# Statistical approaches to estimating Georges Bank yellowtail flounder biomass

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# Outline

- Background and goal
- Methods and results for analyses of twin-trawl studies
- Methods and results for analysis of survey data for any day/night differences in rockhopper efficiency
- Methods and results of alternative biomass estimates that rely on the two sets of analyses.
- Conclusions and recommendations

# Current TRAC assesment of GB yellowtail flounder

- No population model used currently
- Average biomass estimated from NEFSC spring and fall and DFO surveys and an exploitation rate used to set catch advice.
- Currently the three surveys are assumed to catch 37% of the yellowtail flounder in their path (door spread).

# Goal

- Recent paired tow studies conducted to compare efficiencies of Bigelow gear with rockhopper and chain sweeps.
- If the chain sweep is assumed to catch all yellowtail in the path, then
  - the study can be used to estimate the efficiency of the Bigelow gear and compare to what is currently used
  - If appropriate, estimate a minimum swept area abundance/biomass in terms of chain sweep gear

# Analysis of twin trawl data

- Twin trawl studies carried out in 2015 and 2016 aboard Chris Roebuck's twin trawler compared efficiencies of the rockhopper sweep used by the Bigelow with a chain sweep.
- Fit and compared same models that have been used most recently to estimate size effects in the calibration of the Bigelow and Albatross (Miller 2013 CJFAS)
  - These models ultimately just estimate the ratio of expected catches in two different gears.
  - Different models fitted assume different reasons for how the ratio may vary between pairs of tows or with size of the fish.
  - Analysed catches of yellowtail flounder, and also explored whether this ratio is affected by day/night timing of the tows

# Analysis of twin trawl data

| | Model | $n_p$ | ΔAIC |
|---|---|---|---|
| All data | $BI_0$ | 1 | 221.4 |
| | $BI_1$ | 2 | 35.3 |
| | $BI_2$ | 3 | 211.5 |
| | $BI_3$ | 4 | 22.9 |
| | $BI_4$ | 7 | 8.0 |
| | $BB_0$ | 2 | 165.4 |
| | $BB_1$ | 3 | 24.2 |
| | $BB_2$ | 4 | 159.4 |
| | $BB_3$ | 6 | 162.7 |
| | $BB_4$ | 5 | 13.4 |
| | $BB_5$ | 7 | 17.1 |
| | $BB_6$ | 8 | 1.8 |
| | $BB_7$ | 10 | 5.8 |
| Day/night-specific models | $BI_0$ | 2 | 156.1 |
| | $BI_1$ | 4 | 27.9 |
| | $BI_2$ | 6 | 139.3 |
| | $BI_3$ | 8 | 10.6 |
| | $BI_4$ | 14 | 5.6 |
| | $BB_0$ | 4 | 120.5 |
| | $BB_1$ | 6 | 18.2 |
| | $BB_2$ | 8 | 110.2 |
| | $BB_3$ | 12 | 114.4 |
| | $BB_4$ | 10 | 2.7 |
| | $BB_5$ | 14 | 7.9 |
| | $BB_6$ | 16 | 0.0 |
| | $BB_7$ | 20 | 5.7 |

