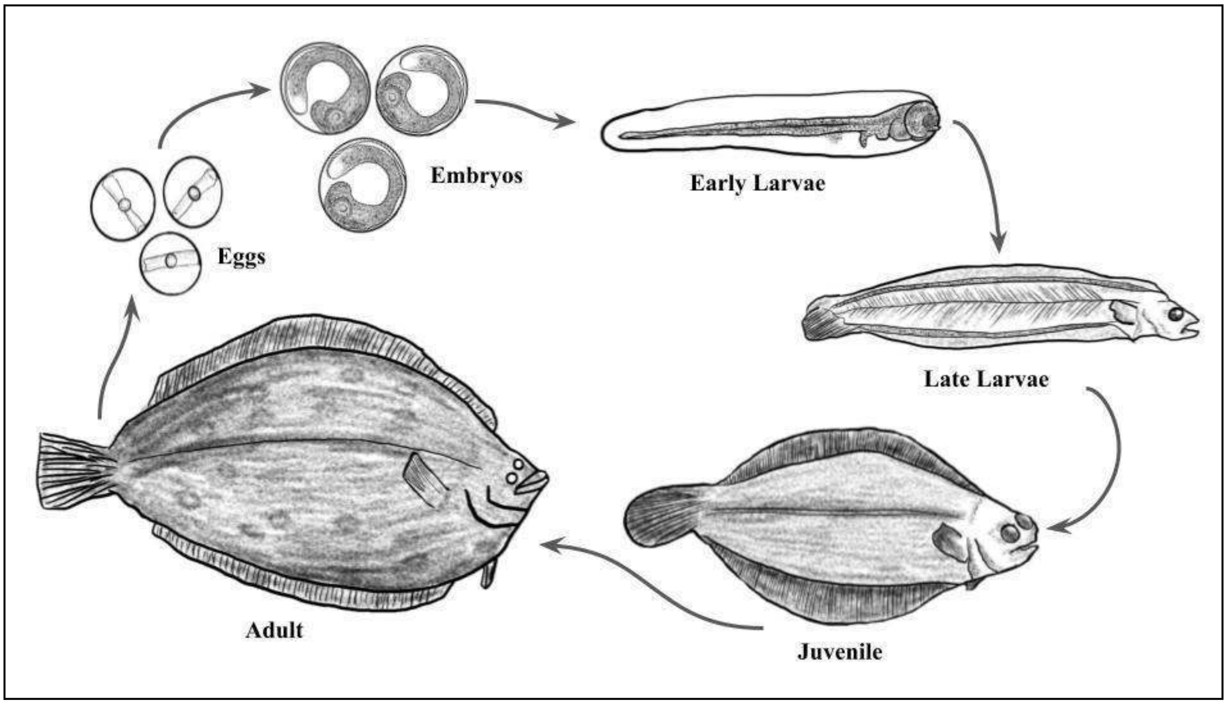



Figure 2.2. Winter Flounder Life History Stages. Winter flounder life history stages, beginning with the egg stage and ending at the adult stage. Images referenced are found in Jordan and Evermann (1896) and were originally drawn by H.L. Todd.

**Distribution and Habitat Use**

*General Description of Distribution by Life Stage*

Winter flounder exhibit variation in habitat preferences and tolerances across different life stages and within various stock areas (Table 2.2, Pereira et al. 1999).

Table 2.2. Winter Flounder Preferences. Preferences of winter flounder at each life stage for depth, substrate type, vegetation type, and currents and the specific temperature, salinity, and dissolved oxygen preferences across life stages. Excerpt from Pereira et al. (1999).

| Life Stage | Depth | Substrate | Vegetation | Currents |
|---|---|---|---|---|
| ***Eggs*** [1] | Found at 0.3-4.5 m (inshore); 90 m or less on Georges Bank. | Mud to sand or gravel. | Diatom mats, drifting macroalgae. | |
| ***Larvae*** [2] | 1-4.5 m inshore. | Fine sand, gravel. | | Hydrodynamics work to retain larvae in nursery areas. |
| ***YOY*** [3] | 0.5-12 m inshore. | Mud to sand with shell or leaf litter. | *Ulva*, eelgrass and unvegetated adjacent areas. | |
| ***Juveniles*** [4] | Peak abundance of flounder less than 200 mm occurs in 18-27 m of water in Long Island Sound in April and May. In Canadian waters, juveniles were most abundant at 11-18 m. Less than 100 m offshore. | Equally abundant on mud or sand shell. | | |
| ***Adults*** [5] | Most 1-30 m inshore, shallowest during spawning; less than 100 m offshore. | Mud, sand, cobble, rocks, boulders. | | |

Table 2.2 continued

| Life Stage | Temperature | Salinity | Dissolved Oxygen |
|---|---|---|---|
| *Eggs* [1] | Spawning initiated at about 3°C; highest percent hatch at 3-5°C; 18°C lethal. | Found from 10-32 ppt; salinity has little effect on survival or hatch. | Found at 11.1-14.2 mg/l. |
| *Larvae* [2] | No feeding or metamorphosis at 2°C; hatch from 1-12°C; larvae most abundant at 2-15°C. | Found at 3.2-30 ppt; higher on Georges Bank. | Found at 10.0-16.1 mg/l. |
| *YOY* [3] | Found at 2-29.4°C; Laboratory study suggests preferred temperature is 19.5°C; 30°C may be lethal. | Found at 23-33 ppt; 5 ppt suggested by laboratory study as lower avoidance salinity. | Constant 2.2 mg/l or diurnal variation from 2.6-6.4 mg/l adversely affects growth. |
| *Juveniles* [4] | Commonly found at 10-25°C during summer and fall. | Collected 19-21 ppt; 10 ppt suggested as lower avoidance level. | |
| *Adults* [5] | 0.6-23°C; 12-15°C suggested as preferred; upper incipient lethal limit is 27°C. | Found at 15-33 ppt. | Lower dissolved oxygen associated with lower mean length of catch suggesting avoidance by larger fish or reduced growth. |

Early Life History

Winter flounder exhibit early life history patterns typical for a flatfish, with a pelagic larval stage and settlement to demersal juveniles (Fig. 2.2). Winter flounder eggs are both demersal and adhesive and therefore less likely to be widely dispersed from their hatching site compared to pelagic eggs (Pearcy 1962; Miller et al. 1991; DeCelles and Cadrin 2011). Winter flounder deposit eggs in depths less than 5 m in estuaries, deeper in coastal waters (DeCelles and Cadrin 2011, Fairchild et al. 2013, Fairchild 2017), and up to 90 m on Georges Bank (Scott 1929; Bigelow and

Schroeder 1953; Pearcy 1962; Crawford and Carey 1985; Monteleone 1992). Frank and Legett's (1983) study in Newfoundland supported the adaptive emergence hypothesis for winter flounder young of year, which contends that the demersal eggs hatch due to the onset of specific environmental conditions, such as increased presence of warm, food-rich waters, and is timed to avoid peak predator abundances in shallow nursery areas (Frank and Legett 1983). This cue for synchronized, local hatching is thought to decrease the risk of mortality due to predator swamping effects (Frank and Legett 1983).

Newly hatched winter flounder larvae are pelagic and have a typical bisymmetric body plan (NOAA 2025). The larval stage lasts 28–42 days, during which larvae may accumulate in nursery areas due to tidal movement (Chant et al. 2000). New larvae depend on yolk-sac absorption during the first 4-14 days post-hatch, after which larvae transition to exogenous feeding behaviors (Buckley 1982). Metamorphosis begins at around 5–6 weeks post hatch and is completed by 8 weeks or when larvae reach around 8–9 mm in length (Collette and Klein-MacPhee 2002). Metamorphosis is characterized by migration of the left eye to the right side of the head along with a loss of pigmentation on the left (blind) side (Klein McPhee 1978; Chambers and Leggett 1987; Collette and Klein-MacPhee 2002). Along with these physical changes, pelagic larvae begin to settle to demersal habitat (Fig. 2.2). As demersal juveniles, estuarine or inshore-spawning individuals tend to stay in these habitats for their first 2-3 years of life (depending on study and by stock), with seasonal movements to avoid colder temperatures nearshore (Pereira et al. 1999). Post-settlement winter flounder are negatively buoyant and are thus more affected by bottom water cycling than surface water cycling within nursery grounds (Pearcy 1962; Pereira et al. 1999). Winter flounder's essential fish habitat source document characterized small and narrow estuary habitat to be productive nursery grounds as they tend to restrict heavy water flow and in turn help retain larvae (Pereira et al. 1999). Notably, winter flounder on Georges Bank spawn, settle, and mature offshore where waters are generally shallower, demonstrating diverse early life history strategies. Estuarine or coastal-spawned winter flounder tend to remain in or near inshore nursery waters until maturity when they begin spawning migrations between inshore and offshore regions (Langan 2021).

Juveniles

Habitat suitability for juvenile winter flounder is highly dynamic and influenced by various regulatory factors essential for growth and survival (Manderson et al. 2002). The suitability of shallow habitats is reported to depend in large part on predator density (Manderson et al. 2004). Larger Young of Year (YOY) tend to concentrate in shallow, structurally complex habitats that can be as shallow as 1-2 m deep, which may provide refuge from predators (Manderson et al. 2004). While some shallow habitats may lack structural complexity, YOYs tend to prefer them over deeper water, where predator density may be higher (Manderson et al. 2004). Manderson et al. (2004) found that YOY movement from deep habitat to shallow shoreline areas is expected in the future if stressors found in shallow water are less influential than the photo-negative benefits of deeper water.

Adults

Winter flounder adults are found in estuarine, coastal, and offshore waters along the Atlantic coast of North America in depths less than 100 m (Mansueti 1962; McCracken 1963; Olla et al. 1969; Kennedy and Steele 1971; Van Guelpen and Davis 1979; Macdonald and Green 1986; Steimle et al. 1993). There is plasticity in the habitat winter flounder utilize for spawning, ranging from shallow estuarine habitat to open ocean depending on the geographic location of the stock

(Table 2.1, Pereira et al. 1999). Adult winter flounder migrate to spawning habitat during the winter and spring months (NOAA 2023) and have been reported to spawn in 3-7℃ (Press et al. 2014). Many adults move into shallower water ahead of spawning and have been observed in estuary depositional habitats less than 5 m deep (Manderson et al. 2004). High-quality spawning habitat for winter flounder was deemed as shallow (<18 m) mud, sand, and transitional bottom sediment and deep (>18 m) mud areas (Howell et al. 2016). The Georges Bank stock is thought to be primarily restricted to offshore spawning while the Gulf of Maine stock uses variable habitats and Southern New England winter flounder are believed to be obligate estuarine spawners with the exception of some offshore residents (DeCelles and Cadrin 2011, Siskey et al. 2020). Winter flounder have been regarded as "total spawners", such that oocytes develop simultaneously, but females may lay multiple batches of benthic eggs throughout the spawning season (Press et al. 2014). However, contrary research suggests that winter flounder should be considered batch spawners, in which females develop and release eggs in batches, and subsequently oocytes develop in batches (Burton and Idler 1984).

Winter flounder are thought to have natal homing tendencies that require them to return to their historical spawning grounds. The results of studies aimed at characterizing the degree of spawning site fidelity have depended on the scale of the tagging study (DeCelles and Cadrin 2011), with some studies determining winter flounder exhibit local spawning (Perlmutter 1947, Saila 1961), another determining they exhibit a homing tendency towards habitat rather than specific spawning grounds (Phelan 1992), and lastly, those determining that winter flounder exhibit natal homing (Pruell et al. 2010, Ziegler et al. 2019).

Distribution and Habitat Use by Stock

Gulf of Maine Stock

Gulf of Maine winter flounder can utilize estuarine habitat for spawning, but evidence supports plasticity in their spawning patterns and locations (DeCelles and Cadrin 2010; Fairchild et al. 2013). Fairchild et al. (2013) observed year-round residence in coastal waters and that the majority of fish did not enter estuaries during the spawning season. Offshore spawning by winter flounder in the Gulf of Maine appears to be the dominant mode, and this is supported through a variety of lines of evidence including tagging, and fisheries-dependent data (Fairchild et al. 2013). The estuaries adjacent to the Gulf of Maine are thought to provide an essential nursery habitat for young-of-year winter flounder (Hammer et al. 2020), although no study has focused on broader habitat use. The change in perception of winter flounder spawning habitat in the Gulf of Maine may result from observation bias (e.g., traditional sampling of estuaries and more recent observations of coastal spawning from acoustic tagging) or a shift from primarily estuarine spawning to coastal spawning associated with warming and deeper distribution of winter flounder in the last decade (e.g., Mills et al. 2024, Table 2.3).

Kerr et al. (2022) examined the Mohn's rho time series of different groundfish stocks in the Gulf of Maine region and identified increases in bottom temperature as a driver of the stock's variant distribution and productivity.

Table 2.3. Winter Flounder Depth and Latitude Change. Average depth and latitude change over time of winter flounder, as well as the significance of these changes. Excerpt from Mills et al. (2024)

| | Latitude (N) | | | Depth (m) | | |
|---|---|---|---|---|---|---|
| | 1970-2009 | 2010-2019 | *P* | 1970-2009 | 2010-2019 | *P* |
| Winter flounder | 41.70 | 41.98 | 0.006 | 61.12 | 68.14 | 0.004 |

Georges Bank Stock

Estuarine spawning is considered non-existent in the Georges Bank stock due to its geographic range and its adaptation to rising sea levels over geological time (DeCelles and Cadrin 2011). However, connectivity with the SNE/MA stock may be an important connection to the estuaries in the southern part of the species range. Migration across the Great South Channel onto Georges Bank is possible, causing a decline in the SNE/MA stock abundance and a subsequent increase in the Georges Bank stock abundance (Bell et al. 2015). Siskey et al. (2020) found some evidence of inshore spawning based on otolith chemistry from winter flounder samples on Georges Bank, but concluded that the sample size was too small to support a robust conclusion; therefore, Georges Bank spawning is still thought to occur only offshore.

Kerr et al. (2022) found that warm core ring formation is one environmental driver affecting the habitat use and distribution of winter flounder in Georges Bank, as the number of warm core rings explained the most variance in groundfish Mohn's rho values across the region (Kerr et al. 2022).

Southern New England/Mid-Atlantic Stock

Since the 1980s, winter flounder within the Southern New England/Mid-Atlantic stock have undergone a significant reduction in biomass and contraction in their habitat use (Frisk et al. 2018). During this same time, a key predator, summer flounder, exhibited a range expansion and increase in abundance (Frisk et al. 2012). However, fishing mortality was estimated to be 3 times the FMSY (fishing mortality rate under maximum sustainable yield) in the late 1980s and early 1990s, and the reduction in stock biomass was concomitant with historical overfishing (NEFSC 2022). Thus, while stock productivity may be suppressed, and overfishing hasn't occurred since 2007, the primary cause of the contraction of habitat is most likely reduced abundance due to historical overfishing.

Environmental Influence on Distribution

Winter flounder are considered eurythermal, exhibiting broad thermal tolerance, including cold-tolerance and the ability to withstand a wide range of temperatures and salinities. They produce an antifreeze protein that protects against cold shock, reducing the likelihood of overwinter mortality (Fletcher 1981; Wilber et al. 2016). Additionally, they are considered euryhaline and able to tolerate a wide range of salinities (Pearcy 1962, McCracken 1963). Despite these broad tolerances, in the Gulf of Maine region, winter flounder adults are typically found mainly in areas with moderate temperatures (15-20℃) and salinities (18-26 ppt) and are rarely found in areas with temperatures >20℃ and salinities >26 ppt (Hammer et al. 2020). The maximum temperature adult winter flounders are known to survive is 19.3℃ (Hammer et al. 2020). However, juveniles are more flexible in their thermal tolerance and can be found at higher than 19.3 C in estuaries (Hammer et al. 2020).

Many organisms' first response to climate change is shifting their distribution (Nye et al. 2009). Species that have been pushed outside their range are susceptible to further disturbance to their population (Langan 2021). Because of winter flounders' plasticity in habitat use, adaptation to climate conditions has been predicted for winter flounder stocks (Butts and Litvak 2007, Klein et al. 2016). However, winter flounder also have a high degree of spawning-site fidelity (Langan 2021), which has the potential to make this species particularly vulnerable to changing ecosystem conditions (Butts and Litvak 2007, Klein et al. 2016). For example, the natal homing tendencies of winter flounder may require them to return to their historical spawning grounds where conditions may no longer be optimal (Bell et al. 2015). In 2015, Bell et al. noted that the center of biomass of winter flounder had varied over time without a clear trend, suggesting that warmer temperatures may not have a significant effect on the possible retraction or expansion of the species (Bell et al. 2015). Additionally, an examination of biomass weighted mean centroid of winter flounder distribution between two time periods (1986–1990 and 2014–2018) showed that winter flounder retained their historical distribution (Roberts et al. 2020). This stability has been attributed to flounder being a benthic species with strong association with the bottom substrate and spawning site fidelity, as well as spawning phenology (Bell et al. 2014, Roberts et al. 2020). However, a more recent evaluation of the distribution of winter flounder over time showed relative stability of mean latitude between the 1970s and 2010s but shifts northward and into deeper habitats since 2010 (Table 2.2, Mills et al. 2024). Winter flounder may have a sub stock structure at the level of individual estuarine habitats, which are disproportionately affected by climate change impacts at the southern extent of their range (Able et al. 2014). Thus, it is possible that individuals are not shifting north but instead are declining in abundance due to low productivity of local spawning groups resulting from exposure to less-suitable conditions (Bell et al. 2015).

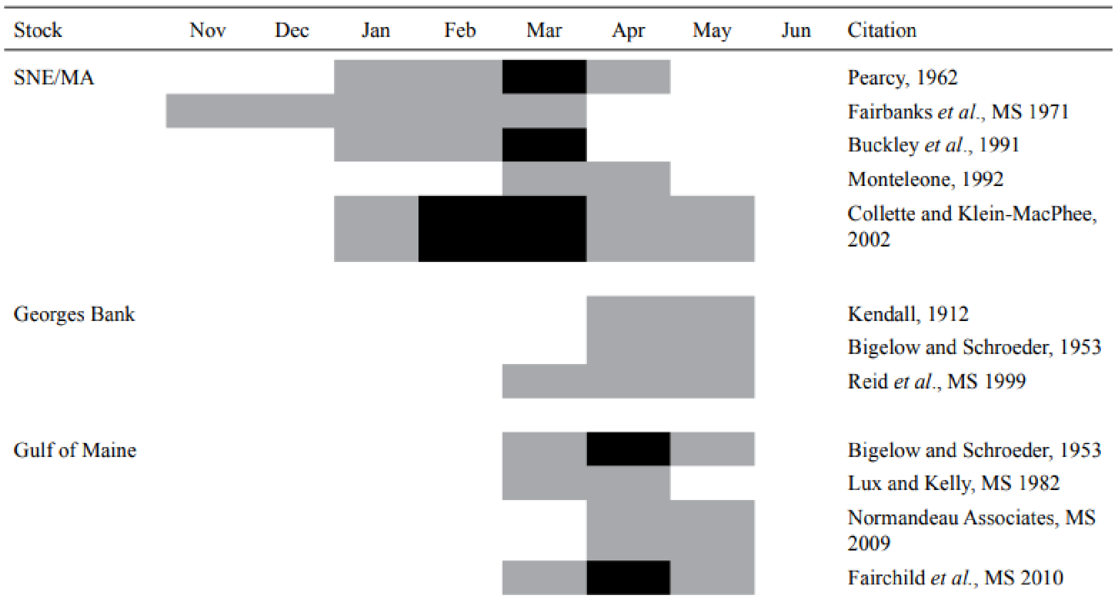
Essential fish habitats like estuaries and inshore bays are especially vulnerable to climate and anthropogenic stressors due to their proximity to human-caused disturbances such as pollution (Langan 2021). Estuaries are considered important nursery habitat for the SNE/MA stock, allowing young-of-year to remain for their first two years before moving offshore (Fairchild et al. 2012). However, these historic nursery habitats, such as the lower Narragansett Bay, are increasingly impacted by warming and pollution (Langan 2021). Winter flounder are highly susceptible to the effects of high temperature, hypoxia, and anthropogenic disturbances within their nursery grounds (Langan 2021). Given that much of the current population depends on these vulnerable habitats, the SNE/MA stock is unlikely to rebuild to historical levels of abundance (Langan 2021).

**Spawning Phenology and Recruitment of Winter Flounder**

*General description for the species*

Environmental factors play an important role in recruitment success and the productivity of winter flounder stocks (Wiedenmann and Jensen 2019). Spawning season varies by latitude with more southerly populations spawning earlier due to warmer temperature differences (Table 2.4, DeCelles and Cadrin 2011). The Southern New England/Mid-Atlantic stock is the earliest of the three stocks to spawn, beginning in early December to late March and occurring in mostly inshore estuaries and embayments (Ziegler et al. 2019). Spawning on Georges Bank occurs from March to May but peaks in April when there are the most egg densities present in their offshore spanning locations (Pereira et al. 1999). The spawning period for Gulf of Maine occurs both offshore (Fairchild et al. 2017) and in inshore estuary habitat from early March to early June with a peak in late April/early May (Fairchild et al. 2013). Due to these differences in spawning time, winter flounder stocks can experience quite different ocean conditions during their early life history. Temperature is an important driver in determining survival during the egg, larval, and settlement phases of the winter flounder due to the amount of suitable thermal habitat available to juveniles in each season (Bell et al. 2014, Table 2.1, Fig. 2.3). Recruitment among all three stocks of winter flounder has declined since the late 1980's (Bell et al. 2014, Fig. 4).

Table 2.4. Spawning Seasons of inter flounder in Different Stock Regions. The range of spawning times is indicated with a gray block, with peak spawning times indicated with a black block. Excerpt from DeCelles and Cadrin (2011).



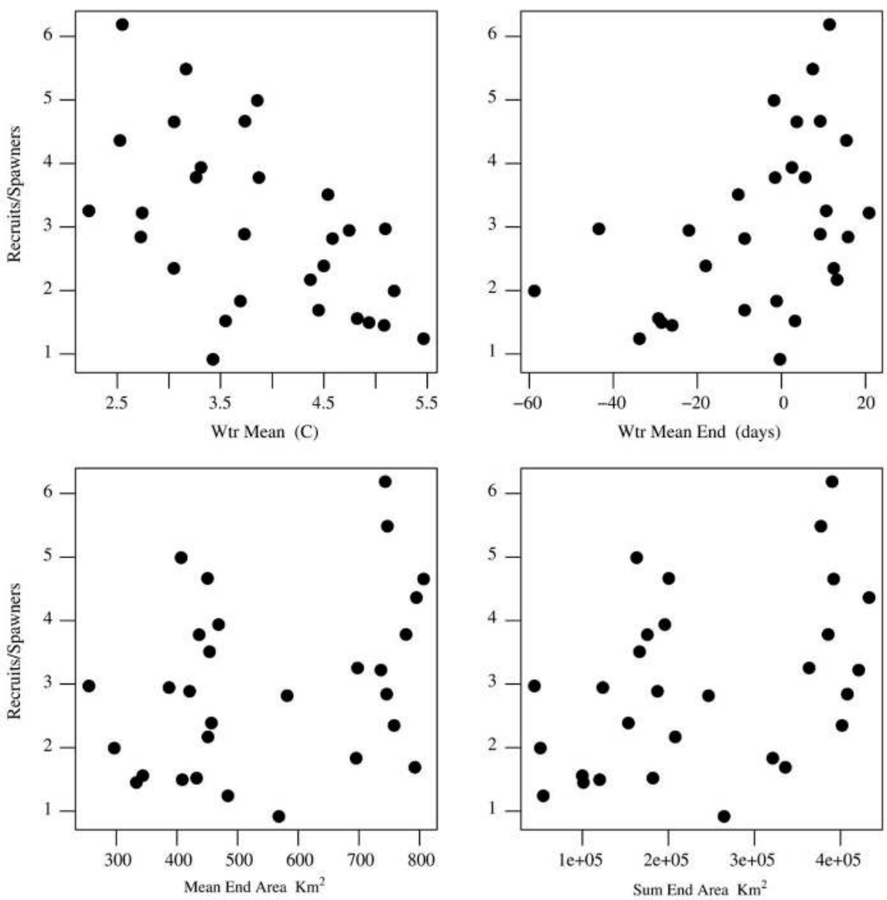



Figure 2.3. Thermal Indices and Potential Environmental Drivers of Winter Flounder. Four thermal indices and potential environmental drivers and winter flounder recruits divided by spawners. (Wtr Mean = mean winter temperature Jan–Mar temperature averaged across estuaries, Wtr Mean End = the number of days between the end of winter and the mean end of winter averaged across estuaries, Mean End Area = the mean thermal habitat area available each year, Sum End Area = the summed thermal habitat area available each year.) Excerpt from Bell et al. (2014).

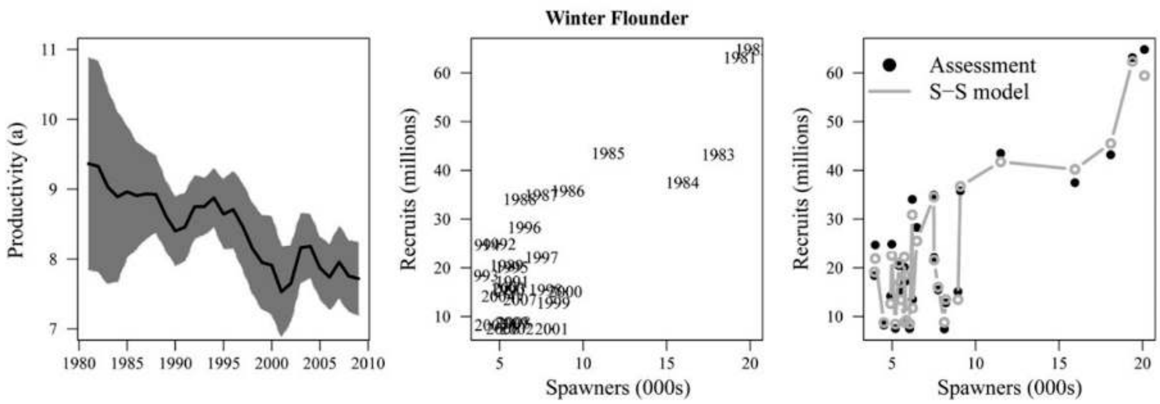



Figure 2.4. State–Space Ricker Model for Winter flounder. Results of the best fit, time-varying, state–space Ricker model for winter flounder. Left column: the estimate of the productivity parameter (a or ln a) over time. Center column: the spawner and recruitment data. Right column: the best-fit stock–recruit relationship. Excerpt from Bell et al. (2014).

*Gulf of Maine Stock*

Press et al. (2014) found thatcolder temperatures and later vernal warming in the Gulf of Maine resulted in spawning one month later than in the other two stocks (Press et al. 2014). In a study of phenology shifts over time for multiple fish species within the Gulf of Maine, winter flounder were observed to shift their spawning times earlier in the year (Staudinger et al. 2019). The study predicted that this shift toward earlier spawning was associated with warming water in the Gulf of Maine (Staudinger et al. 2019). Therefore, spawning seasonality of winter flounder may be changing in response to decadal warming trends in the Gulf of Maine (Press et al. 2014). Press et al. (2014) also examined winter flounder oocyte and larval development in the Gulf of Maine to determine its patterns and seasonality. In general, they found decreased egg survival and increased hatching rate of Gulf of Maine winter flounder with increasing temperature (Press et al. 2014).

*Georges Bank Stock*

Recruitment from the Georges Bank stock varied through the 1980s and early 2000s and gradually declined to a historic low value in 2015 with a subsequent increase in recent years (Fig. 2.5, NEFSC 2022). Mills et al. (2024) compared the mean ratio of recruitment to spawning stock biomass from prior and subsequent to 2010. They found a statistically significant negative difference between recruitment in the two time periods, which they attributed to significantly warmer conditions since 2010 (Fig. 2.6).

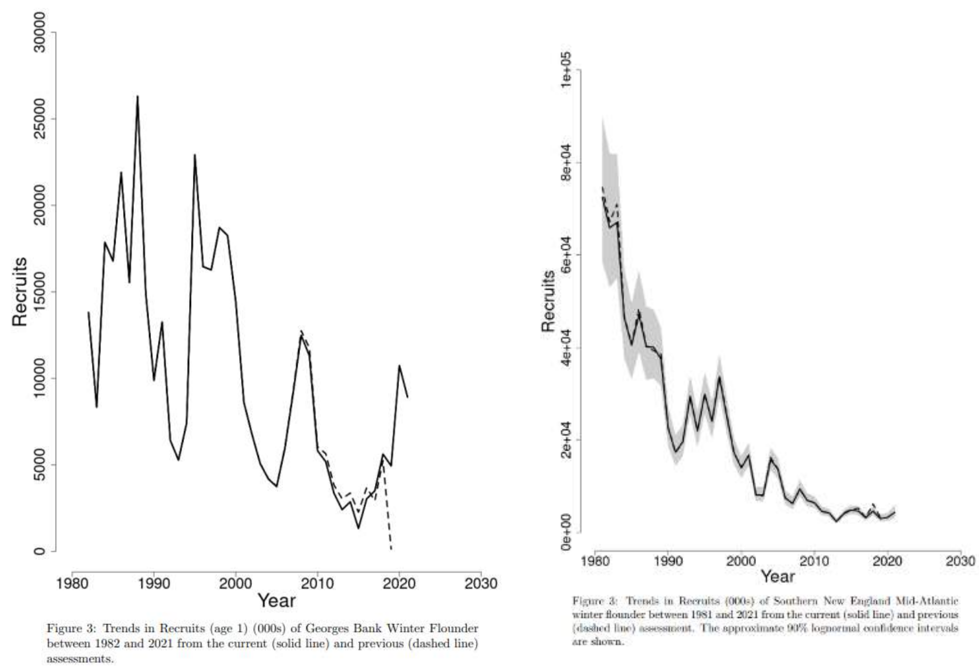



Figure 2.5. Recruitment Time Series of Winter Flounder. Recruitment time series from GB (left) and SNE/MA (right) stocks. Excerpt from NEFSC 2022.

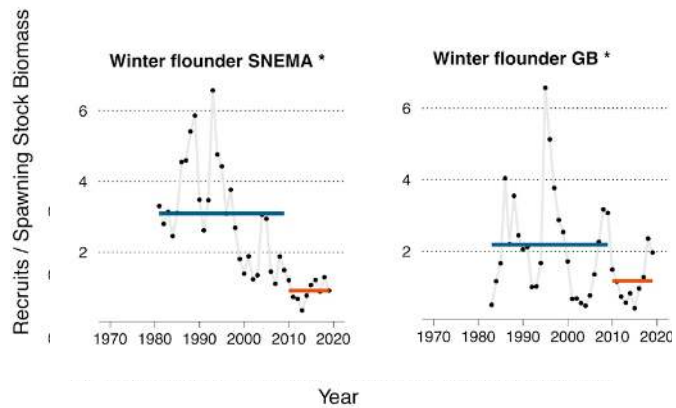



Figure 2.6. Recruits per Spawner Time Series for Winter Flounder. Time series of the Recruits-to-Spawning Stock Biomass ratio for SNE/MA and Georges Bank winter flounder stocks, indicating the mean ratio prior to 2010 in blue and from 2010 onwards in orange. Asterisks following the stock name indicate a statistically significant difference in the ratio during the two time periods. Excerpt from Mills et al. (2024).

*Southern New England/Mid-Atlantic Stock*

Winter flounder in the SNE/MA region are known to spawn earlier in the year due to their location in lower latitudes (DeCelles and Cadrin 2011). Langan et al. (2022) described trends in the abundance of early life stages of winter flounder in Narragansett Bay from 1985 to 2016 (Fig. 2.7). They concluded that abundanceof all winter flounder life stages has declined below the mean (Langan et al. 2022, Fig. 2.7).

Due to their southern-most distribution of this temperate species, the impact of climate change on phenology may have larger implications on SNE/MA winter flounder recruitment than on more northerly distributed stocks. Invading warm-water species into the southern end of endemic fish populations in the Northwest Atlantic can lead to accelerated declines in productivity, causing unprecedented shifts in the marine biological community (Langan 2021).

However, the densities of known predators of winter flounder eggs and juveniles were not found to significantly impact interannual variation in winter flounder juvenile abundances (Wilber et al. 2016). In two estuaries, the abundance of age-1 winter flounder positively correlated with warmer April temperatures from two years previous (Wilber et al. 2016). Wilber et al. (2016) predicted that this could be due to the past warmer temperatures bringing about higher benthic productivity, therefore increasing the overall availability of prey for juvenile winter flounder and allowing energy reserves to be refilled for a more successful spawning season. A recent examination of adult spawning behaviors of winter flounder suggests that spawning multiple cohorts (i.e., early and later in the same spawning season) within the same year-class could be a bet-hedging strategy in the face of uncertain environmental conditions (Gallagher et al. 2015).

Overfishing took place on the SNE/MA winter flounder stock from the 1980s through early 2000s and since this time the stock has not been able to rebuild to its historical abundance levels (NEFSC 2022, Fig. 2.5, Fig. 2.6). This lack of rebuilding has been attributed to decreased recruitment and increased juvenile mortality (Langan 2021, McElroy et al. 2015, Wiedemann and Jensen 2019, Fig 2.8). Recruitment estimates from the 2022 stock assessment show a declining trajectory from the 1980s to today, and the recruitment assumption for projections and management reference points was revised from the previously assumed long-term average to a recent average based on a changepoint analysis (NEFSC 2022, Fig. 2.5), but Frisk et al (2018) found the number of recruits per spawner has remained relatively flat. In support of the importance of adult stock size to the maintenance of populations, Wilber et al. (2016) found that the single best predictor of age-1 winter flounder abundance in the SNE/MA region was egg abundance of the previous year.

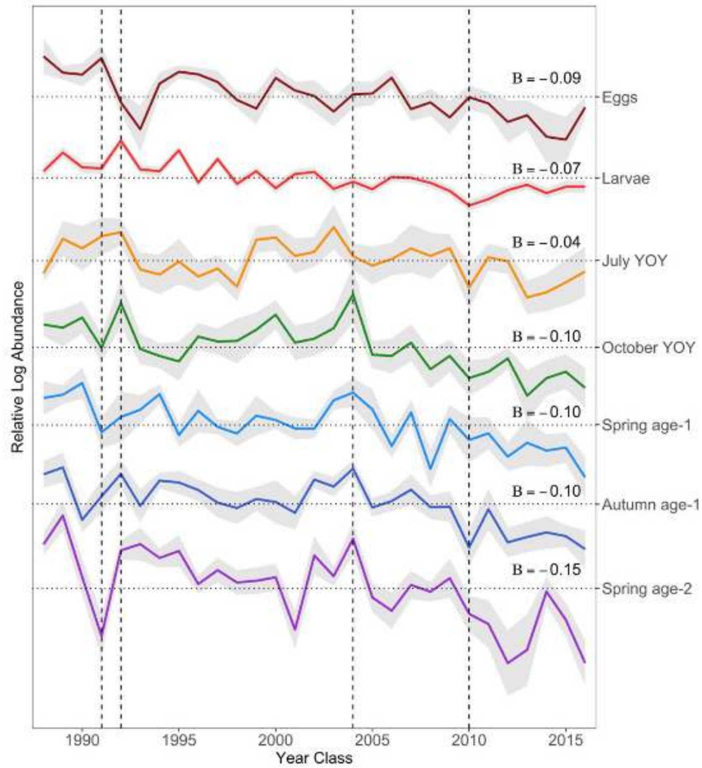



Figure 2.7. Narragansett Bay Winter Flounder Relative Abundance. Relative abundance indices of Narragansett Bay winter flounder within the SNE/MA stock by life-stage and year class with 95% confidence intervals (gray) from the estimated measurement error variances. The horizontal dotted lines represent the mean abundance and are offset by 3 to reduce overlap. B represents the rate of decline of log life stage abundance over time. The vertical dotted lines highlight specific year classes in 1991, 1992, 2004, and 2010. This figure is an excerpt from Langan et al. (2022).

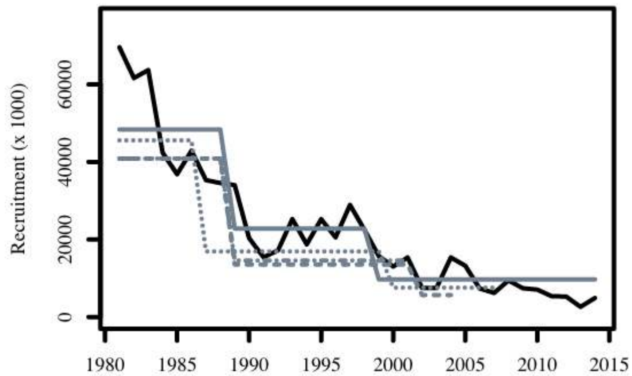



Figure 2.8. Recruitment Estimations of Winter Flounder in SNE/MA. Recruitment estimations of winter flounder in the SNE/MA stock using a regime shift detection algorithm. Past assessments are dotted gray lines, while the solid black line is the most recent assessment. The solid gray line is the estimated recruitment regime given the most recent recruitment estimations. Excerpt from Wiedemann and Jensen (2019).

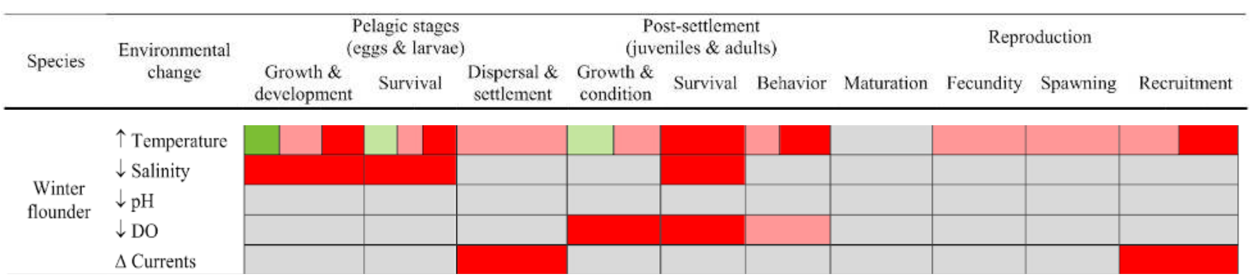
**Growth and Maturity of Winter Flounder**

General description for the species

Winter flounder exhibit sexually dimorphic growth with females generally exhibiting faster growth rates and attaining a larger asymptotic size than males (Figure 2.10 and Table 2.6, DeCelles and Cadrin 2011). The growth rate of winter flounder depends on multiple external conditions, including temperature, salinity, water quality, and food availability (Manderson et al. 2002; NOAA 2023, Fig. 2.9). Klein et al. (2017) summarized the expected impacts of climate change on winter flounder growth and maturity due to changes in temperature, salinity, dissolved oxygen (DO), pH, and ocean currents (Klein et al. 2017, Table 2.5). The study found that warmer temperatures had varied impacts on winter flounder growth in pelagic and post-settlement early life stages (Klein et al. 2017, Table 2.4). Klein et al (2017) also noted that decreased salinity negatively affected winter flounder growth and development in pelagic and post-settlement life stages and lowered DO negatively affected post-settlement growth (Klein et al. 2017, Table 2.5). Manderson et al. (2002) studied the influence of varying nursery conditions on post-settlement winter flounder through lab-based experiments. Their results showed that increased temperature and salinity adversely affected winter flounder growth (Manderson et al. 2002, Fig. 2.9).

