View from the Inshore: Spatial and Temporal Variation in Northern Cod Recovery

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What is the cod sentinel survey?

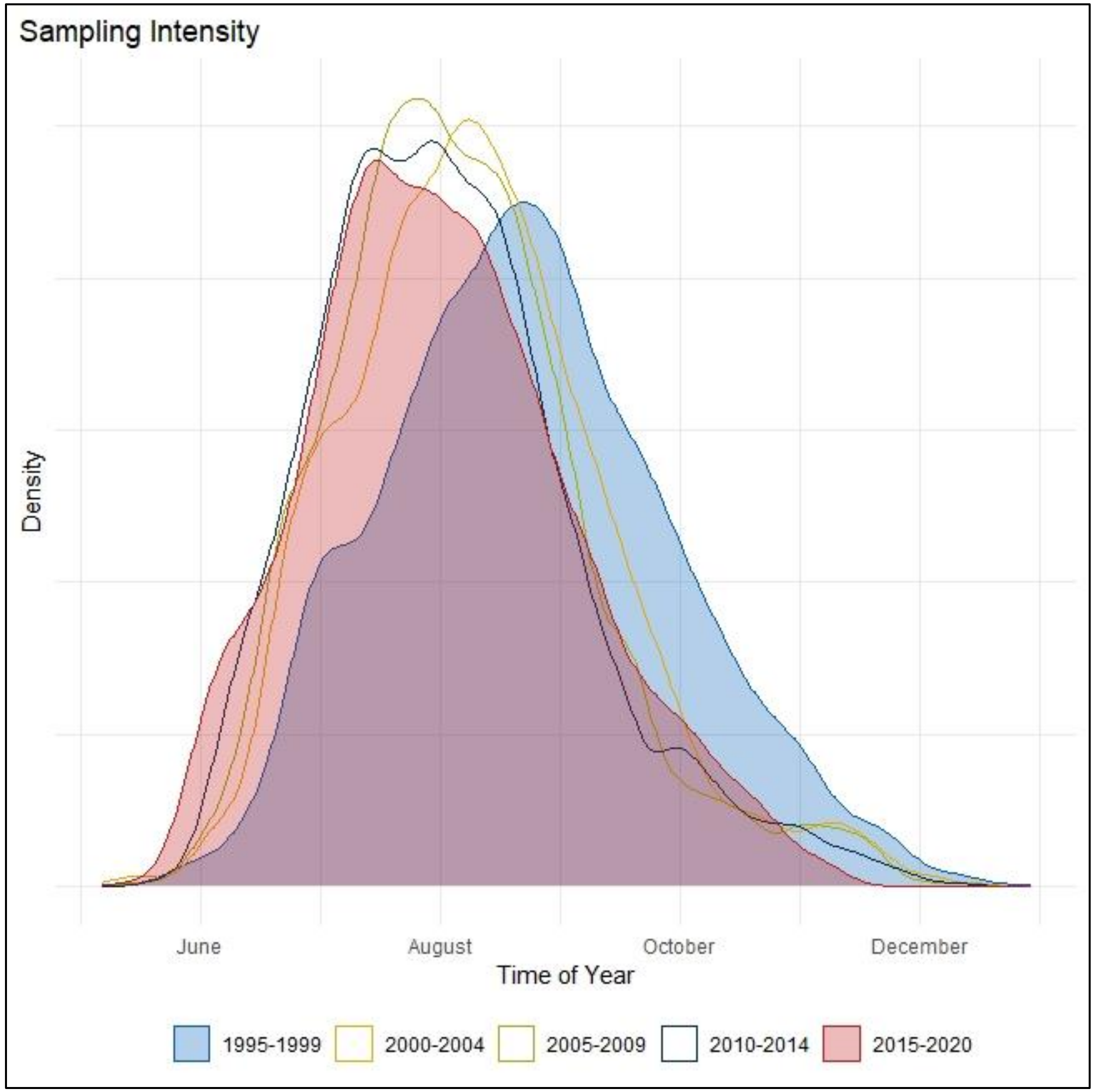
- Annual survey of inshore cod grounds in NAFO Div. 2J3KLPs
- Co-developed by fish harvesters, FFAW-Unifor, and DFO
- 1995-Present
- Intended to collect information on catch rates, inshore cod distribution, and biological information

What can we learn from the cod sentinel survey?

- How have catch rates changed since the start of the sentinel survey, and where/when do we see those changes?
- How does cod availability vary by location?
- Has cod availability changed, and, if so, how and where?

What are the data considerations when using the survey?

Because sampling timing/intensity varies over time and space, it is difficult to make statements about how catch rates have changed over time/space and throughout the season.



VAST Spatial-Temporal Model

- Index Standardization Tool
- Possion-link delta model that estimates density (*d*) at site (*s*) and time (*t*) as a product of the probability that sample *i* encounters a given species (p_i) and the predicted positive catch rate (r_i).

$$1)\ d(s,t) = n(s,t) \times w(s,t) = p_i \times r_i$$

$$2)\ p_i = 1 - \exp(-a_i \times n_i)\,, r_i = \frac{a_i \times n_i}{p_i} \times w_i$$

- where a_i is a measure of effort as number of nets at each sample
- and n_i is the number of fish caught
- and w_i is a unitless parametric link between expected encounter probability and expected numbers given an encounter.
- Sites, or knots, created based on spatial cluster analysis

VAST Spatial-Temporal Model

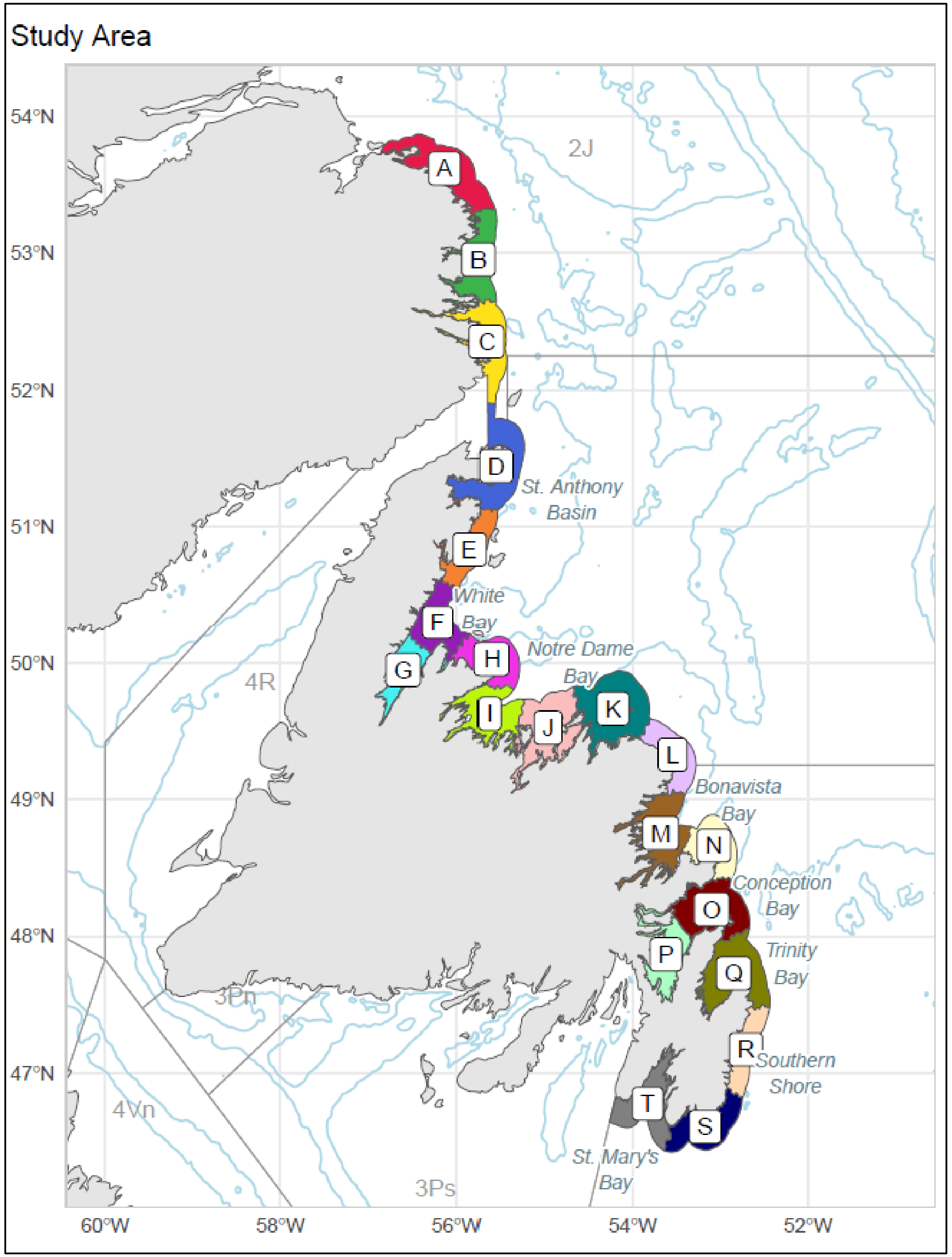
- n_i and w_i are constructed using a log-link function:

$$3)\quad \log(n_i) = \underbrace{\beta_n^*(t_i)}_{\substack{Year-Season\\ i\ intercept}} + \underbrace{\xi_{nu}^*(s_i, u_i)}_{\substack{Season\\ spatial\ effect}} + \underbrace{\xi_{ny}^*(s_i, y_i)}_{\substack{Year\\ spatial\ effect}} + \underbrace{\varepsilon_n^*(s_i, t_i)}_{\substack{Year-Season\\ spatial\ effect}}$$

$$4)\quad \log(w_i) = \underbrace{\beta_w^*(t_i)}_{\substack{Year-Season\\ i\ intercept}} + \underbrace{\xi_{wu}^*(s_i, u_i)}_{\substack{Season\\ spatial\ effect}} + \underbrace{\xi_{wy}^*(s_i, y_i)}_{\substack{Year\\ spatial\ effect}} + \underbrace{\varepsilon_w^*(s_i, t_i)}_{\substack{Year-Season\\ spatial\ effect}}$$