Table 3, Page 9

# Chain sweep/ Rockhopper ratios

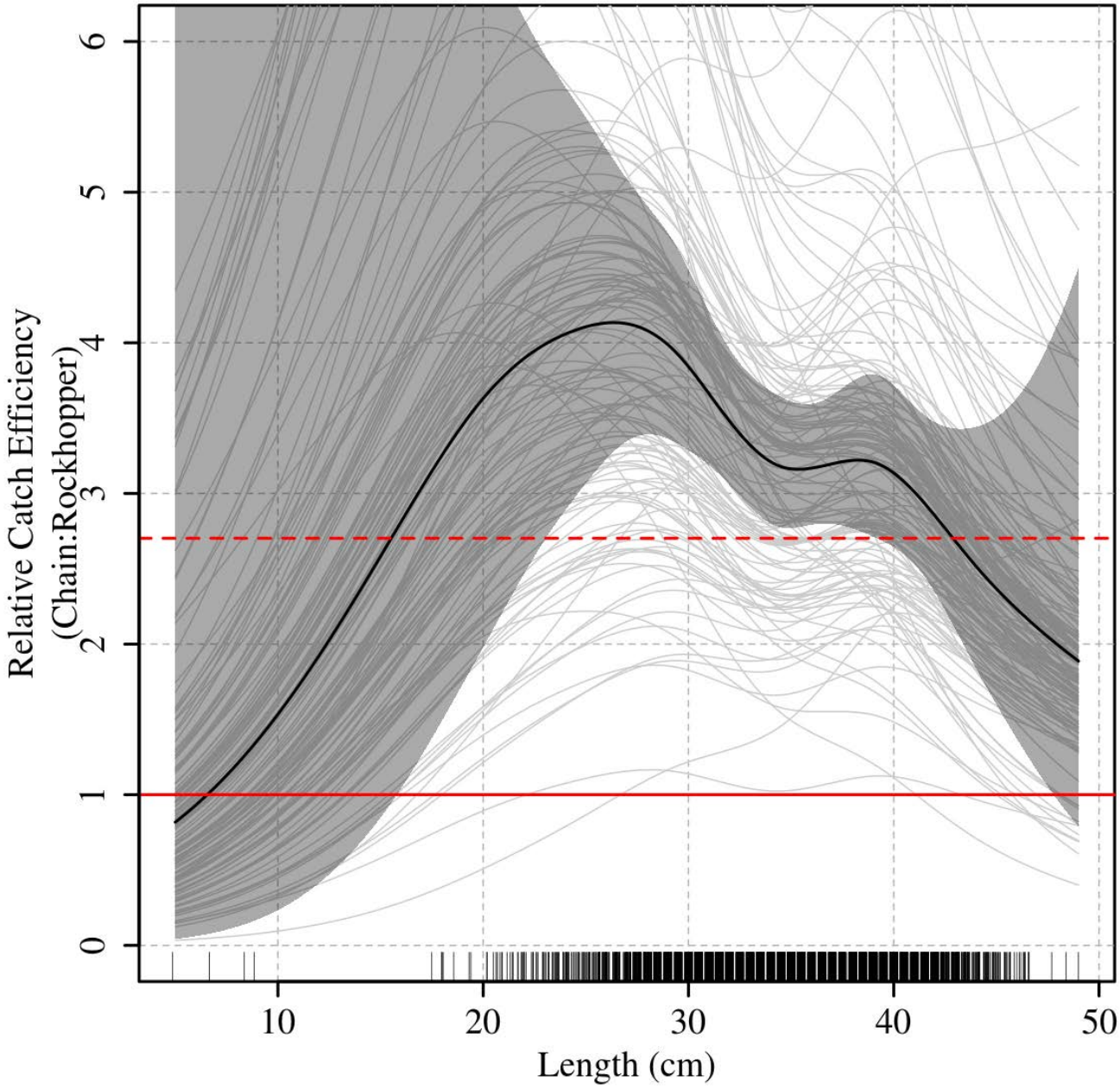



Fig. 5, Page 26

# Chain sweep/ Rockhopper ratios, day and night

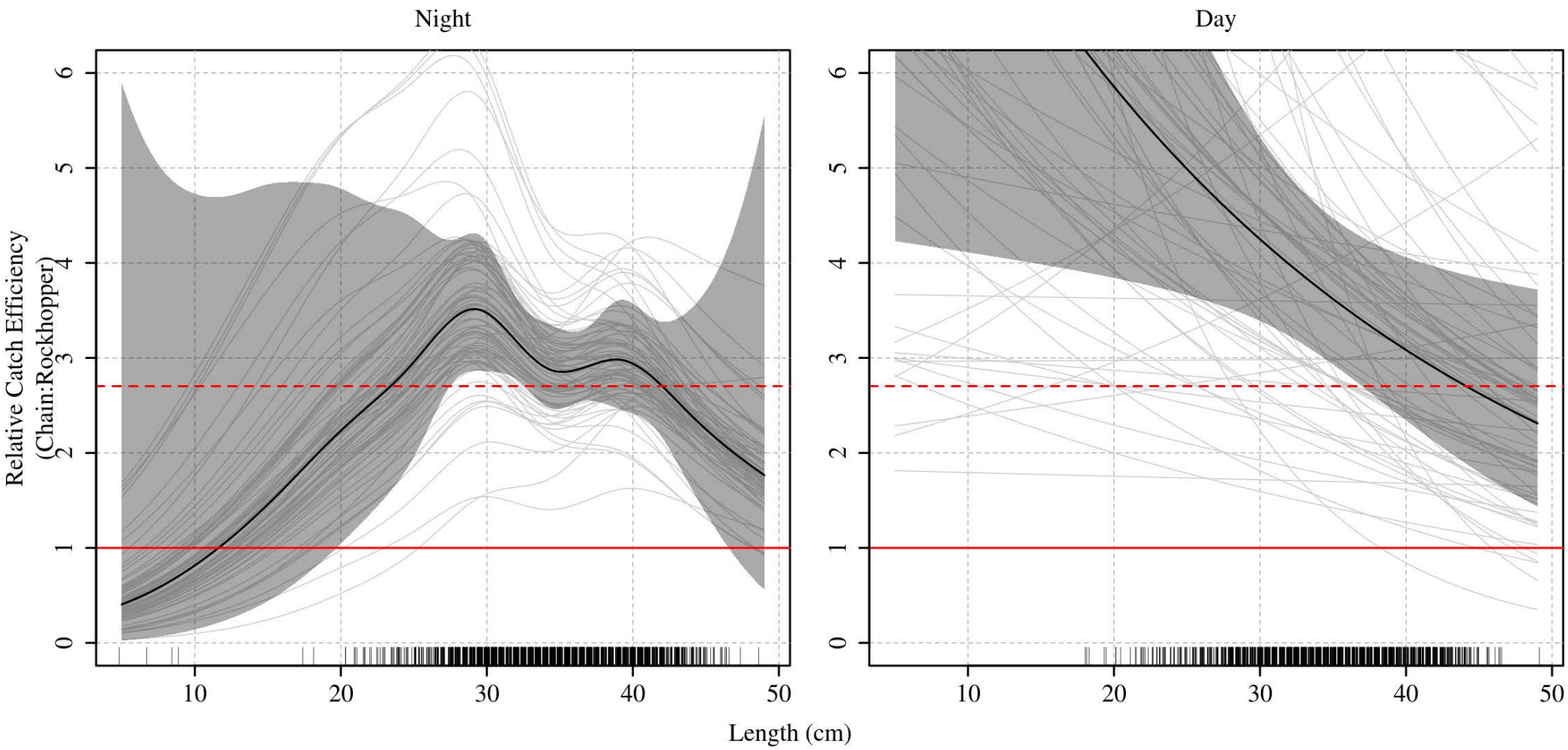



Fig. 7, Page 27

# Analysis of survey data

- What if there are consistent differences in the efficiency of the survey gear depending on whether a tow is made during the day or night?
  - a better estimate of the biomass in the tow path would be based on whatever the higher efficiency is.
    - Example: if fish are less likely to be caught during the day, then convert all of the day catches to night catches.
  - Without a dedicated study, the only alternative is to estimate these effects from existing survey data.
  - Used negative binomial generalized additive mixed models with different assumptions about stratum, size and day/night effects on observable abundance fit separately to the NEFSC spring and fall, and DFO surveys

# Analysis of survey data

| Model | $\log \mu$ | Across-station effects on mean | Station-specific random effects on mean | Random effects Variance |
|---|---|---|---|---|
| $NB_0$ | $\beta_0 + \delta_{0,i}$ | Constant intercepts | Intercept | $\Sigma$ |
| $NB_1$ | $\beta_0 + \delta_{0,\boldsymbol{i}} + \boldsymbol{X}_f^T \beta_L + \boldsymbol{X}_r^T \boldsymbol{b}$ | Smoother for size | Intercept | $\Sigma$ |
| $NB_2$ | $\beta_0 + \delta_{0,\boldsymbol{i}} + \boldsymbol{X}_f^T \left(\beta_L + \delta_{L,\boldsymbol{i}}\right) + \boldsymbol{X}_r^T \left(\boldsymbol{b} + \varepsilon_{\boldsymbol{i}}\right)$ | Smoother for size | Smoother for size | $\Sigma$ |
| $NB_3$ | $\beta_{0,\boldsymbol{h}} + \delta_{0,\boldsymbol{i}}$ | Stratum-specific intercepts | Intercept | $\Sigma$ |