The length and weight-at-age of winter flounder appear to have declined significantly in recent years (2010-2019, Mills et al. 2024, Fig. 2.11), with the greatest declines in the SNE/MA stock (Mills et al. 2024). The decline in early spring condition factor and growth, as well as possible increased predation, may be preventing winter flounder from rebuilding its abundance species-wide (Howell et al. 2016).

Table 2.5. Environmental Impacts on Winter Flounder. Excerpt from Klein et al. (2017). Summary of environmental impacts on winter flounder based on literature review. Green = positive effects, red = negative effects, light green or light red = indirect positive or negative effect, Multiple = mixed effects due to multiple driving factors.



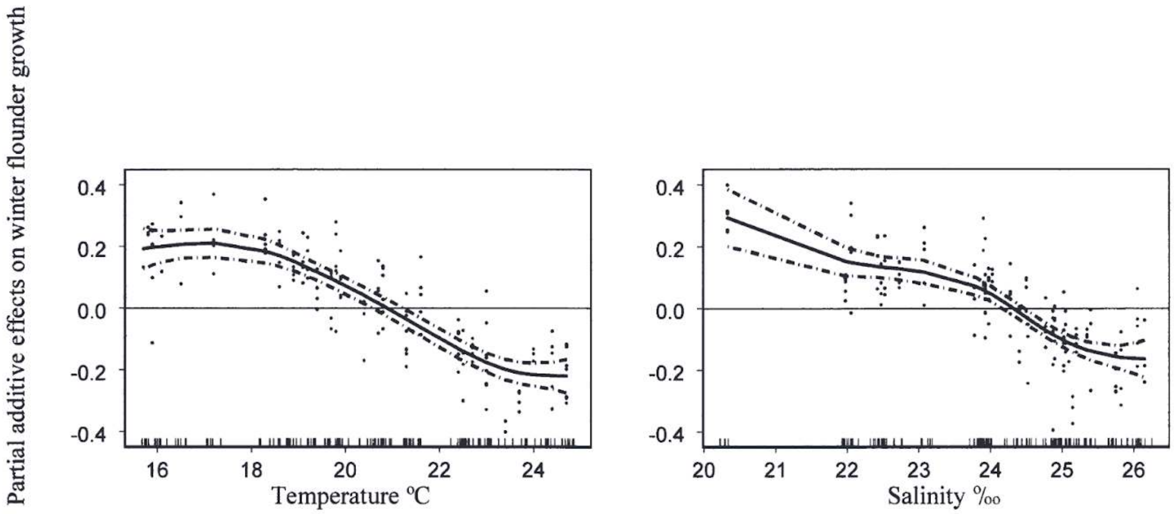



Figure 2.9. Partial Additive Effects of Temperature and Salinity on the Growth of Winter Flounder. Deviance plots derived from a generalized additive model showing the partial additive effects of temperature, salinity, on the growth of winter flounder in enclosures. Horizontal lines indicate thresholds for positive and negative effects, while vertical dashes along the abscissa show the distribution of values for each environmental variable. Dashed lines represent 2 standard error confidence bands. Excerpt from Manderson et al. (2002).

Winter flounder tend to mature at ages 3.7 years for males and 4 years for females (Beacham 1982). The further south the population of winter flounder is distributed, the faster individuals can mature (DeCelles and Cadrin 2011). With overfishing occurring between the 1970s and 1980s and higher selection pressure at certain life stages, the age at maturity of winter flounder has changed over time in all three stocks to varying degrees (DeCelles and Cadrin 2011). Fisheries-induced evolution may be at play in some of these areas, acting to differentiate the vital rates between stocks (DeCelles and Cadrin 2011)

Wilber et al. (2016) examined the growth responses of winter flounder in a Southern New England estuary throughout a spring season with colder temperatures. Although winter flounder are adapted to withstand colder temperature conditions, they observed fewer age-1 juveniles following the colder winter. This suggests that continued colder temperatures can negatively affect survival, foraging success, and reproduction, in addition to a smaller body size (Wilber et al. 2016). A smaller body can have lasting negative effects on the lives of individuals, affecting the risk of predation, reduced foraging success, and a delay in reaching sexual maturity (Wilber et al. 2016).

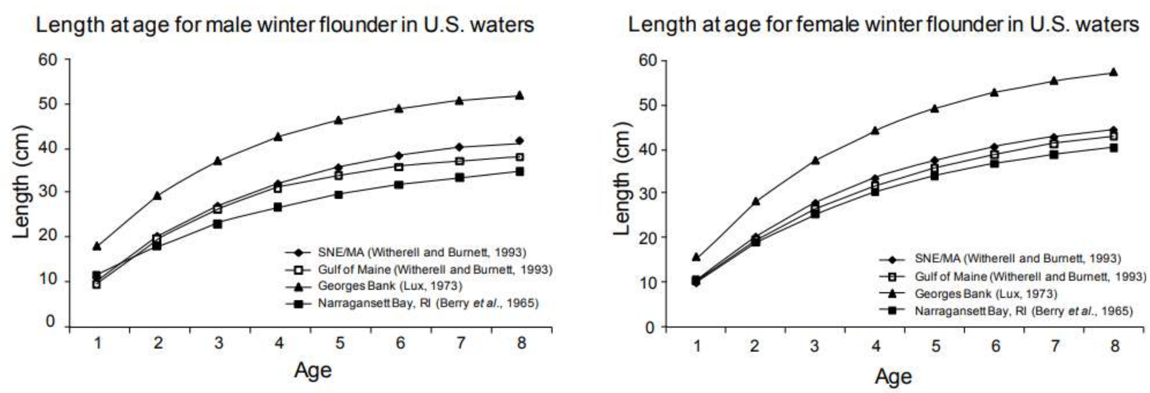



Figure 2.10. Winter Flounder Male and Female Growth Curves. Growth curves for male and female winter flounder in US waters. Figure excerpt from DeCelles and Cadrin (2011).

Table 2.6. Age at 50% Maturity for Male and Female Winter Flounder. Estimates of age at 50% maturity (A50) and length at 50% maturity (L50) for winter flounder males and females in US waters. Excerpt from DeCelles and Cadrin (2011).

| Stock | $A_{50}$ Males (y) | $A_{50}$ Females (y) | $L_{50}$ Males (cm) | $L_{50}$ Females (cm) | Citation |
|---|---|---|---|---|---|
| SNE/MA | 2.0 | 3.0 | 20–25 | 20–25 | Perlmutter, 1947 |
| | 3.3 | 3.0 | 29.0 | 27.6 | O'Brien *et al.*, MS 1993 |
| | 3.1 | 3.0 | 28.0 | 28.3 | Witherell and Burnett, 1993 |
| Georges Bank | 1.9 | 1.9 | 25.6 | 24.9 | O'Brien *et al.*, MS 1993 |
| Gulf of Maine | 3.3 | 3.5 | 27.6 | 29.7 | O'Brien *et al.*, MS 1993 |
| | 3.3 | 3.3 | 27.2 | 28.7 | Witherell and Burnett, 1993 |
| Gulf of St. Lawrence | – | – | 21 | 24 | DFO, MS 2010 |
| Newfoundland | 6.0 | 7.0 | 21.0 | 25.0 | Kennedy and Steele, 1971 |

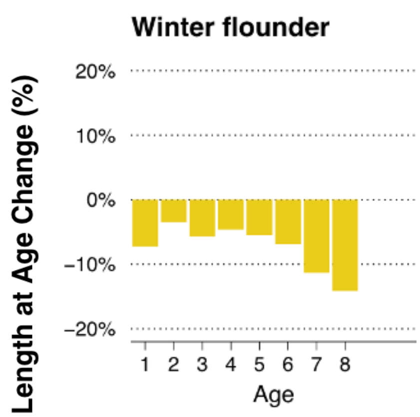



Figure 2.11. Length-at-Age Differences for Winter Flounder Over Time. Percent difference in length-at-age for 1970–2009 versus 2010–2019. Yellow bars indicate significant declines. Excerpt from Mills et al. (2024).

*Gulf of Maine Stock*

Most case studies of environmental effects on the growth and maturity of winter flounder were either based on studies conducted in laboratory conditions or in southern areas. However, Pereira et al. (1999) reported that growth is slower, onset of maturity is older, and the spawning season is later for winter flounder in the Gulf of Maine than more southern areas, presumably because of regional differences in temperature.

*Georges Bank Stock*

Compared to inshore populations that spawn in estuarine habitats, Georges Bank winter flounder are larger and faster-growing as adults and are thought to produce larger and faster-growing larvae (Butts and Litvak 2007). Differences in growth rates of winter flounder in various localities may lead to distinct phenotypic responses to stressors, such as ocean warming (Butts and Litvak 2007).

*Southern New England/Mid-Atlantic Stock*

A 29-year time series of the SNE/MA winter flounder stock located in Long Island Sound revealed complex relationships between population abundance and growth (Howell et al. 2016). As population abundance declined in the stock, so did condition factor and size at maturity for mature females (Howell et al. 2016). This was validated by a significant increase in the proportion of individuals mature at a given length for both sexes (Howell et al. 2016). Conversely, immature winter flounder showed an increase in overall condition factor as well as an unexpected increase in size at maturity as abundance declined (Howell et al. 2016; Fig. 2.12). Howell et al. (2016) suggested that individuals who directed their energy towards somatic growth rather than sexual maturation may have survived longer in a colder environment compared to those who matured at smaller sizes. The SNE/MA stock also revealed growth shifts related to population decline: age 4 and 5 winter flounder experienced a larger growth increment between ages 1 and 2 (Howell et al. 2016). This pattern suggests that natural mortality increased from predation, thereby favoring faster-growing individuals in a highly size-selective environment (Howell et al. 2016).

A two-year study of young-of-year winter flounder in Long Island, NY, found that daily growth was negatively correlated with age and daily average temperature (Gallagher et al. 2015). However, the association between temperature and daily otolith growth was weak, suggesting that temperature may have an indirect effect on growth and that other factors could be influencing growth patterns (Gallagher et al. 2015).

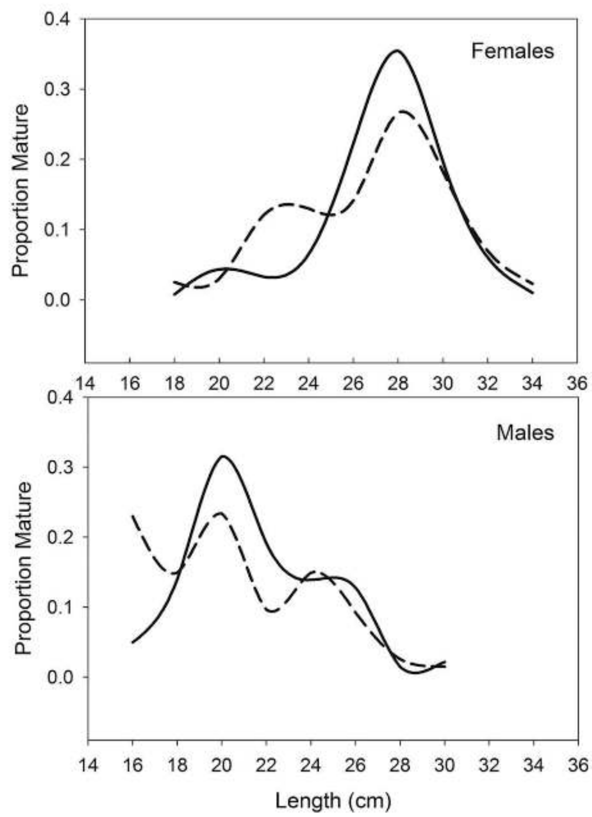



Figure 2.12. Percentages of Mature Winter Flounder Total Length. Percentages of TL (total length, cm) of sampled female or male winter flounder that were newly mature during the moderate-abundance (1992-2002; dashed line) and low-abundance (2003-2013; solid line) time periods in the SNE/MA stock. Excerpt from Howell et al. (2016).

**Natural Mortality of Winter Flounder**

General description for the species

Because of the role that large-scale environmental factors have on survivorship of winter flounder across life stages, fisheries stock assessment scientists predict that the biomass of all three stocks cannot fully recover to historic abundance levels (Langan 2021). Winter flounder are most vulnerable during their first summer at the post-larval stage (Langan et al. 2022). Climate-driven increases in temperature, hypoxia, and predator abundance have contributed to increased juvenile mortality, which may be a primary driver of the long-term declines observed in population abundance and biomass (Langan et al. 2022). In addition to climate-related stressors, winter flounder are also sensitive to other human impacts on environmental conditions, such as thermal effluent from power plants and pollution from wastewater treatment facilities due to their dependence on estuarine habitats for spawning (Langan et al. 2022).

Higher temperatures, in general, can have cascading effects on the food web that ultimately influence the survival of winter flounder (Kerr et al. 2022). For example, the decline of the zooplankton species *Calanus finmarchicus*, an important food source for forage fish, could have a cascading effect on winter flounder who prey on them (Kerr et al. 2022). At the same time, key predators of winter flounder (e.g. striped bass, summer flounder) are also experiencing shifts in abundance, phenology and spatial distributions. How these interacting predator-prey relationships are shaping the natural mortality rates of winter flounder are not well known.

*Gulf of Maine Stock*

No directed studies were identified on the Gulf of Maine stock; however, Swain and Benoit (2015) analyzed the depleted stocks of winter flounder and other demersal fish populations in the nearby Southern Gulf of St. Lawrence in Canada. They hypothesized that the high mortality in those stocks represented a predation-driven allee effect resulting from overexploitation by the fishery and the rise of certain groundfish predators. They found that winter flounder size distribution changed because of overexploitation (Fig. 2.13). The smaller size structure in the Gulf of St. Lawrence is associated with higher mortality and a smaller population (Swain and Benoit 2015).

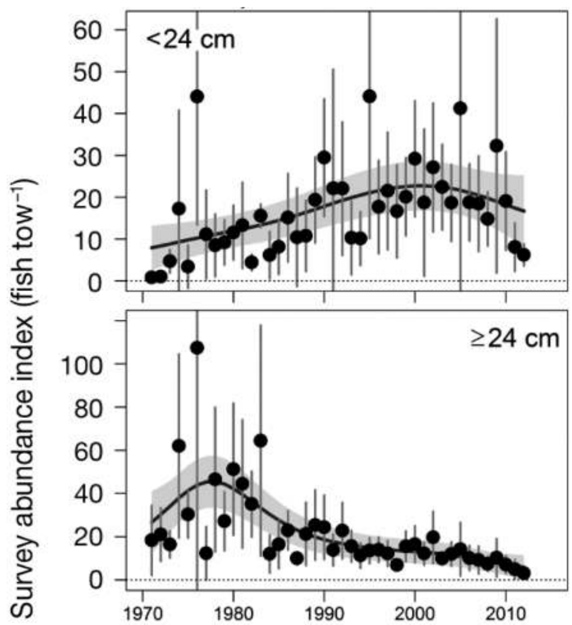



Figure 2.13. Survey abundance Index Trends by Length. Survey abundance index trends by length group for winter flounder in the southern Gulf of St. Lawrence. The two length groups roughly correspond to juveniles (top) and adults (bottom). Circles show annual stratified mean catch rates. Excerpt from Swain and Benoit (2015).

*Georges Bank Stock*

I found no evaluations of environmental impacts on natural mortality of Georges Bank winter flounder in the published literature.

*Southern New England/Mid-Atlantic Stock*

Mortality of juvenile winter flounder is increasing (Langan 2021). Substantial reductions in fishing effort have not had an effect on this loss of juvenile biomass (Langan 2021). Able et al. (2014) found that temperature increases have not directly caused the historical decline in winter flounder abundance. In some situations, climate is not solely responsible for a declining population. Decreased fitness is due to a combination of climate variation and resource competition (Nicholson 1933). Able et al. (2014) suggested that temperature increases may be contributing to a threshold effect that is leading to this decline. Their findings lead to the conclusion that once a certain temperature threshold is reached, an unknown secondary driver affects the temperature/recruitment relationship significantly enough to increase natural mortality (Able et al. 2014). In previous studies within a lab environment, winter flounder survival and growth were positively associated with higher temperatures (Able et al. 2014). Temperature may act indirectly on juvenile winter flounder, and predation may be the more influential secondary driver of juvenile mortality (Able et al. 2014).

Bell et al. (2014) explored the differences in external large-scale drivers that affect summer and winter flounder abundances within the SNE/MA stock. They found that estimates of abundance were negatively correlated with winter bottom water temperature but not with fishing mortality (Bell et al. 2014). They concluded that warming estuarine habitat kept the winter flounder stock at low abundance despite no longer overfishing. In addition to high juvenile mortality, post-settlement mortality is another main concern in winter flounder stock assessment and survivability (Dolan et al. 2021). Dolan et al. (2021) proposed that despite all management measures to prevent further overfishing, the population could be experiencing a “recruitment bottleneck,” which could potentially prevent the fishery's recovery. In 2009, the SNE/MA stock reached a new low point, totaling less than 9% of its historic biomass (Dolan et al. 2021). Despite efforts to stop overfishing and recover the fishery, the stock has not responded positively (Dolan et al. 2021).

Dolan et al. (2021) explored the differences and similarities between juvenile vital rates in five estuary bays in Long Island, NY by conducting weekly beam-trawl surveys of young-of-year winter flounder. They compared estimates of young-of-year (YOY) mortality and growth with location. They found significant differences in growth but not in mortality across locations (Dolan et al. 2021). Natural mortality between sites was not statistically different from each other, meaning that “climate-driven synchronization” may be taking place, with the possibility of increased interactions with other species more directly impacted by climate change (Dolan et al. 2021). Dolan et al. (2021) estimated that these observations resulted from multiple settlement “pulses'' throughout the spawning season. In earlier cohort pulses, YOY juveniles had faster growth, while later cohorts experienced slow and more variable growth, possibly due to increased interactions with other competing species (Dolan et al. 2021). It is assumed that early cohorts may have certain advantages in terms of out-competing other species for necessary resources like space and food (Dolan et al. 2021, Pereira et al. 1999).

Young-of-year fish exposed to habitat destruction and pollutants within essential fish habitat estuaries can have a detrimental effect on the population when combined with higher temperatures and unfavorable dissolved oxygen and salinity (Gallagher et al. 2015). Recent studies suggest that SNE/MA winter flounder exhibit a meta-population structure, with local many populations within the stock nearing full depletion (Frisk et al. 2018). With warmer winters and springs, competitor species like summer flounder may enter estuary habitat earlier, which can lower the amount of time young winter flounder can grow in low predation (Frisk et al. 2018).

Yencho et al. (2015) estimated higher mortality rates in Long Island Sound than in previous years and growth estimates that were within the range of or lower than field and otolith determinations. They observed that predation on young-of-year winter flounder in the Niantic River and Mystic River estuaries within the Long Island Sound is likely the cause of the higher natural mortality, despite other factors that may also be contributing. However, it has been difficult to determine the role of causal factors such as temperature and habitat quality affecting growth rates, as previous data all show high variation in length frequency and otolith increment analysis (Yencho et al. 2015).

Langan et al. (2022) found four environmental factors that had a significant impact on mortality rates in the early life stages of winter flounder in Narragansett Bay (Fig. 2.14). Striped searobin, a known predator of winter flounder, catch-per-tow was associated with increased mortality in larvae transitioning to young of year (Langan et al. 2022, Fig. 2.14). Mortality of young-of-year juveniles was positively related to summer mean sea surface temperature as well as the number of cormorant nesting pairs and negatively related to summer monthly mean dissolved oxygen (Langan et al. 2022, Fig. 2.14).

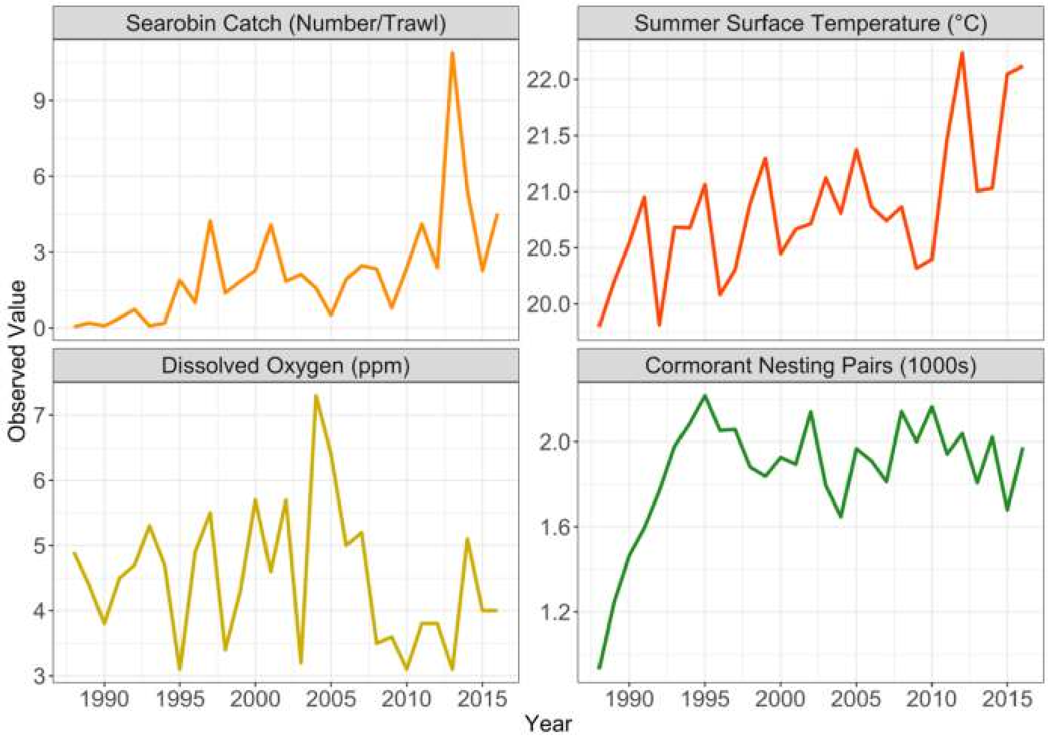



Figure 2.14. Covariates Impacting Natural Mortality Winter Flounder in Narragansett Bay. Covariates identified as having a significant impact on the mortality of winter flounder in Narragansett Bay. Excerpt from Langan et al. (2022).

**Discussion and Conclusions**

This ecosystem profile of winter flounder provides a synthesis of the best available science on the influence of climate and ecosystem drivers on aspects of winter flounder stock dynamics. This synthesis indicates that temperature-related processes are the most consistent and influential drivers across stock regions and population dynamics. Warming ocean temperatures have links to distribution and habitat use, spawning phenology, and changes in growth and maturation (Table 2.7). Additionally, thermal processes also influence natural mortality events, such as reduced egg survival and increased predation and competition with new shifting species (Table 2.7).

Although these environmental drivers are all known to impact winter flounder stock dynamics, the magnitude and direction of these effects appear to be stock-specific. Winter flounder have a wide spatial distribution along the Northwest Atlantic Shelf, and this is reflected in the way each stock responds to environmental stressors. Further work is needed to understand the nuances in these responses and develop stock-specific management strategies that account for dynamic environmental conditions in the Northwest Atlantic.

Collectively, results from this ecosystem profile demonstrate that thermal conditions and associated oceanographic processes are impacting the recovery potential of winter flounder to return to their historical abundance and productivity level. These drivers may have individual roles in reshaping the baseline that managers need to identify in the stock assessment process in order to effectively manage this critical fishery. Further research is needed to test these specific drivers of winter flounder stock dynamics and inform future management decisions that benefit the fishery and all who depend on it.

Ecosystem profiles, such as this one, have become fundamental to integrating climate and ecosystem impacts into fisheries management. By synthesizing the best available knowledge of the environmental and ecological drivers that affect winter flounder stock dynamics, these profiles can inform choices in stock assessment modeling, such as the inclusion of environmental covariates into the process to determine management decisions. They also provide a solid foundation for developing precautionary management practices that take into account the non-stationarity within fish stocks. In doing this, ecosystem profiles can be considered as both strategic and diagnostic tools to use in the stock assessment process.

Table 2.7. Environmental Drivers Impacting Winter Flounder. Outline of the most important environmental drivers affecting the stock indicators for winter flounder by stock.

| ***Stock Indicators*** | **Gulf of Maine** | **Georges Bank** | **Southern New England/ Mid-Atlantic** |
|---|---|---|---|
| Distribution/ Habitat Use | | Number of warm core ring formations affects distribution and habitat use due to variance seen in Mohn's rho values (Kerr et al. 2022). | Abundance estimates were negatively correlated with winter bottom water temperature, but not with fishing mortality (Bell et al. 2014). South of Cape Cod, winter flounder have moved to deeper waters, and these movements appeared to be temperature-related (Howe and Coates 1975). |
| Spawning + Recruitment | Spawning times have shifted earlier in the year due to warming surface water temperatures (Walsh et al. 2015). | | Earlier spawning times in lower latitudes, due to temperature differences (DeCelles and Cadrin 2011). |
| Growth + Maturity | Colder temperatures can result in later spawning and a shorter growing season (Press et al. 2014). | | Daily growth negatively correlates with age and daily average temperature (Gallagher et al. 2015). Temperature could have an indirect effect on the growth of young-of-year winter flounder (Gallagher et al. 2015). |
| Natural Mortality | Egg survival declines and hatching rate increases as a result of higher temperature (Press et al. 2014). | | Warming estuarine habitat has kept winter flounder stock at low levels despite no longer seeing overfishing pressure (Bell et al. 2014). With warmer winters and springs, predator species like summer flounder may enter estuary habitat earlier, which can lower the amount of time young-of-year winter flounder can grow in low-predation environments (Frisk et al. 2018, Langan 2020). |

# CHAPTER 3

# EVALUATING COHERENCE AND TEMPORAL SHIFTS IN WINTER FLOUNDER STOCK DYNAMICS IN US WATERS

## Introduction

The Northeast US shelf marine ecosystem has experienced measurable ecosystem changes, with ocean waters warming rapidly relative to the global ocean (Pershing et al. 2015). Sea Surface Temperature (SST) in the Northeast US Shelf has increased at a rate that is 2.5 times the warming rate experienced over the global oceans (Mills et al. 2024). Directional trends in ocean conditions, such as those experienced under climate change, can trigger large-scale regime shifts in the ecosystem. A regime shift, or a transition from one system state to another, has the potential to impact both the structure and function of an ecosystem, including fishery productivity (Mills et al. 2024).

Abrupt changes in oceanic conditions, such as regime shifts, can fundamentally alter the ecosystem relationships that regulate fish populations. For example, a shift in the stock-recruitment relationship can have significant consequences for population productivity, resilience, and its ability to recover from overfishing (Blöcker et al. 2023, Perälä and Kuparinen 2015). If a regime shift leads to a lowered productivity regime, a fishery's capacity to recover may be reduced. Conversely, a shift towards a higher productivity regime that remains undetected could lead to underfishing and low fishery yields (Perälä and Kuparinen 2015).

Undetected or unaccounted-for regime shifts that alter fundamental stock dynamics can greatly impact our ability to accurately assess a stock, therefore reducing the effectiveness of fisheries management. When underlying environmental conditions change rapidly from a previous regime, the historical information used to characterize the stock in the assessment model may no longer accurately represent the current system dynamics (Perälä and Kuparinen 2015). This is particularly critical for establishing biological reference points (BRPs). BRPs are a crucial component of fisheries management, as they are used to determine stock status and establish management targets and thresholds (e.g., maximum sustainable yield, overfishing limits, acceptable biological catch) that inform catch advice and rebuilding plans. The accuracy of these BRPs relies on assumptions about the stock's future productivity. The presence of a regime shift that alters fundamental ecosystem functions and fisheries stock dynamics can render existing BRPs inaccurate. Determining BRPs without accounting for changes in stock dynamics over time can present significant challenges to management.

Understanding if and when a regime shift has occurred in fish stock dynamics can lead to more accurate management targets and inform better management decisions. Detecting these shifts is particularly critical for managing fisheries under an altered productivity regime (Perälä and Kuparinen 2015). In time series analyses, abrupt shifts associated with ecosystem change can be assessed through changepoint (or breakpoint) analysis. These breakpoints indicate transitions in ecosystem dynamics that may result from a single dominant driver or from multiple interacting factors that collectively produce large-scale changes in population dynamics.

**History of Regime Shifts in the Northwest Atlantic**

Several wide-scale, climate-driven shifts have been observed in the Northwest Atlantic over time. Evidence of regime shifts in this region have been examined from both a bottom-up perspective, focused on physical changes in ocean conditions and primary productivity, and top-down perspective, examining patterns at higher trophic levels, such as fish (e.g., Mills et al. 2024).

A regime shift in the 1990s was attributed to shifts in the Arctic Oscillation (AO), a natural climate phenomenon whose behavior was altered in the late 1980s to mid-1990s due to greenhouse gas emissions cooling the stratosphere and amplifying positive AO conditions (Greene 2012, MERCINA Working Group, 2012). As a result, pulses of low-salinity freshwater from the Arctic Ocean entered the

North Atlantic, resulting in large decreases in salinity (i.e., freshening) and changes in the plankton community in the early 1990s, especially in the Gulf of Maine and Georges Bank region (Greene 2012, MERCINA Working Group, 2012). By the late 1990s plankton blooms returned to the characteristic regime seen in the 1980s (Greene 2012, MERCINA Working Group 2012). Evidence of another regime shift was observed in the early 2000s, when the number of warm core ring formations, an important oceanographic process that occurs when eddies detach from the Gulf Stream, significantly increased from an average of 18 per year (1980-1999) to 33 per year (2000-2007; Gandopadhyay et al. 2019). Silver et al. (2023) proposed that the increased number of warm core rings indicated a regime shift occurred in the Gulf Stream system around the year 2000, resulting in an increase in water exchange between the Northeast Continental US Shelf and the Slope Sea and increase in salinity maximum intrusions on the Northeast U.S. Shelf (Silver et al. 2023). Changepoint analyses confirmed a statistically significant regime shift occurring in the year 2000 (Gangopadhyay et al. 2019, Silver et al. 2023).

In recent years, the Northeast Continental US Shelf has experienced pronounced warming. Friedland et al. (2020) identified the onset of a warming regime beginning in 2011, centered around the Georges Bank region, based on a changepoint analysis of surface water temperatures. Examination of bottom temperature trends revealed this warming regime beginning in 2008 in the Eastern Gulf of Maine and progressed southward, reaching the Southern New England region by 2010 (Friedland et al. 2020a). Subsequent changepoint analysis of indicators of primary production in the Northeast Continental Shelf ecosystem indicated declines in chlorophyll as both sea surface temperature and salinity increased following a 2012 changepoint (Friedland et al. 2020b). These physical and biological changes were most evident in the northernmost parts of the ecosystem, particularly in the Gulf of Maine and Georges Bank.

These transformational changes in the U.S. Northeast Shelf ecosystem have the potential to directly affect various aspects of stock dynamics (e.g., temperature impacts on growth) and to indirectly influence fish population dynamics through trophic cascades and bottom-up effects driven by changes in primary production and forage fish assemblages. Perretti et al. (2017) found evidence of three different fish recruitment regimes occurring in the Northeast Continental US Shelf: a low recruitment regime in the late 1980s, high recruitment success in the 1990s, and a return to low recruitment in the early 2000s, broadly mirroring changes in zooplankton community structure. High recruitment states also coincided with low spawning stock biomass for many fish stocks studied (Perretti et al. 2017). Perretti et al. (2017) predicted that the high recruitment regime in the 1990s was at least partially driven by an increase in copepod prey and an increase in parental condition stemming from the overall decrease in SSB. Mills et al. (2024) identified impacts of the regime shift around 2010, stemming from substantially increased sea surface temperature anomalies in the Northwest Atlantic, on fishery resources. They found evidence that these ecosystem shifts had an adverse cascading effect on sensitive fish populations and their productivity (Mills et al. 2024).

**Winter Flounder**

Winter flounder (*Pseudopleuronectes americanus*) is a groundfish species whose productivity has been impacted by ecosystem changes in the Northeast US shelf ecosystem (Mills et al. 2024). Winter flounder are managed as three stock units in U.S. waters: Gulf of Maine, Georges Bank, and Southern New England/Mid-Atlantic. Winter flounder have been an important target fishery resource and historically was subject to overfishing which may have affected the population’s ability to recover to their historic abundance (Fogarty & Murawski, 1998). Although no longer subject to overfishing, winter flounder populations have yet to recover to their historic abundance, leading scientists to believe that a regime shift had taken place (deYoung et al. 2004).

The Gulf of Maine and Southern New England stocks utilize inshore shallow/estuary habitats for spawning, environments that are particularly vulnerable to environmental variability and anthropogenic stressors, whereas Georges Bank is an offshore located stock area. However, all stocks move offshore to deep demersal waters after the spawning season. The differing habitat use and life history strategies among all three stocks suggest that each may respond differently to regional environmental forcing. In this context, we aim to examine evidence of regime shifts through the lens of temporal changes in winter flounder productivity.

This chapter aims to identify significant changes in winter flounder stock dynamics in US waters using changepoint analysis. Changepoint analysis is a statistical method used to pinpoint breaks in a time series that deviate from a usual (or expected) trend. Breakpoint analysis of stock dynamics is valuable for fisheries management, as it sheds light on non-stationarity in aspects of stock dynamics that can inform choices in stock assessment model fitting, the specification of short-term projections, and the establishment of biological reference points. Results from this study will inform future exploratory modeling aimed at identifying relationships and potential patterns between certain environmental drivers and stock dynamics.

**Methods**

*Data*

To characterize several aspects of winter flounder stock dynamics, I utilized fishery-independent survey data from NOAA's Northeast Fisheries Science Center bottom trawl survey (NEFSC, fall and spring) and Massachusetts Division of Marine Fisheries (MADMF, fall and spring) bottom trawl survey.

The NEFSC bottom trawl survey was initiated in 1962 to collect data on marine species' abundance, distribution, feeding, size, and age composition (Politis et al. 2014). Both the NEFSC and MADMF (King et al. 2010) bottom trawl surveys collect data on winter flounder abundance (number/tow) and biomass (kg/tow) for the spring and fall seasons. The surveys also collect biological data, including weight, maturity, and age information, on a subsample of fish. For each US winter flounder stock, we evaluated the presence of breakpoints in several metrics, including recruitment, recruits per spawner (R/SSB), weight-at-age, relative condition, and species distribution. Metrics were calculated by stock area with the exception of distribution metrics which were calculated throughout the survey footprint. Sources for these data and calculations of metrics are as follows.

*Recruitment Metrics*

Recruitment was characterized as the index of age 1 abundance (i.e., stratified mean number per tow) of winter flounder from the NEFSC and MADMF bottom trawl survey (fall and spring for NMFS and spring only for MADMF due to survey limitations) within each respective stock area. Recruits per Spawner (R/SSB) was calculated using a ratio of indices of age 1 abundance and spawning stock biomass (lagged one year to match year of spawning (age 0) from the NEFSC trawl survey). An index of SSB (Eq. 1) was calculated for each winter flounder stock based on survey indices (fall and spring) of number-at-age and weight-at-age for mature fish in each stock. Winter flounder age at 100% maturity (i.e., 4 years old, Beacham 1982) and stock-specific weight-at-age (WAA) from the NEFSC bottom trawl survey were used for these empirical calculations.

$$SSB_t = W^{-}_{4-7,t} \sum_{a=4}^{7} N_{a,t}$$

Equation 1. SSB for year $t$ was calculated as the mean biomass across ages 4–7 in year $t$ multiplied by the total abundance index summed across ages 4–7+: Where $N_{a,t}$ is the index of fish of age $a$ at time $t$, and $W^{-}_{4-7,t}$ is the annual mean weight across ages 4–7. Note that Age7 represents the 7+ age group in the dataset.

*Growth Metrics*

Growth analyses relied on NEFSC bottom trawl survey WAA data and a condition index derived from trawl survey data. Weight-at-age from the NEFSC bottom trawl survey was defined as the average weight of winter flounder in an age group in each year, with age 7 as a plus group that included age classes 7 and above. The age 7 (plus) group was not included in the changepoint analysis due to the truncated and biased effect that combined older age groups can have on breakpoint results.

Relative condition data (weight at a given length) (Kn) was calculated using the equation: Kn = W/W'. Where W is the weight of an individual fish and W' is the predicted length-specific mean weight for the population in the given region (Le Cren 1951). These data were sourced from the 2024 New England State of the Ecosystem Report, which used indices collected from the NEFSC bottom trawl survey. The regions provided for winter flounder condition were the Gulf of Maine, Georges Bank, and the Mid-Atlantic Bight (spatially encompassing Southern New England/Mid-Atlantic region and used as a proxy for that stock).

*Distribution Metrics*

Distribution data was sourced from NOAA's Distribution and Mapping Analysis Portal (DisMAP), which utilizes latitudinal and depth data from the NEFSC trawl survey to examine species-wide changes in the center of gravity for winter flounder in spring and fall. The portal itself includes interpolated biomass distribution from taxa that are sampled in at least 5% of tows in at least 3/4th of all survey years (NOAA 2025). These include depth and latitude changes from 1974 to 2024. These values for distribution are considered species-wide and are not stock-specific.

**Statistical Analysis**

Breakpoint analysis was used to examine shifts in stock dynamics metrics, including recruitment (age 1 abundance), recruits per spawner (R/SSB), weight-at-age, condition, and species-wide distribution. The R package *EnvCpt* (Killick et al. 2021; Version 1.1.3) was used to calculate changepoints in the winter flounder population dynamics time series, following methods from a previous breakpoint analysis conducted in the most recent Atlantic cod (*Gadus morhua)* stock assessment research track

(Kerr and Behan 2022). Initially designed to analyze climate data, *EnvCpt* is now widely used in ecology for changepoint analysis (Haines et al. 2025).

In addition to breakpoint analysis, I performed a Pearson correlation analysis across the raw survey data (Schober et al. 2018). Because each stock is subject to different regional environmental conditions and may exhibit unique responses to change, I evaluated the coherence in stock responses across different dynamics by conducting this correlation analysis to characterize the degree of correlation between stock areas.

Changepoint detection within a time series determines the optimal number of segments into which the data should be divided to best represent potential trends (Killick and Eckley, 2013). *EnvCp*t fits eight different models and selects the one that provides the best fit to represent the time series being analyzed (Beaulieu and Killick, 2018). The simplest models in *EnvCpt* assume that a series is best represented with either a constant mean or a linear trend (Beaulieu and Killick 2018). They are then superposed to an AR(1), which leads to four models without changepoints identified (Beaulieu and Killick 2018). The models that include changepoints in all model parameters are also fitted, resulting in a total of eight models (Beaulieu and Killick 2018). In *EnvCpt*, each model is fitted using maximum likelihood estimation, and the exact number and location of each changepoint is found through the PELT algorithm (Killick et al. 2012; Killick and Eckley, 2013). PELT performs a search using the modified Bayesian information criterion (MBIC) as the penalty function to select the optimal number of changepoints, subject to a minimum segment length and other parameters (Beaulieu and Killick 2018).