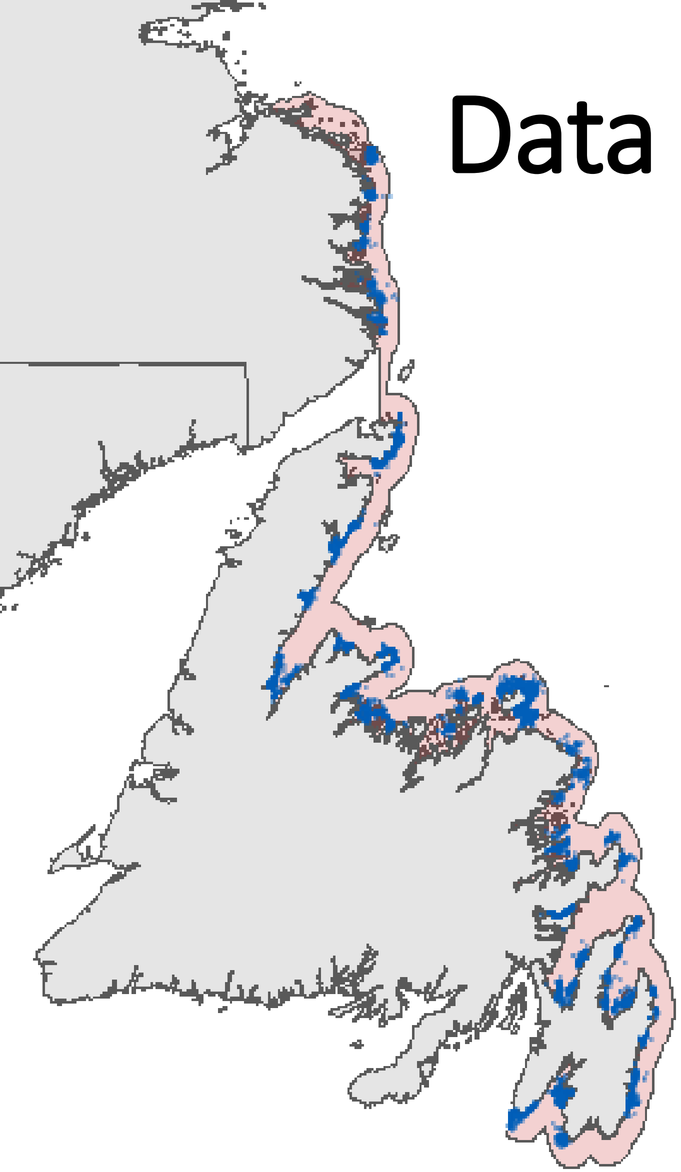
$$5)\quad \beta_n^*(t) = \mu_\beta + \beta_{nu}(u) + \beta_{ny}(y) + \beta_{nt}(t)$$

- where u_i is the season of the sample and y_i is the year of the sample
- μ_β is the average intercept across all seasons and years, $\beta_{nu}(u)$ and $\beta_{ny}(y)$ are season and year main effects
- and $\beta_{nt}(t)$ represents an autocorrelated year-season effect estimated from available data



VAST Spatial-Temporal Model

- When a location is not sampled in a specific season-year, model can use information from adjacent season-years, other years of the same season, or other seasons of the same year to estimate catch rates (fill in the blanks)
- 26 Years of data: 1995-2020
- 17 Seasons: bi-weekly intervals from Week 19, early-May – Week 52 of year
- 20 pre-specified sites
- Final output is biweekly CPUE (fish/net) across 20 sites through 26 years



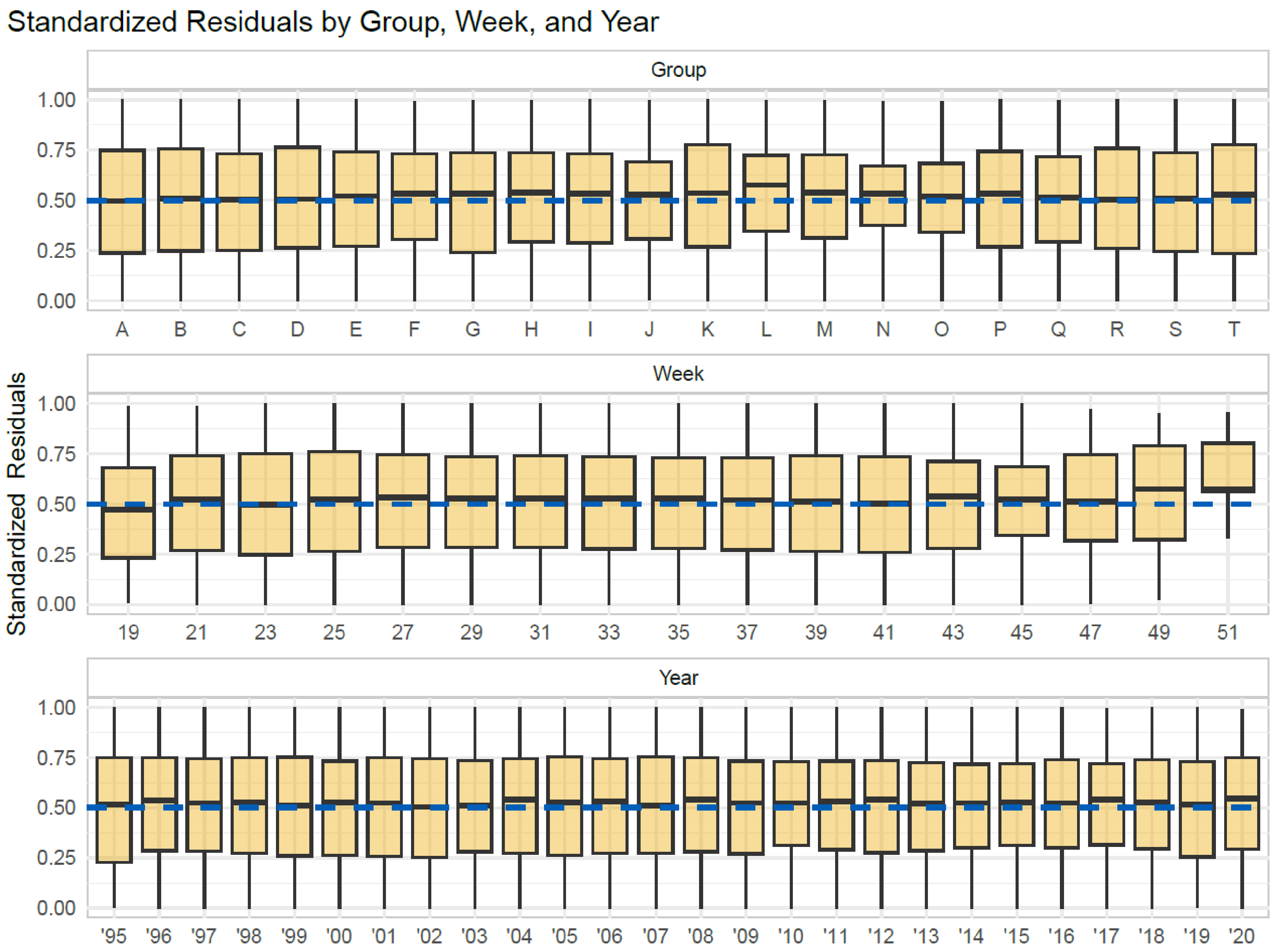
Data Cleaning Procedures

- Only using 2J3KL Homeports
- Removed survey sites with incorrect latitude-longitudes
  - Sites on land or outside NAFO Regions (n = 1,561)
  - Sites further than 18 km from homeport (95th percentile outliers, n = 1,541)
- Only use large gillnets (5.5 in/140 mm soaked between 12 – 32 hours)
- Removed any samples completed before 18th week of year (May 1)
- Resulted in **73** Ports, **98** Harvesters, **19,213** survey sites, and **46,281** sampling events (2.4 times per site)