| $NB_4$ | $\beta_{0,\boldsymbol{h}} + \delta_{0,\boldsymbol{i}} + \boldsymbol{X}_f^T \beta_L + \boldsymbol{X}_r^T \boldsymbol{b}$ | Stratum-specific intercepts and smoother for size | Intercept | $\Sigma$ |
| $NB_5$ | $\beta_{0,\boldsymbol{h}} + \delta_{0,\boldsymbol{i}} + \boldsymbol{X}_f^T \left(\beta_L + \delta_{L,\boldsymbol{i}}\right) + \boldsymbol{X}_r^T \left(\boldsymbol{b} + \varepsilon_{\boldsymbol{i}}\right)$ | Stratum-specific intercepts and smoother for size | Smoother for size | $\Sigma$ |
| $NB_6$ | $\beta_0 + \beta_{\boldsymbol{d}} I_i(D) + \delta_{0,\boldsymbol{i}}$ | Day/night-specific intercepts | Intercept | $\Sigma$ |
| $NB_7$ | $\beta_{0,\boldsymbol{h}} + \beta_{\boldsymbol{d}} I_i(D) + \delta_{0,\boldsymbol{i}}$ | Stratum-specific intercepts and day/night effects | Intercept | $\Sigma$ |
| $NB_8$ | $\beta_{0,\boldsymbol{h}} + \beta_{\boldsymbol{d}} I_i(D) + \delta_{0,\boldsymbol{i}} + \boldsymbol{X}_f^T \beta_L + \boldsymbol{X}_r^T \boldsymbol{b}$ | Stratum-specific intercepts, day/night effects and smoother for size | Intercept | $\Sigma$ |
| $NB_9$ | $\beta_{0,\boldsymbol{h}} + \beta_{\boldsymbol{d}} I_i(D) + \delta_{0,\boldsymbol{i}} + \boldsymbol{X}_f^T \left(\beta_L + \delta_{L,\boldsymbol{i}}\right) + \boldsymbol{X}_r^T \left(\boldsymbol{b} + \varepsilon_{\boldsymbol{i}}\right)$ | Stratum-specific intercepts, day/night effects and smoother for size | Smoother for size | $\Sigma$ |
| $NB_{10}$ | $\beta_{0,\boldsymbol{h},\boldsymbol{d}} + \delta_{0,\boldsymbol{i}} + \boldsymbol{X}_f^T \left(\beta_{L,\boldsymbol{d}} + \delta_{L,\boldsymbol{i}}\right) + \boldsymbol{X}_r^T \left(\boldsymbol{b}_{\boldsymbol{d}} + \varepsilon_{\boldsymbol{i}}\right)$ | Stratum- and day/night-specific intercepts and day/night-specific smoother for size | Smoother for size | $\Sigma_{\boldsymbol{d}}$ |

