MARSS Package in R – R package for fitting linear **M**ultivariate **A**uto-**R**egressive **S**tate-**S**pace Models

- Assumptions
  - Both process and observation error
  - Density-independence
  - Gaussian errors
- Maximum-likelihood techniques to estimate model parameters
- Can estimate probability of extinction
- Allows for missing observations
- Can incorporate multiple unobserved states (x's) and observations (y's)
- Can specify variance-covariance structure of x's and y's

MARSS Package

Model form:

State model

$$\boldsymbol{x}_t = \boldsymbol{B}\boldsymbol{x}_{t-1} + \boldsymbol{u} + \boldsymbol{w}_t \text{ where } \boldsymbol{w}_t \sim \mathrm{MVN}(0, \boldsymbol{Q})$$

$$x_0 \sim \mathrm{MVN}(\pi, \Lambda)$$

Observation model

$$\boldsymbol{y}_t = \boldsymbol{Z}\boldsymbol{x}_t + \boldsymbol{a} + \boldsymbol{v}_t \text{ where } \boldsymbol{v}_t \sim \mathrm{MVN}(0, \boldsymbol{R})$$

Example: 2 hidden states, 3 sets of observations

State model

$$\boldsymbol{x}_t = \boldsymbol{B} * \boldsymbol{x}_{t-1} + \boldsymbol{u} + \boldsymbol{w}_t$$

$$\begin{bmatrix} x_1 \\ x_2 \end{bmatrix}_t = \begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix}_{t-1} + \begin{bmatrix} u_1 \\ u_2 \end{bmatrix} + \begin{bmatrix} w_1 \\ w_2 \end{bmatrix}_t$$

$$\begin{bmatrix} w_1 \\ w_2 \end{bmatrix}_t \sim MVN\left(0, \begin{bmatrix} q_{11} & q_{12} \\ q_{21} & q_{22} \end{bmatrix}\right)$$

Observation model

$$\boldsymbol{y}_t = \boldsymbol{Z} * \boldsymbol{x}_t + \boldsymbol{a} + \boldsymbol{v}_t$$

$$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \end{bmatrix}_t = \begin{bmatrix} z_{11} & z_{12} \\ z_{21} & z_{22} \\ z_{31} & z_{32} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix}_t + \begin{bmatrix} a_1 \\ a_2 \\ a_3 \end{bmatrix} + \begin{bmatrix} v_1 \\ v_2 \\ v_3 \end{bmatrix}_t$$

$$\begin{bmatrix} v_1 \\ v_2 \\ v_3 \end{bmatrix}_t \sim MVN\left(0, \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{bmatrix}\right)$$