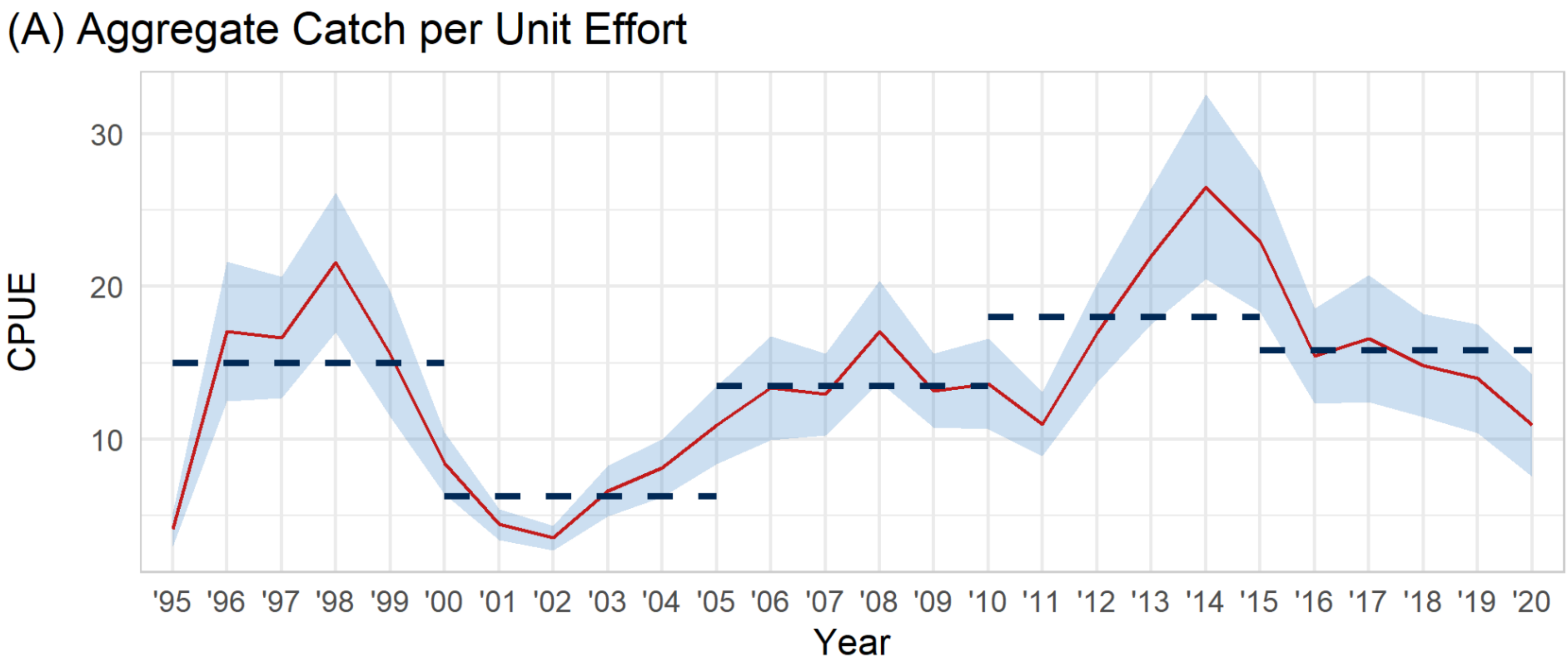
Model Fit

Relatively strong fit, though questionable at end of the year.

Trend towards slight underestimation of CPUE.