Analyzing time series data for potential changepoints can be challenging due to the parameters used to define changepoint detection in the model. Resulting from one's constraints, a false negative or false positive changepoint still could or could not be present in the time series after an analysis. To ensure that my changepoint detection model was both sensitive enough to detect meaningful shifts in the data and robust enough to prevent a single data point from causing a false detection, I applied several constraints. I first set the minimum segment length to 5 years to avoid detecting overly short-lived changes. I then established an adaptive threshold for detecting mean shifts, where changes were only considered valid if they exceeded 0.25 times the standard deviation of the data, with a floor of 0.2 to prevent the threshold from becoming too sensitive in low-variance conditions and help prevent false positives. I also constrained the detection to changes in mean shifts only, excluding shifts in variance to streamline interpretation. Finally, I added a manual penalty of 4xlog($n$), where $n$ denotes the number of data points in the time series, based on BIC but scaled to increase robustness and reduce overfitting. This specific penalty resulted from conservative manual tuning of the standard log(n) penalty and PELT to increase the changepoint model's robustness and control the number of detected changepoints in the time series.

**Results**

Recruitment

Gulf of Maine winter flounder recruitment (age 1 abundance) was highly variable without evidence of changepoints in either fall or spring NMFS time series (Fig. 3.1). However, a changepoint was found in spring of 2014 (Table 3.1) using the MADMF survey time series, which was followed by a positive change in mean recruitment (Fig. 3.1). Recruitment of Georges Bank winter flounder was also variable with no changepoint identified in spring, but a changepoint identified in the fall time series in 2016 (Table 3.1) followed by a decrease in mean recruitment (Fig. 3.1). Recruitment of Southern New England/Mid-Atlantic winter flounder exhibited a changepoint in 1983 (Table 1) in both fall and spring time series followed by a sharp decline in recruitment (Fig. 3.1). However, the fall time series exhibited another changepoint in 1992 (Table 3.1), which shifted recruitment to an overall higher mean, although not back to its notably high historic values seen at the beginning of the time series (Fig. 3.1). No changepoints were found when analyzing the spring MADMF indices of recruitment for Southern New England/Mid-Atlantic (Fig. 3.1).

Table 3.1. Changepoint Years for Winter Flounder. Years of changepoint occurrences from EnvCpt changepoint detection analysis. Colors represent the trajectory of stock response following the changepoint year: Red – Mostly Negative response; Light Red – Slightly Negative response; Green – Mostly Positive response; Light Green – Slightly Positive response. GBK is Georges Bank, GOM is Gulf of Maine, and SNEMA is Southern New England/Mid-Atlantic.

| STOCK RESPONSE VARIABLE | GOM | | GBK | | SNEMA | |
|---|---|---|---|---|---|---|
| Distribution: Depth | **Fall 2009 (↓)** | | | | | |
| Distribution: Latitude | (↑) | | | | | |
| Age 1 Recruitment | 2014 | | 2016 | | 1983 | 1992 |
| Recruits per Spawner | | | 1993 | 2014 | 2015 | |
| Relative Condition | 1999 | | 2001 | 2012 | | |
| Weight at Age 1 | 1985 | 2011 | 2009 | | 1998 | |
| Weight at Age 2 | 1985 | 2012 | 2010 | | 1993 | 1999 |
| Weight at Age 3 | 1983 | | 2014 | | 1993 | |
| Weight at Age 4 | 1983 | | 2015 | | 1991 | 2012 |
| Weight at Age 5 | 1984 | 2009 | | | 1991 | 2012 |
| Weight at Age 6 | 1986 | 2009 | | | 1991 | |

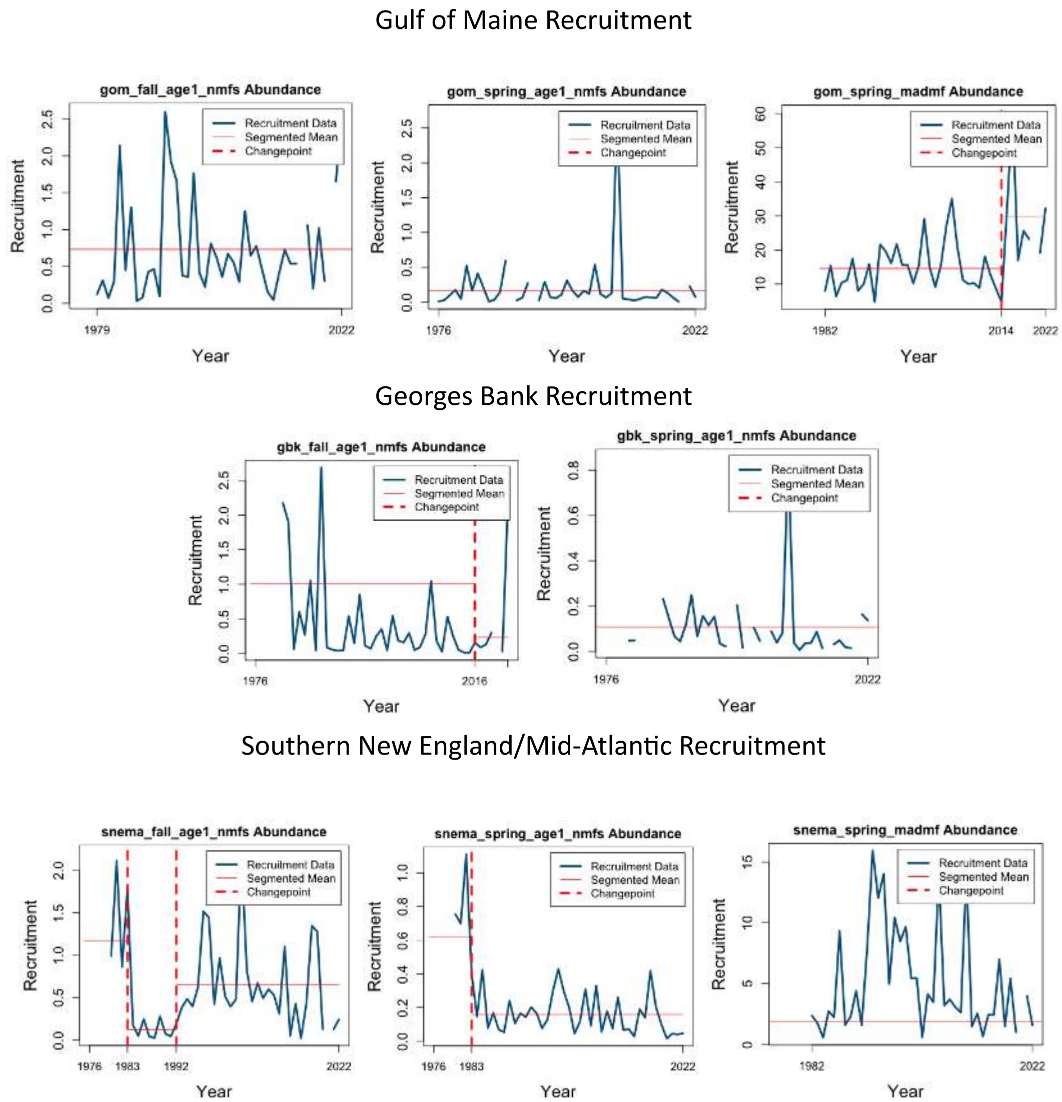



Figure 3.1. Age 1 Recruitment Changepoint Results. Age 1 recruitment changepoint estimates using the EnvCpt package for fall and spring seasons (NMFS trawl survey indices). Recruitment on the y axis is average numbers at age 1 per tow. GBK is Georges Bank, GOM is Gulf of Maine, and SNE/MA is Southern New England/Mid-Atlantic.

The Pearson correlation analysis for winter flounder recruitment provided insight on the cohesiveness of patterns between stocks. Gulf of Maine and Georges Bank spring NMFS recruitment indices were highly correlated with one another (Fig. 3.2). However, Southern New England/Mid-Atlantic recruitment tended to have low positive or negative correlation with the other stocks (Fig. 3.2). Figure 3.3 illustrates the different snapshots of winter flounder recruitment recorded by the NMFS fall and spring surveys with the fall survey exhibiting higher indices at age 1, likely due to not having experienced overwintering mortality at that time, compared to the spring across all stock areas.

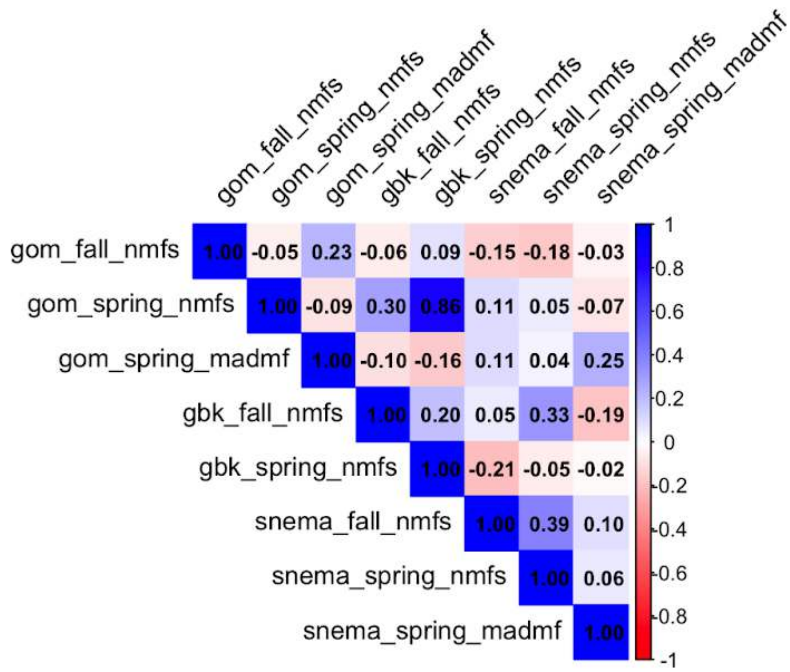



Figure 3.2. Correlation Analysis Results on Age 1 Abundance. Correlations between both the fall and spring NMFS survey indices of age 1 abundance, as well as the MADMF spring survey data (for Southern New England/Mid-Atlantic and Gulf of Maine only). GBK is Georges Bank, GOM is Gulf of Maine, and SNEMA is Southern New England/Mid-Atlantic

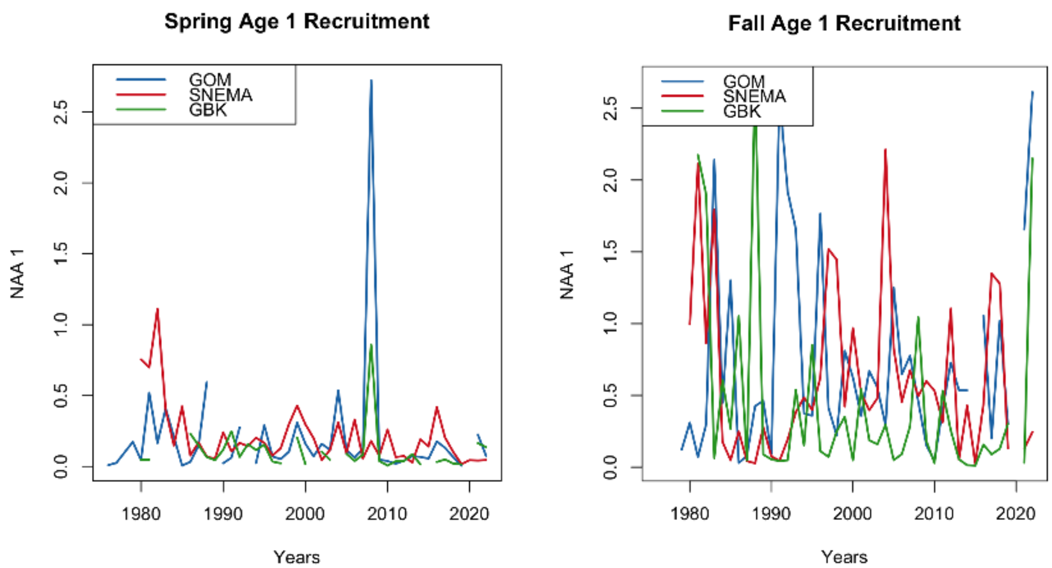



Figure 3.3. Survey Indices Average Number of Age 1 Per Tow. Average number of Age 1 per tow, recruitment survey indices from the NMFS bottom trawl survey in the spring (left) and fall (right) for all three winter flounder stocks. GBK is Georges Bank, GOM is Gulf of Maine, and SNEMA is Southern New England/Mid-Atlantic.

Recruits per spawner in the Georges Bank stock exhibited a changepoint in 1993 (Table 3.1) in both the spring and fall time series (Fig. 3.4). The changepoint in the fall of 1993 (Table 3.1) led to an increased mean in the rest of the time series in Georges Bank (note: this is driven largely by one value in 2017). However, the changepoint in spring 1993 (Table 3.1) led to a decreased mean in R/SSB followed by a second changepoint in 2014 (Table 3.1) associated with a higher mean recruits per spawner (Fig. 3.4). Gulf of Maine winter flounder recruits per spawner were generally present at constant low mean in the spring with the exception of high pulse of recruits per spawner in the early 2000s, however recruits per spawner were variable in the fall time series, with a changepoint in 2003 (Table 3.1) that led to a lowered overall mean (Fig. 3.4). Lastly, Southern New England/Mid-Atlantic recruits per spawner had visually similar time series in fall and spring (Fig. 3.4), with a general trend of increased values toward the end of time series. While no changepoint was detected in the spring time series, a changepoint in 2015 (Table 3.1) was found in the fall, followed by a shift to a higher mean (Fig. 3.4).

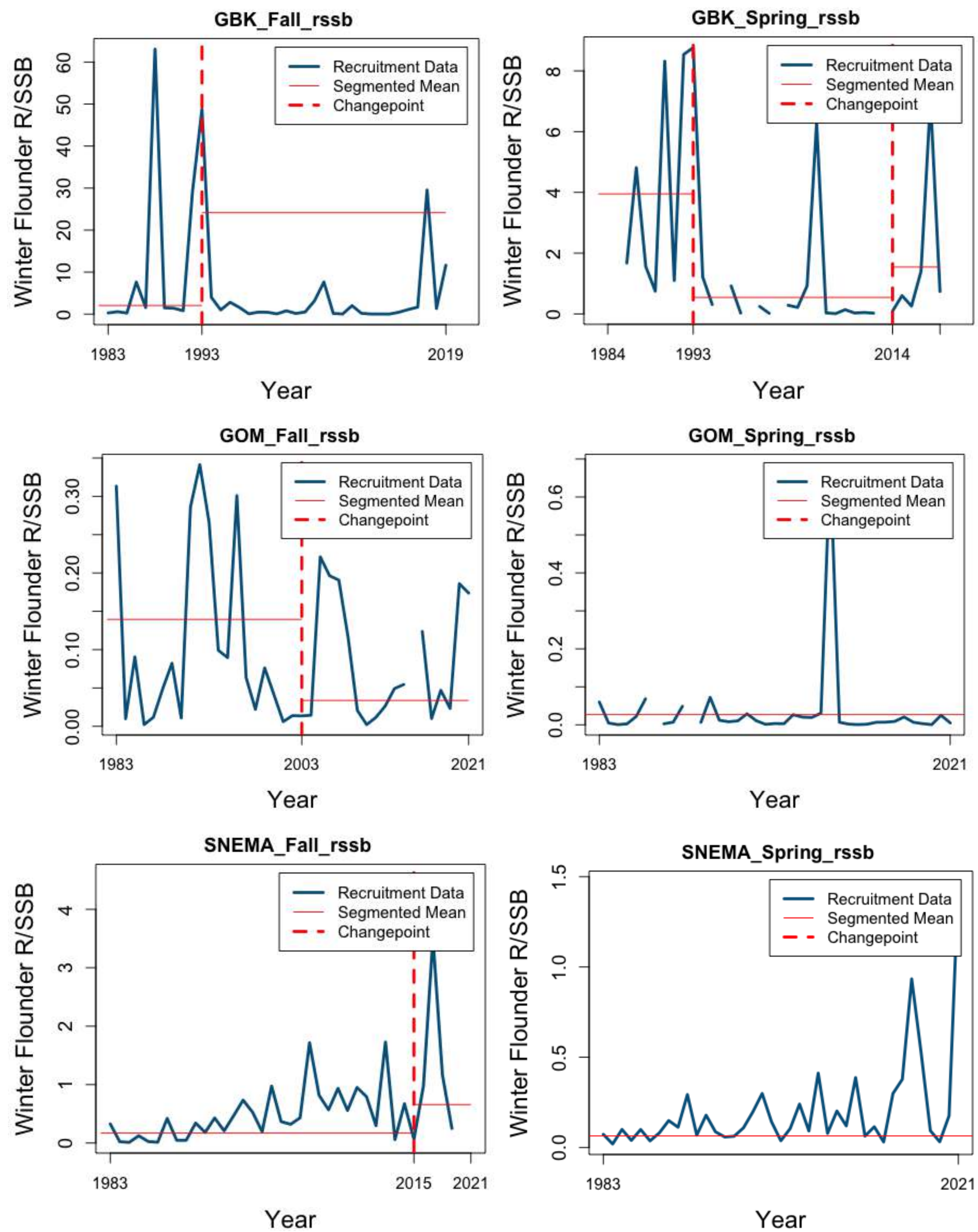



Figure 3.4. Recruits Per Spawner Changepoint Results. Identified changepoints in Recruits per spawner (R/SSB) data from the NMFS trawl survey indices of recruitment using the EnvCpt package by season and stock area. GBK is Georges Bank, GOM is Gulf of Maine, and SNEMA is Southern New England/Mid-Atlantic.

Notably the scaling of productivity across all three winter flounder stocks is considerably different (Fig. 3.6). When comparing the level of recruits per spawner across stocks, there were large differences between Georges Bank and the other two stocks with offshore Georges Bank stock exhibiting considerably higher productivity (Fig. 3.6). In the Pearson correlation analysis for winter flounder recruits per spawner, there was limited correlation across all stocks and seasons (Fig. 3.5).

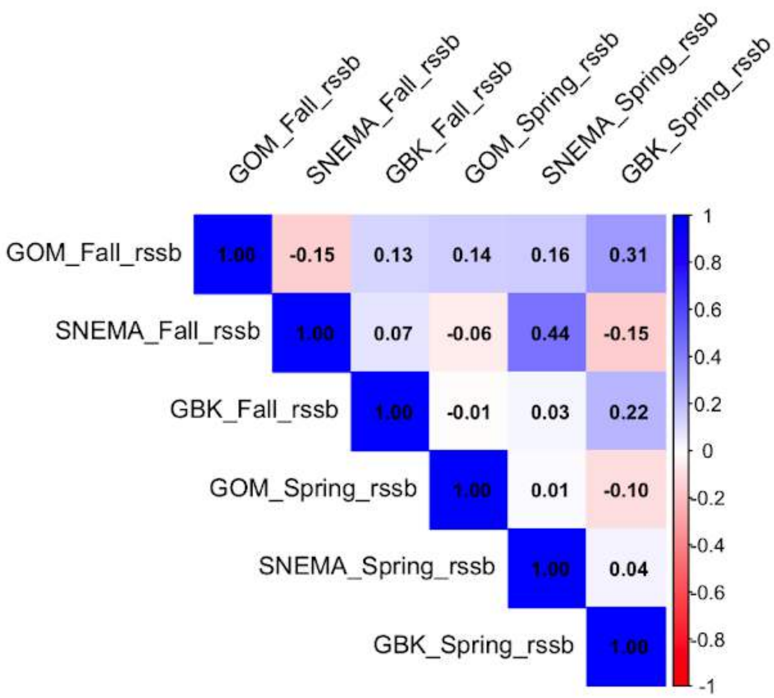



Figure 3.5. Correlation Analysis Results on Recruits Per Spawner. Correlation plot using a Pearson Correlation analysis for all three winter flounder stocks' seasonal recruits per spawner: GBK is Georges Bank, GOM is Gulf of Maine, and SNEMA is Southern New England/Mid-Atlantic.

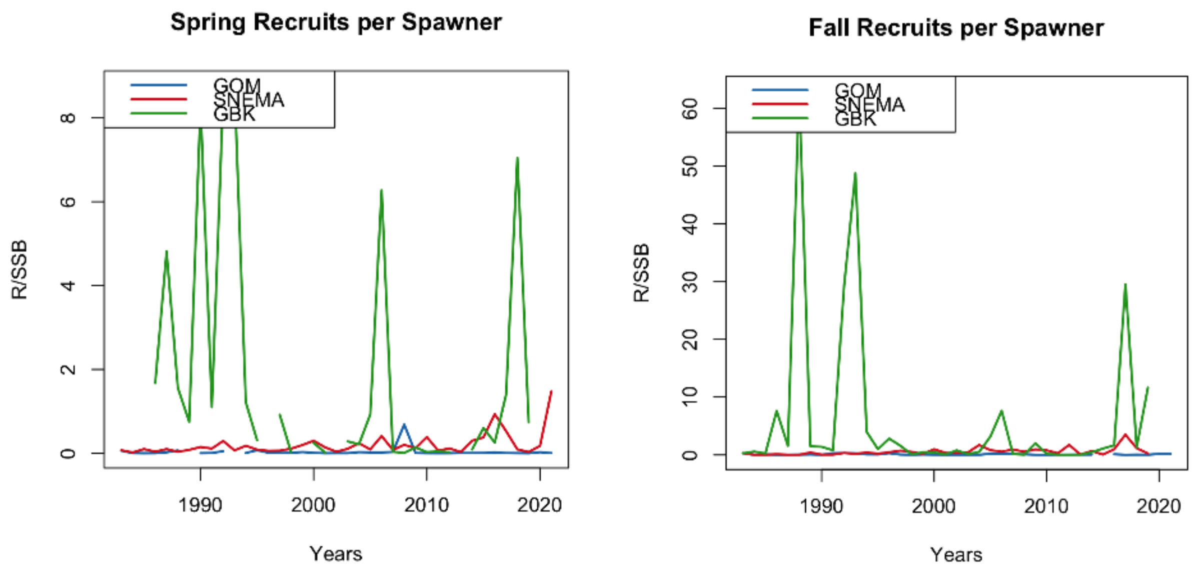



Figure 3.6. Recruits Per Spawner by Stock. Line plot of recruits per spawner for each of the three winter flounder stocks in the spring (left) and fall (right). GBK is Georges Bank, GOM is Gulf of Maine, and SNEMA is Southern New England/Mid-Atlantic.

*Growth*

In the Gulf of Maine stock, all age groups experienced a decrease in WAA over time, except for ages 1 and 2, which exhibited a small increase in mean weight (Fig. 3.7). A similar changepoint in the early 1980s was apparent in all age classes of Gulf of Maine winter flounder, leading to a decrease in WAA (Fig. 3.7). However, for ages 1 and 2, another changepoint occurred in the early 2010s which led to a small increase in mean WAA although not returning to pre-1980s means (Fig. 3.7). Gulf of Maine winter flounder WAA 5 and 6 experienced an additional changepoint in 2009 (Table 3.1) that led to an even lower WAA. Georges Bank winter flounder experienced a changepoint in growth in the early 2010s across all age groups, leading to an increase in mean WAA, except for age classes 5 and 6, which did not exhibit any changepoints over the time series (Fig. 3.7). The Southern New England/Mid-Atlantic stock experienced changepoints in the early 1990s and in 2012 (ages 4 and 5, Table 3.1) that led to increased WAA over time for most ages (Fig. 3.7). In contrast, ages 1 and 2 experienced similar changepoints in the 1990s but exhibited decreased WAA (Fig. 3.7).

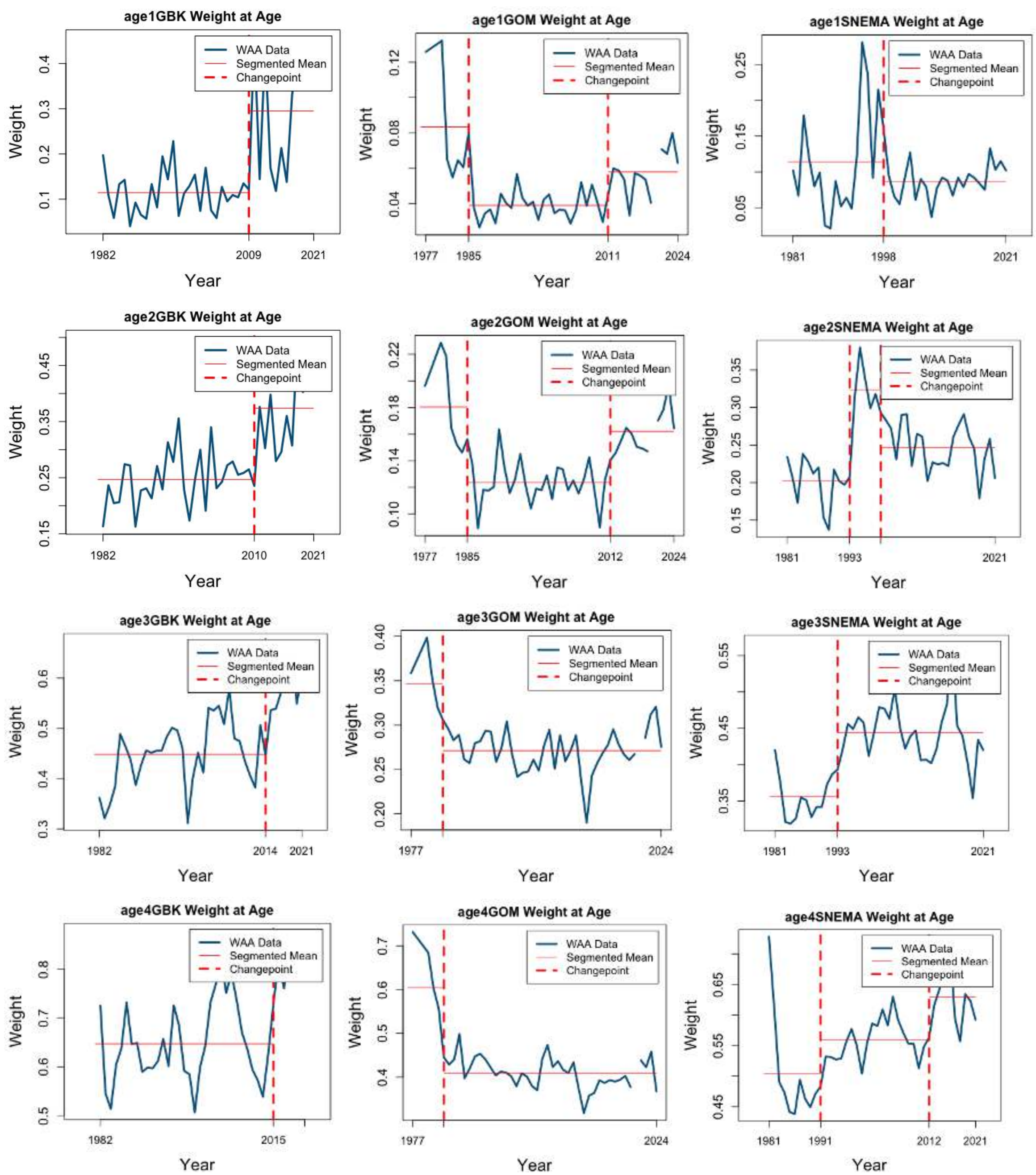


Figure 3.7 continued

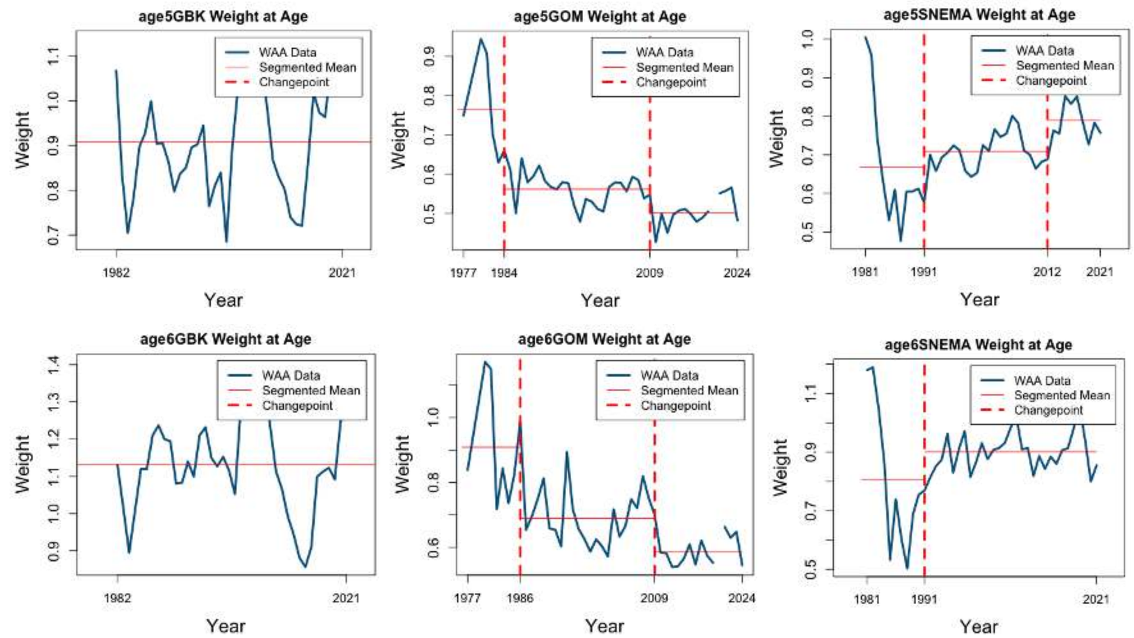



Figure 3.7. Weight at Age Changepoint Results. Weight-at-age changepoint estimates for age classes 1 through 6 using the EnvCpt package. Scaling of the x axis is varied across stocks and age groups.

The Pearson correlation analysis of winter flounder WAA reveals interesting patterns across all three stocks. As expected, the younger age classes contrast sharply with the oldest age groups among all stocks (Fig. 3.8). At mature ages, SNE/MA and GB winter flounder showed the strongest positive correlations in WAA (Fig. 3.8). Older age classes in Gulf of Maine and Georges Bank stocks were also highly correlated (Fig. 3.8). In contrast, mature ages in Southern New England/Mid-Atlantic and Gulf of Maine were negatively correlated (Fig. 3.8).

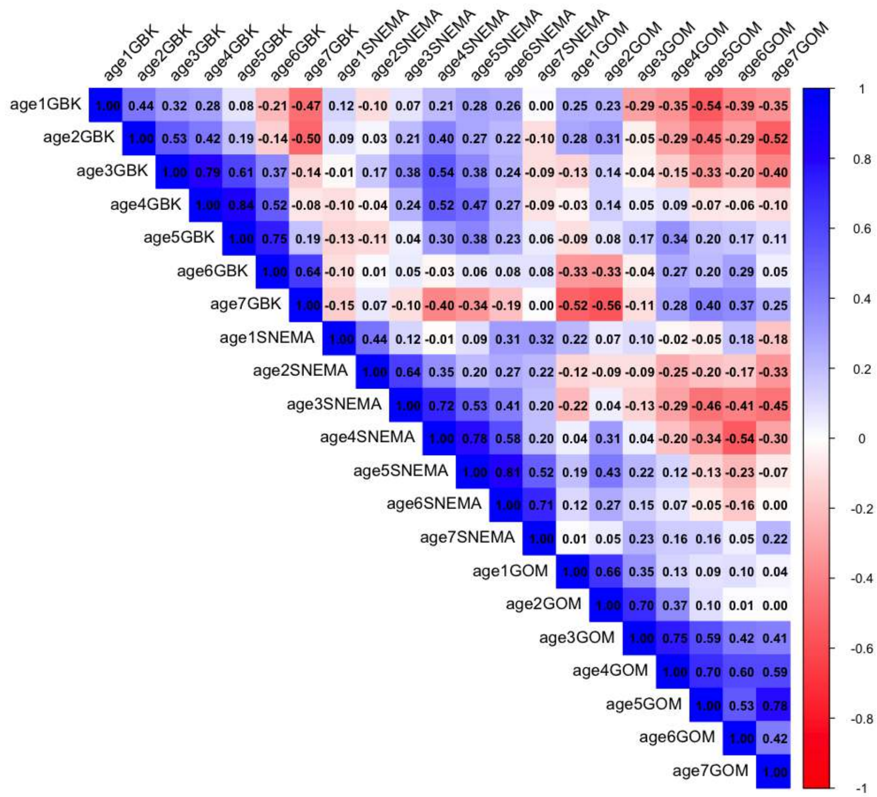



Figure 3.8. Correlation Analysis Results on Weight at Age. Pearson Correlation Plot for Weight at Age, comparing all winter flounder stocks and age classes to one another.

Both Gulf of Maine and Georges Bank winter flounder exhibited a changepoint in relative condition around 2000 (Table 3.1), marking a shift to a lower condition state (Fig. 3.9). Since that time, the Gulf of Maine stock has shown fluctuating trends with no additional changepoints (Fig. 3.9). In contrast, the Georges Bank stock experienced another changepoint in 2012 (Table 3.1), corresponding with a rebound to average relative condition levels comparable to those observed in the 1990s (Fig. 3.9). Winter flounder in the Mid-Atlantic Bight, used as a proxy for the Southern New England/Mid-Atlantic stock, experienced no changepoints throughout the time series, maintaining a relatively consistent condition index (Fig. 3.9).

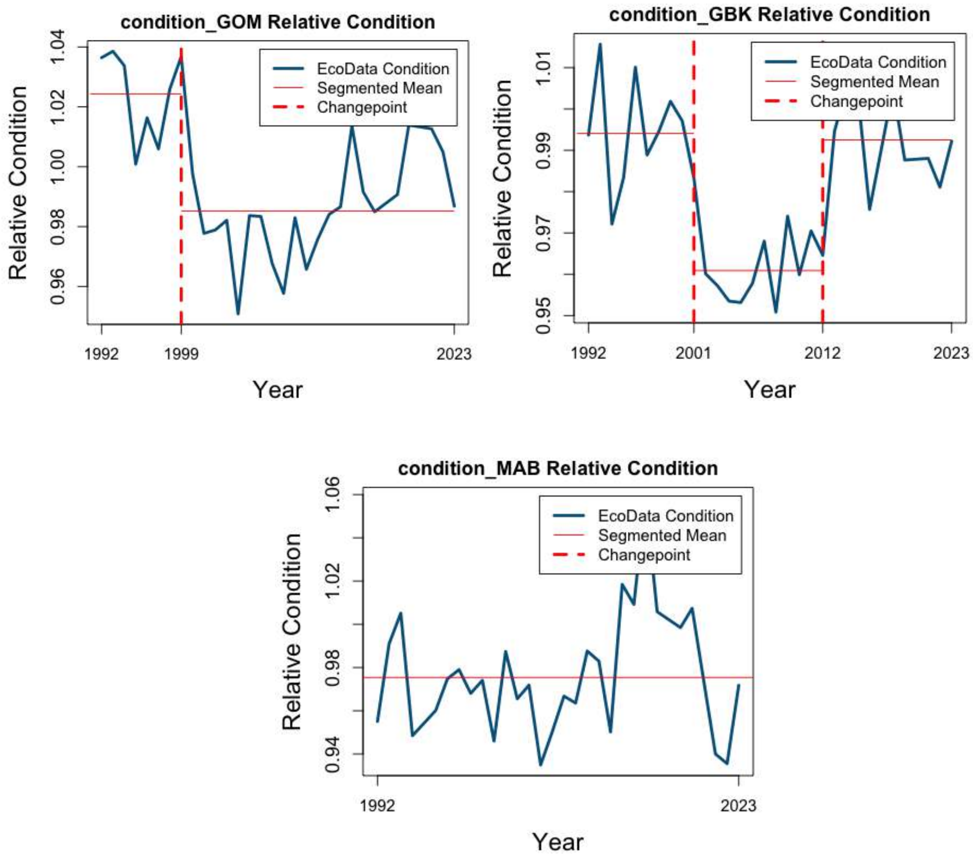



Figure 3.9. Relative Condition Changepoint Results. Relative Condition changepoint estimates for Gulf of Maine (GOM), Georges Bank (GBK), and Mid-Atlantic Bight (MAB) (used as a proxy for Southern New England/Mid-Atlantic) using the State of the Ecosystem's Fish Relative Condition Indicator from *ecodata* and *EnvCpt* package for analysis.

The Pearson correlation analysis for winter flounder relative condition showed a high positive correlation between Georges Bank and Gulf of Maine stocks and a lower correlation with the Mid Atlantic Bight (proxy for Southern New England/Mid-Atlantic stock, Fig. 3.10). However, the general trends of each stock's relative condition over time show a general cohesiveness between all stocks in the time series (Fig. 3.11).

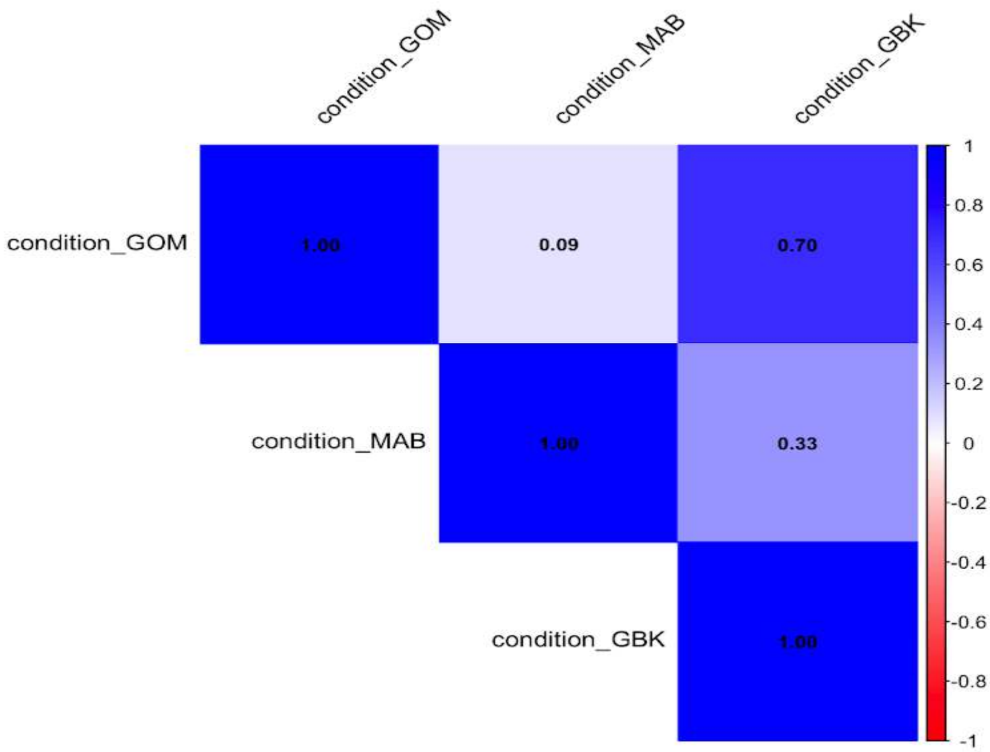



Figure 3.10. Correlation Analysis Results on Condition. Pearson correlation analysis plot of relative fish condition in Gulf of Maine (GOM), Georges Bank (GBK), and Mid-Atlantic Bight (MAB) (used as a proxy for Southern New England/Mid-Atlantic).