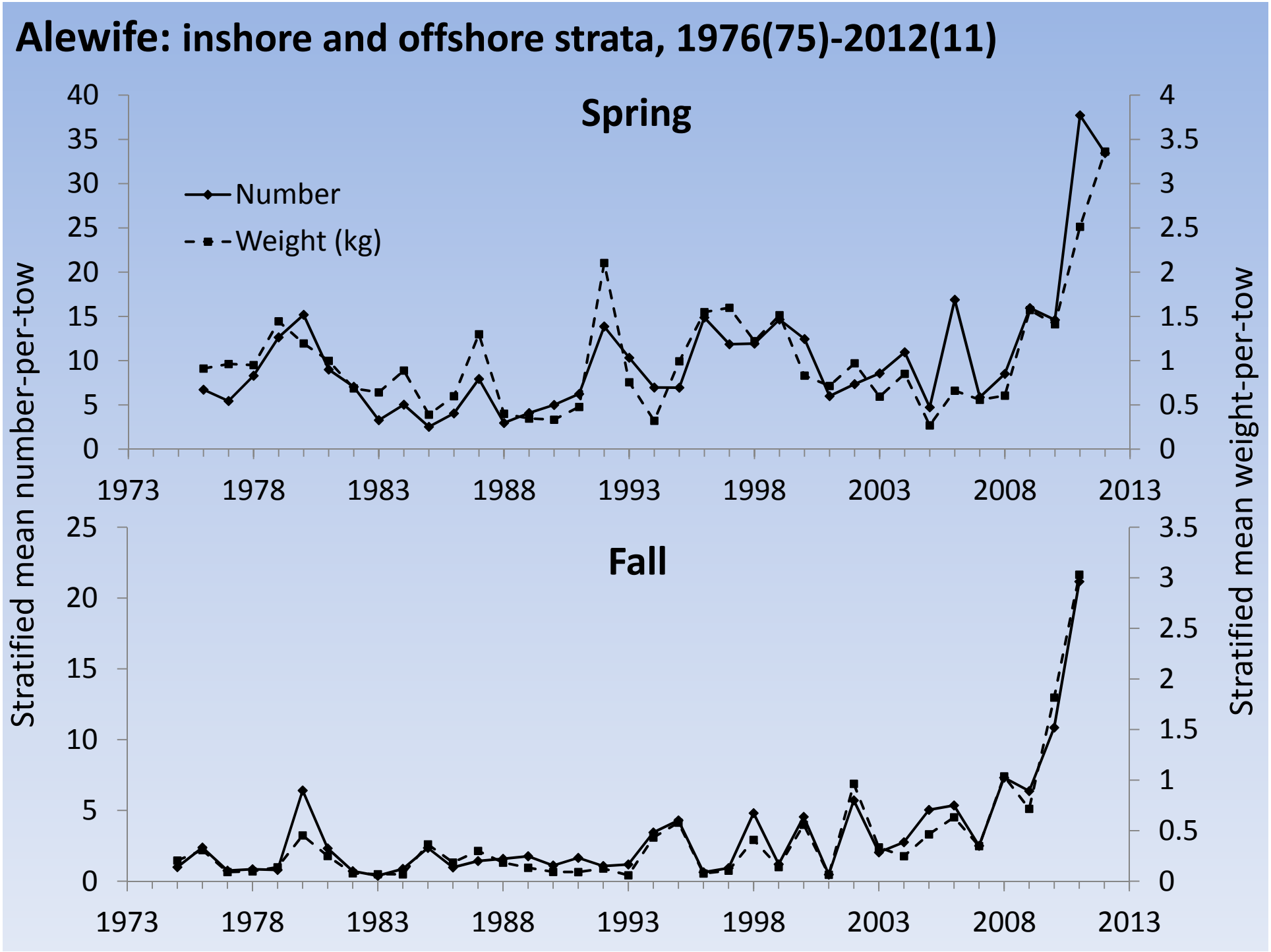
River Herring Data Inputs

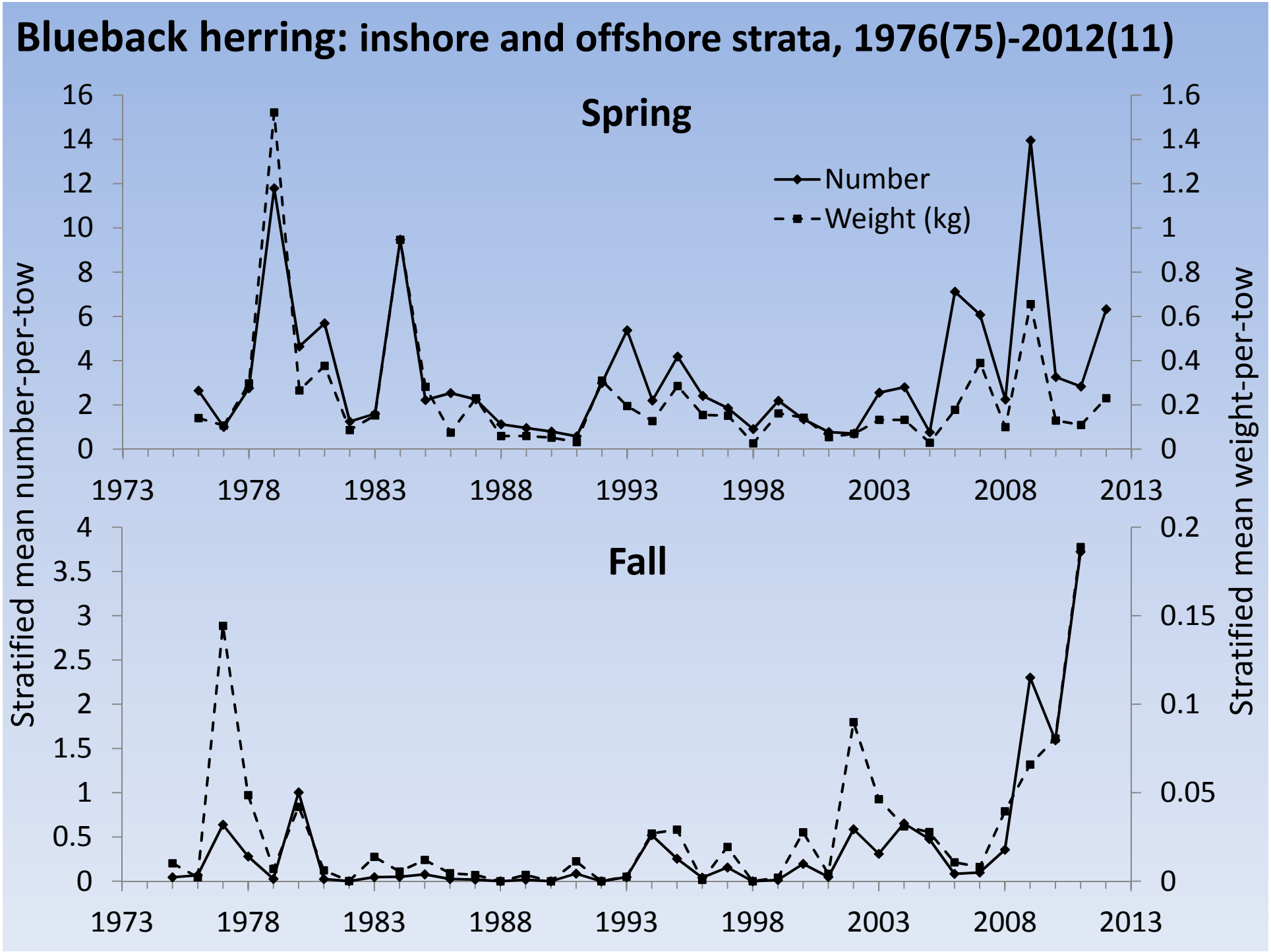
Coastwide: NEFSC spring and fall bottom trawl surveys
River-specific: Run counts where available

Regional: State surveys?

Pros and Cons of NEFSC Bottom Trawl Survey

- Only coastwide index available for river herring
- Consistently sampled, long time series (> 35 years), used in nearly all assessments