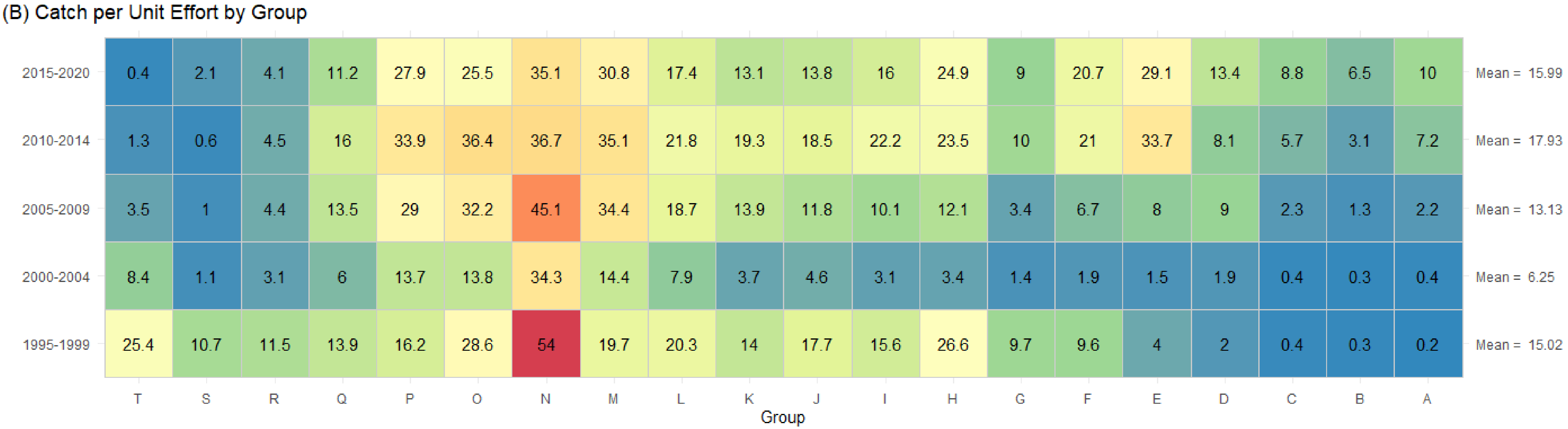


Aggregate Catch Rates

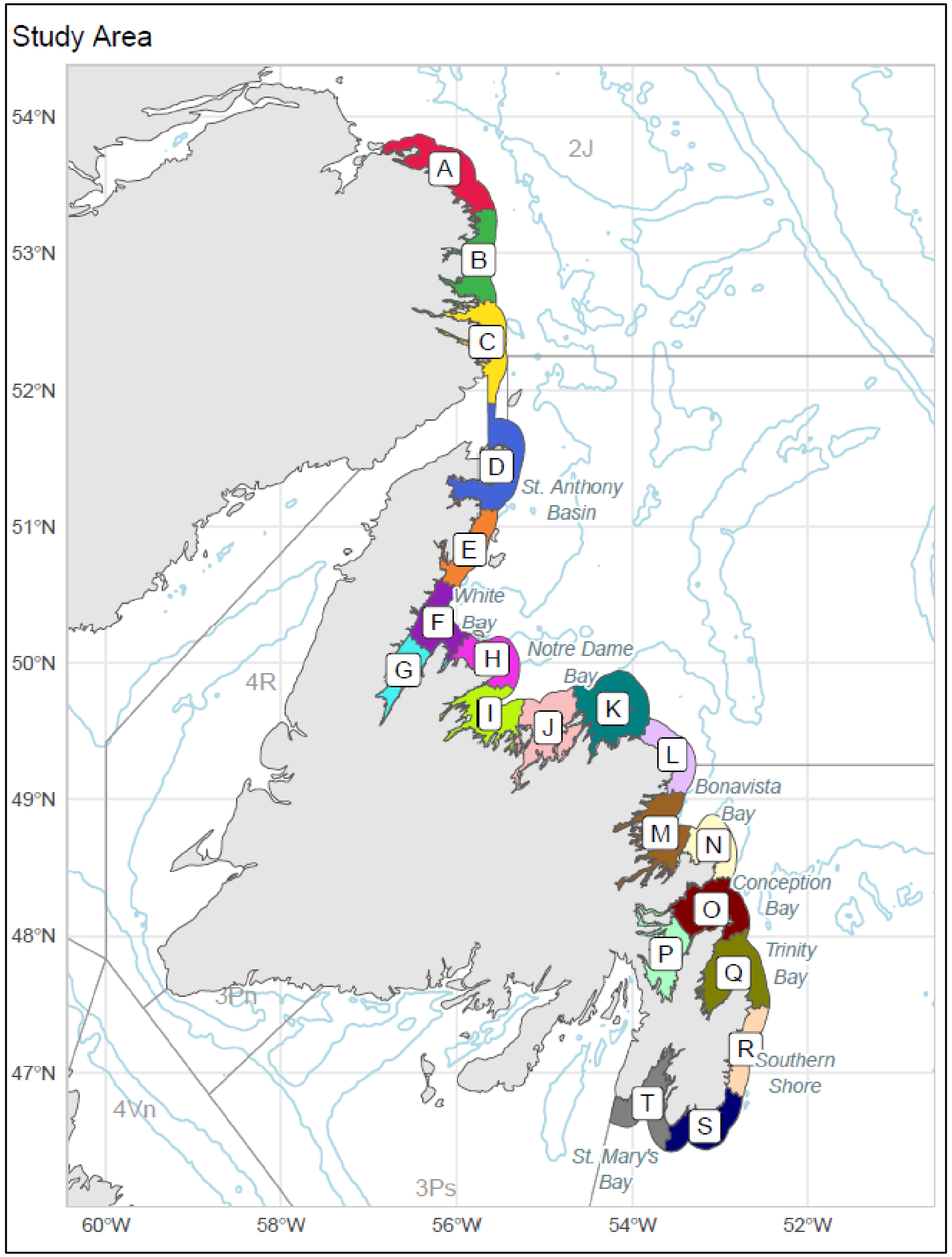


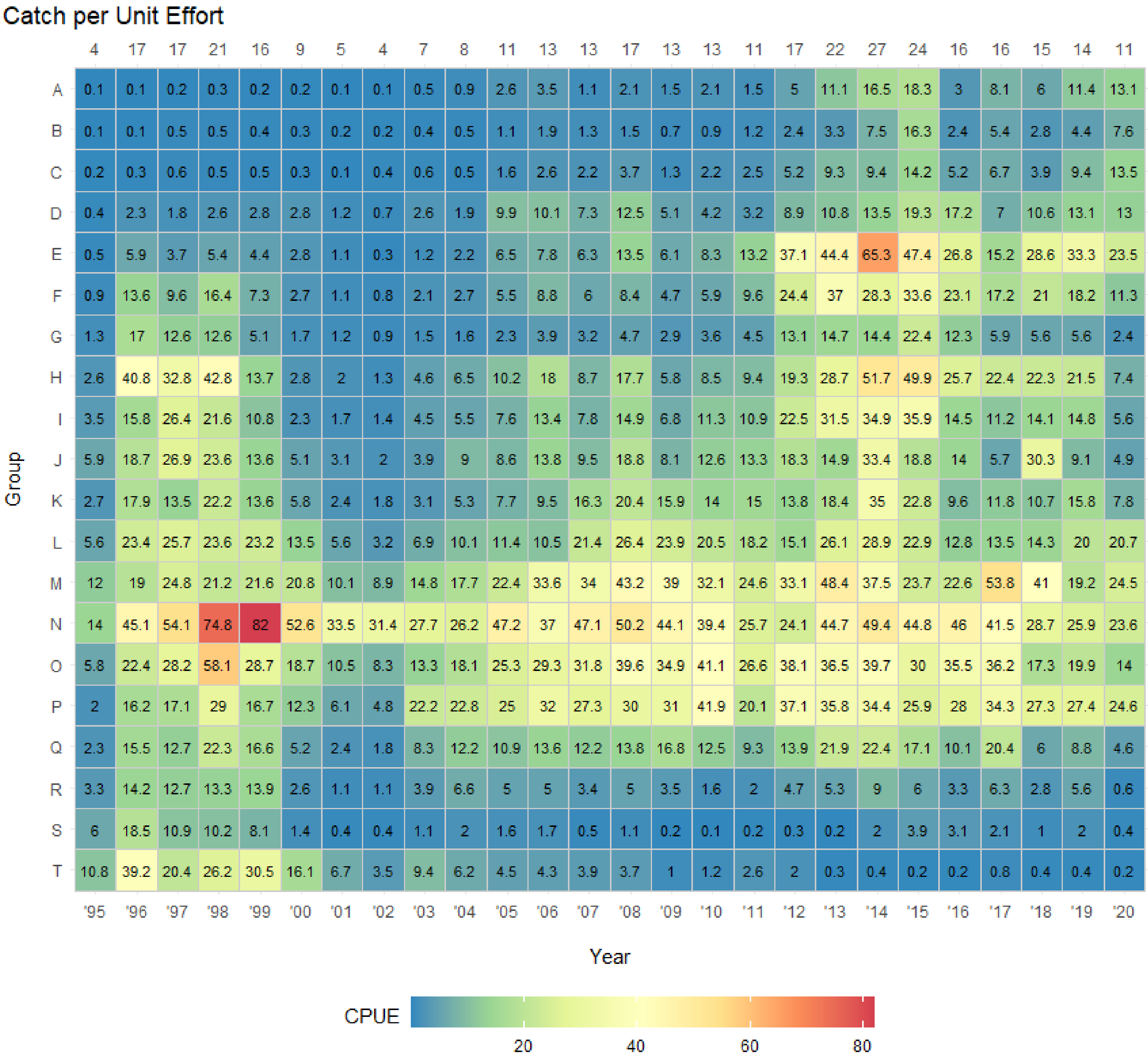
- **On the aggregate, catch rates between 2015-20 are only slightly higher than they were in 1995-1999, but about 3X higher than they were during the lowest period (2000-2004) of the time series.**
- **Aggregate catch rates have remained relatively steady since 2005.**

Catch Rates over Time/Space

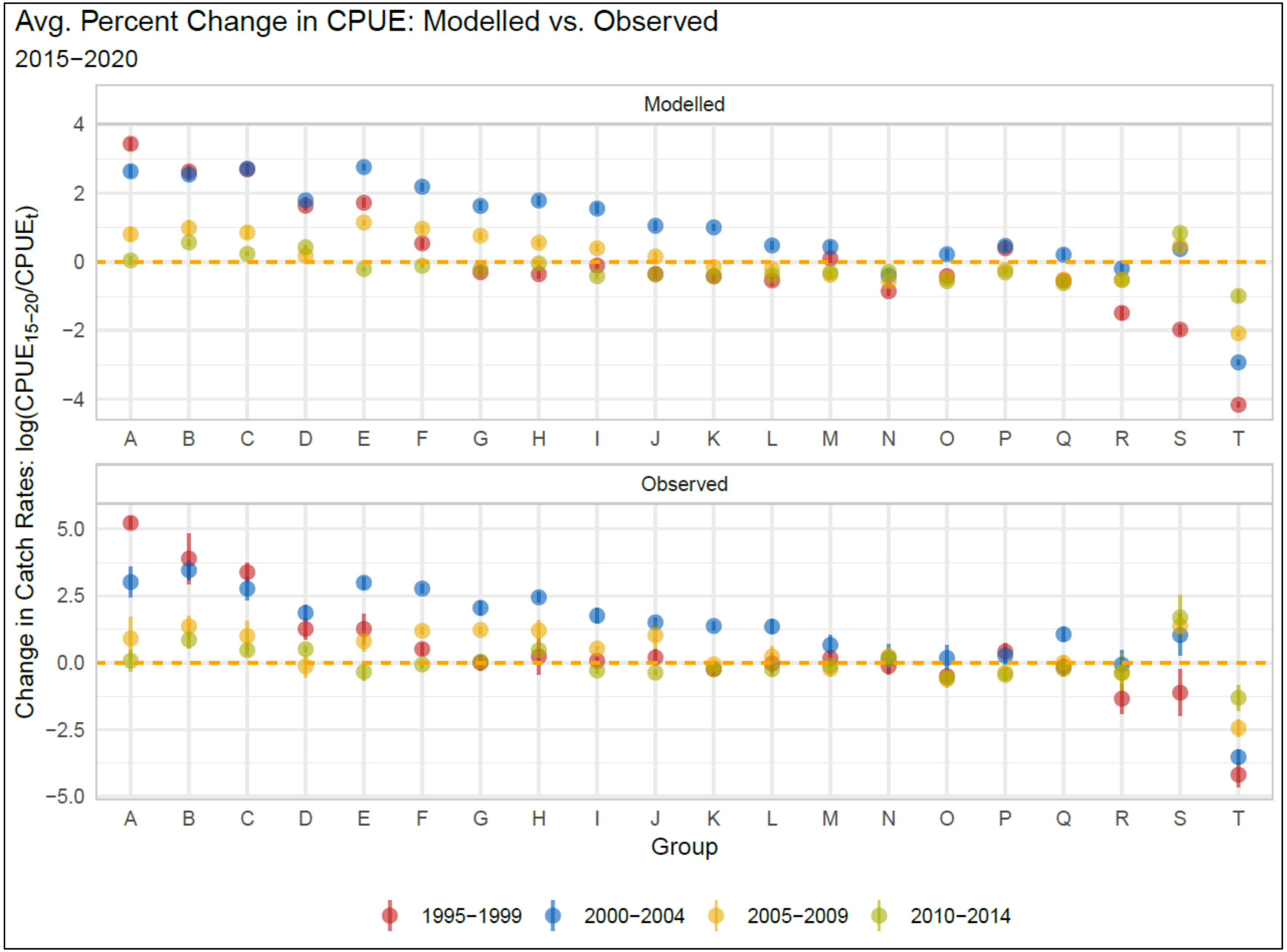


- **Catch rates have consistently been highest near Conception and Bonavista Bays (Groups P – L), where rates are nearly 2X the aggregate average each period**
- **There appears to be a shift from relatively higher catch rates in St. Mary's Bay and the Southern Shore in the early part of the time series to relatively higher catch rates in in White Bay and in Northern 3K and Southern 2J**