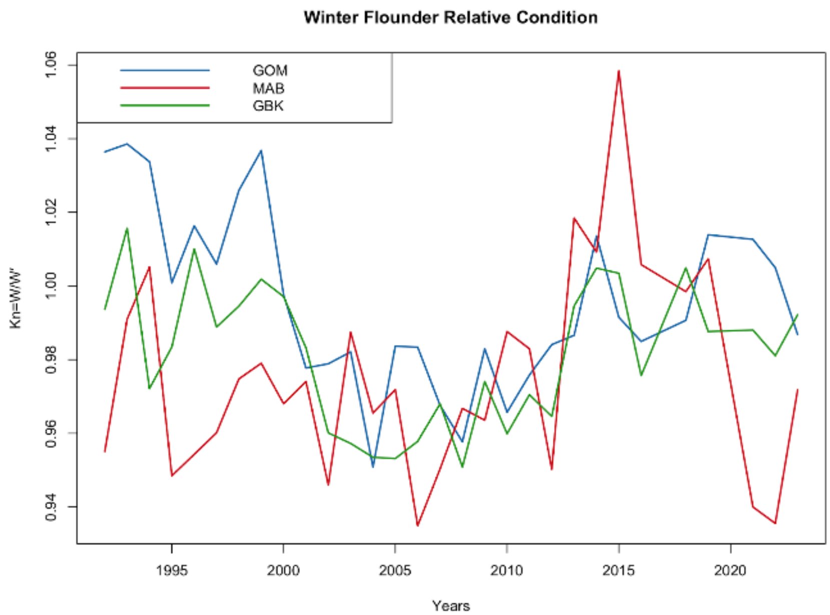



Figure 3.11. Relative Condition by Stock. Line plot of each stock area's temporal difference in relative fish condition using the Mid-Atlantic Bight (MAB) as a proxy for Southern New England/Mid-Atlantic, data were excerpted from the State of the Ecosystem's Fish Relative Condition Indicator (*ecodata*).

*Distribution*

The Center of Gravity (COG) of winter flounder depth varied seasonally, with a changepoint detected in the fall of 2009 (Table 3.1) and no changepoints identified in the spring (Fig. 3.12). Both seasonal time series show an overall declining trend in depth (Fig. 3.12). COG of winter flounder latitude also varied seasonally, with no changepoints detected in either spring or fall, however, both series display an overall increasing trend, indicating a gradual northward shift in distribution over time (Fig. 3.12).

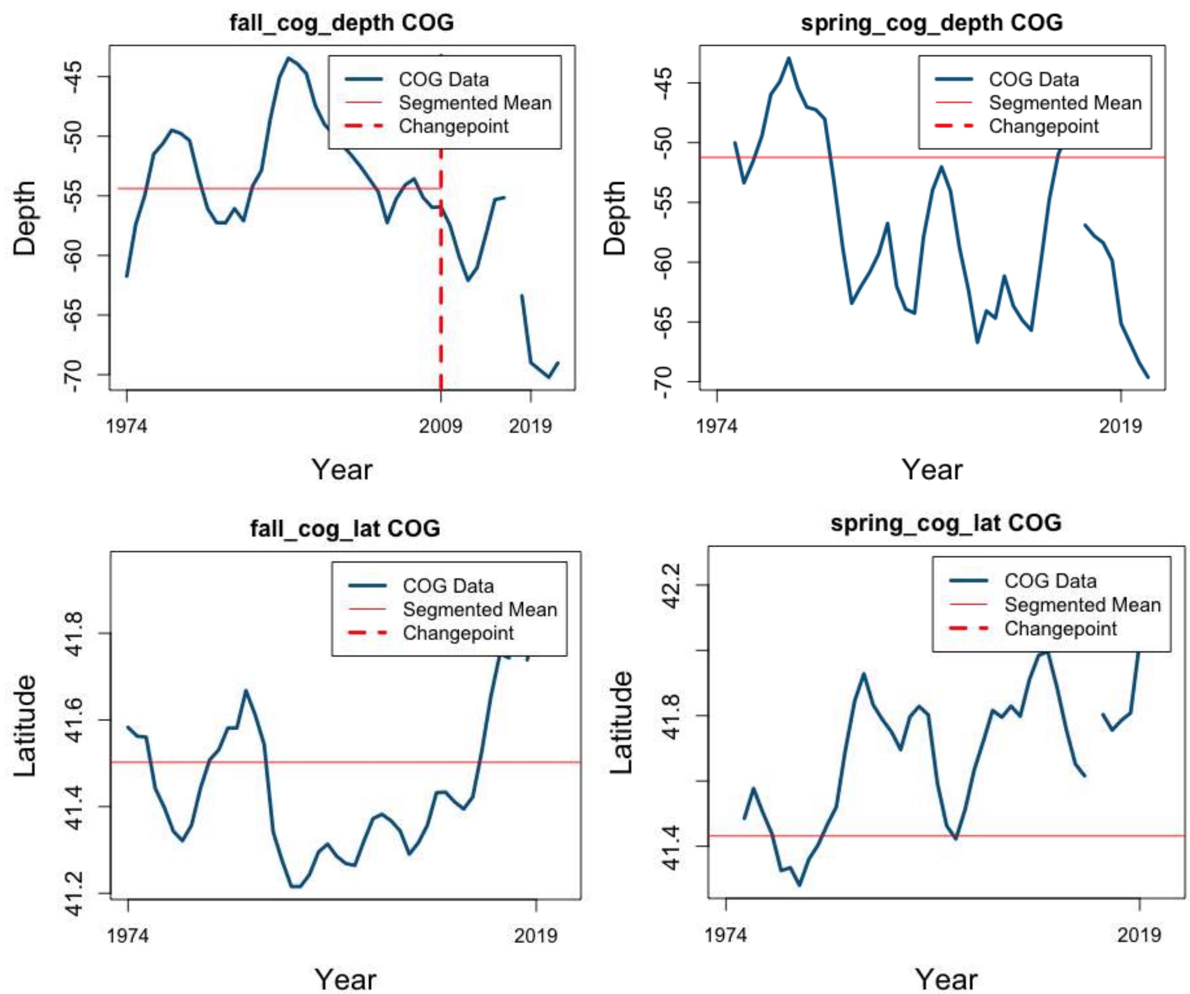



Figure 3.12. Center of Gravity Changepoint Results. Center of Gravity (COG) species-wide changepoint estimates for winter flounder distribution in both depth and latitude (lat) for fall and spring using the EnvCpt package.

**Discussion**

**General Trends and Observations**

Using changepoint analysis, I identified temporal differences in winter flounder stock dynamics (i.e., recruitment, growth, and distribution). In addition, Pearson correlation analysis across the three winter flounder stocks revealed patterns of coherence and differences in U.S. flounder stock dynamics. My results suggest that winter flounder exhibit stock-specific responses to regime shifts on the Northeast Continental US Shelf, with the timing and nature of change aligning with known oceanographic processes in the region, despite not directly testing these environmental variables in this analysis.

A review of the changepoints found across all stocks confirm the non-stationarity of winter flounder population dynamics, with mean shifts detected in every analyzed stock dynamic parameter (recruitment, growth, and distribution). However, these changepoints were not consistent across all 3 regions in when and where mean shifts occurred. Correlation analysis showed that coherence of recruitment indices within winter flounder stocks is limited (Fig. 3.2), but there is some correlation in weight at older ages between Southern New England/Mid-Atlantic and Georges Bank (Fig. 3.8) and in condition between Georges Bank and the Gulf of Maine (Fig. 3.10).

Another key finding of this study was that each stock exhibited unique response parallels to known decadal-scale shifts in oceanographic processes and broad-scale regime shifts (Table 3.2). Gulf of Maine winter flounder experienced the most changepoints during the mid-1980's, while Georges Bank winter flounder was primarily impacted by the more recent changepoints in the mid-2010's. In contrast, the Southern New England/Mid-Atlantic stock was most influenced by changepoints in the mid-1990's (Table 3.2). The temporal patterns and timing of changepoints identified across winter flounder stocks generally align with previously identified regime shifts in the northwest Atlantic.

The Gulf of Maine exhibited stability in recruitment with no changepoints detected in Age 1 abundance or R/SSB. Dynamics in the Gulf of Maine were more so defined by changepoints in growth (1985 for WAA 1) and relative condition (1999). The Gulf of Maine winter flounder stock seems to have responded in parallel to the Arctic Oscillation shifts of the mid to late 1980s, with the freshening of the North Atlantic possibly leading to changes in growth efficiency as a result of long-term changes in the plankton community (Greene 2012, MERCINA 2012).

Georges Bank winter flounder exhibited changepoints in different aspects of stock dynamics in the mid-2010s that align with the elevated sea-surface temperature regime shift in 2010 (Mills et al. 2024; Table 3.2). This stock exhibited both negative (i.e., declines in age 1 recruitment) and positive responses, an overall increase in growth and rebound in relative condition (2012) (Fig. 3.7, Fig. 3.9). The Southern New England/Mid-Atlantic stock experienced the earliest and most complex changes, mostly found in the mid-1990s (Table 3.2). This is likely a reflection of severe thermal stress at the southern range limit of winter flounder. This stock experienced severe shifts, with a 1983 changepoint that led to a sharp decline in Age 1 recruitment, followed by another changepoint in 1992 that shifted recruitment to a higher mean but did not return to historic values (Fig. 3.1). WAA exhibited contrasting trends across age groups. Younger age groups experienced decreased WAA while Age 2+ groups experienced positive growth trends following the 1990s changepoints (Fig 3.7). These 1990s changepoints align with the late arrival of Arctic Oscillation freshened water (Greene 2012), suggesting that these large-scale environmental shifts have both positive and negative effects on winter flounder.

Table 3.2. Changepoint Decades for Winter Flounder. Years of changepoint occurrences from EnvCpt changepoint detection analysis. Colors represent decade of changepoint year: Blue – 1980s; Orange – 1990s; Yellow – 2000s; Purple – 2010s. GBK is Georges Bank, GOM is Gulf of Maine, and SNEMA is Southern New England/Mid-Atlantic.

<table>
<tr><th>STOCK RESPONSE VARIABLE</th><th colspan="2">GOM</th><th colspan="2">GBK</th><th colspan="2">SNEMA</th></tr>
<tr><td>Distribution: Depth</td><td colspan="6">Fall 2009<br>(↓)</td></tr>
<tr><td>Distribution: Latitude</td><td colspan="6">(↑)</td></tr>
<tr><td>Age 1 Recruitment</td><td colspan="2">2014</td><td colspan="2">2016</td><td>1983</td><td>1992</td></tr>
<tr><td>Recruits per Spawner</td><td colspan="2"></td><td>1993</td><td>2014</td><td colspan="2"></td></tr>
<tr><td>Relative Condition</td><td colspan="2">1999</td><td>2001</td><td>2012</td><td colspan="2"></td></tr>
<tr><td>Weight at Age 1</td><td>1985</td><td>2011</td><td colspan="2">2009</td><td colspan="2">1998</td></tr>
<tr><td>Weight at Age 2</td><td>1985</td><td>2012</td><td colspan="2">2010</td><td>1993</td><td>1999</td></tr>
<tr><td>Weight at Age 3</td><td colspan="2">1983</td><td colspan="2">2014</td><td colspan="2">1993</td></tr>
<tr><td>Weight at Age 4</td><td colspan="2">1983</td><td colspan="2">2015</td><td>1991</td><td>2012</td></tr>
<tr><td>Weight at Age 5</td><td>1984</td><td>2009</td><td colspan="2"></td><td>1991</td><td>2012</td></tr>
<tr><td>Weight at Age 6</td><td>1986</td><td>2009</td><td colspan="2"></td><td colspan="2">1991</td></tr>
</table>

Limitations of the Approach

Lack of correspondence within and among stocks was most apparent in the recruitment indices of winter flounder. This could be partly due to the specific surveys used to index stock productivity in this analysis. Evaluation of additional survey indices to inform this analysis could potentially influence the results of this changepoint analysis. Observation error may be another contributor to the noisy recruitment indices and lack of identifiable changepoints in some recruitment time series. In addition, while range-wide distribution indices provide a big picture view of winter flounder distribution shifts, stock-specific distribution indices may reveal important population-scale latitude and depth change points and are worth evaluating in the future. Along similar lines, it is recommended that further research is conducted to evaluate age-based condition temporal changes among winter flounder stocks.

Although changepoint analysis is considered a useful tool for quantifying shifts in temporal data, it has some inherent limitations, especially when interpreting results as well-defined regime shifts. Recent studies have demonstrated that current methods can be unreliable and inaccurate for detecting regime shifts in marine systems (Haines et al. 2025). Hillebrand et al. (2020) suggested that breakpoint analysis methods are not fully capable of identifying the intrinsic, system-level changes that characterize a true regime shift. How the model characterizes a valid changepoint (or regime shift) is essential to determine the detection or non-detection's validity (Haines et al. 2025). As such, the assumptions made of model fit inherently influence breakpoint identification. Some changepoint results in this particular study appear to have been driven by the large influence of one or two years in the time series, which should affect the overall understanding of whether or not a breakpoint is truly present.

The results of this analysis are influenced by both the model parameters and the temporal extent of the data analyzed. My decisions in the methods section to set up my changepoint analysis are imperative and relevant to how the model's determined if a changepoint(s) had occurred and when. It also depends on the time-scale of the data input. More years of data can mean more changepoints being identified due to the innate non-stationarity of fish population dynamics. Conversely, shorter time scales may lack the statistical robustness to determine a valid shift.

Furthermore, an identified regime shift in a changepoint analysis may simply reflect natural variability in climate and ecosystem drivers occurring simultaneously, rather than a true regime shift (Friedland et al. 2020). It is essential to note that even with changing thermal conditions, a regime shift doesn't always occur in the natural world (Friedland et al. 2020). Therefore, while this study compares winter flounder changepoints to previously identified regime shifts, it is important to examine all aspects of the focal ecosystem to determine whether a regime shift has occurred (Friedland et al. 2020).

Changepoint analysis can still be an important aspect of fisheries management, because it enables the determination of whether the baseline of fish productivity has changed significantly over time, and provides managers with a more holistic understanding of the stock.

Potential Applications

Despite extensive precautionary management of the fishery over the past 40 years to mitigate the effects of overfishing, winter flounder stocks have yet to return to their historical levels of abundance. This suggests that external drivers beyond fishing mortality are limiting the recovery of the fishery, underscoring the need to update biological reference points to reflect new ecosystem baselines.

Ongoing environmental change in marine ecosystems has been increasingly recognized as a major factor impacting fish population recovery (Britten et al. 2017). The non-stationary behavior in most fish stocks worldwide means that they may be unable to recover to their previous historic abundance (Britten et al. 2017). The potential to recover for a fish stock depends on the population's ability to increase in biomass, which is a fundamental constraint (Duarte et al. 2020).

These results highlight the need for dynamic biological reference points and adaptive management tailored to each stock's productivity regime, while still maintaining precautionary measures to ensure the long-term sustainability of the fishery in a rapidly changing ecosystem. More broadly, this analytical framework can help quantify shifts in productivity, identify regime changes, and detect cross-stock patterns, ultimately guiding management strategies for winter flounder.

Results from this changepoint study can help identify the scales of change in external environmental drivers affecting winter flounder productivity. For instance, if another large Great Salinity

Anomaly occurs in the future, Greene (2012) predicted that a regime shift will occur in the lower trophic levels similar to the one observed at the beginning of the 1990s. Typically, fish recruitment is less likely to be impacted by a regime shift that primarily affects lower trophic levels (Perretti et al. 2017). However, it is still crucial to monitor whether a regime shift has affected fish recruitment, given the significant consequences of recruitment failures for fisheries and fishery communities (Perretti et al. 2017).

This research provides empirical evidence of stock-specific responses to regime shifts in winter flounder dynamics, highlighting the need for adaptive management. A future multispecies analysis, most likely including the entire groundfish complex in the Northeast US, would be beneficial for assessing the widespread effects of ecosystem regime shifts on fish productivity (Perretti et al. 2017). Overall, this method helps to quantify potential changes in the current process of defining biological reference points for fisheries stock assessment, identify past or present changepoints or regime shifts, and evaluate potential patterns within and across each winter flounder stock. This encourages progress towards Ecosystem-Based Fisheries Management (EBFM) which takes a more holistic approach to fisheries management. Based on the results of this analysis, I recommend that the winter flounder stock assessment consider a more recent, moving-window approach to determine biological reference points for all three stocks Before this is accomplished, however, additional productivity indices will need to be evaluated alongside the NEFSC and MADMF bottom trawl surveys. I also recommend future exploration of changepoints using additional recruitment indices from nearshore and estuarine habitats, pariticlarly for Southern New England/Mid-Atlantic and the Gulf of Maine stocks, to further resolve potential shifts in productivity. This research should stand as a guide for management priorities for the winter flounder fishery and how strategies for recovery can be actively adapted to each stock-specific productivity dynamic.

# CHAPTER 4

# MODELING CLIMATE AND ECOSYSTEM DRIVERS OF WINTER FLOUNDER POPULATION DYNAMICS

## Introduction

Winter flounder, once a sought-after fishery resource both commercially and recreationally, is considered an indicator species of ecosystem change due to its unique life-history traits and habitat use (NOAA 2024). As a demersal flatfish species, it relies on estuaries and nearshore habitat for spawning; therefore, its productivity is innately vulnerable to warming temperatures, hypoxia, and human interference in critical habitat (Able et al. 2014). A climate vulnerability analysis of fish species in the Northeast US gave winter flounder a “very high” vulnerability score, driven by high biological sensitivity (resilience and adaptability of the species) and climate exposure (exposure to changing environmental factors that could affect the species; Hare et al. 2016).

With the growing body of knowledge surrounding the effects of climate change on fish stocks and the evolution of more flexible modeling platforms for stock assessment, there has been a growing push to integrate climate and ecosystem knowledge into stock assessments of managed species. Recent fisheries stock assessments have incorporated the analysis of ecosystem drivers of fisheries stock dynamics, in some cases leading to specific drivers being incorporated into the official stock assessment model. Groundfish species, such as American plaice, Atlantic cod, and yellowtail flounder, have all undergone studies of ecosystem drivers as part of their stock assessment process (NCLIM 2025, NEFSC 2025). This helps promote an Ecosystem Approach to Fisheries Management (EAFM; MAFMC 2019), moving towards a more holistic understanding of how the ecosystem, directly or indirectly, impacts the population and productivity of a fish species.

This chapter aims to quantify the relationships between winter flounder population dynamics and climate and ecosystem drivers, as suggested by the ecosystem profile (Chapter 2), across the three

US stocks: Gulf of Maine, Georges Bank, and Southern New England/Mid-Atlantic. Bottom temperature and sea surface temperature were two of the most recurring and well-defined drivers of winter flounder productivity in all stocks. Other suggested drivers were warm core rings (warm eddy offshoots from the Gulf Stream) and other oceanographic processes like the Atlantic Multidecadal Oscillation and North Atlantic Oscillation. These large-scale climate indices control the underlying dynamics of the Northeast US Continental Shelf ecosystem, as well as the phenology of species life history (Greene et al. 2013). All of these ecosystem and climate drivers were implemented into this exploratory analysis.

Often, non-linear relationships exist between environmental drivers and fish population dynamics. For example, temperature may have a positive effect on an individual's growth until it reaches an optimal thermal threshold, beyond which the effect becomes sharply negative (Pörtner & Knust 2007). Using a generalized linear model (GLM) to analyze ecological drivers and their potential effects on fish stock dynamics is not recommended in this case, as the results do not capture the often-nuanced relationships under study. Instead, this study utilizes generalized additive models (GAMs), which are more flexible than GLMs and employ smoothing spline functions to characterize non-linear relationships (Hastie & Tibshirani 1990).

This chapter's objectives are to quantitatively identify and evaluate the key environmental mechanisms that drive winter flounder stock-specific dynamics (age-1 recruitment, recruits per spawner, weight at age, relative condition, and mean depth and latitude). The purpose of this research is to understand the nature and strength of these environmental influences on stock dynamics with the aim of informing more accurate stock assessment and effective management.

**Methods**

Data Sources

<u>Stock Response Variables</u>

Data from the NEFSC bottom trawl survey were used to characterize recruitment (age-1 abundance, recruits per spawner), growth (weight-at-age, condition), and distribution (center of gravity and latitude) of winter flounder stocks. These metrics were calculated as described in Chapter 3. The MADMF spring bottom trawl survey provided additional abundance indices for age 1 only in the Southern New England/Mid-Atlantic and Gulf of Maine regions.

Given the particular importance of bottom temperature as a driver of winter flounder stock dynamics in Chapter 2, all time series were truncated to 1990 - 2025 to account for the start year of the bottom temperature dataset.

<u>Environmental Variables</u>

Environmental indices used in this analysis included bottom temperature (BT), sea surface temperature (SST), Gulf Stream Index, Atlantic Multidecadal Oscillation, North Atlantic Oscillation, and Warm Core Ring Index.

*Sea surface temperature time series (Stock Specific and Basin Scale):*

Sea surface temperature was sourced from the NOAA Daily Optimum Interpolation Sea Surface Temperature (DOISST; Huang et al. 2020; https://psl.noaa.gov/data/gridded/data.noaa.oisst.v2.highres.html). The dataset extends from 1981 to the present. The data were formatted as monthly mean SST by winter flounder stock area.

The same long-term monthly sea surface temperature dataset was formatted as monthly mean SST spanning winter flounder stock areas for relating the distribution metrics that spanned the range of winter flounder in US waters.

*Bottom temperature time series (Stock Specific and Basin Scale):*

Bottom temperature (BT) was sourced from NOAA (Pontavice et al. 2023; https://noaa-edab.github.io/tech-doc/bottom-temperature---glorys.html). BT was derived from GLORYS, (Global Ocean Data Assimilated Models) and downloaded from the CMEMS (Copernicus Marine Service, https://marine.copernicus.eu/). Anomalies were calculated using a reference period from 1990 to 2020. The weighted mean was used by the area of each GLORYS grid cell to obtain the monthly mean bottom temperature by winter flounder stock area (Source: Joe Caracappa, NOAA). This same dataset was formatted as a monthly mean bottom temperature at the Northeast US Shelf scale for relating to winter flounder distribution metrics which span their range in US waters.

*Gulf Stream Index (Basin Scale):*

The Gulf Stream Index (GSI) time series was sourced from NOAA's ecodata and is the degrees latitude above the average Gulf Stream position based on ocean temperature at 200 m depth at areas between 55°W to 75°W (Joyce and Zhang 2010). Positive values represent a more northerly Gulf Stream, and negative values represent a more southerly Gulf Stream. (https://noaa-edab.github.io/ecodata/reference/gsi.html)

*Warm core ring time series (Basin Scale):*

Gangopadhyay et al. (2020) analyzed a census of warm-core rings of the Gulf Stream from 1980 to 2017. This yearly census of Gulf Stream warm-core ring formation from 1980 to 2017 was sourced from this study and manually transformed to display the number of warm-core ring events per year across the time series. The number of warm-core ring formations was found to influence Georges Bank winter flounder stock dynamics (Kerr et al. 2022). (https://www.bco-dmo.org/dataset/810182)

*North Atlantic Oscillation (Basin Scale):*

The North Atlantic Oscillation (NAO) index is based on the difference in surface sea-level pressure between the Subtropical High and the Subpolar Low (NOAA 2025). A positive trend in NAO indicates a warming effect, and a negative NAO trend is linked to colder conditions. (https://www.ncei.noaa.gov/access/monitoring/nao/)

*Atlantic Multidecadal Oscillation (Basin Scale):*

The Atlantic Multidecadal Oscillation index was accessed from NOAA and calculated from the Kaplan SST anomaly dataset (Enfield et al. 2001). This dataset is an index of North Atlantic air temperatures, and covers 1856 to January 2023. The "AMO unsmooth, long: Standard PSL Format" was used for the GAMs analysis, meaning that the data were raw and non-averaged, without any time-series smoothing applied, covering the entire historical period available, and in a standardized file format used by the NOAA Physical Sciences Laboratory. (https://psl.noaa.gov/data/timeseries/AMO/)

*Temporal Characterization of Environmental Variables:*

Environmental drivers used for the GAMs analysis were summarized as 6 and 12-month means prior to the start of the NMFS spring and fall bottom trawl survey. The fall survey generally starts in September; therefore, the 12-month means spanned October to September, and the 6-month means spanned April to September. The spring survey generally begins in February; therefore, 12-month means spanned March to February, and 6-month means spanned September to February. This lag approach is based on methods used in Fredston-Hermann (2020) and ensures that the environmental data used in this analysis precedes the fisheries-independent survey data.

**Statistical Analysis**

Temporally lagged environmental indices were related to season-specific indicators of winter flounder stock dynamics using generalized additive models (GAMs). GAMs are a nonparametric form of generalized linear models (GLMs) that can iteratively fit scatter-plot smoothers to nonlinear relationships with multiple explanatory variables (Hastie & Tibshirani 1990). The initial equations of GAMs are described in Table 2 and includes all candidate explanatory variables prior to their subsequent elimination in a backward elimination GAM function using the *mgcv* package in R (Wood 2023; version 1.9-1). The backward fitting technique used covariate (smoother) significance ($p < 0.05$) and AIC to select the best-fitting model for each response variable. Gaussian error distributions were adopted for analyses of log-transformed recruitment indices (both age-1 abundance and R/SSB), weight at age 1, condition, and distribution indices, as they follow normal bell-shaped distributions. The scaled t (*scat*) error family was used for weight at ages 2-7 (plus group) due to heteroskedasticity in the error terms.

To obtain the deviance explained for each individual smooth variable, the deviance explained of all significant variables together, excluding the chosen variable, was subtracted from the deviance explained of the full final model. This reduced model used the same smoothing parameters as the final model. This calculation is a commonly used approximation of individual drivers' deviance explained and should not necessarily add up to the final model's deviance explained.

Table 4.1. Explanatory Variables Used in GAMs. Explanatory variables examined in generalized additive models (GAMs) using environmental and stock data of winter flounder. GSI = Gulf Stream Index, AMO = Atlantic Multidecadal Oscillation, NAO = North Atlantic Oscillation, WCR = Warm Core Ring Index, BT = Bottom Temperature, SST = Sea Surface Temperature, SSB = Spawning Stock Biomass. Environmental variables were lagged 6 months and 12 months prior to the start of the widely used seasonal bottom trawl survey used for GAMs calculations (NMFS).

| Recruitment | Distribution | Growth |
|---|---|---|
| GSI (6-month mean)<br>GSI (annual mean) | GSI (6-month mean)<br>GSI (annual mean) | GSI (6-month mean)<br>GSI (annual mean) |
| AMO (6-month mean)<br>AMO (annual mean) | AMO (6-month mean)<br>AMO (annual mean) | AMO (6-month mean)<br>AMO (annual mean) |
| NAO (6-month mean)<br>NAO (annual mean) | NAO (6-month mean)<br>NAO (annual mean) | NAO (6-month mean)<br>NAO (annual mean) |
| WCR (6-month mean)<br>WCR (annual mean) | WCR (6-month mean)<br>WCR (annual mean) | WCR (6-month mean)<br>WCR (annual mean) |
| BT (6-month mean)<br>BT (annual mean)<br>SST (6-month mean)<br>SST (annual mean) | BT (6-month mean)<br>BT (annual mean)<br>SST (6-month mean)<br>SST (annual mean) | BT (6-month mean)<br>BT (annual mean)<br>SST (6-month mean)<br>SST (annual mean) |
| SSB (annual mean) (in age 1 recruitment GAM only) | SSB is by stock only, not included in distribution GAMs | SSB (annual mean) |

Table 4.2. Equations used in GAMs. Generalized additive model (GAM) equations developed for each winter flounder seasonal stock dynamic process, including all candidate explanatory variables explored. Each variable was assigned 5 knots to standardize models. The REML method was also applied to all models. The term *s* is a spline smoother and the following acronyms index environmental time series: GSI = Gulf Stream Index; AMO = Atlantic Multidecadal Oscillation; NAO = North Atlantic Oscillation; WCR = Warm Core Ring Index; BT = Bottom Temperature; SST = Sea Surface Temperature; SSB = Spawning Stock Biomass.

| **Stock Dynamic** | **Initial GAM Equation** |
|---|---|
| Recruitment | $Recruits/SSB = s(SST) + s(BT) + s(GSI) + s(AMO) + s(NAO) + s(WCR)$ |
| Recruitment | $Age\ 1\ Abundance = s(SST) + s(BT) + s(GSI) + s(AMO) + s(NAO) + s(SSB) + s(WCR)$ |
| Distribution | $Mean\ Depth = s(GSI) + s(AMO) + s(NAO) + s(BT) + s(SST) + s(WCR)$ |
| Distribution | $Mean\ Latitude = s(GSI) + s(AMO) + s(NAO) + s(BT) + s(SST) + s(WCR)$ |
| Growth | $Weight\ at\ Age(1 - 11 +) = s(BT) + s(SST) + s(GSI) + s(AMO) + s(NAO) + s(SSB) + s(W$ |
| Growth | $Condition\ Index = s(SST) + s(BT) + s(GSI) + s(AMO) + s(NAO) + s(SSB) + s(WCR)$ |

Results

**Recruitment**

Winter flounder recruitment exhibited variable responses to environmental drivers and climate forcing depending on the stock. Overall, temperature and circulation-related predictors emerged as the most influential drivers of recruitment, but the direction of these relationships varied by stock region.

Recruitment of Gulf of Maine winter flounder exhibited relationships with environmental drivers. Bottom temperature (12-month lag) was identified as a significant driver influencing age 1 recruitment based on the NEFSC fall survey, explaining 23% of variance (Fig. 4.1, Table 4.3). In addition, the Gulf Stream Index (6-month lag) was identified as having the largest partial effect on the MADMF spring Age 1 abundance index of winter flounder, explaining 39% of variance (Fig. 4.1, Table 4.3). Both of these factors exhibited a positive effect on winter flounder recruitment, with the shape of the curve indicating a possible threshold effect. Gulf of Maine winter flounder recruits per spawner (NEFSC fall survey) also showed a significant relationship with the GSI (6-month lag) with a varied trend in the response curve with the lowest R/SSB at intermediate GSI (18% deviance explained, Fig. 4.1, Table 4.3). SSB was not a significant predictor of Gulf of Maine winter flounder recruitment (Table 4.3).

Georges Bank winter flounder recruitment responses to environmental drivers were comparatively weaker than the other stocks. No final GAMs for recruitment (age 1 abundance) identified significant relationships with environmental variables (Table 4.3). Recruits per spawner (NEFSC fall survey) exhibited a positive relationship with both AMO (12-month lag: 15% deviance explained) and GSI (12-month lag:  8% deviance explained; Fig. 4.2, Table 4.3). In addition, the Georges Bank winter flounder spring index of recruits per spawner exhibited a strong, positive relationship with the WCR index (12-month lag), with 46% deviance explained by the trend (Fig. 4.2, Table 4.3).

Southern New England/Mid-Atlantic winter flounder recruitment was associated with both climate and thermal indices. SST (12-month lag) was an influential driver of age 1 abundance, explaining 22% of the variance and having a negative relationship with age-1 abundance from the MADMF spring survey (Fig. 4.3, Table 4.3). SST (12-month lag) was also a prominent driver of Age 1 abundance derived from the NEFSC spring survey, explaining 25% of the full model deviance, with a predominantly negative influence on recruitment (Fig. 4.3, Table 4.3). In contrast, the fall NEFSC survey Age 1 abundance index exhibited significant positive relationships with AMO (12-month lag; 19.1% deviance explained), NAO (12-month lag; 20% deviance explained), and WCR (12-month lag; 8% deviance explained; Fig. 4.3, Table 4.3). SSB was another significant positive driver for this particular survey index, explaining the most variance out of all explanatory variables (46% deviance explained; Fig. 4.3, Table 4.3). SST (12-month lag) was also a significant factor for Southern New England/Mid-Atlantic recruits per spawner, with 18% deviance explained in the fall and 25% in the spring with a positive relationship (Fig. 4.3, Table 4.3).

Table 4.3. Recruitment GAMs Summary. Summary of final recruitment models for winter flounder, including significant variables, deviance explained (DE) of full models and single predictors, error distribution family, P values of the smooth terms, and characterization of overall relationship trends (i.e., general directional trend over where the majority of the data observations occur in each rug plot).

| **Stock** | **Response Variable** | **Family** | **DE** | **Significant Predictors with Individual DE** | **P Values** | **Overall Relationship Trend** |
|---|---|---|---|---|---|---|
| GOM | Age 1 NMFS Fall (log) | gaussian | 0.23 | BT (12mo, 0.23) | 0.013 | Positive |
| | Age 1 MADMF Spring (log) | gaussian | 0.39 | GSI (6mo, 0.39) | <0.001 | Positive |
| | Fall R/SSB | gaussian | 0.18 | GSI (6mo, 0.18) | 0.043 | Varied |
| GBK | Fall R/SSB | gaussian | 0.21 | GSI (12mo, 0.08),<br>AMO (12mo, 0.15) | 0.043,<br>0.048 | Positive<br>Positive |
| | Spring R/SSB | gaussian | 0.46 | WCR (12mo, 0.46) | <0.001 | Positive |
| SNEMA | Age 1 NMFS Fall (log) | gaussian | 0.57 | AMO (12mo, 0.19),<br>NAO (12mo, 0.20), | <0.001,<br><0.001, | Positive<br>Positive |

Table 4.3 continued

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | WCR (12mo, 0.08),<br>SSB (0.46) | 0.018,<br><0.001 | Positive<br>Positive |
| | Age 1 NMFS Spring (log) | gaussian | 0.25 | SST (12mo, 0.25),<br>GSI (6mo, 0.07) | 0.008,<br>0.047 | Varied<br>Positive |
| | Age 1 MADMF Spring (log) | gaussian | 0.21 | SST (12mo, 0.21) | 0.001 | Negative |
| | Fall R/SSB | gaussian | 0.27 | SST (12mo, 0.16),<br>AMO (12mo, 0.10) | 0.046,<br>0.028 | Varied<br>Positive |
| | Spring R/SSB | gaussian | 0.25 | SST (12mo, 0.25) | 0.002 | Positive |

**Gulf of Maine Recruitment**

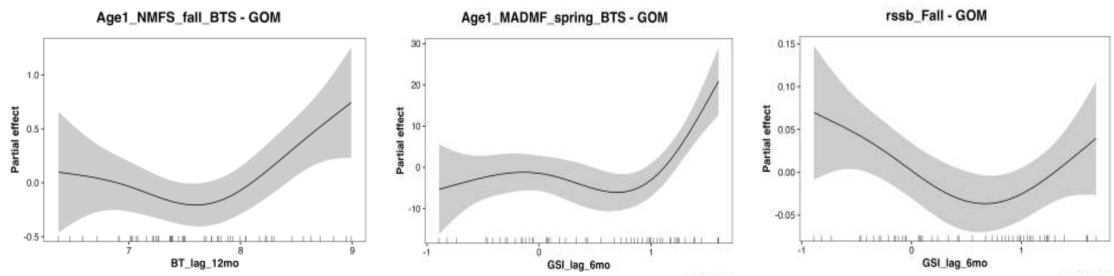



Figure 4.1. Gulf of Maine Age 1 GAM Results. Gulf of Maine Age 1 Abundance (no/tow) and R/SBB GAM analysis plots with significant predictors identified.

**Georges Bank Recruitment**

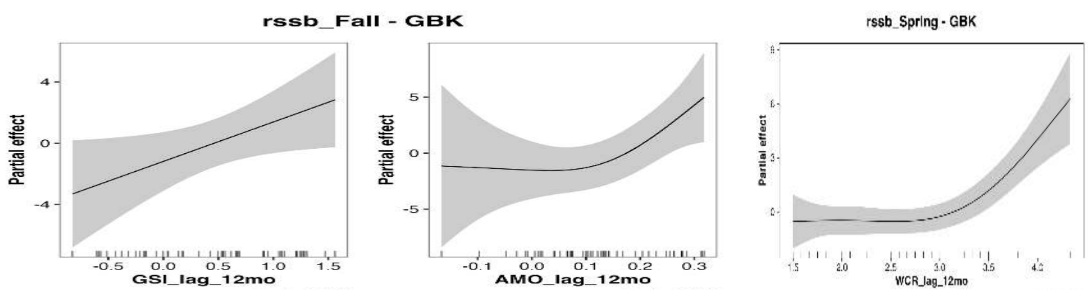



Figure 4.2. Georges Bank Recruits Per Spawner GAM Results. Georges Bank R/SBB GAM analysis plots with significant predictors identified (no models run for Age 1 abundance had significant results).

**Southern New England/Mid-Atlantic Recruitment**

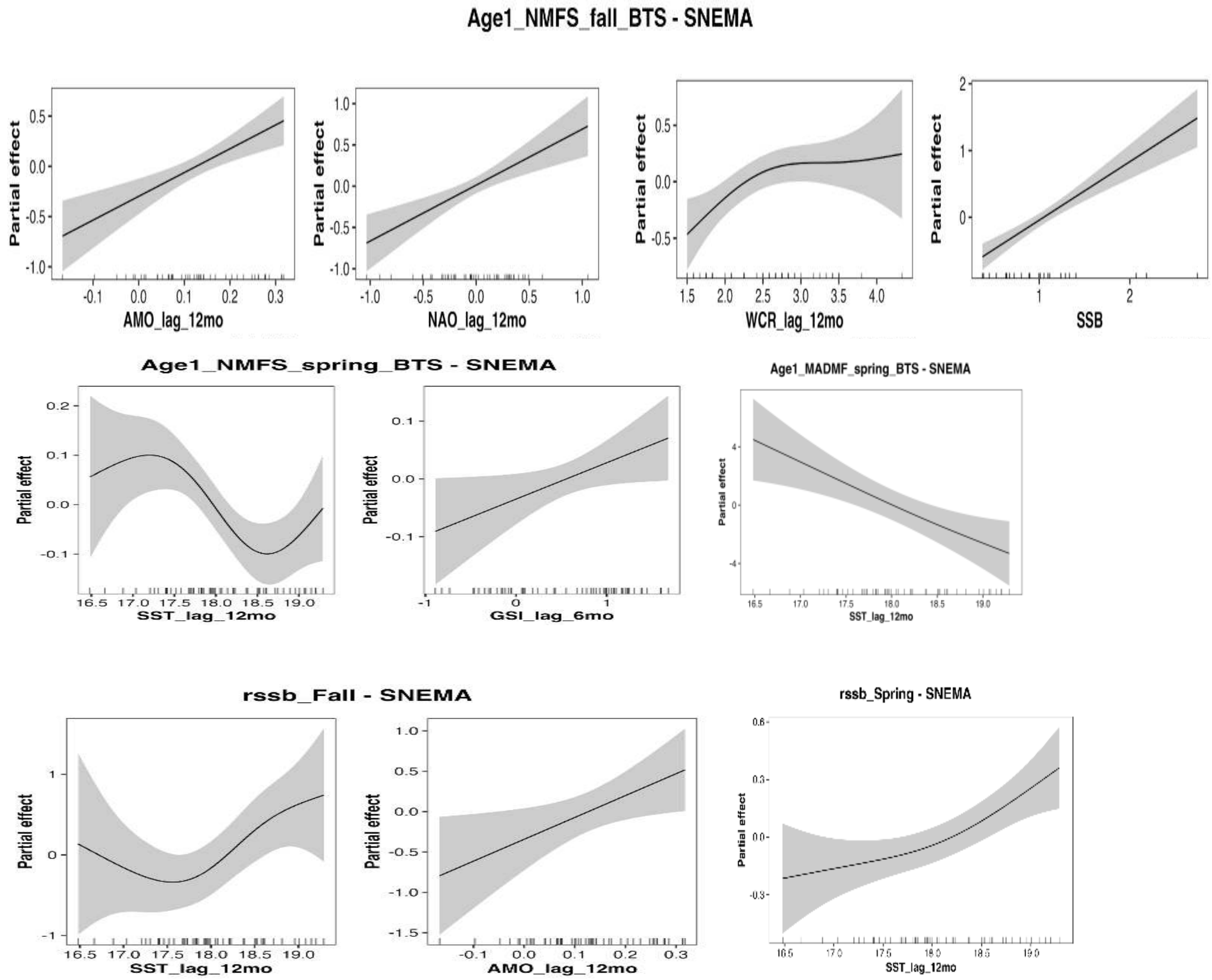



Figure 4.3. Southern New England/Mid-Atlantic Recruitment GAM Results. Southern New England/Mid-Atlantic Age 1 Abundance (no/tow) and R/SBB GAM analysis plots with significant predictors identified.