Table 1, Page 7

# Analysis of survey data

## Fitted to all years data from a given survey

| Model | $\log \mu$ | Across-station effects on mean | Station-specific random effects on mean | Random effects Variance |
|---|---|---|---|---|
| $NB_A$ | $\beta_{0,d} + \delta_{0,i}$ | Day/night-specific intercepts | Intercept | $\Sigma$ |
| $NB_B$ | $\beta_{0,y,h} + \beta_d I_i(D) + \delta_{0,i}$ | Year- and stratum-specific intercepts and day/night effect | Intercept | $\Sigma$ |
| $NB_C$ | $\beta_{0,y,h} + \beta_d I_i(D) + \delta_{0,i} + X_f^T \beta_L + X_r^T b$ | Year- and stratum-specific intercepts, day/night effect, and smoother for size | Intercept | $\Sigma$ |
| $NB_D$ | $\beta_{0,y,h} + \beta_{d,y} I_i(D) + \delta_{0,i} + X_f^T \beta_L + X_r^T b$ | Year- and stratum-specific intercepts, year-specific day/night effects, and smoother for size | Intercept | $\Sigma$ |

Table 2, Page 8

# Analysis of survey data

## NEFSC Fall survey

| Model | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | Total |
|---|---|---|---|---|---|---|---|---|---|
| $NB_0$ | 995.2 | 695.0 | 596.7 | 448.6 | 349.6 | 400.9 | 165.6 | 190.0 | 3835.9 |
| $NB_1$ | 123.4 | 78.6 | 67.4 | 47.9 | 47.3 | 75.5 | 35.4 | 46.9 | 516.7 |
| $NB_2$ | 22.0 | 35.0 | 34.8 | 18.6 | 25.6 | 26.1 | 22.7 | 12.6 | 191.9 |
| $NB_3$ | 972.5 | 661.0 | 572.0 | 428.0 | 337.8 | 372.8 | 141.9 | 177.3 | 3657.8 |
| $NB_4$ | 100.9 | 44.9 | 42.7 | 27.6 | 35.0 | 47.6 | 10.8 | 33.7 | 337.3 |
| $NB_5$ | 0.0 | 4.9 | 7.3 | 3.3 | 12.6 | 0.0 | 0.0 | 0.0 | 22.5 |
| $NB_6$ | 988.0 | 696.4 | 594.3 | 450.3 | 347.8 | 402.7 | 165.7 | 192.0 | 3831.6 |
| $NB_7$ | 973.4 | 655.3 | 569.0 | 425.2 | 323.9 | 374.3 | 143.9 | 178.2 | 3637.5 |
| $NB_8$ | 101.7 | 39.6 | 39.6 | 24.8 | 21.3 | 49.1 | 12.7 | 34.6 | 317.7 |
| $NB_9$ | 0.9 | 0.0 | 0.0 | 0.0 | 0.0 | 1.4 | 2.0 | 1.3 | 0.0 |
| $NB_{10}$ | 20.7 | 26.2 | 24.2 | 19.9 | 26.5 | 16.3 | 27.2 | 23.7 | 178.8 |
| $NB_A$ | | | | | | | | | 3853.7 |
| $NB_B$ | | | | | | | | | 3632.1 |
| $NB_C$ | | | | | | | | | 343.9 |
| $NB_D$ | | | | | | | | | 343.6 |