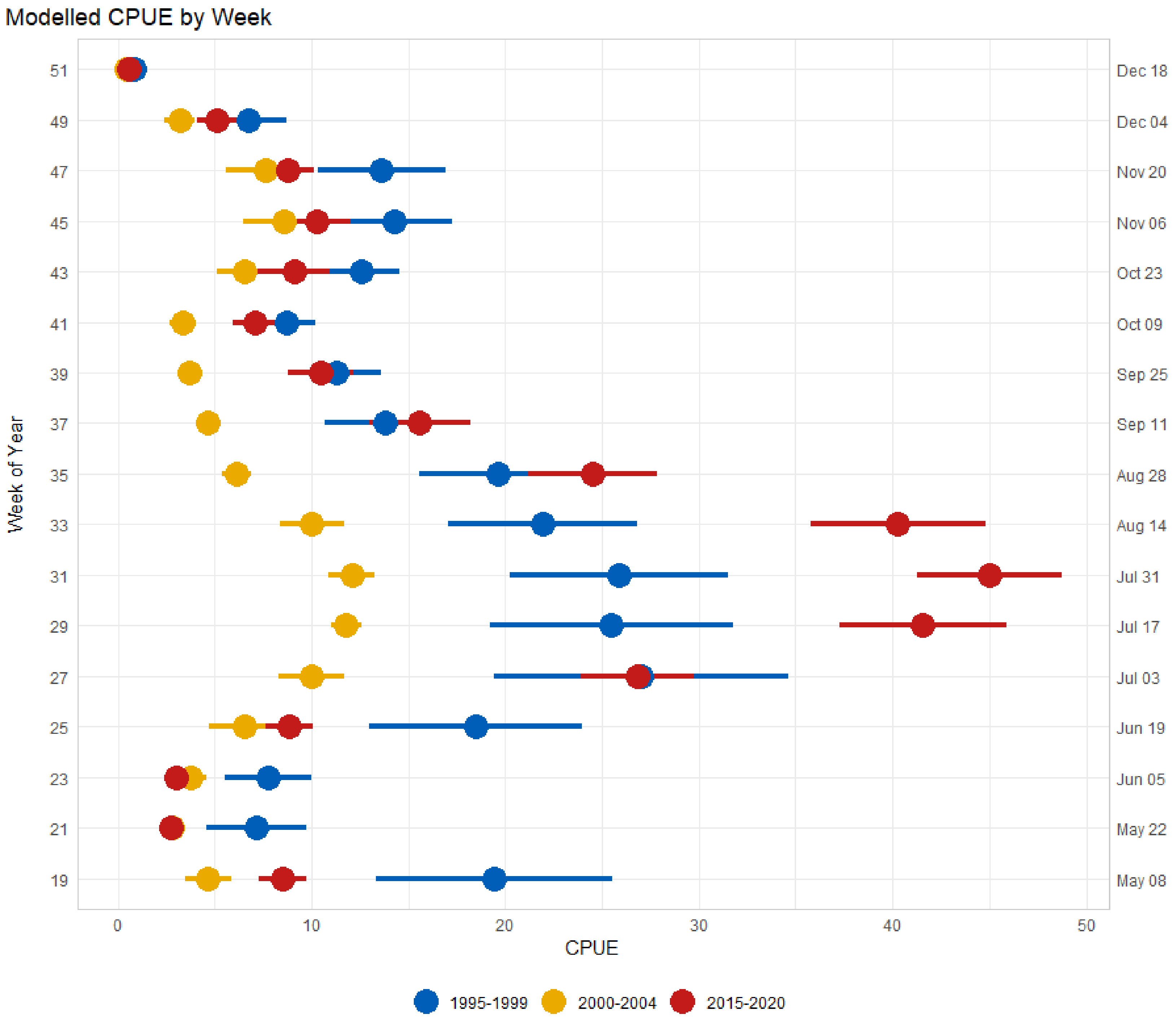


Group	'95	'96	'97	'98	'99	'00	'01	'02	'03	'04	'05	'06	'07	'08	'09	'10	'11	'12	'13	'14	'15	'16	'17	'18	'19	'20
	4	17	17	21	16	9	5	4	7	8	11	13	13	17	13	13	11	17	22	27	24	16	16	15	14	11
A	0.1	0.1	0.2	0.3	0.2	0.2	0.1	0.1	0.5	0.9	2.6	3.5	1.1	2.1	1.5	2.1	1.5	5	11.1	16.5	18.3	3	8.1	6	11.4	13.1
B	0.1	0.1	0.5	0.5	0.4	0.3	0.2	0.2	0.4	0.5	1.1	1.9	1.3	1.5	0.7	0.9	1.2	2.4	3.3	7.5	16.3	2.4	5.4	2.8	4.4	7.6
C	0.2	0.3	0.6	0.5	0.5	0.3	0.1	0.4	0.6	0.5	1.6	2.6	2.2	3.7	1.3	2.2	2.5	5.2	9.3	9.4	14.2	5.2	6.7	3.9	9.4	13.5
D	0.4	2.3	1.8	2.6	2.8	2.8	1.2	0.7	2.6	1.9	9.9	10.1	7.3	12.5	5.1	4.2	3.2	8.9	10.8	13.5	19.3	17.2	7	10.6	13.1	13
E	0.5	5.9	3.7	5.4	4.4	2.8	1.1	0.3	1.2	2.2	6.5	7.8	6.3	13.5	6.1	8.3	13.2	37.1	44.4	65.3	47.4	26.8	15.2	28.6	33.3	23.5
F	0.9	13.6	9.6	16.4	7.3	2.7	1.1	0.8	2.1	2.7	5.5	8.8	6	8.4	4.7	5.9	9.6	24.4	37	28.3	33.6	23.1	17.2	21	18.2	11.3
G	1.3	17	12.6	12.6	5.1	1.7	1.2	0.9	1.5	1.6	2.3	3.9	3.2	4.7	2.9	3.6	4.5	13.1	14.7	14.4	22.4	12.3	5.9	5.6	5.6	2.4
H	2.6	40.8	32.8	42.8	13.7	2.8	2	1.3	4.6	6.5	10.2	18	8.7	17.7	5.8	8.5	9.4	19.3	28.7	51.7	49.9	25.7	22.4	22.3	21.5	7.4
I	3.5	15.8	26.4	21.6	10.8	2.3	1.7	1.4	4.5	5.5	7.6	13.4	7.8	14.9	6.8	11.3	10.9	22.5	31.5	34.9	35.9	14.5	11.2	14.1	14.8	5.6
J	5.9	18.7	26.9	23.6	13.6	5.1	3.1	2	3.9	9	8.6	13.8	9.5	18.8	8.1	12.6	13.3	18.3	14.9	33.4	18.8	14	5.7	30.3	9.1	4.9
K	2.7	17.9	13.5	22.2	13.6	5.8	2.4	1.8	3.1	5.3	7.7	9.5	16.3	20.4	15.9	14	15	13.8	18.4	35	22.8	9.6	11.8	10.7	15.8	7.8
L	5.6	23.4	25.7	23.6	23.2	13.5	5.6	3.2	6.9	10.1	11.4	10.5	21.4	26.4	23.9	20.5	18.2	15.1	26.1	28.9	22.9	12.8	13.5	14.3	20	20.7
M	12	19	24.8	21.2	21.6	20.8	10.1	8.9	14.8	17.7	22.4	33.6	34	43.2	39	32.1	24.6	33.1	48.4	37.5	23.7	22.6	53.8	41	19.2	24.5
N	14	45.1	54.1	74.8	82	52.6	33.5	31.4	27.7	26.2	47.2	37	47.1	50.2	44.1	39.4	25.7	24.1	44.7	49.4	44.8	46	41.5	28.7	25.9	23.6
O	5.8	22.4	28.2	58.1	28.7	18.7	10.5	8.3	13.3	18.1	25.3	29.3	31.8	39.6	34.9	41.1	26.6	38.1	36.5	39.7	30	35.5	36.2	17.3	19.9	14
P	2	16.2	17.1	29	16.7	12.3	6.1	4.8	22.2	22.8	25	32	27.3	30	31	41.9	20.1	37.1	35.8	34.4	25.9	28	34.3	27.3	27.4	24.6
Q	2.3	15.5	12.7	22.3	16.6	5.2	2.4	1.8	8.3	12.2	10.9	13.6	12.2	13.8	16.8	12.5	9.3	13.9	21.9	22.4	17.1	10.1	20.4	6	8.8	4.6
R	3.3	14.2	12.7	13.3	13.9	2.6	1.1	1.1	3.9	6.6	5	5	3.4	5	3.5	1.6	2	4.7	5.3	9	6	3.3	6.3	2.8	5.6	0.6
S	6	18.5	10.9	10.2	8.1	1.4	0.4	0.4	1.1	2	1.6	1.7	0.5	1.1	0.2	0.1	0.2	0.3	0.2	2	3.9	3.1	2.1	1	2	0.4
T	10.8	39.2	20.4	26.2	30.5	16.1	6.7	3.5	9.4	6.2	4.5	4.3	3.9	3.7	1	1.2	2.6	2	0.3	0.4	0.2	0.2	0.8	0.4	0.4	0.2