**Growth**

GAM results for winter flounder show distinct environmental and density-dependent drivers of growth across stock regions and life stages. Growth responses were mostly explained by variance in temperature, large-scale climate oscillations, Gulf Stream movement, and SSB.

In the Gulf of Maine, growth of early age classes was strongly linked to thermal and oceanographic processes. For weight-at-age (WAA) 1, the final model (62% total variance explained 62%) was driven mostly by BT (12-month lag), which showed a positive relationship with 33% deviance explained (Fig. 4.4, Table 4.4). SSB was an additional predictor (1% deviance explained) with a negative relationship, suggesting slight density-dependent growth (Fig. 4.4, Table 4.4). For WAA 2 (full model deviance explained 68%), BT (12-month lag; 8.6% deviance explained), GSI (12-month lag; 14.4% deviance explained), and the NAO (12-month lag; 3% deviance explained) were all identified as significant positive drivers (Appendix F, Table 4.4). SSB was a consistent negative predictor across WAA 1 to 4, and 6 (the WAA 5 model for Gulf of Maine was not significant and was not included in the final model table, Table 4.4). WAA 7 plus winter flounder (62% deviance explained) was driven by SSB (25% deviance explained), BT (12-month lag; 8.3% deviance explained) and WCR (12-month lag; 7.6% deviance explained; Fig. 4.4, Table 4.4). In contrast to positive trends at younger ages, BT had a negative influence on WAA at older ages and SSB had a varied relationship, although WCR had a positive influence. Relative condition of Gulf of Maine winter flounder served as another metric of growth and was significantly related to a sole predictor, WCR (12-month lag), with 61% deviance explained (Fig. 4.7, Table 4.4). The partial effect of the increased frequency of WCRs caused a negative trend in relative condition (Fig. 4.7).

Georges Bank winter flounder growth was largely driven by oceanographic processes. For the WAA 1 model (52% deviance explained), GSI (6-month lag; 27% deviance explained) showed a positive relationship, while SSB (25% deviance explained) showed a varied relationship (Fig. 4.5, Table 4.4). WAA 2 (52% deviance explained) exhibited a positive relationship with BT (12-month lag; 6.5% deviance explained) (Appendix F, Table 4.4). SSB (5.4% deviance explained) exhibited a varied relationship (Appendix F, Table 4.4). For WAA 3 (64% deviance explained), SSB was the most significant factor (25% deviance explained; Appendix G, Table 4.4). WCR (12-month lag) maintained a positive relationship

(11.2% deviance explained), while BT (6-month lag; 4%) and GSI (12-month lag; 3.3% deviance explained) both showed varied effects (Appendix G, Table 4.4). The WAA 4 model exhibited the highest deviance explained (71%) of all the WAA models (Appendix H, Table 4.4). It was dominated by SSB with 23% variance explained and a negative effect, and WCR (12-month lag), with 18% deviance explained and a positive relationship (Appendix H, Table 4.4). GSI (6-month lag) showed a varied relationship with 9.1% deviance explained (Fig. 4.5, Table 4.4). WAA 4 and 5 were both driven by SSB and WCR, (both 12-month lag) with WCR having a positive partial effect and SSB having a negative effect for both age groups (Appendix H and I, Table 4.4). BT (6-month lag) was present in the WAA 5 model with a negative relationship and explaining 6.3% variance (Appendix I, Table 4.4). For WAA 7 plus in Georges Bank, (final model 61% deviance explained), both BT (12-month lag; 8% deviance explained) and GSI (6-month lag; 20% deviance explained) had negative relationships (Fig. 4.5, Table 4.4). SSB showed a varied relationship with 15% deviance explained (Fig. 4.5, Table 4.4). Relative condition of Georges Bank winter flounder was driven by WCRs (12-month lag) with 61% deviance explained with a varied relationship, followed by BT (6-month lag; 3.5% deviance explained; positive effect) (Fig. 4.7, Table 4.4).

In the Southern New England/Mid-Atlantic stock, growth responses were more variable across ages. For WAA 1, (53% deviance explained), AMO (12-month lag; 18% deviance explained) showed a negative relationship, while WCR (12-month lag; 18% deviance explained) also showed a negative response (Fig. 4.6, Table 4.4). WAA 2 was driven by a sole predictor, WCR (12-month lag), explaining 64% of variance and driving a negative trend (Appendix F, Table 4). WAA 3 (16% deviance explained) had a single driver, NAO (12-month lag) that had a varied effect (Appendix G, Table 4.4). The final WAA 3 model had the weakest explanatory power of all Southern New England/Mid-Atlantic WAA models (Table 4.4). WAA 4 (46% deviance explained) had SSB (negative) and BT (12-month lag, varied) as drivers, explaining 23% and 18% of variance, respectively (Appendix H, Table 4.4). WAA 5 (37% deviance explained) included three drivers: GSI (12-month lag; 16% deviance explained), AMO (6-month lag; 13% deviance explained), and NAO (6-month lag; 12% deviance explained), all of which had a positive relationship with winter flounder WAA (Appendix I, Table 4.4). WAA 6 indicated two significant predictors, WCR (12-month lag; positive) that explained 33% of variance and GSI (12-month lag; varied), which explained 11% of variance in the model (Appendix J, Table 4.4). The WAA 7 Plus group model had three significant covariates with varied and negative relationships: SSB, AMO (12-month lag), and GSI (6-month lag), explaining 9.5%, 4.8%, and 3.3% of variance, respectively (Fig. 4.6, Table 4.4). The relative condition final model had 33% deviance explained, with GSI and SSB as the main predictors (Table 4). SSB explained 22% of the overall variance with a varied trend, while GSI (12-month lag) explained 28% of variance with a positive trend (Fig. 4.7, Table 4.4).

Table 4.4. Growth GAMs Summary. Summary of final growth models for winter flounder, including significant variables, deviance explained (DE) of full models and single predictors, error distribution family, P values of the smooth terms, and characterization of overall relationship trends (i.e., general directional trend over where the majority of the data observations occur in each rug plot).

| **Stock** | **Target** | **Family** | **DE** | **Significant Predictors with individual DE** | **P Values** | **Overall Relationship Trend** |
|---|---|---|---|---|---|---|
| GOM | Weight at Age1 | gaussian | 0.62 | BT (12mo, 0.33),<br>NAO (6mo, 0.004),<br>SSB (0.01) | <0.001,<br>0.034,<br>0.017 | Positive<br>Positive<br>Negative |
| | Weight at Age2 | scaled t | 0.68 | BT (12mo, 0.09)<br>GSI (12mo, 0.14)<br>NAO (12mo, 0.03)<br>SSB (0.13) | 0.010,<br><0.001,<br>0.033,<br><0.001 | Positive<br>Positive<br>Positive<br>Negative |
| | Weight at Age3 | scaled t | 0.54 | GSI (12mo, 0.12),<br>NAO (12mo, 0.11),<br>WCR (12mo, 0.083),<br>SSB (0.074) | 0.003,<br><0.001,<br>0.008,<br>0.002 | Positive<br>Positive<br>Varied<br>Negative |
| | Weight at Age4 | scaled t | 0.31 | AMO (12mo, 0.088),<br>NAO (12mo, 0.062),<br>SSB (0.032) | 0.002,<br>0.004,<br>0.003 | Positive<br>Positive<br>Negative |
| | Weight at Age6 | scaled t | 0.59 | WCR (12mo, 0.21),<br>SSB (0.17) | 0.004,<br>0.003 | Varied<br>Negative |
| | Weight at Age7 Plus | scaled t | 0.62 | BT (12mo, 0.083),<br>WCR (12mo, 0.076),<br>SSB (0.25) | 0.025,<br>0.007,<br><0.001 | Negative<br>Varied<br>Varied |
| GBK | Weight at Age1 | gaussian | 0.52 | GSI (6mo, 0.27),<br>SSB (0.29) | <0.001,<br><0.001 | Positive<br>Varied |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Weight at Age2 | scaled t | 0.52 | BT (2mo, 0.065),<br>GSI (6mo, -0.14*),<br>WCR (12mo, 0.01),<br>SSB (0.054) | 0.003,<br>0.027,<br><0.001,<br>0.014 | Positive<br>Positive<br>Positive<br>Varied |
| | Weight at Age3 | scaled t | 0.64 | BT (6mo, 0.04),<br>GSI (12mo, 0.033),<br>WCR (12mo, 0.11),<br>SSB (0.25) | 0.050,<br>0.014,<br><0.001,<br><0.001 | Varied<br>Varied<br>Positive<br>Negative |
| | Weight at Age4 | scaled t | 0.71 | GSI (6mo, 0.09),<br>WCR (12mo, 0.18),<br>SSB (0.23) | 0.007,<br><0.001,<br><0.001 | Varied<br>Positive<br>Negative |
| | Weight at Age5 | scaled t | 0.66 | BT (6mo, 0.063),<br>WCR (12mo, 0.22),<br>SSB (0.26) | 0.047,<br><0.001,<br><0.001 | Negative<br>Positive<br>Negative |
| | Weight at Age6 | scaled t | 0.49 | BT (12mo, 0.18),<br>AMO (12mo, 0.06) | <0.001,<br>0.031 | Negative<br>Positive |
| | Weight at Age7 Plus | scaled t | 0.61 | BT (12mo, 0.08),<br>GSI (6mo, 0.20),<br>SSB (0.15) | 0.011,<br>0.002,<br>0.009 | Negative<br>Negative<br>Varied |
| SNEMA | Weight at Age1 | gaussian | 0.53 | AMO (12mo, 0.18),<br>WCR (12mo, 0.18) | 0.005,<br>0.008 | Negative<br>Negative |
| | Weight at Age2 | scaled t | 0.64 | WCR (12mo, 0.64) | <0.001 | Negative |
| | Weight at Age3 | scaled t | 0.16 | NAO (12mo, 0.16) | 0.009 | Varied |
| | Weight at Age4 | scaled t | 0.46 | BT (12mo, 0.18),<br>SSB (0.23) | 0.016,<br><0.001 | Varied<br>Negative |
| | Weight at Age5 | scaled t | 0.37 | GSI (12mo, 0.16),<br>AMO (6mo, 0.13),<br>NAO (6mo, 0.12) | 0.022,<br>0.004,<br>0.023 | Positive<br>Positive<br>Positive |
| | Weight at Age6 | scaled t | 0.45 | GSI (12mo, 0.11),<br>WCR (12mo, 0.33) | 0.043,<br><0.001 | Varied<br>Positive |
| | Weight at Age7 Plus | scaled t | 0.44 | GSI (6mo, 0.033),<br>AMO (12mo, 0.048),<br>SSB (0.095) | <0.001,<br><0.001,<br>0.001 | Negative<br>Varied<br>Varied |
| GOM | Relative Condition | gaussian | 0.61 | WCR (12mo, 0.61) | <0.001 | Varied |
| GBK | Relative Condition | gaussian | 0.71 | BT (6mo, 0.035),<br>WCR (12mo, 0.61) | 0.024,<br><0.001 | Positive<br>Varied |
| SNEMA | Relative Condition | gaussian | 0.33 | GSI (12mo, 0.28),<br>SSB (0.22) | 0.002,<br>0.030 | Positive<br>Varied |

*Negative deviance explained implies that there is strong collinearity or fit instability for that variable

**Gulf of Maine Weight at Age 1 and 7 (Plus Group)**

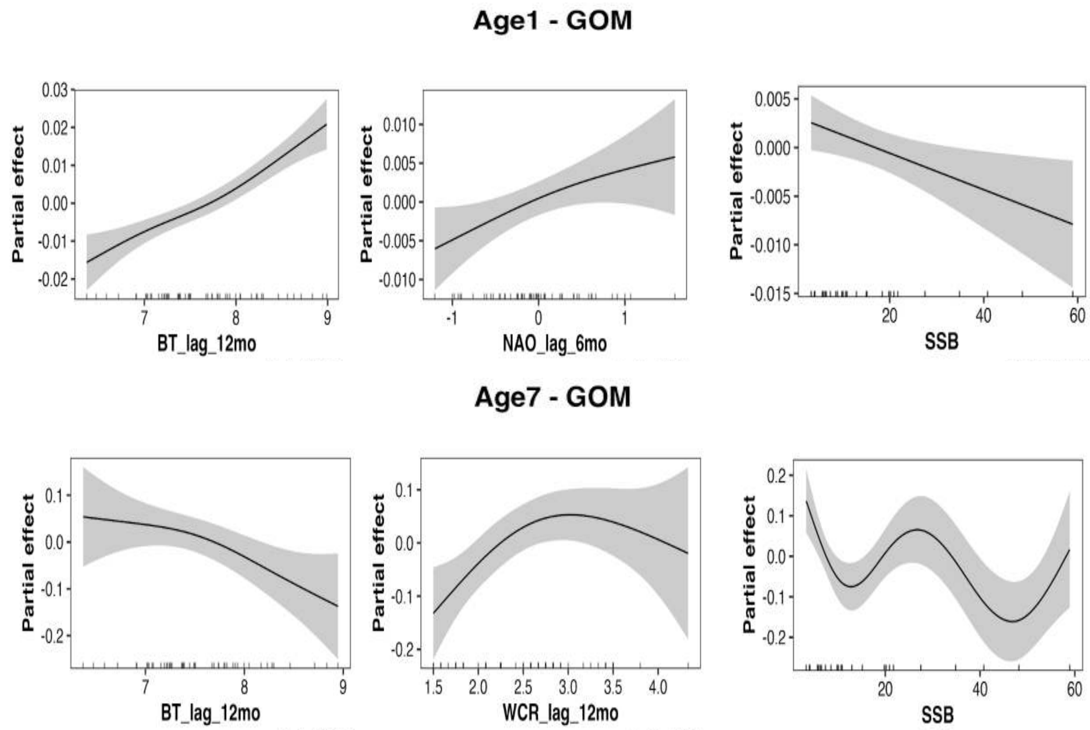



Figure 4.4. Gulf of Maine Weight at Age 1 and 7 GAM Results. Gulf of Maine Weight at Age 1 and 7 Plus final GAMs analysis results with significant predictors identified.

**Georges Bank Weight at Age 1 and 7 (Plus Group)**

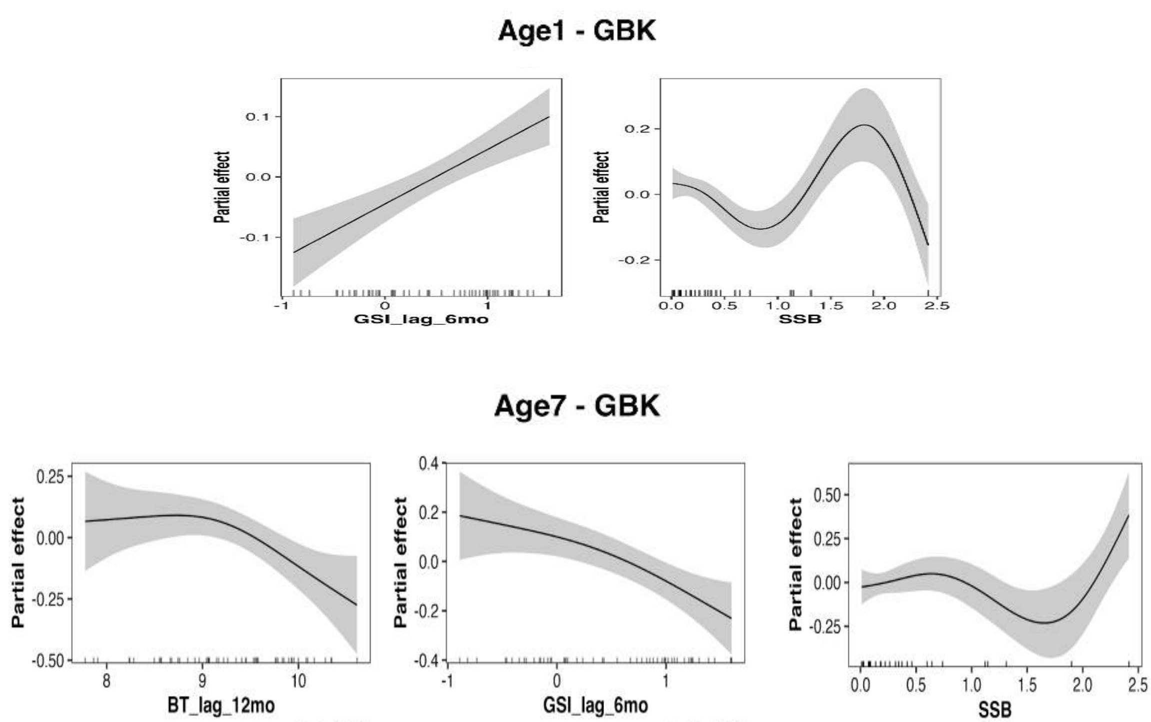


Figure 4.5. Georges Bank Weight at Age 1 and 7 GAM Results. Georges Bank Weight at Age 1 and 7 Plus final GAMs analysis results with significant predictors identified.

**Southern New England-Mid/Atlantic Weight at Age 1 and 7 (Plus Group)**

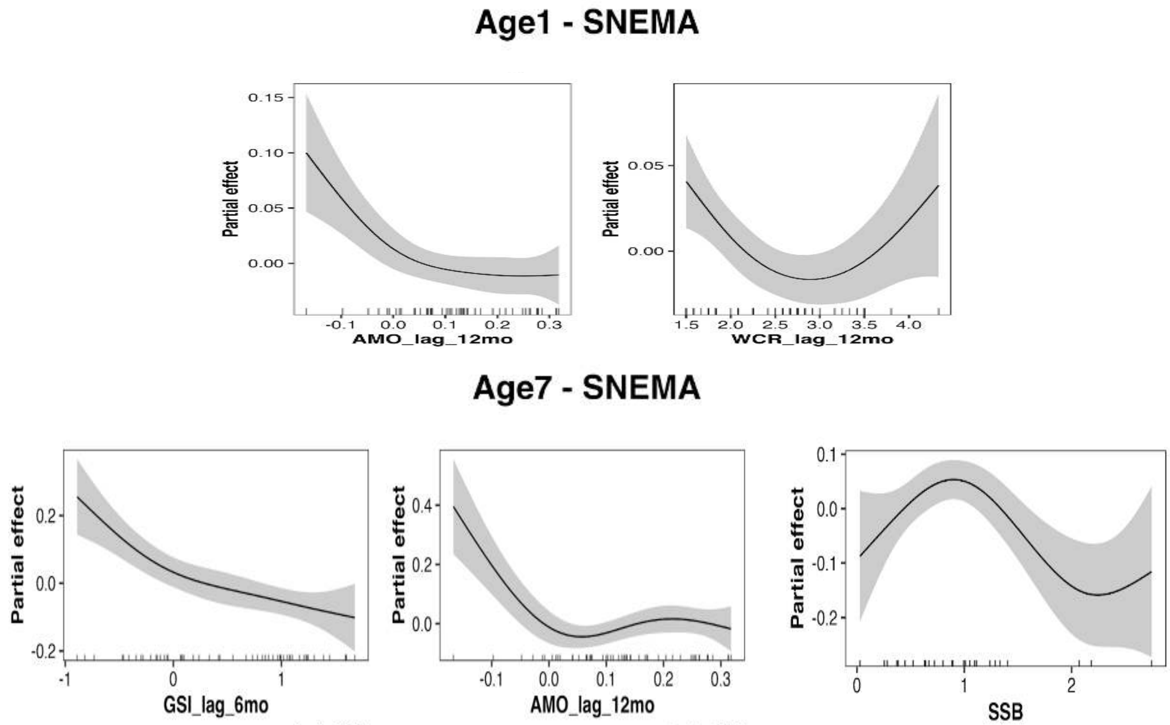



Figure 4.6. Southern New England/Mid-Atlantic Weight at Age 1 and 7 GAM Results. Southern New England/Mid-Atlantic Weight at Age 1 and 7 Plus final GAMs analysis results with significant predictors identified.

**Winter Flounder Relative Condition**

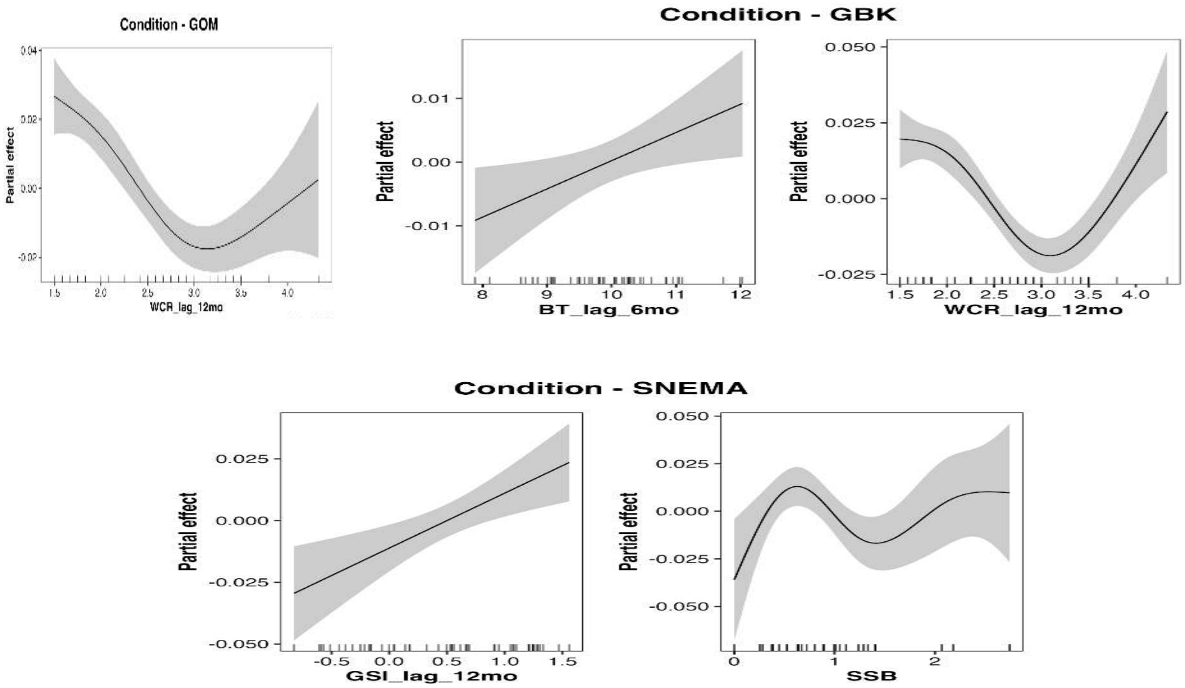



Figure 4.7. Relative Condition GAM Results. Final GAM results of Relative Condition of Winter Flounder with significant predictors identified.

**Distribution**

The final winter flounder species-wide distribution GAMs showed strong relationships between climate drivers and spatial shifts of winter flounder with seasonally specific behaviors (Table 5). Most identified drivers were associated with increasing depth, as well as a northward shift in the distribution of winter flounder.

The final models for mean depth had strong explanatory power, explaining 66% (fall) and 50% (spring) of the total variance (Table 4.5), which demonstrates the sensitivity of winter flounder to environmental drivers influencing their seasonal vertical distribution. Fall depth was influenced by four interacting environmental drivers. SST (6-month lag) was the largest contributor (16% deviance explained), but showed a varied trend (Fig. 4.8, Table 4.5). This suggests that a threshold exists for winter flounder's response to warming surface waters. Once crossed, winter flounder mean depth increased.

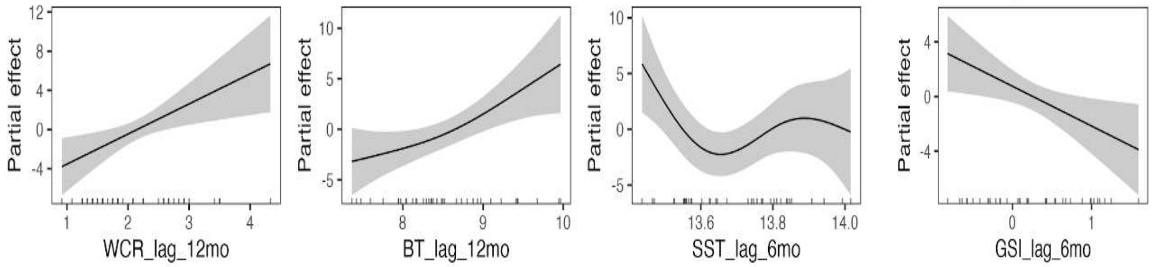
Both WCRs (12-month lag; 4% deviance explained) and BT (12-month lag; 9% deviance explained) showed a positive relationship on winter flounder depth (Fig. 4.8, Table 4.5), implying that the frequency of WCRs and increased BT also increased winter flounder mean depth distribution. Conversely, the GSI (6-month lag; 7% deviance explained) exhibited a negative relationship (Fig. 4.8, Table 4.5), implying that a more northern Gulf Stream can shift winter flounder populations to shallower waters. The spring depth model was dominated by SST (12-month lag), which individually explained 48% of the variance (Fig. 4.8, Table 4.5). The strong positive relationship between SST and the NAO index (6-month lag, 20% deviance explained) suggests strong coupling of environmental drivers that influence winter flounder mean depth, pushing the center of gravity towards deeper waters (Fig. 4.8, Table 4.5).

Winter flounder's latitudinal models show a significant linkage between climate forcing and a poleward shift in species range. The fall mean latitude model was the most predictive model in all distribution results, accounting for 79% of the variance (Fig. 4.9, Table 4.5). This model was almost entirely driven by the influence of SST (6-month lag), which individually explained 76% of the variance (Fig. 4.9, Table 4.5). The response of increasing SST on winter flounder latitudinal distribution shows evidence of a threshold beyond which movement is driven northward (Fig. 4.9, Table 4.5). The AMO (8% deviance explained) has a varied effect, associated with shifts northward up to a point followed by a shift in directionality (Fig. 4.9, Table 4.5). The spring latitude model (51% deviance explained) was also driven primarily by SST (12-month lag), which individually accounted for 50% of the variance (Fig. 4.9, Table 4.5). SST was a positive driver of winter flounder latitudinal movement northward (Fig. 4.9, Table 4.5). The NAO index was also a significant driver, with 17% of the deviance explained and a varied trend (Fig. 4.9, Table 4.5), suggesting that there is a threshold of increased thermal pressure impacting winter flounder latitudinal movement in the spring.

Table 4.5. Distribution GAMs Summary. Summary of final distribution models for winter flounder, including significant variables, deviance explained (DE) of full models and single predictors, error distribution family, P values of the smooth terms, and characterization of overall relationship trends (i.e., general directional trend over where the majority of the data observations occur in each rug plot).

| Response Variable | Family | DE | Significant Predictors with Individual DE | P Values | Overall Relationship Trend |
|---|---|---|---|---|---|
| Fall COG Depth (abs value) | gaussian | 0.66 | WCR (12mo, 0.04)<br>BT (12mo, 0.09)<br>SST (6mo, 0.16)<br>GSI (6mo, 0.07) | 0.0011,<br>0.030,<br>0.022,<br>0.023 | Positive (Deeper)<br>Positive (Deeper)<br>Varied<br>Negative (Shallower) |
| Spring COG Depth (abs value) | gaussian | 0.50 | SST (12mo, 0.48),<br>NAO (6mo, 0.20) | <0.001,<br>0.026 | Positive (Deeper)<br>Positive (Deeper) |
| Fall COG Lat | gaussian | 0.79 | SST (6mo, 0.76),<br>AMO(6mo, 0.08) | <0.001,<br>0.030 | Varied<br>Varied |
| Spring COG Lat | gaussian | 0.51 | SST (12mo, 0.50),<br>NAO (6mo, 0.17) | <0.001<br>0.043 | Positive<br>Varied |

**Fall COG Depth**




**Spring COG Depth**

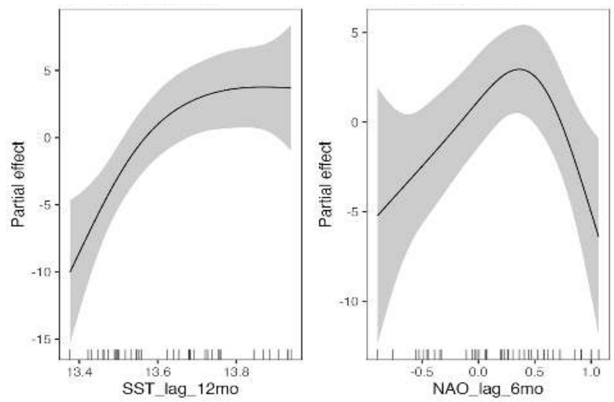
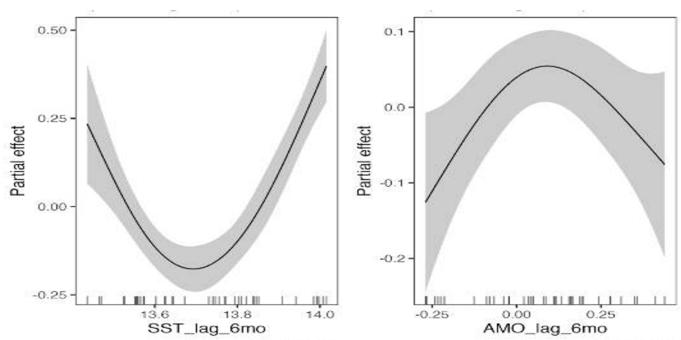



Figure 4.8. Depth Center of Gravity GAM Results. Center of Gravity of winter flounder depth in the fall (top) and spring (bottom) GAM analysis results. The absolute value of the negative depth values were taken prior to the analysis, therefore, a positive trend = increasing depth (deeper), and a negative trend = decreasing depth (shallower).

**Fall COG Latitude**




**Spring COG Latitude**

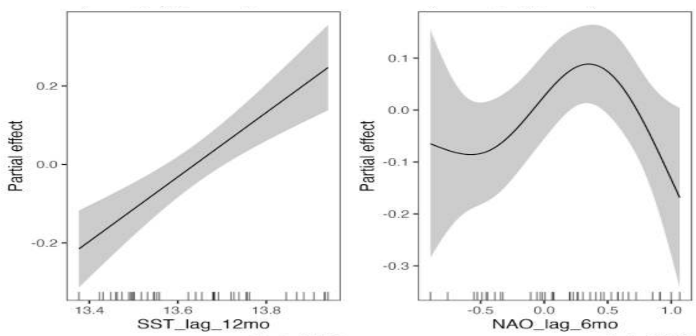



Figure 4.9. Latitude Center of Gravity GAM Results. Center of Gravity of winter flounder latitude in the fall (top) and spring (bottom) GAM analysis results. A positive trend = shift northward, whereas a negative trend = shift southward.

**Discussion**

The Northeast U.S. continental shelf ecosystem supports abundant and diverse living marine resources that many coastal communities in New England rely upon. Over the last 40 years, the Northwest Atlantic has undergone unprecedented change, impacting both marine and human communities (Pershing et al. 2015, Townsend et al. 2023). This study used GAM analysis to examine the potential drivers of winter flounder stock dynamics (i.e., recruitment, growth, and distribution) in US waters. Overall, the results indicate that winter flounder are responsive to dynamic ocean conditions and have stock-specific relationships with environmental drivers and density dependence. Results from this study suggest that there is no sole climate/ecosystem driver with complete control over winter flounder stock dynamics and productivity. While some drivers have subtle effects on the fishery resource, others are more impactful, and their combined effect has the potential to change the trajectory of winter flounder stock productivity.

Gulf of Maine winter flounder stock dynamics are influenced by both thermal factors and oceanic circulation. The relationship that both the GSI and BT have on recruitment in this stock suggests that recruitment success is tied to oceanic currents. Since winter flounder larvae are pelagic (Pearcy 1962) and are more influenced by ocean current movement, drivers of circulation could have an effect on dispersal and phenology of younger year classes. Results also showed environmental effects on age-specific growth in the Gulf of Maine. The strong, positive effect of BT on younger fish (Age 1) growth contrasts sharply with the negative response to BT at the oldest age classes. This suggests a thermal tolerance to growth, and that winter flounder being exposed to variable temperatures at different points in their life history can affect their fitness and function in the ecosystem (Pörtner 2010). There is also evidence of density dependence in this stock, with SSB significantly influencing the growth and distribution trends of Gulf of Maine winter flounder. Together, these findings highlight that Gulf of Maine winter flounder are increasingly responding to both thermal and circulation changes, which have the potential to alter recruitment, growth potential, and habitat use under a changing climate.

Georges Bank winter flounder showed a high sensitivity to the WCR index in all aspects of stock-specific dynamics analyzed in this study, as well as clear density dependence in their growth. In the recruitment model, the high deviance explained by the number of WCRs suggests a strong coupling between physical oceanographic variability and environmental drivers influencing winter flounder recruitment. The positive association between WCRs and recruits per spawner could mean that WCRs are a consistent facilitator of export and flow of warm water eddies from the Gulf Stream, where spawning winter flounder are located in Georges Bank (Aretxabaleta et al. 2005). Another important driver with a positive influence on winter flounder recruitment was the AMO, which is known to link fish productivity with long-term shifts in zooplankton community structure (Greene et al. 2012). This suggests that a warmer AMO regime could improve Georges Bank recruitment by positively impacting early-age winter flounder food sources. Winter flounder growth for Ages 3, 4, and 5 in Georges Bank is positively correlated with the number of WCRs and negatively correlated with SSB, suggesting strong density dependence, as well as a large-scale flow-regime influence on growth.

The Southern New England/Mid-Atlantic stock is at the southern limit of winter flounder's spatial distribution, and therefore exhibits strong responses to thermal and physical drivers. The finding that SST is a primary negative driver of Age 1 recruitment in Southern New England/Mid-Atlantic supports studies indicating that estuarine temperature variability can lead to reduced recruitment success (Able et al. 2014). Additionally, both NAO and AMO had a positive effect on Southern New England/Mid-Atlantic recruitment, indicating that multiple drivers are associated with recruitment success in this region. Environmental effects on age-specific growth in Southern New England/Mid-Atlantic were also apparent in my results. For example, the relationship between the number of WCRs and WAA 2 to 6, moving from a negative to strongly positive effect over a few year classes shows winter flounder's physiological sensitivity to ecosystem drivers throughout their life history.

While thermal and circulation patterns have stock-specific effects on certain life history dynamics of winter flounder, ecosystem drivers have also been identified as a mechanism for the spatial contraction of winter flounder over time. The analysis of the environmental drivers of species-wide distribution shifts (seasonal COG depth and latitude) provides clear evidence of winter flounder's range inhabiting more northern, deeper waters. Additionally, this analysis identifies the primary ecosystem drivers that impact winter flounder seasonally. SST was highlighted as the most influential driver of winter flounder latitudinal shifts, including a threshold for spatial movement response from the species. Concurrently, the vertical habitat use of winter flounder in the water column is highly dynamic, with multiple interacting drivers identified. While the spring mean depth model showed how warming conditions drive the species to move deeper, the complexity in the drivers identified in the fall model suggests a thermal trade-off. While increasing BT and WCRs promote deeper distribution shifts, the latitudinal position of the Gulf Stream has a contrasting partial effect, suggesting that a more northerly Gulf Stream can cause winter flounder populations to shift to shallower waters. Overall, the distribution analysis of winter flounder confirms that the species is utilizing both latitude and depth spatial areas to survive in a rapidly changing ecosystem.

Reviewing the results of this GAM analysis, winter flounder stock dynamics appear to be influenced by density-dependent processes in addition to ecosystem drivers. This was apparent in the recruitment and growth final models, where SSB had a mostly negative or varied (indicating a possible threshold) partial effect. Compensatory density dependence implies that a population's growth rate slows at high densities and subsequently increases at lower densities (Rose et al. 2002). Compensatory density dependence can act to stabilize populations, whereas depensatory density dependence tends to accelerate population decline for depleted populations (Rose et al. 2002). This study reveals a predominantly negative relationship between SSB and stock dynamics, such as growth and recruitment, supporting the presence of compensatory density dependence. This pattern suggests that reductions in biomass could lead to increased individual growth and recruitment rates; therefore, managers might expect population biomass to increase following periods of lower stock abundance. Density dependence, coupled with the identified environmental variables driving winter flounder productivity, is contributing to the species' inability to recover to its historic abundance following overfishing conditions.

Climate drivers are not the only ecosystem aspects that can impact winter flounder stock dynamics. With continued warming of the Gulf of Maine and surrounding regions, future research is needed to better understand the full effects of increased competition and predation on winter flounder stocks. In some situations, climate is not the sole factor responsible for declining populations. Beaumont et al. (2008) attributes the decline in winter flounder at the southern extent of their range partly to broader ecosystem shifts that include resident demersal species being replaced by pelagic species due to both climate and overfishing. This could also be contributing to the retreat of winter flounder from their southern species limit. Winter flounder may be experiencing decreased fitness due to a combination of climate variation and resource competition (Nicholson 1933). This suggestion aligns with ecosystem-based fisheries management (EBFM), in which multiple fish stocks and their ecosystem drivers can be analyzed together in stock assessments, leading to more ecosystem-informed management decisions (Large et al. 2015).

Limitations of this Study

While GAMs are a very useful tool to show the non-linear and sometimes indirect relationship between environmental drivers and fish stock dynamics, there are a few limitations to the method. One caveat of this approach is the potential for collinearity and correlations between environmental predictors in the model. This is seen with most thermal and oceanographic-related drivers. The oceanic indices (GSI, WCR, AMO, and NAO) and the local stock variables of SST and BT are driven by the same large-scale atmospheric patterns. Therefore, high concurvity is expected in this type of analysis. Due to the specific life history of winter flounder that is captured in spring and fall surveys, these similar environmental variables were grouped together in the backward-elimination GAM function. Results of a correlation analysis that compared the potentially colinear environmental predictors to one another using a threshold of 0.7 showed that only SST and BT were highly correlated (0.90 and above depending on the lag comparison), as well as the 12- and 6- month lags of the same variable. No final models included both BT and SST as significant predictors. Another modification was made to the function to prevent the final model from including both lagged versions of the same variable, thereby further maximizing the individual explanatory power of each significant driver. The exploration of the significant effects of variables lagged at different time intervals has the potential to provide a clearer understanding of the scale at which environmental drivers affect winter flounder productivity. Further analysis is recommended, using different lag times with an underlying ecological basis (e.g., SST lagged according to spawning times for each stock).