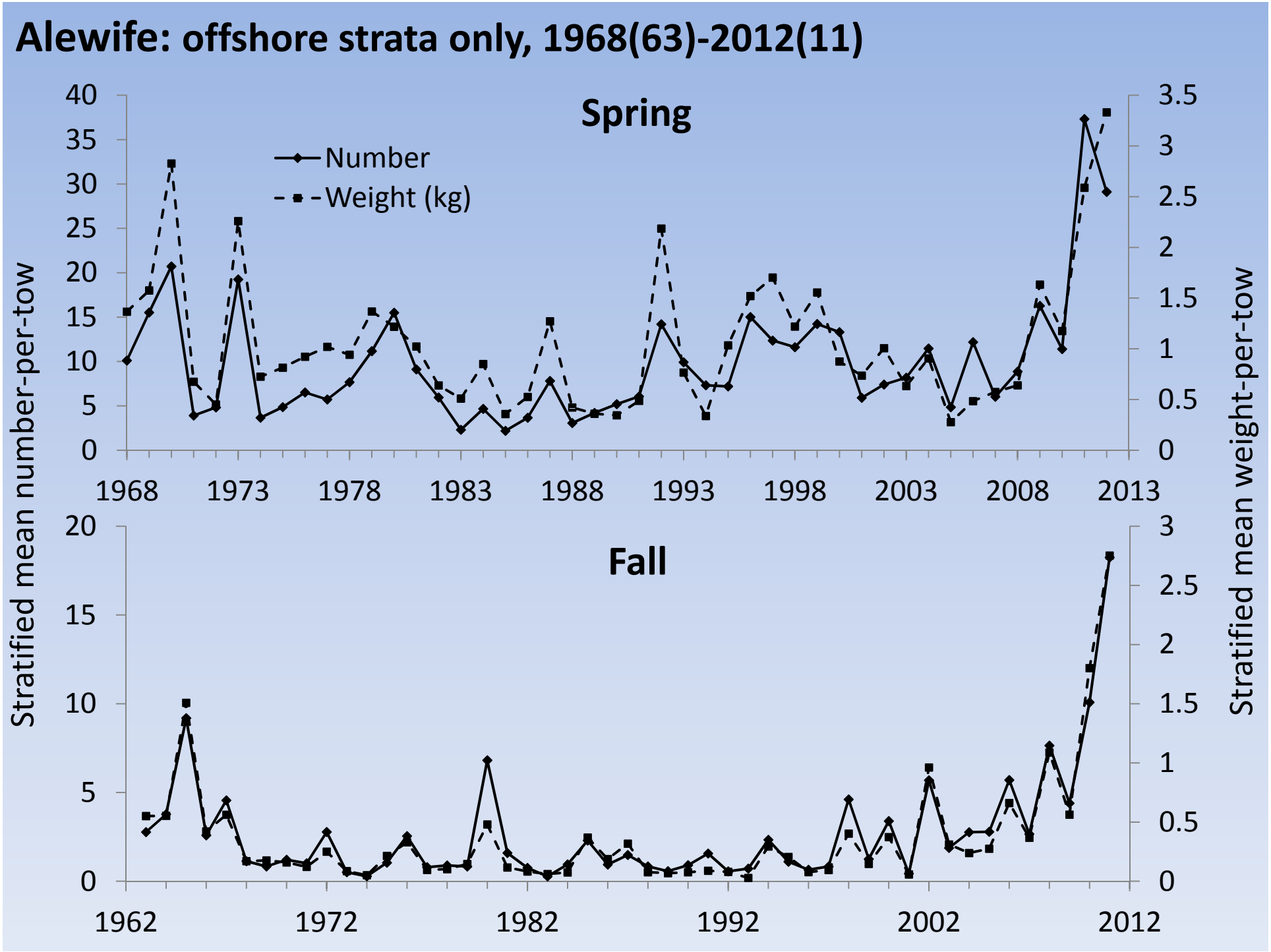

Alewife: inshore and offshore strata, 1976(75)-2012(11)
Spring
Number
Weight (kg)
Fall
Stratified mean number-per-tow
Stratified mean weight-per-tow
40
35
30
25
20
15
10
5
0
4
3.5
3
2.5
2
1.5
1
0.5
0
1973
1978
1983
1988
1993
1998
2003
2008
2013