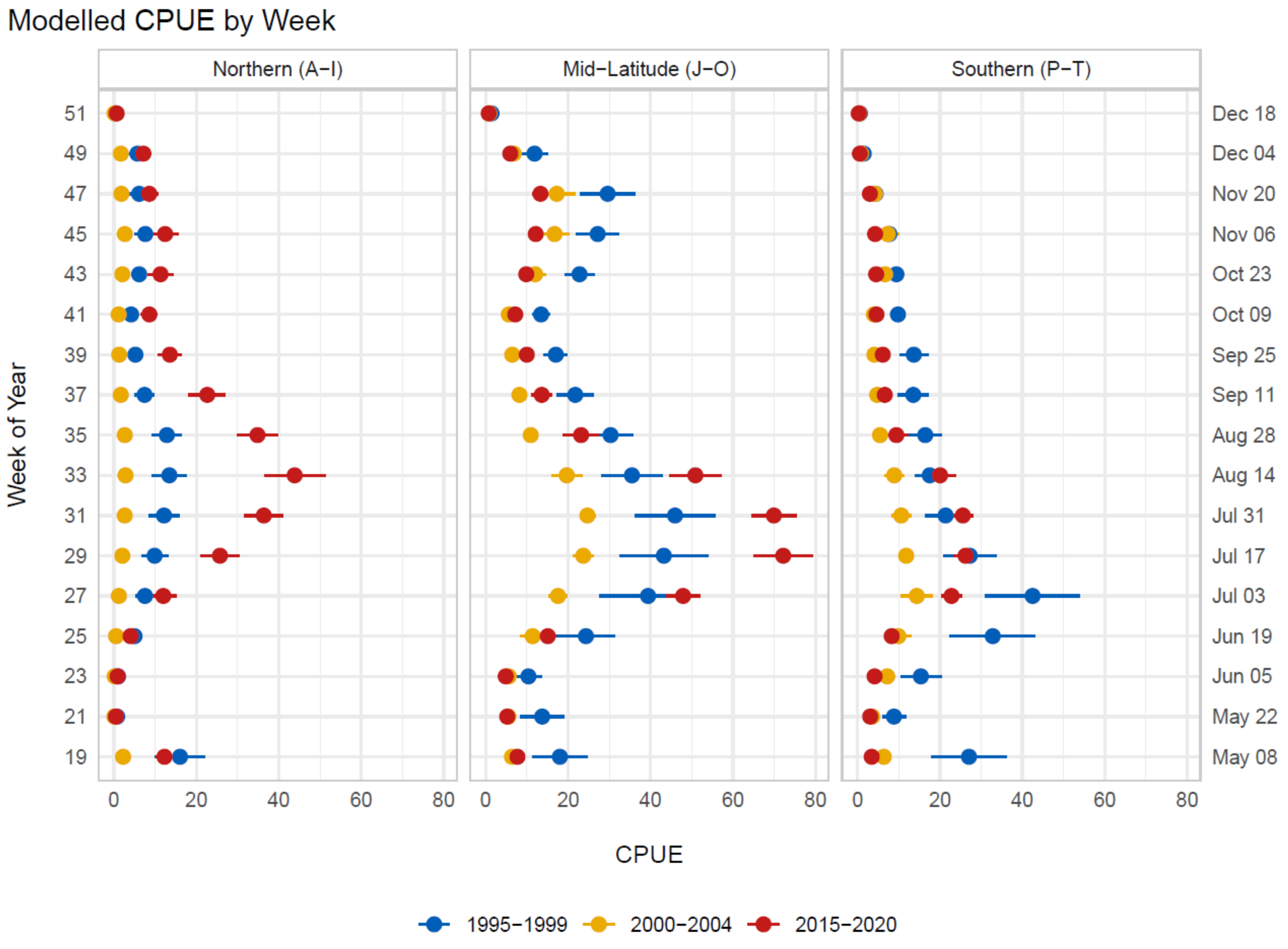
Catch Rates

- $change = \log(\frac{CPUE_{P_2Gw}}{CPUE_{P_1Gw}})$
- Catch rates are up across most (but not all) of the study area
- Catch rates are up more in Northern areas than in Southern areas
- Both modelled catch rates and observed catch rates show the same pattern, but to different degrees (observed values show greater degrees of magnitude in both directions)
  - This is expected given the way the model works



Catch Rates – 2J3KL

- On aggregate, catch rates are up week-by-week compared to 2000-2004.
- Catch rates at the peak of the year are significantly higher than the early periods.
- Catch rates at the beginning and end of the year remain similar