Given the potential for concurvity among the environmental drivers chosen in this analysis, the final interpretation of the results should be specifically framed. Results should indicate correlation, not causation, between environmental drivers and winter flounder stock dynamics. As such, the individual deviance explained reported for each predictor in the results of this analysis should not be treated as the isolated effect of a sole variable. Instead, the final interpretation of this study should be focused on the collective explanatory power of the final models. The total deviance explained should be interpreted as the influence of a suite of environmental drivers working together to impact winter flounder stock dynamics, as this acknowledges the inherent connection between these environmental drivers and the specific ecosystem sensitivities within winter flounder's unique life history strategies.

A recommendation for further analysis of environmental effects on winter flounder productivity is to explore the relationships using different survey indices of recruitment, growth, and stock-specific distribution. Results may show different non-linear relationships that should also be considered in stock assessment.

Application to Stock Assessment and Management

Failure to account for the non-linear, variable, and coupled effects of environmental and density drivers, as highlighted by this GAM analysis, introduces significant and lasting uncertainty into the stock assessment and modeling process for scientists and fisheries managers. The relationship among these many drivers and their effects on winter flounder during critical life stages must be addressed to accurately represent and analyze winter flounder populations in stock assessments. Specific recommendations based on this analysis that would be useful to the stock assessment modeling process are to explore GSI and BT for the Gulf of Maine, WCRs for Georges Bank, and SST and SSB on Southern New England/Mid-Atlantic. These variables provided the most variance explained across stock dynamics processes in the final models of this analysis.

Given these often-varied effects on winter flounder population dynamics, winter flounder populations are at risk of being inaccurately modeled in stock assessments. This highlights the importance of this study in gaining a more holistic understanding of the impacts of changing ocean conditions on the winter flounder fishery. This research sets a precedent for mitigating further uncertainty in the stock assessment process, thereby achieving a sustainable fishery, while providing economic stimulation and maintaining stability within the fishery community for the foreseeable future.

## BIBLIOGRAPHY


Able, K. W., T. M. Grothues, J. M. Morson, and K. E. Coleman. 2014. Temporal variation in winter flounder recruitment at the southern margin of their range: is the decline due to increasing temperatures? ICES Journal of Marine Science 71:2186–2197.

Akaike, H. 1998. Information Theory and an Extension of the Maximum Likelihood Principle. Pages 199–213 *in* E. Parzen, K. Tanabe, and G. Kitagawa, editors. Selected Papers of Hirotugu Akaike. Springer, New York, NY.

Aretxabaleta, A., J. Manning, F. E. Werner, K. Smith, B. O. Blanton, and D. R. Lynch. 2005. Data assimilative hindcast on the Southern Flank of Georges Bank during May 1999: frontal circulation and implications. Continental Shelf Research 25:849–874.

Atlantic States Marine Fisheries Commission. 2025, November 7. https://asmfc.org/.

Balouskus, R. G., J. M. Lake, K. E. Rodrigue, S. D. Olszewski, and M. C. McManus. 2024. A coastal lagoon-spawning Winter Flounder subpopulation during ecosystem and fisheries shifts. https://repository.library.noaa.gov.

Beacham, T. D. 1982. Biology and Exploitation of Winter Flounder (Pseudopleuronectes americanus) in the Canadian Maritimes Area of the Northwest Atlantic Ocean. Department of Fisheries and Oceans Fisheries Research Branch Canadian Technical Report of Fisheries and Aquatic Sciences.

Beaulieu, C., and R. Killick. 2018. Distinguishing Trends and Shifts from Memory in Climate Data. Journal of Climate 31:9519–9543.

Beaumont, L. J., L. Hughes, and A. J. Pitman. 2008. Why is the choice of future climate scenarios for species distribution modelling important? Ecology Letters 11:1135–1146.

Behan, J., and L. Kerr. In Prep. Environmental Influences on American Plaice Stock Dynamics.

Bell, R. J., B. Grieve, M. Ribera, J. Manderson, and D. Richardson. 2022. Climate-induced habitat changes in commercial fish stocks. ICES Journal of Marine Science 79:2247–2264.

Bell, R. J., J. A. Hare, J. P. Manderson, and D. E. Richardson. 2014. Externally driven changes in the abundance of summer and winter flounder. ICES Journal of Marine Science 71:2416–2428.

Bell, R. J., D. E. Richardson, J. A. Hare, P. D. Lynch, and P. S. Fratantoni. 2015. Disentangling the effects of climate, abundance, and size on the distribution of marine fish: an example based on four stocks from the Northeast US shelf. ICES Journal of Marine Science 72:1311–1322.

Bi, R., C. Collier, R. Mann, K. E. Mills, V. Saba, J. Wiedenmann, and O. P. Jensen. 2023. How consistent is the advice from stock assessments? Empirical estimates of inter-assessment bias and uncertainty for marine fish and invertebrate stocks. Fish and Fisheries 24:126–141.

Bigelow, H. B., W. C. Schroeder, and Woods Hole Oceanographic Institution. 1953. Fishes of the Gulf of Maine, by Henry B. Bigelow and William C. Schroeder. United States Government Printing Office, Washington,.

Blöcker, A. M., H. M. Gutte, R. L. Bender, S. A. Otto, C. Sguotti, and C. Möllmann. 2023. Regime shift dynamics, tipping points and the success of fisheries management. Scientific Reports 13:289.

Britten, G. L., M. Dowd, L. Kanary, and B. Worm. 2017. Extended fisheries recovery timelines in a changing environment. Nature Communications 8:15325.

Britten, G. L., C. M. Duarte, and B. Worm. 2021. Recovery of assessed global fish stocks remains uncertain. Proceedings of the National Academy of Sciences 118:e2108532118.

Brodziak, J., and L. O'Brien. 2005. Do environmental factors affect recruits per spawner anomalies of New England groundfish? ICES Journal of Marine Science 62:1394–1407.

Burton, M. P., and D. R. Idler. 1984. The reproductive cycle in winter flounder, Pseudopleuronectes americanus (Walbaum). Canadian Journal of Zoology 62:2563–2567.

Butts, I. a. E., and M. K. Litvak. 2007. Stock and parental effects on embryonic and early larval development of winter flounder Pseudopleuronectes americanus (Walbaum). Journal of Fish Biology 70:1070–1087.

Cadrin, S. X., D. R. Goethel, M. R. Morse, G. Fay, and L. A. Kerr. 2019. "So, where do you come from?" The impact of assumed spatial population structure on estimates of recruitment. Fisheries Research 217:156–168.

Chant, R. J., M. C. Curran, K. W. Able, and S. M. Glenn. 2000. Delivery of Winter Flounder (Pseudopleuronectes americanus) Larvae to Settlement Habitats in Coves Near Tidal Inlets. Estuarine, Coastal and Shelf Science 51:529–541.

Collie, J. S., A. D. Wood, and H. P. Jeffries. 2008. Long-term shifts in the species composition of a coastal fish community. Canadian Journal of Fisheries and Aquatic Sciences 65:1352–1365.

Crawford, R. E., and C. G. Carey. 1985. Retention of winter flounder larvae within a Rhode Island salt pond. Estuaries 8:217–227.

Cren, E. D. L. 1951. The Length-Weight Relationship and Seasonal Cycle in Gonad Weight and Condition in the Perch (Perca fluviatilis). Journal of Animal Ecology 20:201.

Decelles, G. R., and S. X. Cadrin. 2010. Movement patterns of winter flounder (Pseudopleuronectes americanus) in the southern Gulf of Maine: observations with the use of passive acoustic telemetry. Fishery Bulletin 108:408–419.

DeCelles, G. R., and S. X. Cadrin. 2011. An Interdisciplinary Assessment of Winter Flounder( *Pseudopleuronectes americanus* ) Stock Structure. Journal of Northwest Atlantic Fishery Science 43:103–120.

deYoung, B., R. Harris, J. Alheit, G. Beaugrand, N. Mantua, and L. Shannon. 2004. Detecting regime shifts in the ocean: Data considerations. Progress in Oceanography 60:143–164.

Dolan, T. E., A. E. McElroy, R. Cerrato, L. A. Hice-Dunton, C. Fede, and M. G. Frisk. 2021. Winter Flounder Navigate the Postsettlement Gauntlet with a Bet-Hedging Strategy. Marine and Coastal Fisheries 13:435–449.

Duarte, C. M., S. Agusti, E. Barbier, G. L. Britten, J. C. Castilla, J.-P. Gattuso, R. W. Fulweiler, T. P. Hughes, N. Knowlton, C. E. Lovelock, H. K. Lotze, M. Predragovic, E. Poloczanska, C. Roberts, and B. Worm. 2020. Rebuilding marine life. Nature 580:39–51.

Ecosystem Approach to Fisheries Management. 2025, November 5. https://www.mafmc.org/eafm.

Fairchild, E. A. 2017. Indications of Offshore Spawning by Southern Gulf of Maine Winter Flounder. Marine and Coastal Fisheries 9:493–503.

Fairchild, E. A., L. Siceloff, W. H. Howell, B. Hoffman, and M. P. Armstrong. 2013. Coastal spawning by winter flounder and a reassessment of Essential Fish Habitat in the Gulf of Maine. Fisheries Research 141:118–129.

Frank, K. T., and W. C. Leggett. 1983. Multispecies larval fish associations: Accident or Adaptation? Canadian Journal of Fisheries and Aquatic Sciences 40:754–762.

Fredston-Hermann, A., R. Selden, M. Pinsky, S. D. Gaines, and B. S. Halpern. 2020. Cold range edges of marine fishes track climate change better than warm edges. Global Change Biology 26:2908–2922.

Free, C. M., J. T. Thorson, M. L. Pinsky, K. L. Oken, J. Wiedenmann, and O. P. Jensen. 2019. Impacts of historical warming on marine fisheries production. Science 363:979–983.

Friedland, K. D., J. A. Langan, S. I. Large, R. L. Selden, J. S. Link, R. A. Watson, and J. S. Collie. 2020a. Changes in higher trophic level productivity, diversity and niche space in a rapidly warming continental shelf ecosystem. Science of The Total Environment 704:135270.

Friedland, K. D., R. E. Morse, J. P. Manning, D. C. Melrose, T. Miles, A. G. Goode, D. C. Brady, J. T. Kohut, and E. N. Powell. 2020b. Trends and change points in surface and bottom thermal environments of the US Northeast Continental Shelf Ecosystem. Fisheries Oceanography 29:396–414.

Friedland, K. D., R. E. Morse, N. Shackell, J. C. Tam, J. L. Morano, J. R. Moisan, and D. C. Brady. 2020c. Changing Physical Conditions and Lower and Upper Trophic Level Responses on the US Northeast Shelf. Frontiers in Marine Science 7.

Frisk, M. G., T. E. Dolan, A. E. McElroy, J. P. Zacharias, H. Xu, and L. A. Hice. 2018. Assessing the drivers of the collapse of Winter Flounder: Implications for management and recovery. Journal of Sea Research 141:1–13.

Gallagher, B. K., L. A. Hice, A. E. McElroy, R. M. Cerrato, and M. G. Frisk. 2015. Factors Influencing Daily Growth in Young-of-the-Year Winter Flounder along an Urban Gradient Revealed Using Hierarchical Linear Models. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 7:200–219.

Gangopadhyay, A., G. Gawarkiewicz, E. N. S. Silva, M. Monim, and J. Clark. 2019. An Observed Regime Shift in the Formation of Warm Core Rings from the Gulf Stream. Scientific Reports 9:12319.

Gascoigne, J. C., and R. N. Lipcius. 2004. Allee effects driven by predation. Journal of Applied Ecology 41:801–810.

Greene, C. 2012. Recent Arctic Climate Change and Its Remote Forcing of Northwest Atlantic Shelf Ecosystems. Oceanography 25.

Guelpen, V., and L. Collier. 1974. Seasonal movements of the winter flounder, Pseudopleuronectes Americanus (Walbaum), in two contrasting inshore locations in Newfoundland. Memorial University of Newfoundland.

Haines, H., B. Planque, and L. Buttay. 2025. Poor performance of regime shift detection methods in marine ecosystems. ICES Journal of Marine Science 82:fsae103.

Hammer, L. J., N. B. Furey, W. Y. Koh, and J. A. Sulikowski. 2020. Movements of Juvenile Winter Flounder in a Southern Maine Estuary. Northeastern Naturalist 27:502–519.

Hare, J. A., W. E. Morrison, M. W. Nelson, M. M. Stachura, E. J. Teeters, R. B. Griffis, M. A. Alexander, J. D. Scott, L. Alade, R. J. Bell, A. S. Chute, K. L. Curti, T. H. Curtis, D. Kircheis, J. F. Kocik, S. M. Lucey, C. T. McCandless, L. M. Milke, D. E. Richardson, E. Robillard, H. J. Walsh, M. C. McManus, K. E. Marancik, and C. A. Griswold. 2016. A Vulnerability Assessment of Fish and Invertebrates to Climate Change on the Northeast U.S. Continental Shelf. PLOS ONE 11:e0146756.

Hastie, T., and R. Tibshirani. 1986. Generalized Additive Models. Statistical Science 1:297–310.

Hendrickson, L. C., P. Nitschke, and B. Linton. 2014. 2014 Operational stock assessments for Georges Bank winter flounder, Gulf of Maine winter flounder, and pollock.

Hilborn, R., J.-J. Maguire, A. M. Parma, and A. A. Rosenberg. 2001. The Precautionary Approach and risk management: can they increase the probability of successes in fishery management? Canadian Journal of Fisheries and Aquatic Sciences 58:99–107.

Honda, I. A., R. Ji, G. L. Britten, C. Thompson, A. R. Solow, Z. Zang, and J. A. Runge. 2025. Shifting phenology as a key driver of shelf zooplankton population variability. Limnology and Oceanography 70:178–188.

Howe, A. B., and P. G. Coates. 1975. Winter Flounder Movements, Growth, and Mortality off Massachusetts. Transactions of the American Fisheries Society 104:13–29.

Howell, P. T., J. J. Pereira, E. T. Schultz, and P. J. Auster. 2016. Habitat Use in a Depleted Population of Winter Flounder: Insights into Impediments to Population Recovery. Transactions of the American Fisheries Society 145:1208–1222.

Jordan, D. S., and B. W. Evermann. 1896. The fishes of North and Middle America : a descriptive catalogue of the species of fish-like vertebrates found in the waters of North America, north of the Isthmus of Panama. Smithsonian Institution, United States National Museum, Washington.

Kennedy, V. S., and D. H. Steele. 1971. The Winter Flounder (Pseudopleuronectes americanus) in Long Pond, Conception Bay, Newfoundland. Journal of the Fisheries Research Board of Canada 28:1153–1165.

Kerr, L. A., N. T. Hintzen, S. X. Cadrin, L. W. Clausen, M. Dickey-Collas, D. R. Goethel, E. M. C. Hatfield, J. P. Kritzer, and R. D. M. Nash. 2017. Lessons learned from practical approaches to reconcile mismatches between biological population structure and stock units of marine fish. ICES Journal of Marine Science 74:1708–1722.

Kerr, L., M. Barajas, and J. Wiedenmann. 2022. Coherence and potential drivers of stock assessment uncertainty in Northeast US groundfish stocks. ICES Journal of Marine Science 79:2217–2230.

Killick, R., C. Beaulieu, S. Taylor, and H. Hullait. 2016, October 13. EnvCpt: Detection of Structural Changes in Climate and Environment Time Series.

Killick, R., C. Beaulieu, S. Taylor, and H. Hullait. 2021, March 29. EnvCpt: Detection of Structural Changes in Climate and Environment Time Series.

Killick, R., and I. A. Eckley. 2014. changepoint: An R Package for Changepoint Analysis. Journal of Statistical Software 58:1–19.

Killick, R., P. Fearnhead, and I. A. Eckley. 2012. Optimal detection of changepoints with a linear computational cost. Journal of the American Statistical Association 107:1590–1598.

Killick, R., K. Haynes, H. Hullait, I. Eckley, P. Fearnhead, R. Long, and J. Lee. 2024, November 4. changepoint: Methods for Changepoint Detection.

King, J. R., M. J. Camisa, and V. M. Manfredi. 2010. Massachusetts Division of Marine Fisheries Trawl Survey Effort, Lists of Species Recorded, and Bottom Temperature Trends, 1978-2007. Technical Report, Commonwealth of Massachusetts Executive Office of Energy and Environmental Affairs Department of Fish and Game Massachusetts Division of Marine Fisheries, Massachusetts Division of Marine Fisheries 1213 Purchase Street New Bedford, MA 02740.

Klein, E. S., S. L. Smith, and J. P. Kritzer. 2017. Effects of climate change on four New England groundfish species. Reviews in Fish Biology and Fisheries 27:317–338.

Kleisner, K. M., M. J. Fogarty, S. McGee, J. A. Hare, S. Moret, C. T. Perretti, and V. S. Saba. 2017. Marine species distribution shifts on the U.S. Northeast Continental Shelf under continued ocean warming. Progress in Oceanography 153:24–36.

Langan, J. A. 2021. The Role of Climate Change in the Decline of Narragansett Bay Winter Flounder. University of Rhose Island ProQuest Dissertations.

Langan, J. A., J. S. Collie, and C. Minto. 2022. Detecting population regulation of winter flounder from noisy data. Canadian Journal of Fisheries and Aquatic Sciences 79:1097–1108.

Large, S. I., G. Fay, K. D. Friedland, and J. S. Link. 2015. Quantifying Patterns of Change in Marine Ecosystem Response to Multiple Pressures. PLOS ONE 10:e0119922.

Levangie, P. E. L., P. J. Blanchfield, and J. A. Hutchings. 2022. The influence of ocean warming on the natural mortality of marine fishes. Environmental Biology of Fishes 105:1447–1461.

Liermann and Hilborn. 2001. Depensation: evidence, models and implications. Fish and Fisheries 2:33–58.

Liermann, M., and R. Hilborn. 1997. Depensation in fish stocks: a hierarchic Bayesian meta-analysis. Canadian Journal of Fisheries and Aquatic Sciences 54:1976–1984.

Macdonald, J. S., and R. H. Green. 1986. Food Resource Utilization by Five Species of Benthic Feeding Fish in Passamaquoddy Bay, New Brunswick. Canadian Journal of Fisheries and Aquatic Sciences 43:1534–1546.

Manderson, J. P. 2005. Marine habitat dynamics: A case study of habitat suitability for a temperate flatfish (winter flounder, Pseudopleuronectes americanus, Walbaum) on an estuarine nursery ground. Ph.D., University of Massachusetts Amherst, United States -- Massachusetts.

Manderson, J. P., J. Pessutti, J. G. Hilbert, and F. Juanes. 2004. Shallow water predation risk for a juvenile flatfish (winter flounder; Pseudopleuronectes americanus, Walbaum) in a northwest Atlantic estuary. Journal of Experimental Marine Biology and Ecology 304:137–157.

Manderson, J. P., B. A. Phelan, C. Meise, L. L. Stehlik, A. J. Bejda, J. Pessutti, L. Arlen, A. Draxler, and A. W. Stoner. 2002. Spatial dynamics of habitat suitability for the growth of newly settled winter flounder Pseudopleuronectes americanus in an estuarine nursery. Marine Ecology Progress Series 228:227–239.

Mansueti, R. J. 1962. Distribution of small, newly metamorphosed sea lampreys,Petromyzon marinus, and their parasitism on menhaden,Brevoortia tyrannus, in mid-Chesapeake Bay during winter months. Chesapeake Science 3:137–139.

Mazur, M. D., J. Jesse, S. X. Cadrin, S. B. Truesdell, and L. Kerr. 2023. Consequences of ignoring climate impacts on New England groundfish stock assessment and management. Fisheries Research 262:106652.

McCracken, F. D. 1963. Seasonal Movements of the Winter Flounder, Pseudopleuronectes americanus (Walbaum), on the Atlantic Coast. Journal of the Fisheries Research Board of Canada 20:551–586.

McElroy, A. E., L. A. Hice, M. G. Frisk, S. L. Purcell, N. C. Phillips, and M. D. Fast. 2015. Spatial patterns in markers of contaminant exposure, glucose and glycogen metabolism, and immunological response in juvenile winter flounder (Pseudoplueronectes americanus). Comparative Biochemistry and Physiology Part D: Genomics and Proteomics 14:53–65.

Mills, K. E., A. Kemberling, L. A. Kerr, S. M. Lucey, R. S. McBride, J. A. Nye, A. J. Pershing, M. Barajas, and C. S. Lovas. 2024a. Multispecies population-scale emergence of climate change signals in an ocean warming hotspot. ICES Journal of Marine Science 81:375–389.

Mills, K. E., A. Kemberling, L. A. Kerr, S. M. Lucey, R. S. McBride, J. A. Nye, A. J. Pershing, M. Barajas, and C. S. Lovas. 2024b. Multispecies population-scale emergence of climate change signals in an ocean warming hotspot. ICES Journal of Marine Science 81:375–389.

Monteleone, D. M. 1992. Seasonality and abundance of ichthyoplankton in great South Bay, New York. Estuaries 15:230–238.

Morley, J. W., R. L. Selden, R. J. Latour, T. L. Frölicher, R. J. Seagraves, and M. L. Pinsky. 2018. Projecting shifts in thermal habitat for 686 species on the North American continental shelf. PLOS ONE 13:e0196127.

NCLIM - Northeast Climate Integrated Modeling · GitHub. 2025. . https://github.com/Northeast-Climate-Integrated-Modeling.

NEFMC - New England Fishery Management Council. 2022. . https://www.nefmc.org/.

Nicholson, A. J. 1933. Supplement: the Balance of Animal Populations. Journal of Animal Ecology 2:131–178.

NOAA. 2023, May 18. Winter Flounder | NOAA Fisheries. https://www.fisheries.noaa.gov/species/winter-flounder.

Northeast Stock Assessment Workshop. (n.d.). . https://apps-nefsc.fisheries.noaa.gov/saw/sasi.php.

Nye, J. 2010. Climate Change Impacts on the Gulf of Maine Ecosystem.

Nye, J. A., J. S. Link, J. A. Hare, and W. J. Overholtz. 2009. Changing spatial distribution of fish stocks in relation to climate and population size on the Northeast United States continental shelf. Marine Ecology Progress Series 393:111–129.

Olla, B. L., R. Wicklund, and S. Wilk. 1969. Behavior of Winter Flounder in a Natural Habitat. Transactions of the American Fisheries Society 98:717–720.

Pearcy, W. 1962. Volume 18. Article 1. Ecology of an estuarine population of winter flounder, Pseudopleuronectes americanus (Walbaum). Parts I-IV. Bulletin of the Bingham Oceanographic Collection.

Perälä, T., and A. Kuparinen. 2015. Detecting regime shifts in fish stock dynamics. Canadian Journal of Fisheries and Aquatic Sciences 72:1619–1628.

Pereira Campos, C., S. D. B. Bitar, and C. Freitas. 2023. Uncertainties regarding the natural mortality of fish can increase due global climate change. PeerJ 11:e14989.

Pereira, J. J., R. Goldberg, J. J. Ziskowski, P. L. Berrien, W. W. Morse, and D. L. Johnson. 1999. Essential fish habitat source document: Winter flounder, Pseudopleuronectes americanus, life history and habitat characteristics. U.S. Department of Commerce.

Perretti, C. T., M. J. Fogarty, K. D. Friedland, J. A. Hare, S. M. Lucey, R. S. McBride, T. J. Miller, R. E. Morse, L. O'Brien, J. J. Pereira, L. A. Smith, and M. J. Wuenschel. 2017. Regime shifts in fish recruitment on the Northeast US Continental Shelf.

du Pontavice, H., Z. Chen, and V. S. Saba. 2023. A high-resolution ocean bottom temperature product for the northeast U.S. continental shelf marine ecosystem. Progress in Oceanography 210:102948.

Pörtner, H. O., and R. Knust. 2007. Climate change affects marine fishes through the oxygen limitation of thermal tolerance. Science (New York, N.Y.) 315:95–97.

Pörtner, H.-O. 2010. Oxygen- and capacity-limitation of thermal tolerance: a matrix for integrating climate-related stressor effects in marine ecosystems. The Journal of Experimental Biology 213:881–893.

Press, Y. K., R. S. McBride, and M. J. Wuenschel. 2014. Time course of oocyte development in winter flounder Pseudopleuronectes americanus and spawning seasonality for the Gulf of Maine, Georges Bank and southern New England stocks. Journal of Fish Biology 85:421–445.

Roberts, S. M., A. M. Boustany, and P. N. Halpin. 2020. Substrate-dependent fish have shifted less in distribution under climate change. Communications Biology 3:1–7.

Rose, K. A., J. H. Cowan Jr, K. O. Winemiller, R. A. Myers, and R. Hilborn. 2001. Compensatory density dependence in fish populations: importance, controversy, understanding and prognosis. Fish and Fisheries 2:293–327.

Schober, P., C. Boer, and L. A. Schwarte. 2018. Correlation Coefficients: Appropriate Use and Interpretation. Anesthesia and Analgesia 126:1763–1768.

SCOTT, W. C. M. 1929. A note on the effect of temperature and salinity on the hatching of the eggs of the winter flounder: (pseudopleuronectes americanus walbaum). Contributions to Canadian Biology and Fisheries 4:137–141.

Silver, A., A. Gangopadhyay, G. Gawarkiewicz, P. Fratantoni, and J. Clark. 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.

Siskey, M. R., M. G. Frisk, R. M. Cerrato, and K. E. Limburg. 2020. Redefining spatial population structure of winter flounder (Pseudopleuronectes americanus): implications for stock assessment and management. Canadian Journal of Fisheries and Aquatic Sciences 77:1189–1200.

Staudinger, M. D., K. E. Mills, K. Stamieszkin, N. R. Record, C. A. Hudak, A. Allyn, A. Diamond, K. D. Friedland, W. Golet, M. E. Henderson, C. M. Hernandez, T. G. Huntington, R. Ji, C. L. Johnson, D. S. Johnson, A. Jordaan, J. Kocik, Y. Li, M. Liebman, O. C. Nichols, D. Pendleton, R. A. Richards, T. Robben, A. C. Thomas, H. J. Walsh, and K. Yakola. 2019. It's about time: A synthesis of changing phenology in the Gulf of Maine ecosystem. Fisheries Oceanography 28:532–566.

Steimle, F. W., D. Jeffress, S. A. Fromm, R. N. Reid, J. J. Vitaliano, and A. Frame. 1994. Predator-prey relationships of winter flounder, Pleuronectes americanus, in the New York Bight apex. Fishery Bulletin 92(3).

Swain, D. P., and H. P. Benoît. 2015. Extreme increases in natural mortality prevent recovery of collapsed fish populations in a Northwest Atlantic ecosystem. Marine Ecology Progress Series 519:165–182.

Tirronen, M., T. Perälä, and A. Kuparinen. 2022. Temporary Allee effects among non-stationary recruitment dynamics in depleted gadid and flatfish populations. Fish and Fisheries 23:392–406.

Wiedenmann, J., and O. P. Jensen. 2018. Uncertainty in stock assessment estimates for New England groundfish and its impact on achieving target harvest rates. Canadian Journal of Fisheries and Aquatic Sciences 75:342–356.

Wiedenmann, J., and O. P. Jensen. 2019. Could recent overfishing of New England groundfish have been prevented? A retrospective evaluation of alternative management strategies. Canadian Journal of Fisheries and Aquatic Sciences 76:1006–1018.

Wiedenmann, J., and C. M. Legault. 2022. Something strange in the neighborhood: Diverging signals in stock assessment data for Northeast U.S. fish stocks. Fisheries Management & Ecology 29:269–285.

Wilber, D. H., D. G. Clarke, C. M. Alcoba, and J. Gallo. 2016. Windowpane flounder (*Scophthalmus aquosus*) and winter flounder (*Pseudopleuronectes americanus*) responses to cold temperature extremes in a Northwest Atlantic estuary. Journal of Sea Research 107:23–30.

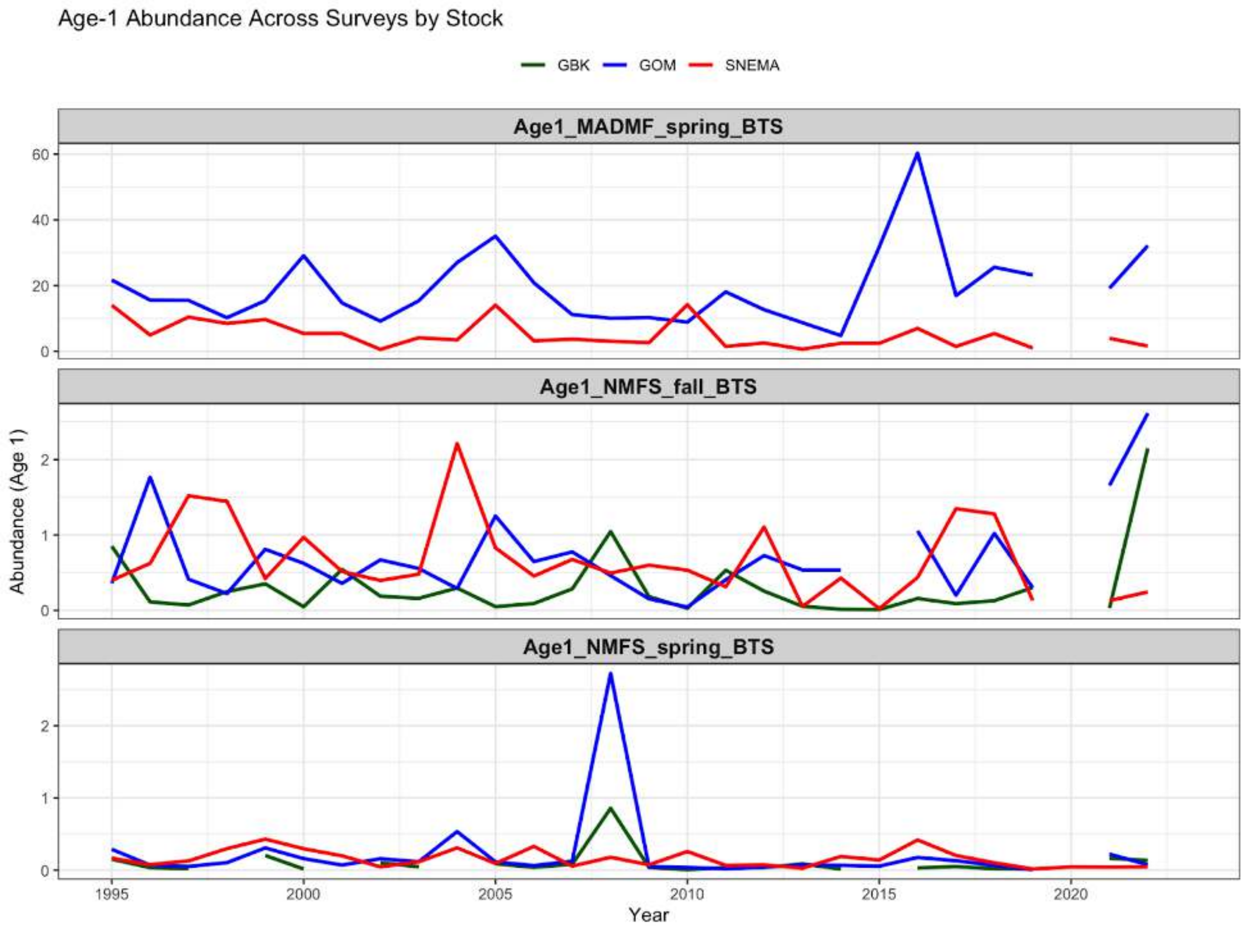
Wood, S. N. (n.d.). Generalized Additive Models: an introduction with R.

Yencho, M. A., A. Jordaan, R. M. Cerrato, H. Baumann, and M. G. Frisk. 2015. Growth and Mortality in Coastal Populations of Winter Flounder: Implications for Recovery of a Depleted Population. Marine and Coastal Fisheries 7:246–259.

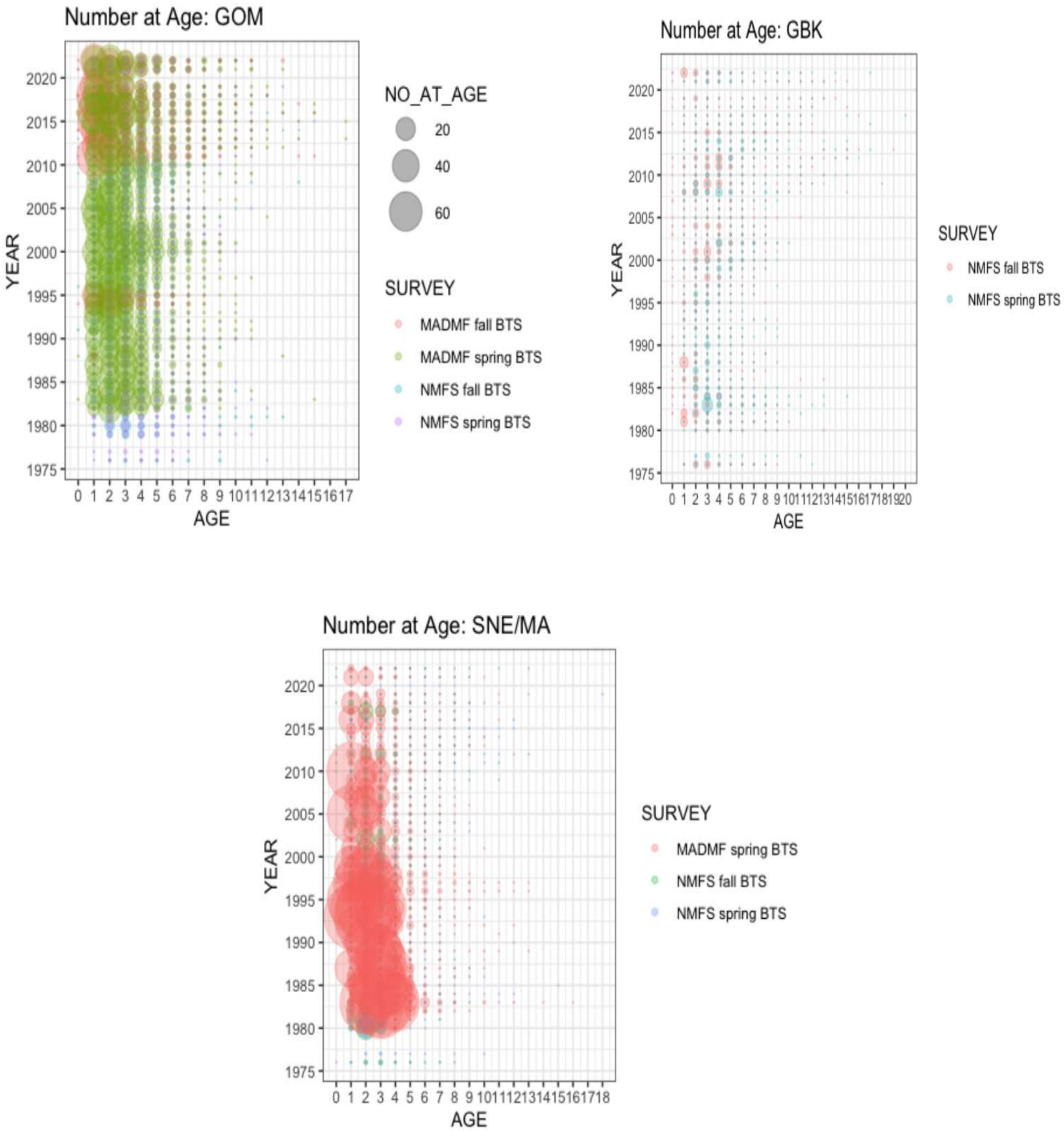
Ziegler, C. M., and M. G. Frisk. 2019. Flatfish utilize sediment blanket to facilitate thermoregulation. Marine Ecology Progress Series 609:179–186.

Zuur, A. F., E. N. Ieno, N. Walker, A. A. Saveliev, and G. M. Smith. 2009. Mixed effects models and extensions in ecology with R. Springer New York, New York, NY.