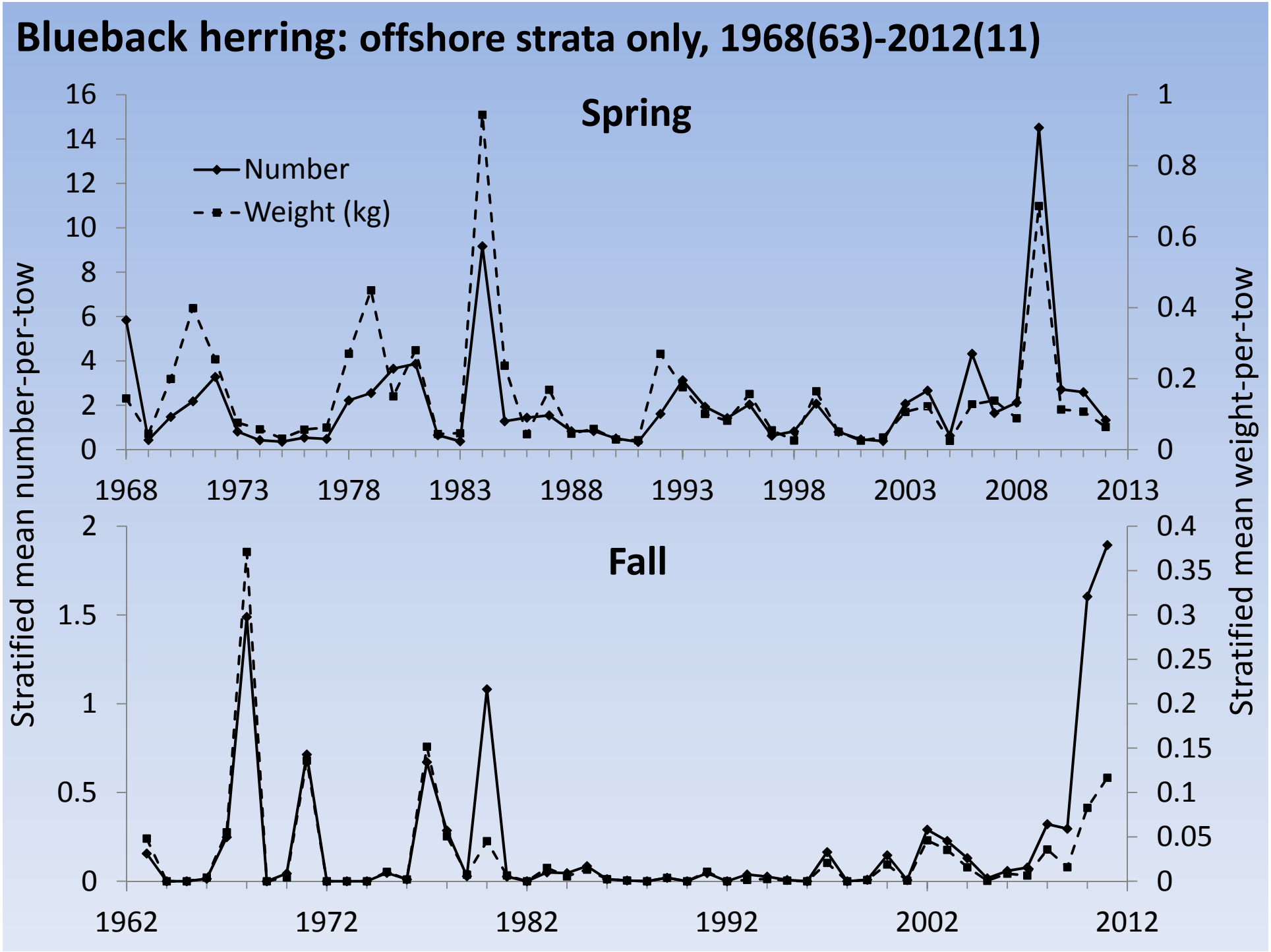

Blueback herring: inshore and offshore strata, 1976(75)-2012(11)
Spring
Number
Weight (kg)
Fall
Stratified mean number-per-tow
Stratified mean weight-per-tow
16
14
12
10
8
6
4
2
0
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
4
3.5
3
2.5
2
1.5
1
0.5
0
0.2
0.15
0.1
0.05
0
1973
1978
1983
1988
1993
1998
2003
2008
2013

Pros and Cons of NEFSC Bottom Trawl Survey

- Only coastwide index available for river herring
- Consistently sampled, long time series (> 35 years), used in nearly all assessments

- Pelagic species, bottom trawl
  - Atlantic herring, Atlantic mackerel, squid....
  - Only daytime tows
- Survey does not sample entire range (anadromous)
  - Striped bass, Atlantic mackerel, etc...
- Did not show much contrast in 1990's
  - During this time, some run counts increased, some decreased --- would we expect a coastwide average to show a trend?
- Trawl survey time series began after time period of high landings and decline in abundance
  - Calculated trawl survey indices using only offshore strata, extending time series back to period of high landings


Alewife: offshore strata only, 1968(63)-2012(11)
Spring
Number
Weight (kg)
Fall
Stratified mean number-per-tow
Stratified mean weight-per-tow
40
35
30
25
20
15
10
5
0
3.5
3
2.5
2
1.5
1
0.5
0
1968
1973
1978
1983
1988
1993
1998
2003
2008
2013
20
15
10
5
0
3
2.5
2
1.5
1
0.5
0
1962
1972
1982
1992
2002
2012


Blueback herring: offshore strata only, 1968(63)-2012(11)
Spring
Number
Weight (kg)
Stratified mean number-per-tow
Stratified mean weight-per-tow
16
14
12
10
8
6
4
2
0
1
0.8
0.6
0.4
0.2
0
1968
1973
1978
1983
1988
1993
1998
2003
2008
2013
Fall
2
1.5
1
0.5
0
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
1962
1972
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