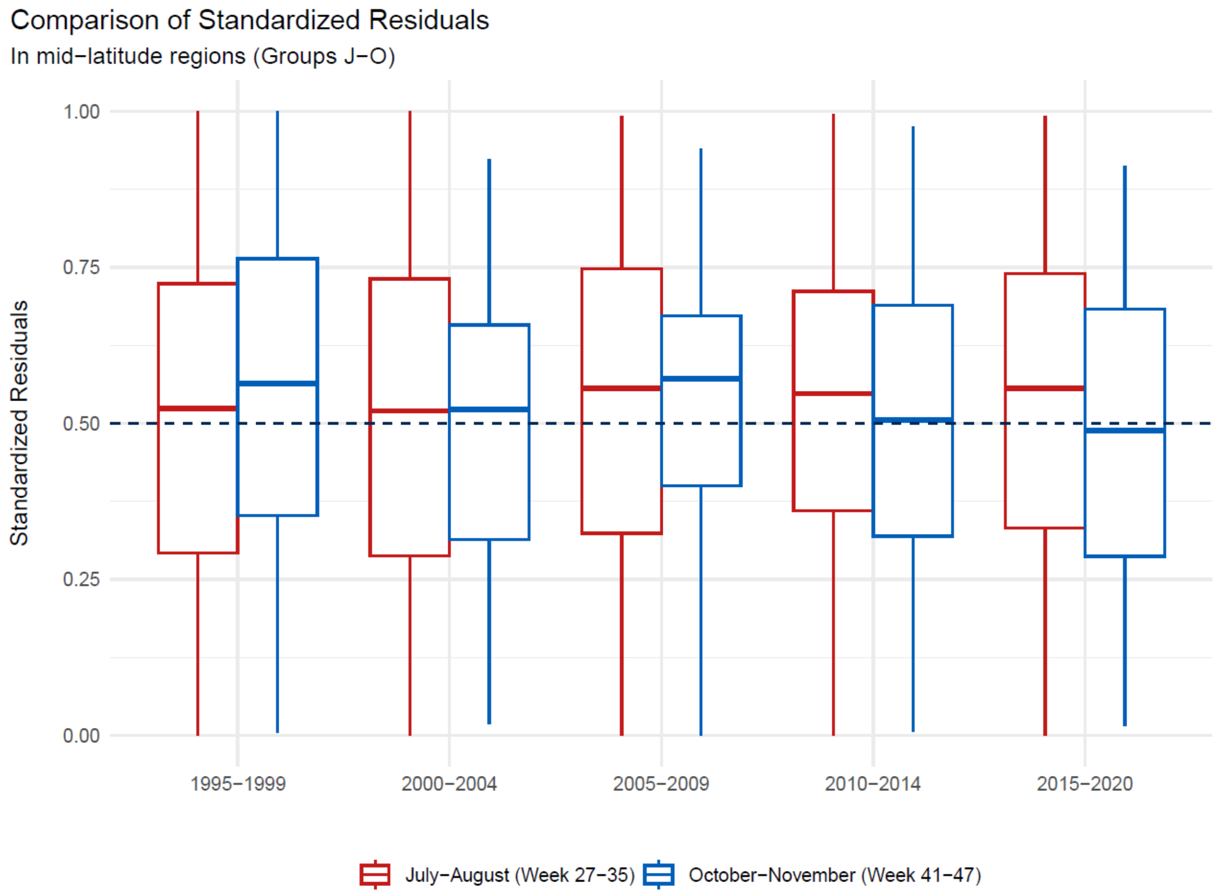


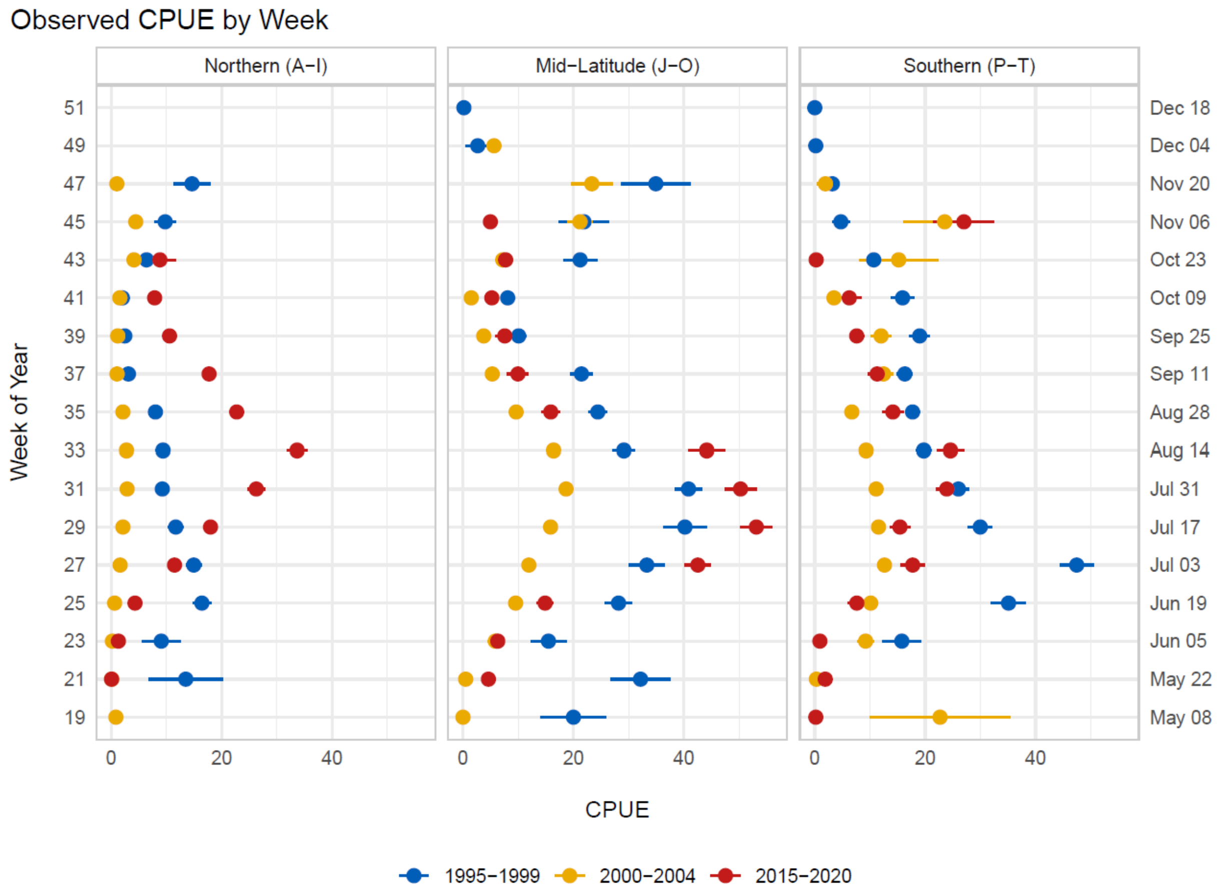
Catch Rates

- Catch rates appear to be up week-by-week in almost all groups, but not in southern regions
- Magnitude of changes is variable across space (more from North to South)

Something Interesting in the Mid-Latitudes

- Initial peak tends to be larger between 2015-2020, but peak is less sustained throughout season
- Alternative interpretation might be that secondary peak is higher in early time-series

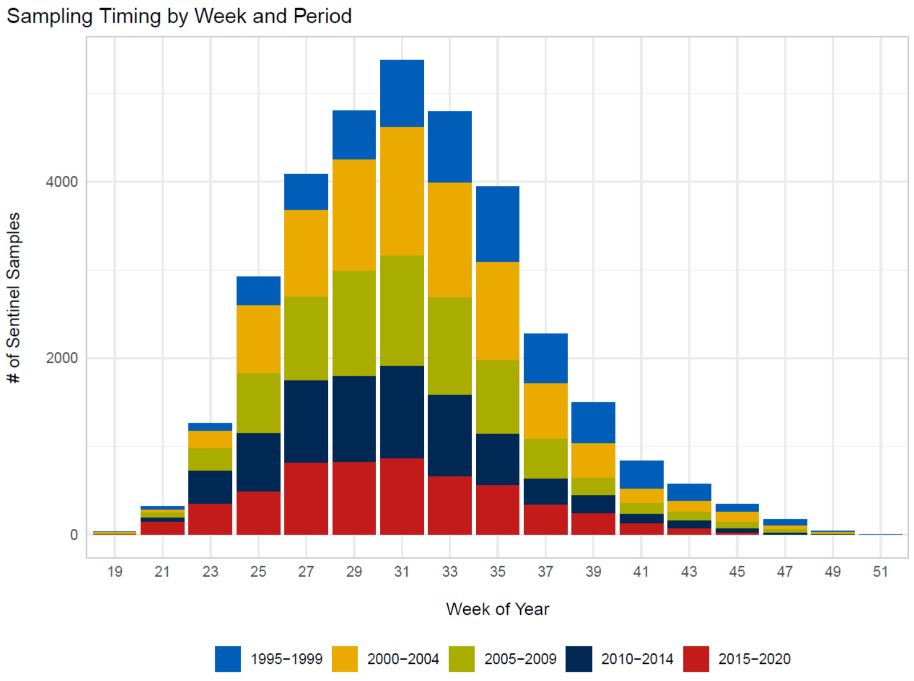


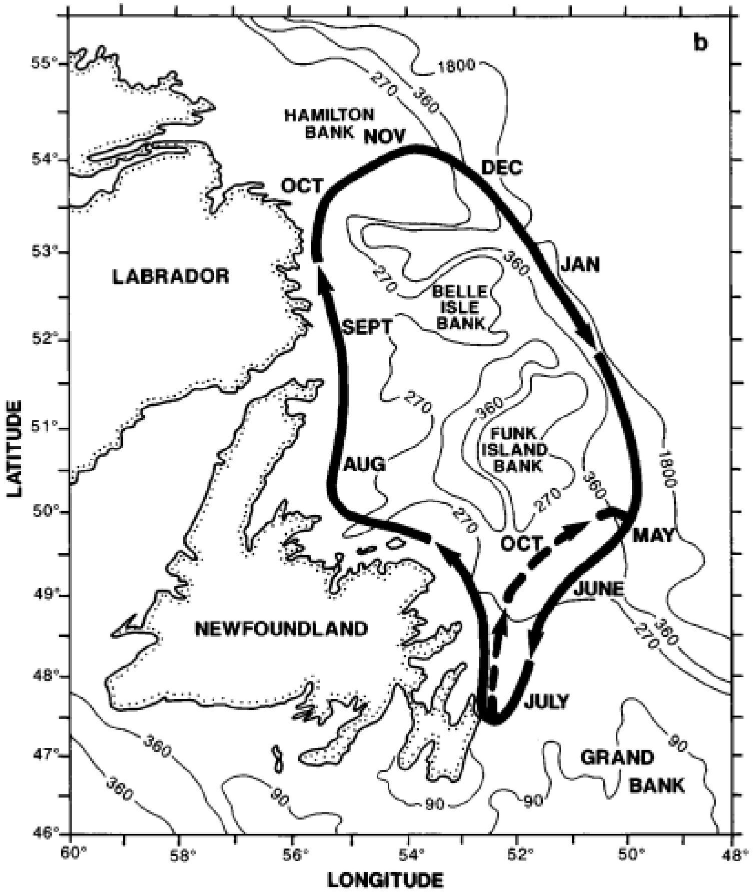


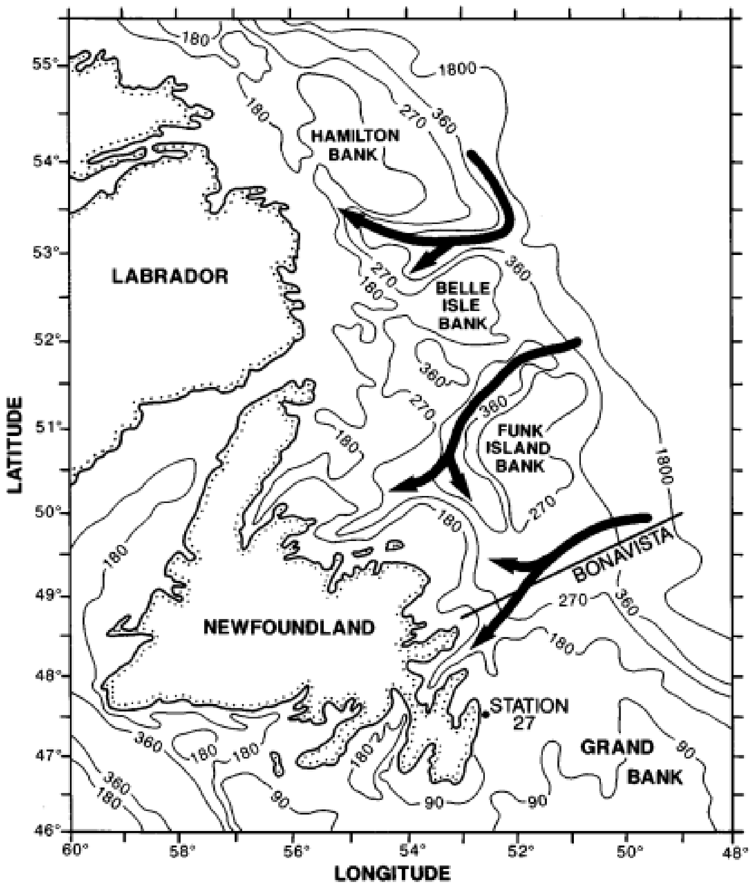
- Residual patterns suggest trend is real, and may be more pronounced than model suggests in mid-latitude regions
  - Underestimating second-wave (Fall) catch rates in 1995-99, 2005-2009
  - Underestimating first wave (Summer) catch rates 2005-2020
- Similar patterns were observed in the mid-latitude region, although could not be validated in either the northern or southern regions.
- The observed values in the survey clearly demonstrate a divergence in trends between the first summer wave of cod and the fall wave in the mid-latitude regions.