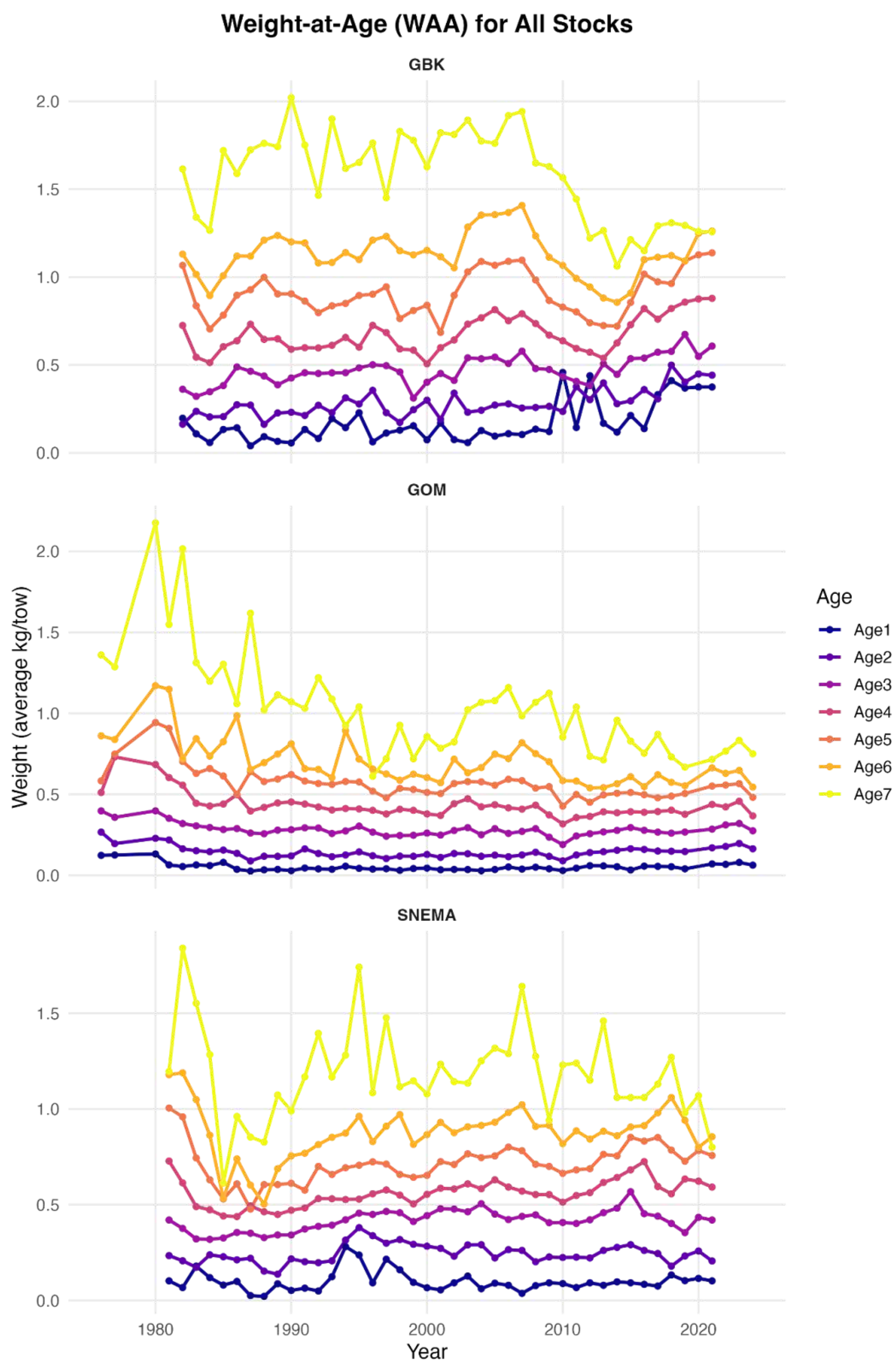
**APPENDIX**



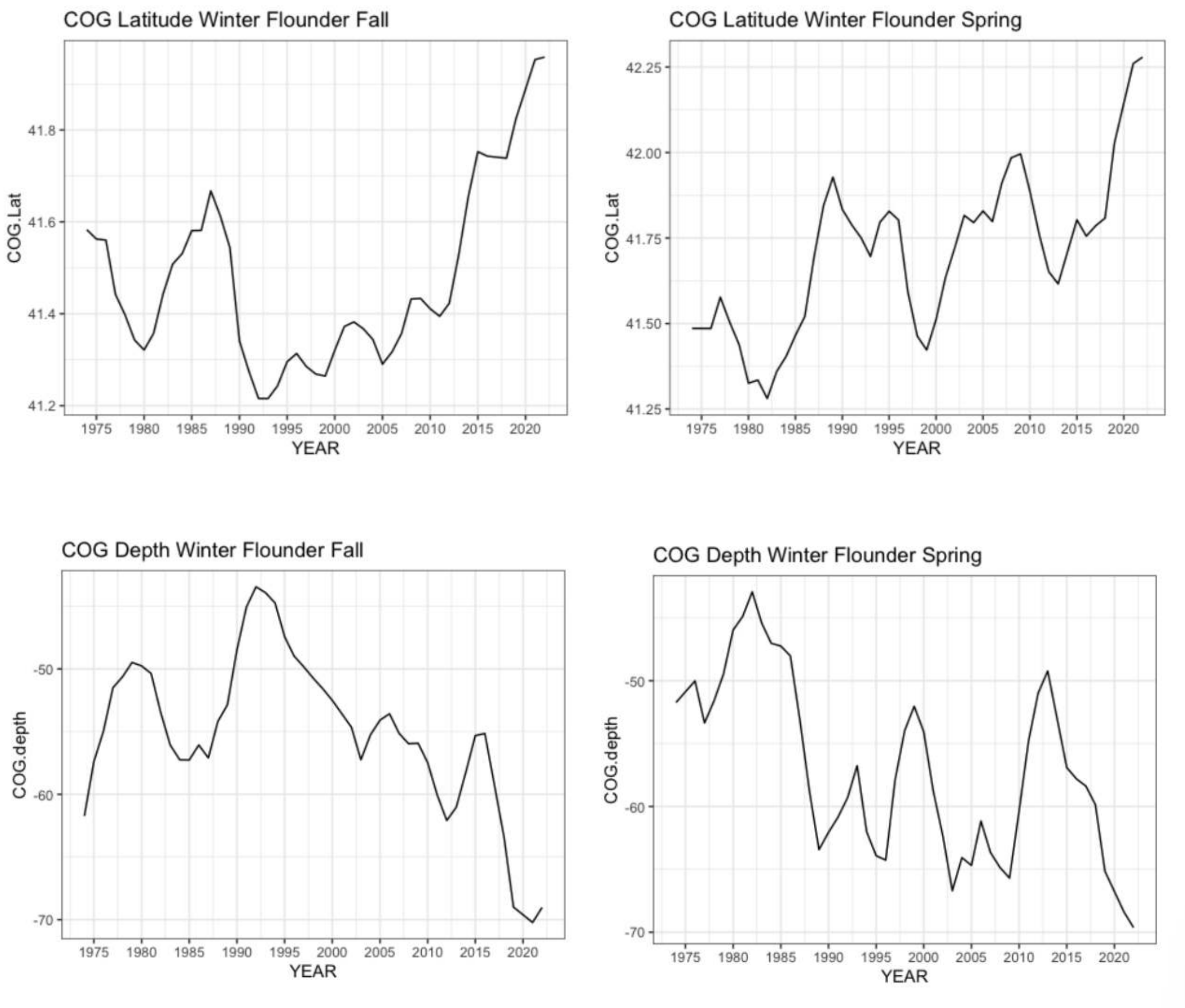

Appendix A. Numbers at Age 1 of Winter Flounder. Numbers at age 1 (abundance) recruitment indices for all winter flounder stocks by survey index.



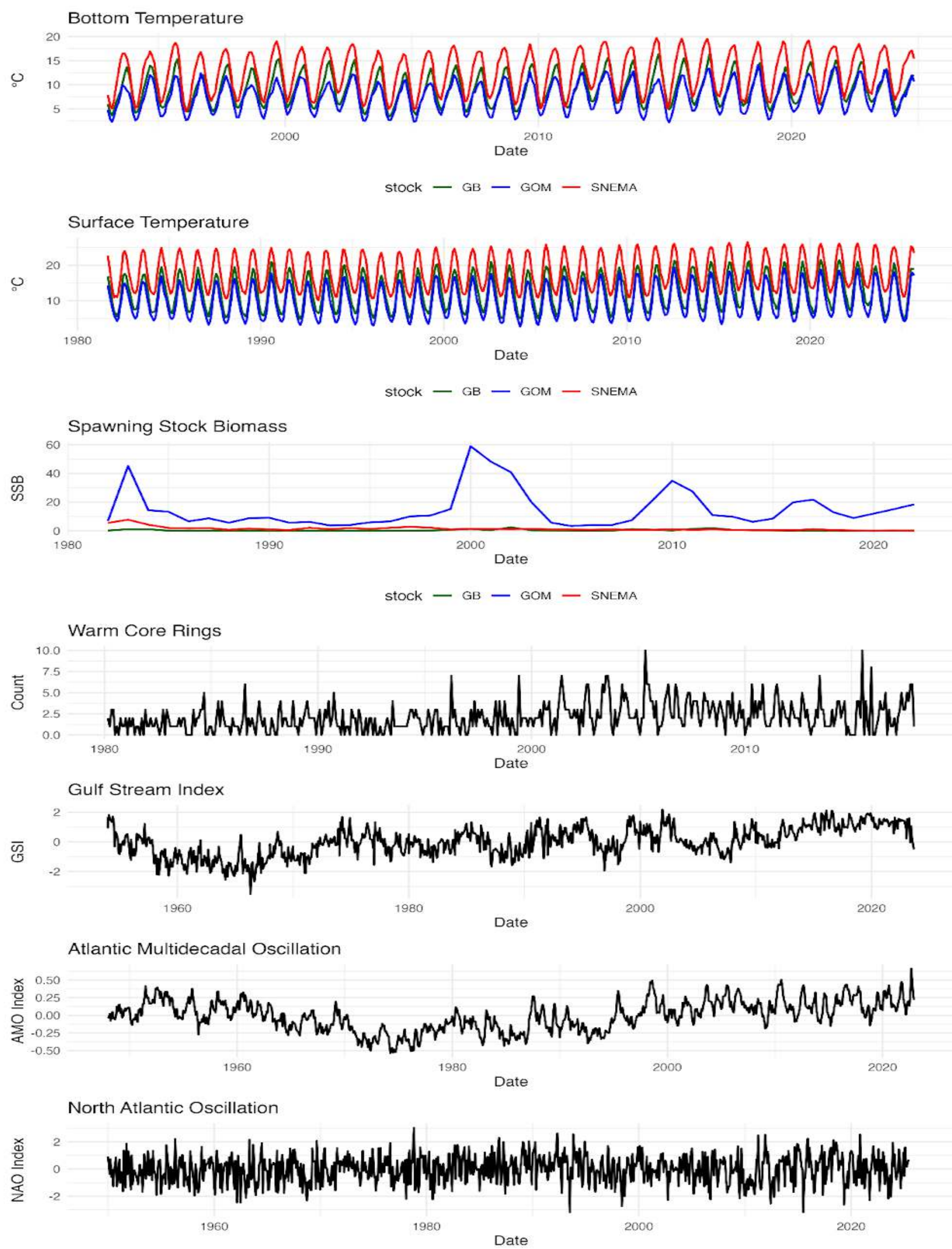

Appendix B. Numbers at Age of Winter Flounder. Numbers at Age for all three winter flounder stocks, labeled by survey index.




Appendix C. Weight at Age of Winter Flounder. Weight at Age (average kg/tow) of each winter flounder stock. "Age 7" represents the Age 7 Plus group

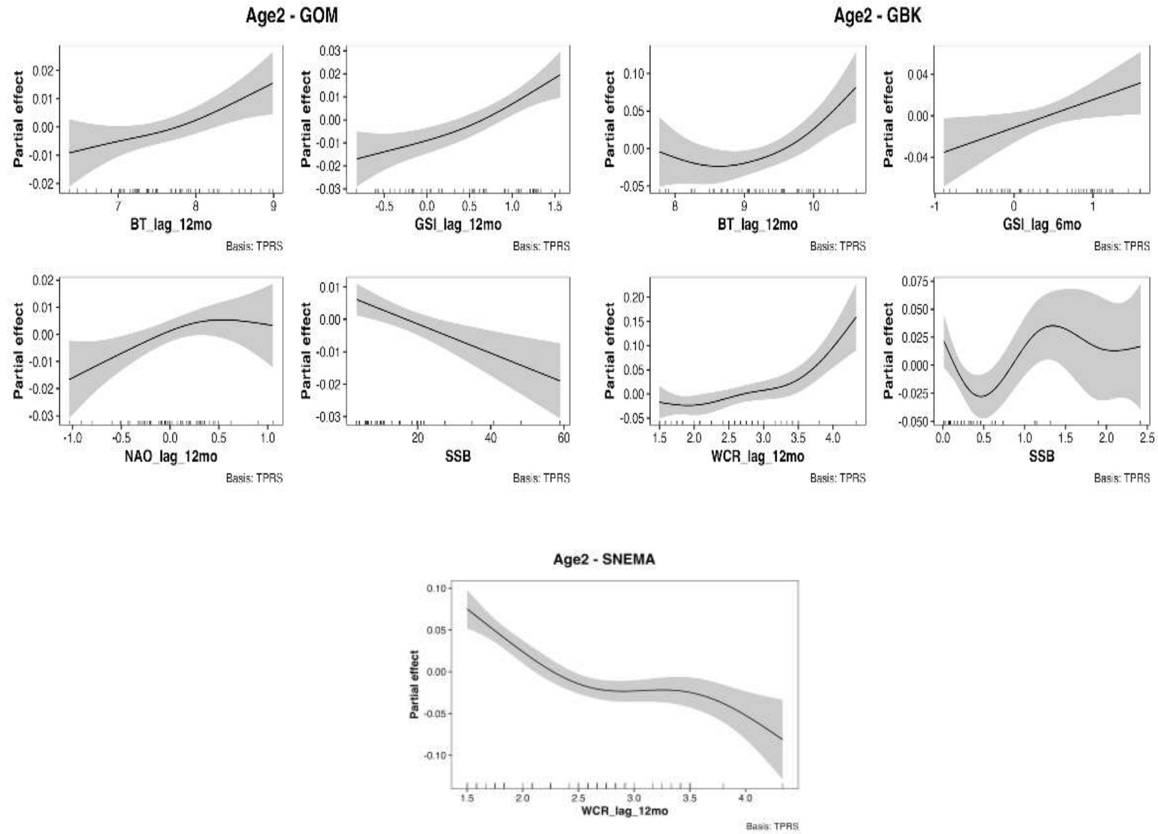



Appendix D. Distribution of Winter Flounder. Distribution plots of species-wide winter flounder distribution, sourced from DisMap (NOAA).



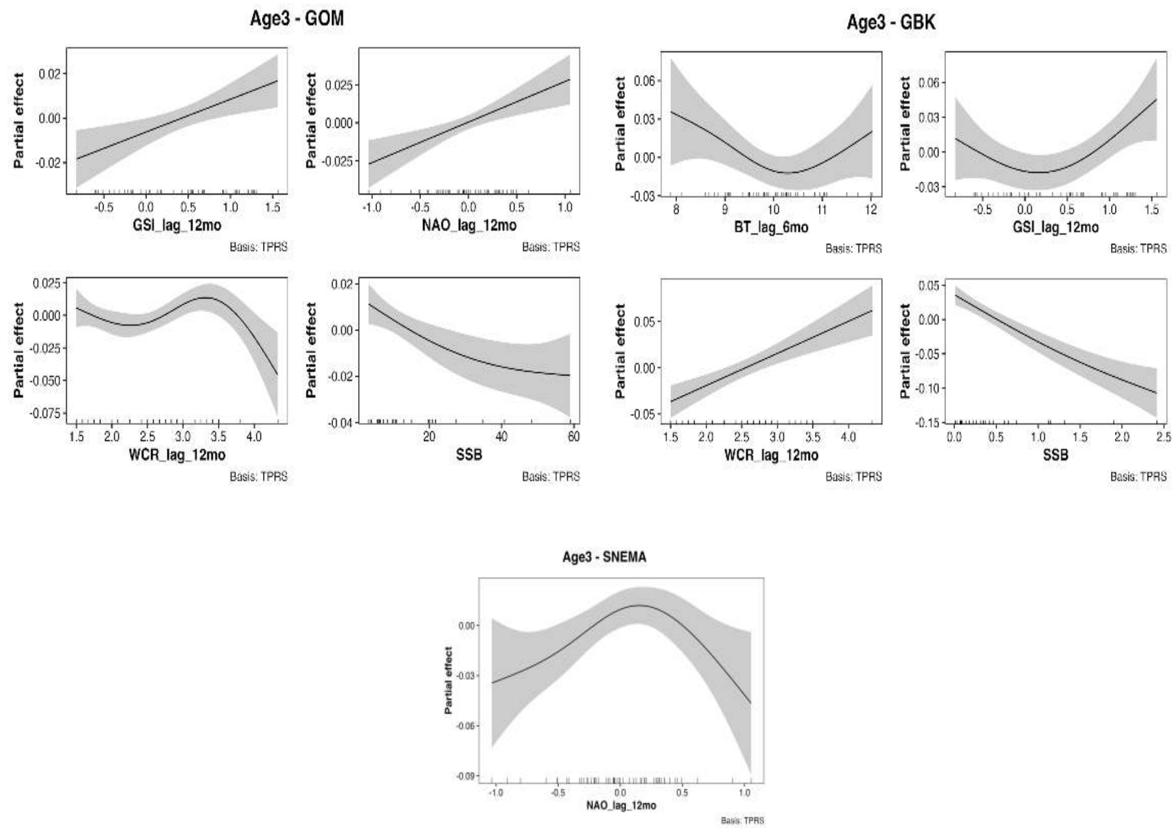

Appendix E. Predictor Variables in GAM Analysis. A comparison of all predictor variables used in the Chapter 4 GAMs analysis.

**Weight at Age 2**



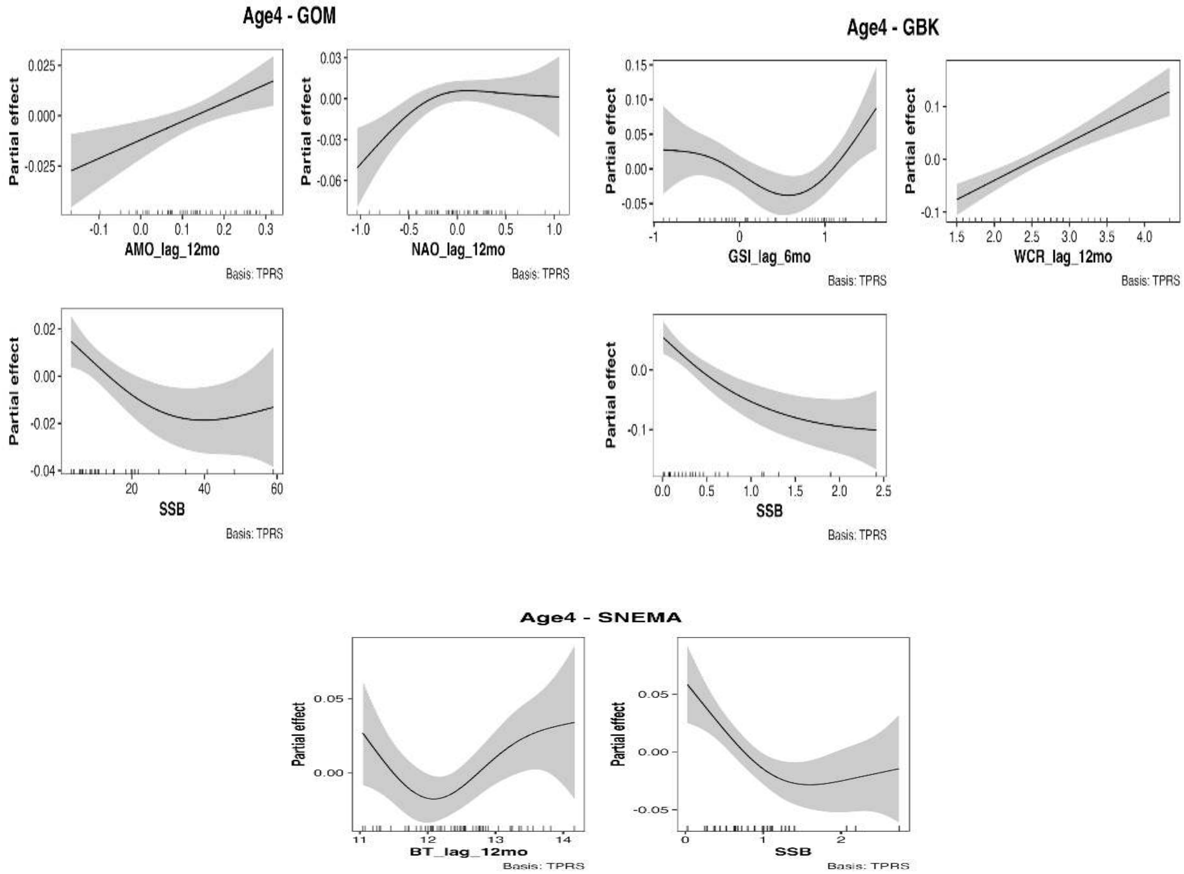

Appendix F. Weight at Age 2 GAM Results. Weight at Age 2 GAMs final model results of all three stocks: Gulf of Maine (GOM), Georges Bank (GBK), and Southern New England/Mid-Atlantic (SNEMA).

**Weight at Age 3**



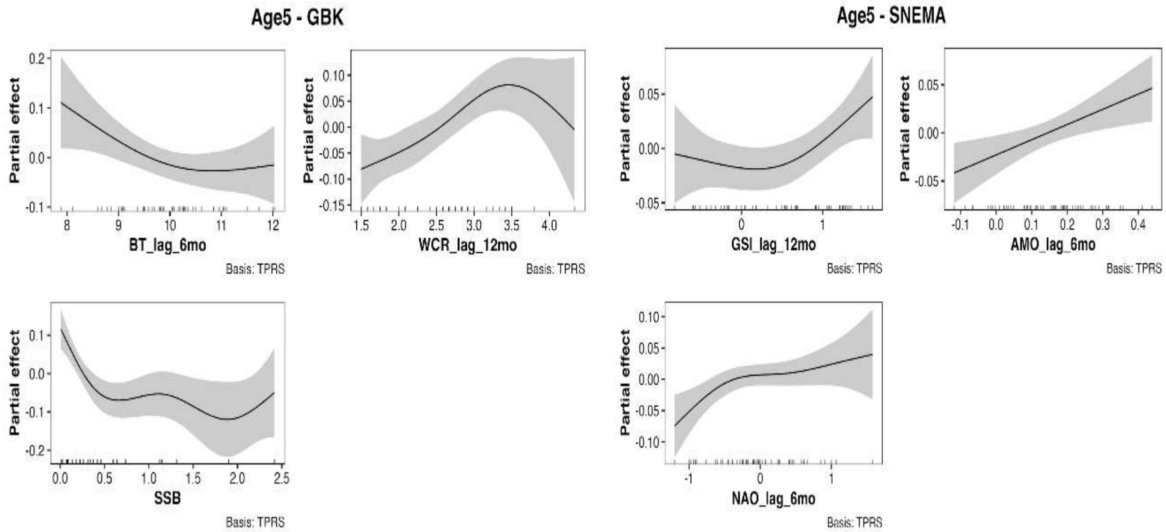

Appendix G. Weight at Age 3 GAM Results. Weight at Age 3 GAMs final model results of all three stocks: Gulf of Maine (GOM), Georges Bank (GBK), and Southern New England/Mid-Atlantic (SNEMA).

## Weight at Age 4



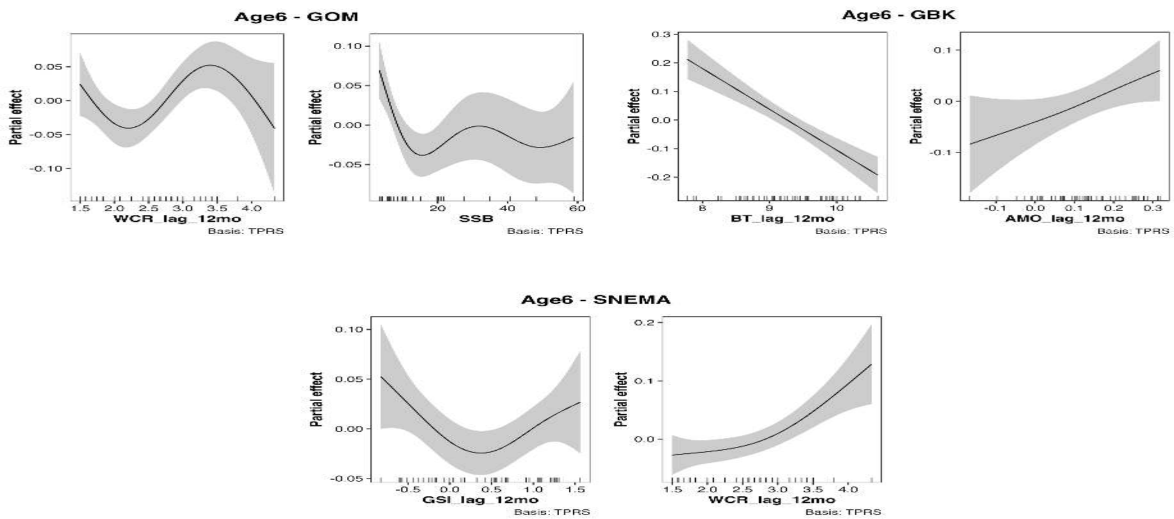

Appendix H. Weight at Age 4 GAM Results. Weight at Age 4 GAMs final model results of all three stocks: Gulf of Maine (GOM), Georges Bank (GBK), and Southern New England/Mid-Atlantic (SNEMA).

**Weight at Age 5**

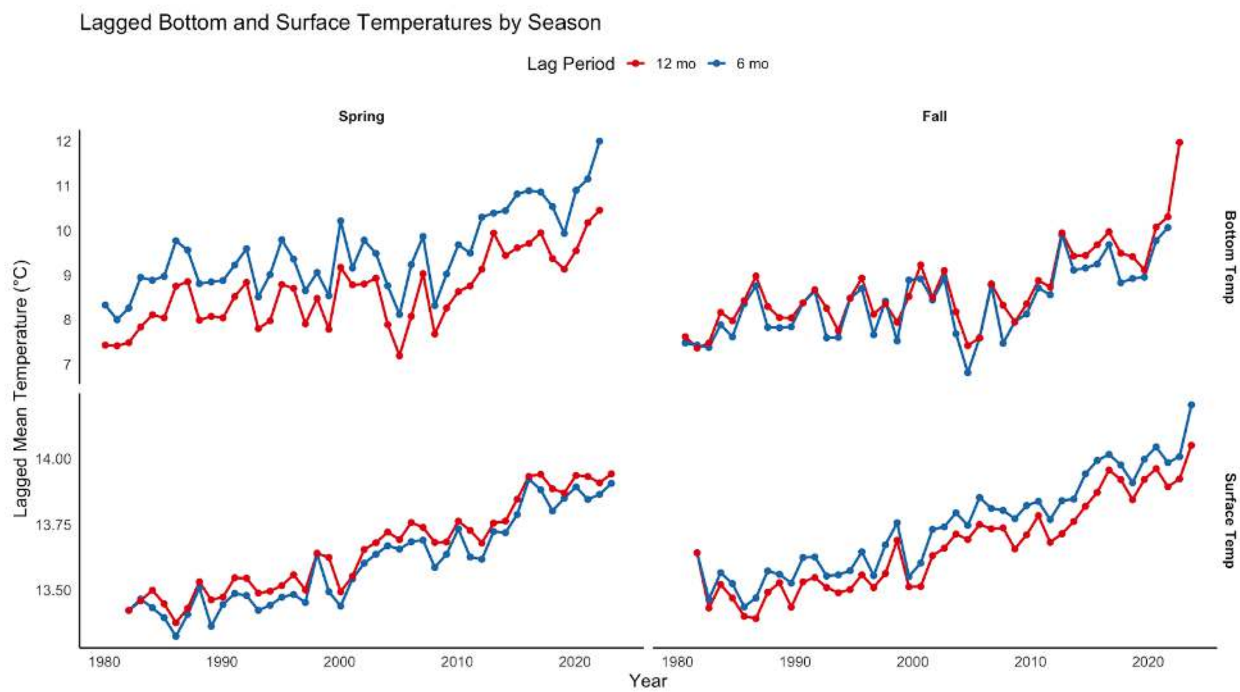



Appendix I. Weight at Age 5 GAM Results. Weight at Age 5 GAMs final model results of all three stocks: Gulf of Maine (GOM), Georges Bank (GBK), and Southern New England/Mid-Atlantic (SNEMA).

**Weight at Age 6**




Appendix J. Weight at Age 6 GAM Results. Weight at Age 6 GAMs final model results of all three stocks: Gulf of Maine (GOM), Georges Bank (GBK), and Southern New England/Mid-Atlantic (SNEMA).




Appendix K. Basin-Scale Bottom and Sea Surface Temperature. Basin-scale Fall and Spring lagged bottom temperature and sea surface temperature (by NEFSC bottom trawl survey start dates) used in the winter flounder distribution GAMs analysis.

## BIOGRAPHY OF THE AUTHOR

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# Atlantic States Marine Fisheries Commission

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## MEMORANDUM

**TO:** **Winter Flounder Management Board**

**FROM:** **Winter Flounder Technical Committee**

**DATE:** **July 20, 2026**

**SUBJECT:** **Analysis of Proposal for an Increase in SNE/MA Recreational Bag Limit**

At the February 3, 2026 meeting, the Winter Flounder Management Board (Board) tasked the Winter Flounder Technical Committee (TC) with analyzing available data to assess the potential for increasing the daily bag limit in the recreational Southern New England/Mid-Atlantic (SNE/MA) winter flounder fishery. This task was in response to both public input and Board member request. An increase in the daily bag limit aims to provide greater incentive for both private and for-hire anglers to target winter flounder which are currently held to a 2 fish per day trip limit in state waters. The TC met via webinar on March 17, May 15, and June 16, 2026 to review and provide input on the Board requests. To address the Board task, the TC 1) discussed potential stock implications and 2) analyzed Marine Recreational Information Program (MRIP) data, both of which are described in this memo.

In summary, the TC does not recommend an increased bag limit for SNE/MA winter flounder at this time, due to a high risk of adverse impacts to the SNE/MA winter flounder population. Any increased fishing effort/targeting of SNE/MA winter flounder would likely negatively impact the stock which is currently at time series low biomass and showing no signs of recovery. Additionally, the TC does not believe the available MRIP data, which is highly imprecise due to very low intercepts, is appropriate to conduct an accurate bag limit analysis on the SNE/MA stock.

**Stock Implications**

The Atlantic States Marine Fisheries Commission (Commission) and New England Fishery Management Council (Council) have had complementary management plans for winter flounder since 1992. Cooperative management between state and federal waters is necessary because of the unique migration patterns and spawning site fidelity of this species. When winter flounder migrate to inshore state water spawning grounds, they become concentrated in certain areas, making it easy for anglers to locate and remove a substantial portion of them. Concentrated fishing effort on spawning females, the reproductive portion of the population, can result in a larger net loss to the population than the landings may suggest with the potential loss of reproductive subpopulations. In addition, fishing induced disruptions on spawning can reduce spawning success and subsequent recruitment. These nearshore grounds are also vulnerable to water pollution and habitat loss. Tagging studies have consistently shown

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spawning-site fidelity in winter flounder, meaning that individuals will often return to the location where they were hatched, or close by. This suggests that reproductive subpopulations of winter flounder may be vulnerable to localized depletion which results in reductions in spawning success and productivity. In their discussions, the TC notes that an increase of targeting winter flounder due to a higher bag limit could increase that potential for localized depletion, particularly where relatively larger spawning aggregations still occur. Doing so can result in further reduction in stock productivity.

The SNE/MA winter flounder stock was recently in a rebuilding plan with a rebuild date of 2023. The projections and biological reference points (BRP) calculations for the 2022 assessment updates used a truncated stanza for recruitment, incorporating values from 2002-2021. Previous assessments had used the entire time-series of recruitment, which included historical recruitments that are well beyond the current productivity of the stock. For example, recruitment estimates in recent years have been up to 20 times lower than some of the recruitment estimates from the beginning of the time series. The truncated recruitment stanza used in the 2022 management track led to a much lower biomass target and, as a result, the overfished status of the stock changed. Although the stock was considered rebuilt by the 2023 deadline, the perception of the health of the SNE/MA stock has not changed. SNE/MA spawning stock biomass continues to be estimated at record lows.

Winter flounder discard mortality is estimated at 15% from the recreational hook and line fishery and any fish landed in excess of the current 2 fish limit would increase total fishing mortality (F). Therefore, any increase in recreational effort targeting winter flounder would be expected to increase overall mortality. The TC feels that this option is inconsistent with the originally intended purpose of Addendum I and Amendment 1 to reduce fishing pressure and mortality on spawning fish and promote rebuilding of spawning stock biomass.

**Marine Recreation Information Program (MRIP) Data Analysis**

The TC conducted a review of MRIP data, and in particular of MRIP data at the intercept level, to explore what information is currently available for SNE/MA winter flounder. This exploration has been split into three directives:

1) A comparison of effort and harvest pre- and post- the 2010 reduction in bag limit.
2) PSEs of estimates of harvest.
3) A comparison of discards and releases to landed fish.

Management measures relevant to this analysis include:

- Amendment 1 (2005): Established minimum size limit, shortened seasons, and lowered trip/bag limits.
- Addendum 1 to Amendment 1 (2009): Established the two-fish recreational bag limit.
- Addendum 2 (2012): Expanded the recreational season to the entire year.

Addendum I to the Winter Flounder FMP established a daily bag limit of 2 fish in the recreational SNE/MA fishery. This low bag limit was implemented in response to results of the 2008 Winter Flounder Stock Assessment which concluded that the SNE/MA winter flounder stock was severely depleted, with spawning stock biomass at only 9% of the target biomass (NEFSC 2008). The measures for the SNE/MA stock were designed to achieve the lowest possible F rate while minimizing economic and social impacts and dead discards, and prevent an influx of effort into state waters. Zero possession limits were considered by the Board, but were deemed problematic for two main reasons—discarding may increase with zero possession limits and fisheries-dependent data beneficial to the assessment would not get collected.

The two-fish bag limit was established in 2009 but different states may have had it earlier and it may have been implemented at different times. For this analysis we assume a 2010 implementation.

***Directive 1: Effort and Harvest Pre- and Post- Bag Limit***

The TC received MRIP intercept data pulled by Paul Nitschke of NEFSC. A custom MRIP query was used as the SNE/MA winter flounder stock splits Massachusetts. These data (adjusted observed catch, CLAIM) are used here to summarize positive trips, defined as trips where at least one winter flounder was observed landed. The number of observed trips and catch were pulled by the TC as a first step to determine whether there was adequate data to be able to perform a robust bag limit analysis.

The number of trips with observed SNE/MA winter flounder, the total observed catch of winter flounder, and the mean observed catch per angler have all decreased between 1982 and 2025 (Table 1). Observations began to sharply decline around 2000 and have remained extremely low since approximately 2007. The number of observed SNE/MA winter flounder trips averaged approximately 460 between 1982 and 1999, and averaged 43 between 2000-2025. A mean of 2,600 SNE/MA winter flounder were observed annually between 1982-1999, but fell to a mean of 119 winter flounder between 2000-2025. In the most recent 10 years (2016-2025), the annual mean observed catch in SNE/MA fell to approximately 22 winter flounder. The mean observed catch per angler ranged between 5.21 winter flounder per angler in 1982 and 0.51 winter flounder per angler in 2025. The mean observed catch per angler of SNE/MA winter flounder averaged approximately 3.4 between 1982 and 1999 and fell to 1.55 between 2000-2025.

Based on the limited available data in any given year, particularly in the last 26 years, the TC did not believe there was enough data to perform a bag limit analysis similar to those conducted for stocks such as black sea bass. However, these data may still be informative to the Board based on trends in recreational effort and catch.

In their discussion of the annual data, the TC noted that the number of observed trips, catch, and the mean catch per angler of SNE/MA winter flounder all began a steep decline well before the implementation of the 2-fish bag limit in ~2010 (Table 1; Figure 1). The mean number of fish per angler fell below 2 fish around 2005, prior to the implementation of the bag limit. This provides evidence that the 2-fish bag limit is likely not the only factor limiting winter flounder recreational effort and catches in the SNE/MA.

Observed number of trips, total catch, and mean winter flounder caught per angler were also explored by MRIP wave and by state, summed across all years 1982-2025 (Tables 2 & 3). A majority of trips and catch (approximately 68% and 70%, respectively) of SNE/MA winter flounder were observed in waves 2 and 3 (March-April and May-June) when aggregated spawning and post-spawn fish are most available to in-shore anglers. The TC noted unusually low numbers of observed trips and catch of SNE/MA winter flounder from Massachusetts, compared to other neighboring states.

The TC also explored breaking down the available data on observed trips by mode, summed across all years (1982-2025; Table 4). A majority of observed recreational trips and catch in SNE/MA were from the private/rental boat mode (53% of observed trips and 72% of total observed catch), followed by the shore mode (14%). The for-hire sector (i.e., charter boats and headboats) only constituted 4% and 1% of the total observed SNE/MA winter flounder trips and catch, respectively.

When these data are further broken down by year (limited to 2000-2025 so trends are more apparent), the number of observed trips and total catch from the private/rental boat and shore modes both show declines prior to the implementation of the 2 fish bag limit (Figure 2). The number of observed headboat trips and catch also suggest a decline prior to the implementation of the bag limit in 2010.

Lastly, the TC explored the available MRIP catch data broken out to all three catch types (i.e., Type A, Type B1, and Type B2) and year (Table 5; Figures 3 & 4). Similarly to observed harvest, reported harvest and releases also show a steep decline well prior to the implementation of the 2-fish bag limit in ~2010. Reported harvest began declining around 1994, and releases began declining around 1995. Thus, anglers were not only harvesting less fish, but were also releasing less fish before the adoption of the lower bag limit in 2010.

***Directive 2: PSE on Harvest Estimates***

The TC next explored PSE (percent standard error) estimates on available MRIP data. MRIP does not provide PSE values for data parsed to a fine scale (e.g., by stock, by fishing mode). The formula to calculate PSE is the square root of variance over the estimate, multiplied by 100. The key challenge is understanding the scale at which to calculate PSE. It must be done according to survey design and primary sampling unit. The state-level data available from the MRIP public website includes PSE, but this does not allow separation of Massachusetts sites by stock. The TC collaborated with various partners to utilizing existing R code to calculate PSE values for MRIP data parsed to various scales.

Figures 5 & 6 show annual PSE values for all harvest types by state and mode, respectively. Overall, PSE values for all harvest types, including total catch, harvest (A+B1), and releases (B2), by state and mode, have been above 30% PSE since approximately 2002, and a majority of PSEs have fallen above 50% since approximately 2006. The MRIP program suggests PSE values between 30 and 50 be ‘treated with caution’. PSE values greater than 50 are highly imprecise and MRIP ‘does not support its use’. The TC does not believe such highly imprecise data would be appropriate for use in a bag limit analysis.

***Directive 3: Size Composition Analysis***
Other sources of uncertainty in available data include the length distribution of recreational discards. Recreational discards are typically a small component of total catch, and the SNE/MA winter flounder stock assessment suffers from very little length information used to characterize recreational discards (Table 6).

For this analysis a cumulative discard length distribution over all available years was used to characterize recreational discards. Size information is used to understand what proportion of discards are of legal size. Comparing discards and releases to landed fish may be used to address which fish might be kept if a bag limit liberalization occurs.

The MRIP size data contain individual fish measurements from intercept interviews. Paul Nitschke provided MRIP length data from the 2025 SNE/MA winter flounder management track stock assessment. Note that sample sizes are sparse in recent years (Table 6). Data are only available from 2005 through 2024 as that was what was available from the stock assessment. Reduced sampling of recreational fishery information could be an issue for the stock assessment moving forward.

Again, the TC does not believe a bag limit analysis is possible with the sparse data and therefore just made observations on the raw information. Overlaid length frequency distributions of kept and released fish across pre- and post-bag limit regulatory periods show an increase in released legal sized fish post-bag limit implementation (Figure 7). This suggests the potential for increased recreational harvest of legal sized fish with an increased bag limit. More small fish were kept in the 2005–2009 period, before the two-fish bag limit was instated (Table 7; Figure 8). This suggests the bag limit has been effective at reducing harvest of smaller fish.

The proportion of legal fish that were released by year indicates a very slight increase in the percent of legal fish that are released in recent years (Figure 9). However, this seems only minimally related to the decrease in bag limits when viewing data from 2008 through 2015 across that transition time period.

**References**

Northeast Fisheries Science Center (NEFSC). 2008. Report of the 3rd Groundfish Assessment Review Meeting (GARM III). US Dept Commer, Northeast Fish Sci Cent National Marine Fisheries Service, 166 Water Street, Woods Hole, MA. https://www.nefsc.noaa.gov/publications/crd/crd0815/crd0815.pdf

NEFSC. 2025. Southern New England Mid-Atlantic Winter Flounder 2025 Management Track Assessment Report. US Dept Commer, Northeast Fish Sci Cent National Marine Fisheries Service, 166 Water Street, Woods Hole, MA. Compiled 09-30-2025.