Sources of Uncertainty

- Lack of data in consistent data in early/late season, particularly in northern areas.
- Questions about population connectivity & seasonal selectivity







Summary Results

- There are large changes in CPUE across the survey
- These changes appear to have a spatial and temporal dynamic
  - Southern regions have seen a decrease in catch rates while northern areas have seen an increase.
  - Distribution of sampling has a meaningful impact on final index.
- The change in catch rates has not been linear: peak catch rates are significantly higher than early/late season catch rates.
- Peak timing has not changed, but evidence of changing availability across time and space, particularly in mid-latitude regions where peak catch rates are not sustained & second wave is smaller. Could be indicative of changing movement patterns.

Directions for Future Research

- Why have northern regions seen greater recovery while southern regions have not?
- What accounts for the non-linear increase in within-season catch rates?
- Can these patterns help explain divergence between RV Survey and Sentinel Survey indices?


Thank You
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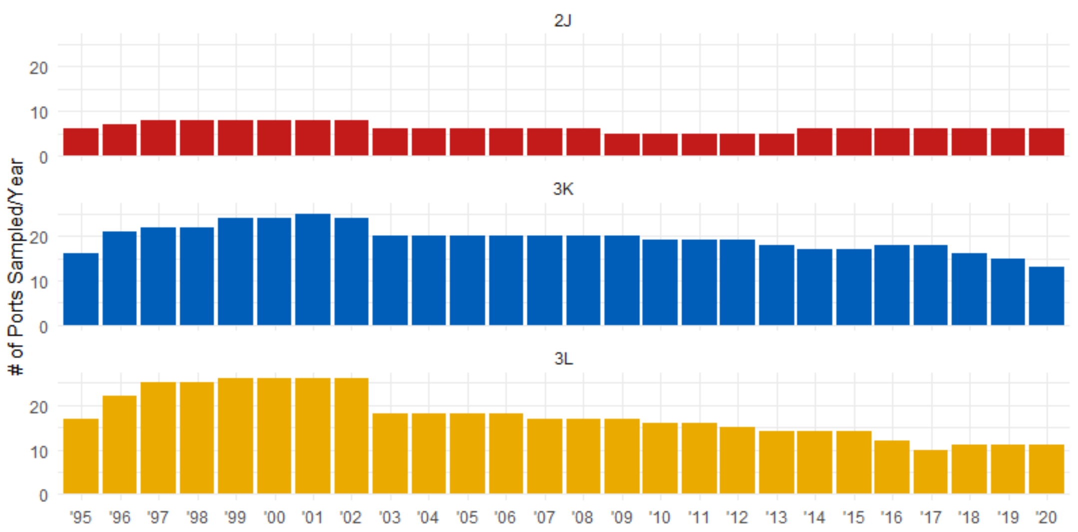
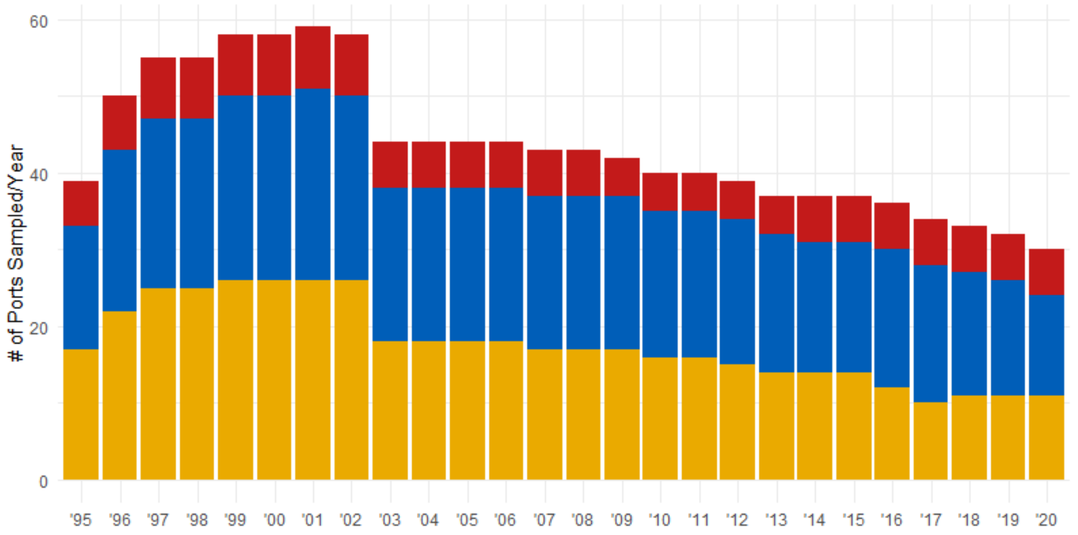
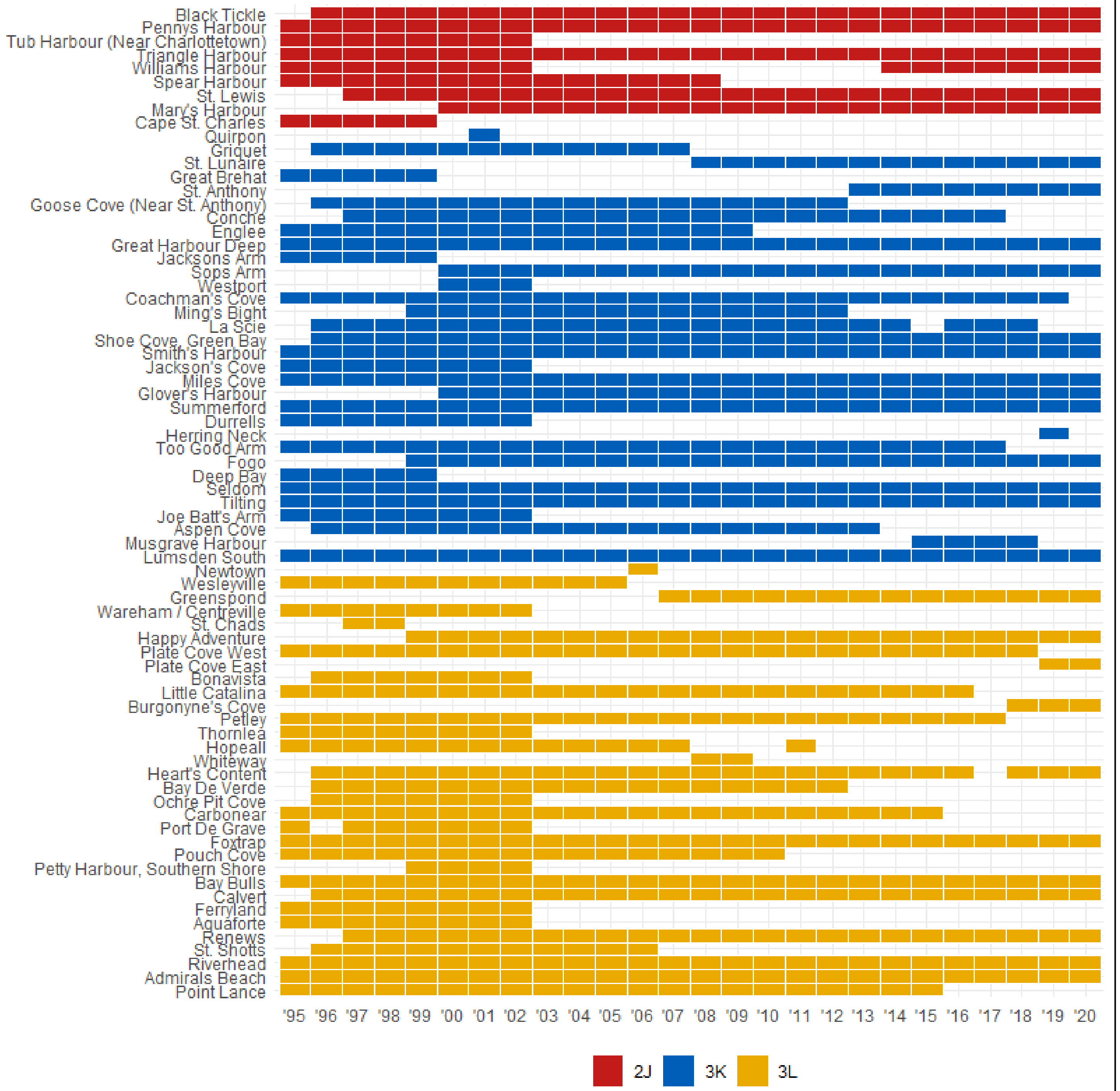
Sentinel Sampling





- 2001 most active year
  - 59 total ports participated
  - 8 in 2J, 25 in 3K, and 26 in 3L
- ~50% decline in sampling from 2001-2020
  - 30 ports participated in 2020
  - 6 in 2J (25%), 13 in 3K (48%), 11 in 3L (58%)



Cod Timing based on Rate of Change