**Tables and Figures**

***Table 1. Observed trips and catch by year from SNE/MA states. 'N Trips' shows the number of MRIP intercepts that occurred within the given year with observed winter flounder. 'Total Obs. Catch' shows the total number of fish directly observed during MRIP intercepts each year. 'Mean per Angler' shows the average number of winter flounder caught per intercept event each year.***

| Year | N trips | Total obs. Catch | Mean per angler |
|---|---|---|---|
| **1982** | 431 | 3,551 | 5.21 |
| **1983** | 517 | 3,570 | 4.06 |
| **1984** | 664 | 5,526 | 4.97 |
| **1985** | 511 | 4,354 | 4.93 |
| **1986** | 688 | 3,636 | 3.67 |
| **1987** | 383 | 2,466 | 3.83 |
| **1988** | 648 | 3,600 | 3.22 |
| **1989** | 922 | 3,892 | 3.02 |
| **1990** | 813 | 3,915 | 3.28 |
| **1991** | 565 | 2,995 | 3.14 |
| **1992** | 370 | 1,495 | 2.63 |
| **1993** | 485 | 1,760 | 2.29 |
| **1994** | 297 | 1,254 | 2.62 |
| **1995** | 186 | 919 | 2.88 |
| **1996** | 273 | 1,249 | 2.84 |
| **1997** | 222 | 1,150 | 3.11 |
| **1998** | 151 | 900 | 3.53 |
| **1999** | 153 | 579 | 2.42 |
| **2000** | 71 | 220 | 2.48 |
| **2001** | 158 | 678 | 2.36 |
| **2002** | 93 | 269 | 2.24 |
| **2003** | 116 | 605 | 3.72 |
| **2004** | 114 | 326 | 2.21 |
| **2005** | 71 | 164 | 1.9 |
| **2006** | 42 | 110 | 1.96 |
| **2007** | 31 | 55 | 1.51 |
| **2008** | 39 | 85 | 1.99 |
| **2009** | 31 | 71 | 1.82 |
| **2010** | 37 | 61 | 1.38 |
| **2011** | 33 | 66 | 1.55 |
| **2012** | 38 | 77 | 1.61 |
| **2013** | 16 | 18 | 1.11 |
| **2014** | 34 | 49 | 1.34 |
| **2015** | 18 | 23 | 1.25 |
| **2016** | 33 | 41 | 1.14 |
| **2017** | 35 | 46 | 1.2 |
| **2018** | 27 | 30 | 0.99 |
| **2019** | 5 | 5 | 0.8 |
| **2020** | 30 | 33 | 1.02 |
| **2021** | 16 | 16 | 0.96 |
| **2022** | 9 | 27 | 1.55 |
| **2023** | 7 | 7 | 0.9 |
| **2024** | 12 | 12 | 0.82 |
| **2025** | 3 | 2 | 0.52 |

***Table 2. Observed SNE/MA winter flounder catch by wave 1982-2025 (Wave 2 = March-April; Wave 3 = May-June; Wave 4 = July-August; Wave 5 = September-October; Wave 6 = November-December). 'N Trips' shows the number of MRIP intercepts with winter flounder present that occurred within the given wave. 'Total Obs. Catch' shows the total number of fish directly observed during MRIP intercepts each wave. 'Mean per Angler' shows the average number of winter flounder caught per intercept event each wave (for events when winter flounder were present).***

| Wave | N Trips | Total Obs. Catch | Mean Per Angler |
|---|---|---|---|
| 2 | 3,695 | 18,917 | 3.33 |
| 3 | 2,673 | 16,094 | 3.53 |
| 4 | 655 | 2,613 | 2.49 |
| 5 | 1,231 | 5,255 | 2.84 |
| 6 | 1,144 | 7,027 | 4.05 |

***Table 3. Observed catch by state 1982-2025. 'N Trips' shows the number of MRIP intercepts that occurred within the given state with winter flounder present. 'Total Obs. Catch' shows the total number of fish directly observed during MRIP intercepts in each state. 'Mean per Angler' shows the average number of winter flounder caught per intercept event in each state (for events when winter flounder were present).***

| State | N Trips | Total Obs. Catch | Mean Per Angler |
|---|---|---|---|
| Massachusetts | 357 | 1,618 | 3.14 |
| Rhode Island | 1,132 | 5,687 | 3.06 |
| Connecticut | 1,457 | 7,642 | 3.15 |
| New York | 4,878 | 25,159 | 3.34 |
| New Jersey | 1,541 | 9,686 | 3.89 |
| Delaware | 8 | 18 | 1.39 |
| Maryland | 5 | 21 | 1.85 |
| Virginia | 20 | 75 | 1.74 |

***Table 4. Observed SNE/MA winter flounder recreational catch by fishing mode, 1982-2025. 'N Trips' shows the number of MRIP intercepts that occurred among fishing modes. 'Total Obs. Catch' shows the total number of fish directly observed during MRIP intercepts among each mode. 'Mean per Angler' shows the average number of winter flounder caught per intercept event among each mode. The NA mode consists of trips where mode was either Headboat or Private/Rental Boat prior to 2013.***

| Mode | N Trips | Total Obs. Catch | Mean Per Angler |
|---|---|---|---|
| Charter Boat | 19 | 38 | 1.71 |
| Headboat | 362 | 541 | 1.41 |
| Private/Rental Boat | 5,051 | 36,225 | 3.96 |
| Shore | 2,398 | 6,986 | 2.40 |
| NA | 1,568 | 6,116 | 3.33 |

***Table 5. Catch in numbers of fish by harvest type and year across the entire SNE/MA winter flounder stock. Catch is split into Type A (observed harvest), Type B1 (reported harvest), and Type B2 (releases), using adjusted claim values. These values do not account for the number of anglers on a trip.***

| Year | Type A (Claim) | Type B1 (Harvest) | Type B2 (Release) |
|---|---|---|---|
| 1982 | 6,732 | 1,495 | 1,380 |
| 1983 | 5,364 | 1,588 | 2,183 |
| 1984 | 6,485 | 1,634 | 2,606 |
| 1985 | 4,887 | 994 | 2,159 |
| 1986 | 4,452 | 2,637 | 2,502 |
| 1987 | 3,455 | 1,176 | 1,610 |
| 1988 | 4,529 | 2,169 | 2,299 |
| 1989 | 5,756 | 2,362 | 2,654 |
| 1990 | 4,661 | 3,127 | 3,443 |
| 1991 | 3,301 | 3,161 | 3,037 |
| 1992 | 1,802 | 1,318 | 1,540 |
| 1993 | 2,132 | 1,272 | 2,635 |
| 1994 | 1,427 | 619 | 1,500 |
| 1995 | 1,092 | 707 | 1,356 |
| 1996 | 1,407 | 928 | 1,100 |
| 1997 | 1,285 | 825 | 1,260 |
| 1998 | 994 | 530 | 1,001 |
| 1999 | 656 | 565 | 681 |
| 2000 | 287 | 656 | 574 |
| 2001 | 713 | 434 | 764 |
| 2002 | 346 | 153 | 433 |
| 2003 | 661 | 324 | 258 |
| 2004 | 346 | 151 | 107 |
| 2005 | 192 | 60 | 211 |
| 2006 | 172 | 69 | 207 |
| 2007 | 106 | 58 | 107 |
| 2008 | 210 | 136 | 155 |
| 2009 | 113 | 154 | 283 |
| 2010 | 124 | 82 | 223 |
| 2011 | 104 | 94 | 155 |
| 2012 | 79 | 75 | 106 |
| 2013 | 96 | 60 | 91 |
| 2014 | 143 | 58 | 124 |
| 2015 | 164 | 61 | 196 |
| 2016 | 140 | 45 | 216 |
| 2017 | 150 | 69 | 83 |
| 2018 | 227 | 55 | 136 |
| 2019 | 133 | 121 | 91 |
| 2020 | 254 | 64 | 149 |
| 2021 | 87 | 148 | 150 |
| 2022 | 167 | 68 | 49 |
| 2023 | 75 | 53 | 56 |
| 2024 | 49 | 34 | 34 |
| 2025 | 281 | 193 | 217 |

***Table 6. Number of individual SNE/MA winter flounder measured in MRIP observations by year and release disposition***.

| Year | Kept | Released |
|---|---|---|
| 2005 | 208 | 21 |
| 2006 | 146 | 3 |
| 2007 | 70 | 5 |
| 2008 | 101 | 11 |
| 2009 | 101 | 12 |
| 2010 | 81 | 14 |
| 2011 | 71 | 5 |
| 2012 | 98 | 11 |
| 2013 | 22 | 2 |
| 2014 | 54 | 1 |
| 2015 | 27 | 0 |
| 2016 | 51 | 3 |
| 2017 | 50 | 8 |
| 2018 | 40 | 9 |
| 2019 | 6 | 0 |
| 2020 | 39 | 9 |
| 2021 | 16 | 10 |
| 2022 | 21 | 4 |
| 2023 | 16 | 3 |
| 2024 | 18 | 3 |

***Table 7. Number and percentage of SNE/MA winter flounder measured in MRIP observations by release disposition and length***.

| Regulatory period | Disposition | Legal (≥12in) | Sublegal (<12in) | Total N |
|---|---|---|---|---|
| **2005-2009** | Kept | 96% | 4% | 626 |
| | Released | 32.7% | 67.3% | 52 |
| **Post-2010** | Kept | 98.4% | 1.6% | 610 |
| | Released | 64.6% | 35.4% | 82 |

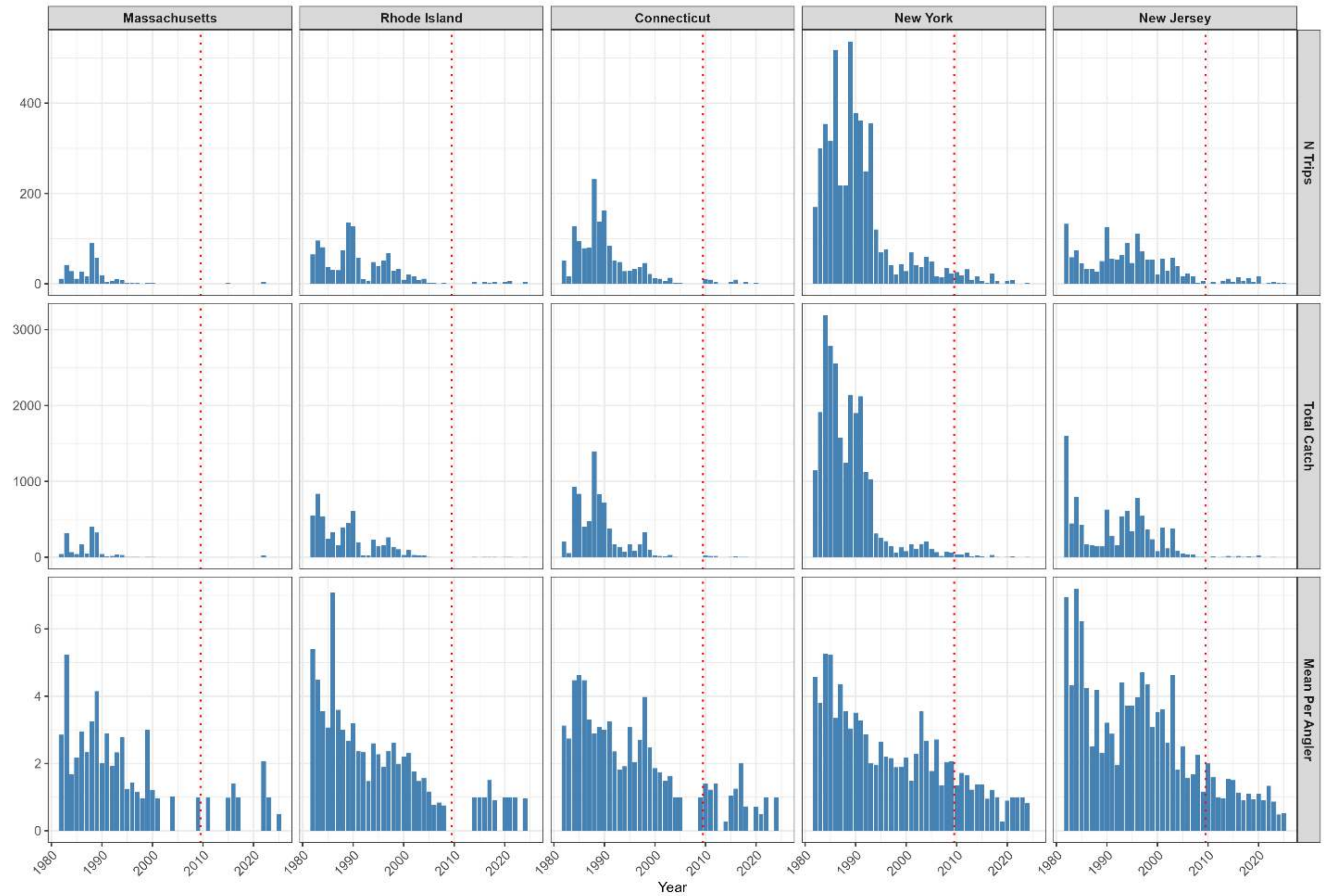


***Figure 1. Observed number of trips, total catch in numbers of fish, and mean number of fish per angler of SNE/MA winter flounder by state and year. Massachusetts only includes trips observed within the SNE/MA area. Delaware, Maryland, and Virginia are excluded from the plot below because landings were minimal. The timing of the two-fish bag limit (vertical red dotted line) varied by state but all states had adopted it by 2010.***

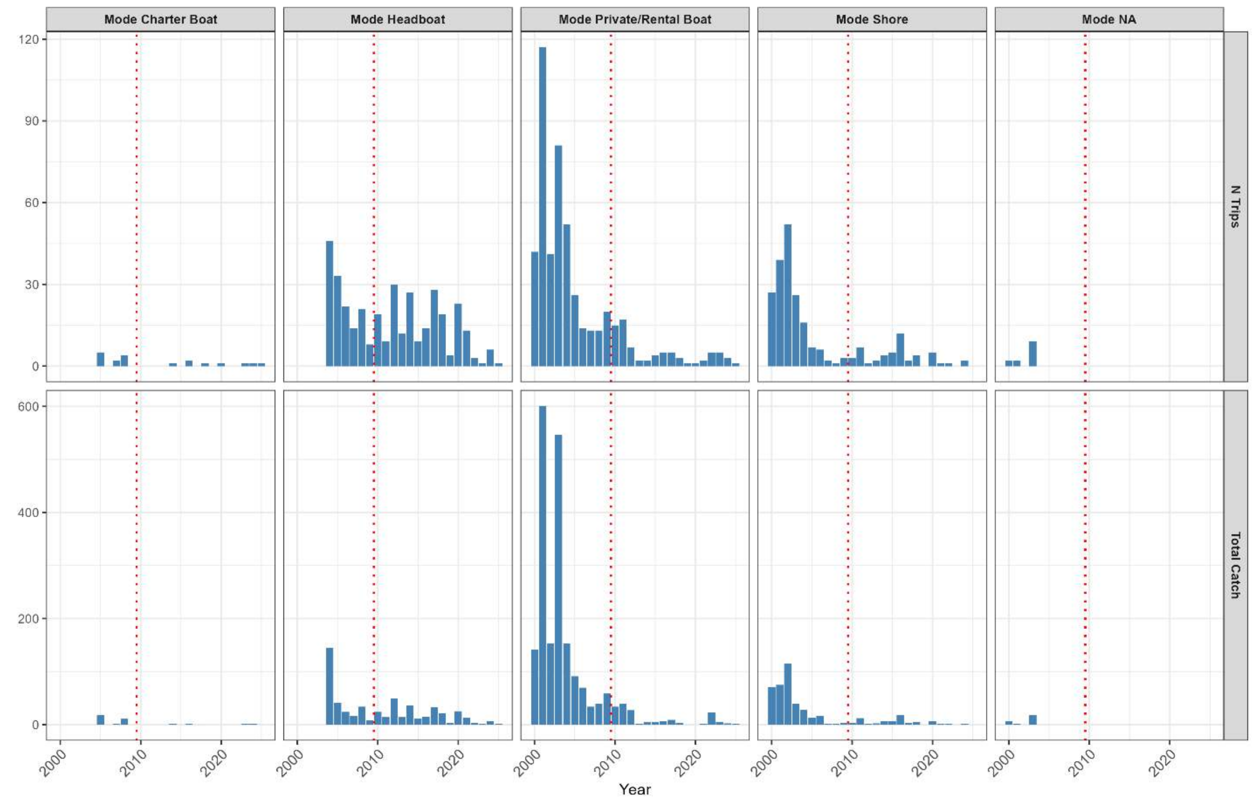


***Figure 2. Number of trips and observed catch by year and mode 2000-2025. Filtered to years ≥ 2000 so that trends are more apparent. The timing of the two-fish bag limit varied by state but all states had adopted it by 2010 (denoted by the red dotted line).***

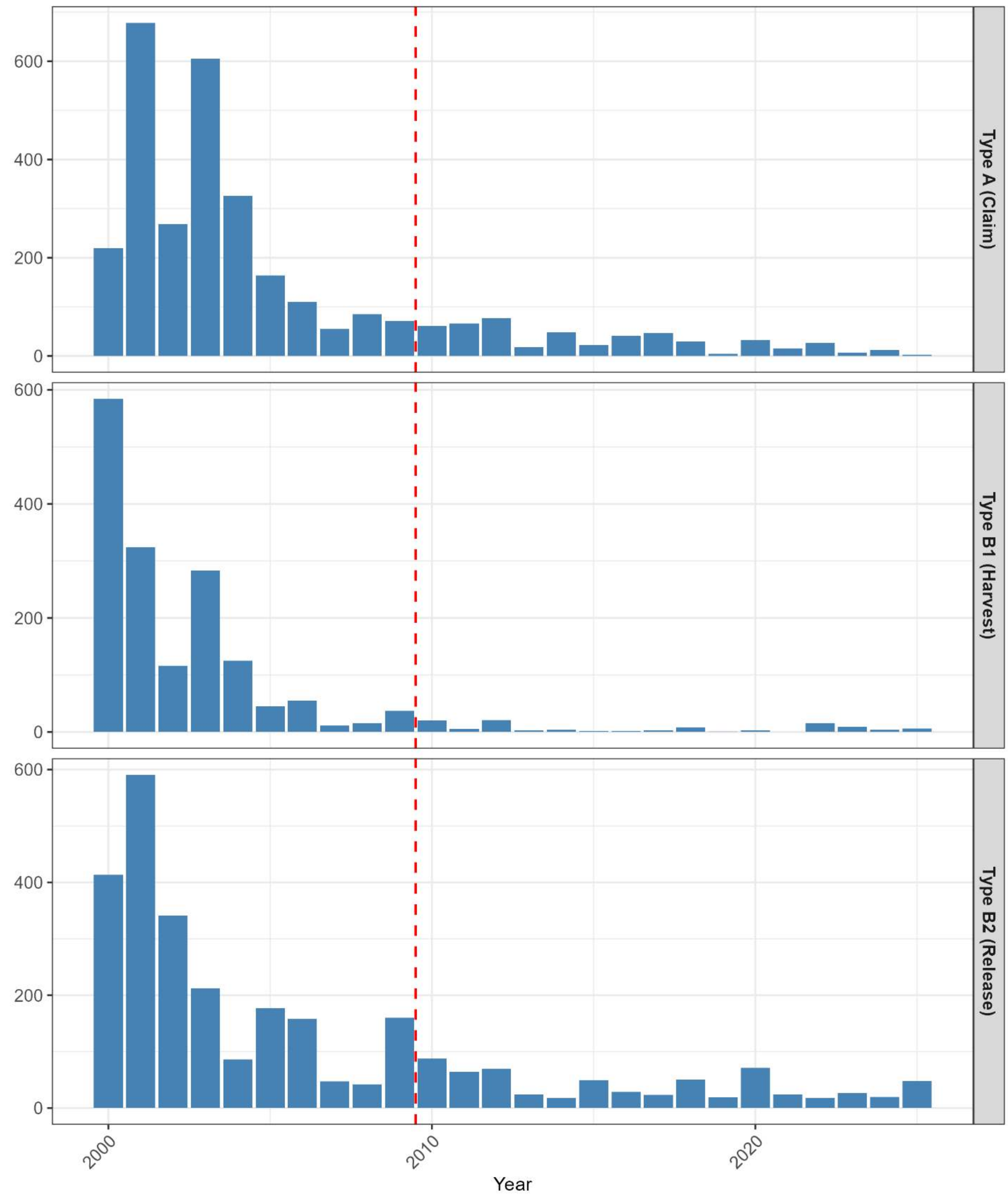


***Figure 3. Winter Flounder catch by catch type and year. Catch is split into Type A (observed harvest), Type B1 (reported harvest), and Type B2 (releases), using adjusted values. Filtered to years ≥ 2000 so that trends are more apparent. The dashed red line indicates approximate bag limit change (2 fish, ~2010).***

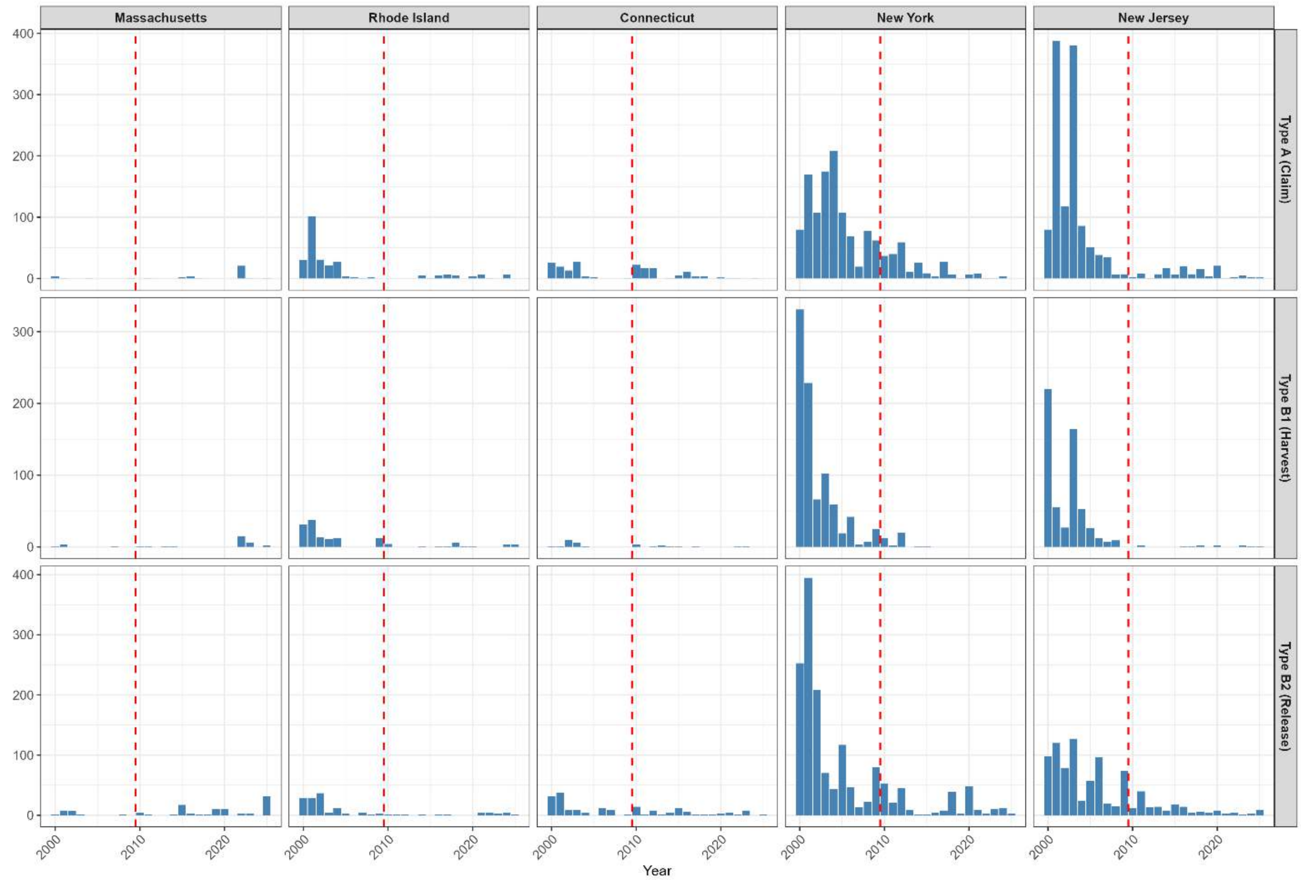


***Figure 4. Winter Flounder catch in numbers of fish by catch type, state and year. Catch is split into Type A (observed harvest), Type B1 (reported harvest), and Type B2 (releases), using adjusted values. Filtered to years ≥ 2000 so that trends are more apparent. Delaware, Maryland, and Virginia excluded due to minimal landings. The dashed red line indicates approximate bag limit change (2 fish, ~2010).***

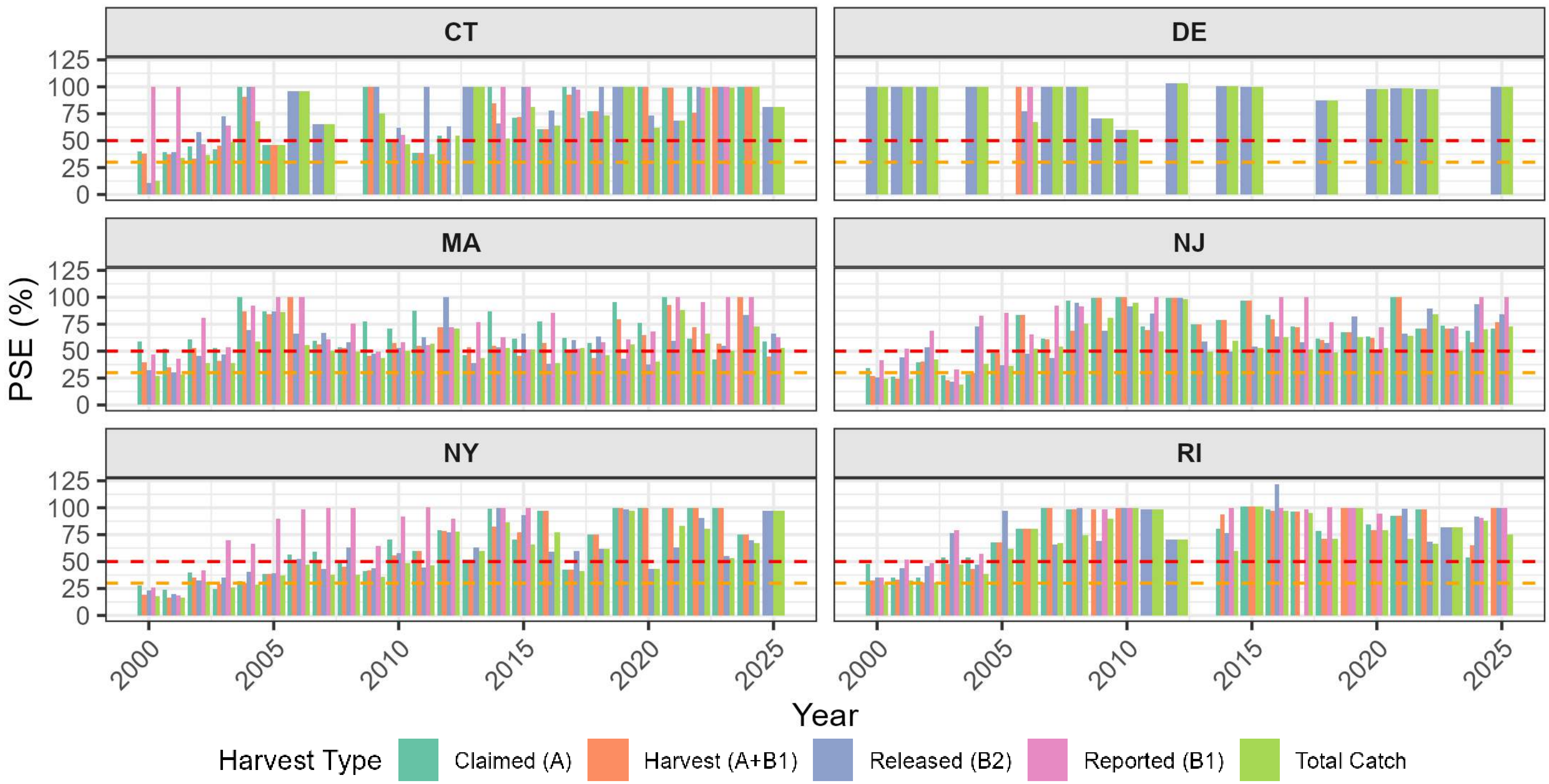


***Figure 5. Percent Standard Error (PSE) values for SNE/MA winter flounder by state, harvest type, and year (2000-2025). Dashed orange line indicates PSE value of 30; dashed red line indicates PSE value of 50.***


*Figure 6. PSE values for SNE/MA winter flounder by fishing mode, harvest type, and year (2000-2025). Dashed orange line indicates PSE value of 30; dashed red line indicates PSE value of 50.*

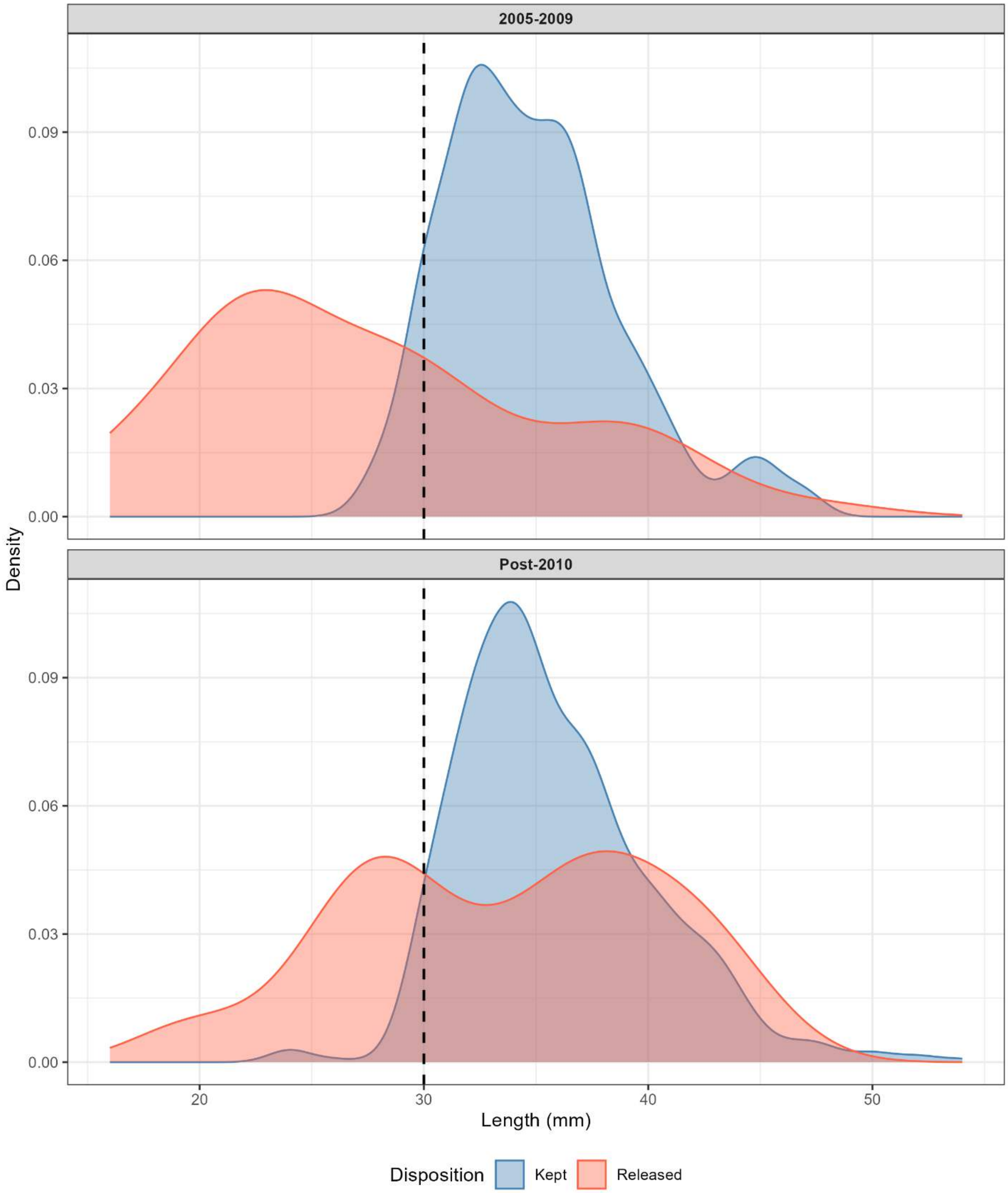


***Figure 7. Overlaid length frequency distributions of kept and released fish across pre- and post- bag limit regulatory periods. The dashed vertical line indicates the 12-inch (304.8mm) minimum size limit. This directly shows whether released fish were sublegal or legal sized.***

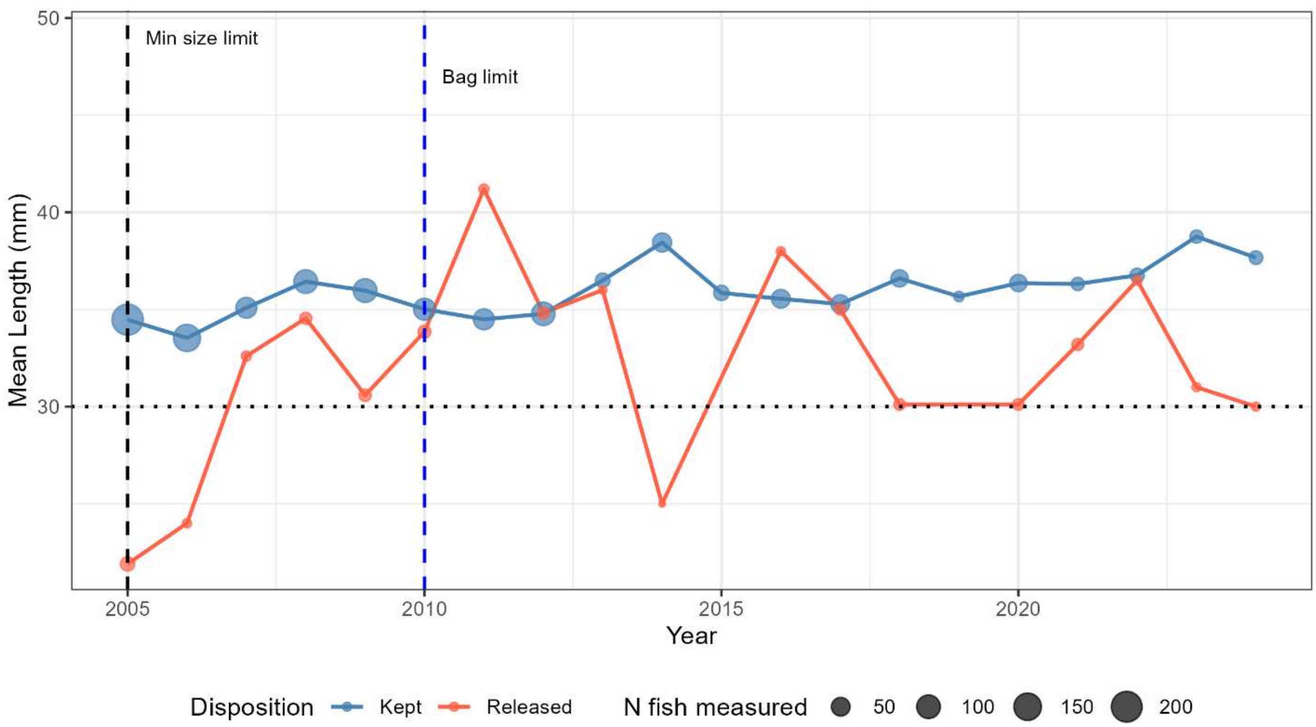


***Figure 8. Mean length of kept vs. released winter flounder by year. The vertical black dashed line denotes when the minimum size limit (12-inches) was implemented, and the vertical blue dashed line denotes when the 2 fish bag limit was implemented. The size of each individual data point denotes the approximate number of fish measured. Note the small sample size of released fish across all years.***

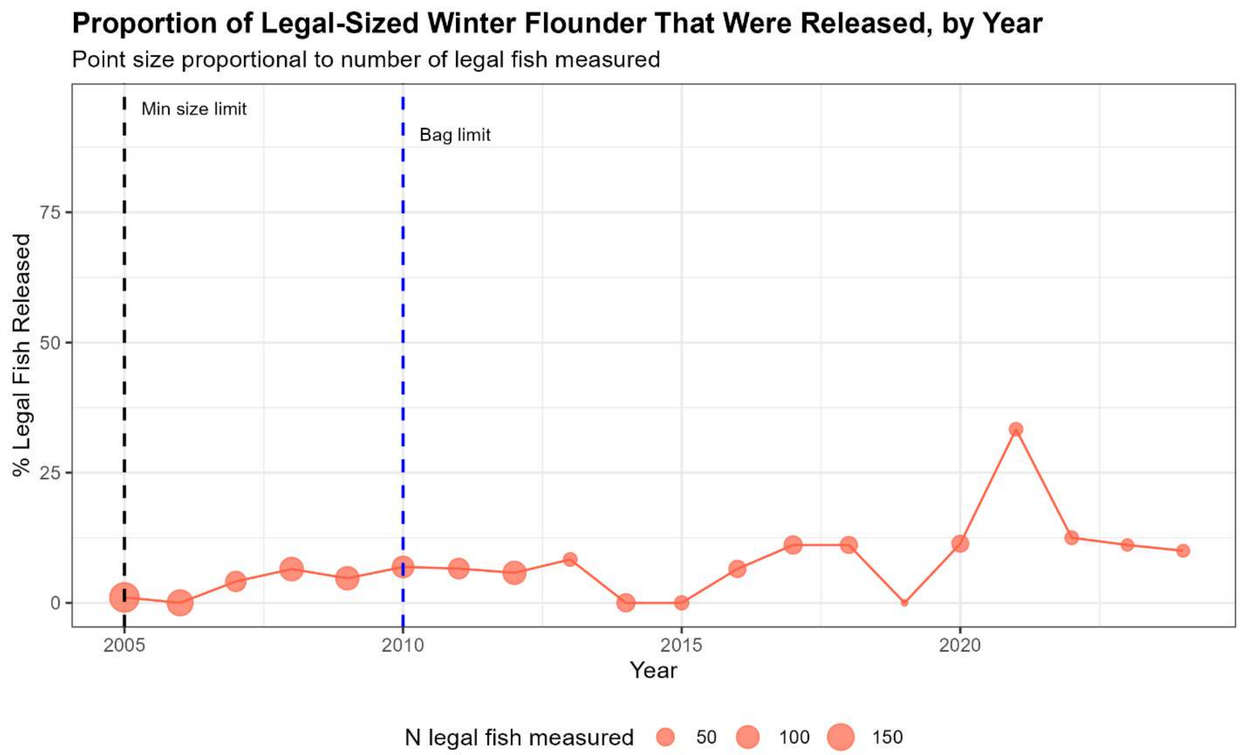


***Figure 9. Percentage of legal-sized fish (≥12 inches) that were released rather than kept by year. The vertical black dashed line denotes when the minimum size limit (12-inches) was implemented, and the vertical blue dashed line denotes when the 2 fish bag limit was implemented. The size of each individual data point denotes the number of fish measured. A high value suggests anglers were already catching legal fish but releasing them, which is directly relevant to bag limit liberalization. If the bag limit were increased, some of these fish could be retained.***