Table 4, Page 10

# Analysis of survey data

## NEFSC Spring survey

| Model | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | Total |
|---|---|---|---|---|---|---|---|---|---|
| $NB_0$ | 872.8 | 1075.6 | 764.6 | 748.0 | 452.3 | 357.0 | 827.0 | 130.2 | 4797.8 |
| $NB_1$ | 199.5 | 70.7 | 47.1 | 111.1 | 70.4 | 118.5 | 557.9 | 5.2 | 750.5 |
| $NB_2$ | 36.4 | 29.7 | 36.5 | 35.3 | 41.3 | 0.0 | 562.7 | 8.4 | 320.4 |
| $NB_3$ | 835.6 | 1044.4 | 729.1 | 721.7 | 409.0 | 341.9 | 814.0 | 125.5 | 4591.5 |
| $NB_4$ | 163.0 | 39.8 | 11.9 | 84.7 | 27.2 | 103.6 | 544.8 | 0.0 | 545.1 |
| $NB_5$ | 0.4 | 2.2 | 0.0 | 8.0 | 0.0 | 93.5 | 549.5 | 2.0 | 225.8 |
| $NB_6$ | 873.9 | 1077.5 | 763.6 | 748.9 | 452.3 | 358.6 | 828.8 | 129.9 | 4803.7 |
| $NB_7$ | 836.0 | 1043.8 | 730.7 | 716.6 | 410.7 | 343.7 | 815.0 | 125.8 | 4592.6 |
| $NB_8$ | 163.3 | 39.2 | 13.6 | 79.2 | 28.8 | 105.4 | 0.0 | 0.3 | 0.0 |
| $NB_9$ | 0.0 | 0.0 | 2.0 | 0.0 | 1.1 | 94.9 | 550.3 | 3.5 | 222.0 |
| $NB_{10}$ | 18.6 | 27.5 | 28.4 | 22.9 | 34.0 | 114.6 | 566.1 | 28.5 | 410.7 |
| $NB_A$ | | | | | | | | | 4830.4 |
| $NB_B$ | | | | | | | | | 4594.5 |
| $NB_C$ | | | | | | | | | 551.1 |
| $NB_D$ | | | | | | | | | 552.6 |

Table 5, Page 11

# Analysis of survey data

## DFO survey

| Model | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | Total |
|---|---|---|---|---|---|---|---|---|---|
| $NB_0$ | | 1142.6 | 993.9 | 1626.5 | 425.3 | 244.6 | 257.2 | 347.1 | 5027.0 |
| $NB_1$ | | 35.0 | 28.2 | 47.8 | 29.2 | 8.0 | 6.8 | 22.7 | 167.4 |
| $NB_2$ | | 22.1 | 18.6 | 20.7 | 2.6 | 8.4 | 12.7 | 4.9 | 79.8 |
| $NB_3$ | | 1115.4 | 973.7 | 1604.2 | 420.3 | 241.8 | 251.5 | 342.8 | 4939.6 |
| $NB_4$ | | 8.1 | 7.3 | 25.7 | 23.8 | 4.2 | 1.0 | 15.0 | 74.8 |
| $NB_5$ | | 0.0 | 1.7 | 0.0 | 0.0 | 5.3 | 7.0 | 0.1 | 3.9 |
| $NB_6$ | | 1144.5 | 995.4 | 1625.5 | 427.0 | 243.3 | 256.9 | 348.1 | 5030.5 |
| $NB_7$ | | 1117.4 | 973.0 | 1605.5 | 421.1 | 238.9 | 250.4 | 342.4 | 4938.7 |
| $NB_8$ | | 10.1 | 6.6 | 27.1 | 24.5 | 1.2 | 0.0 | 14.6 | 73.9 |
| $NB_9$ | | 2.0 | 0.0 | 1.7 | 0.6 | 0.0 | 6.0 | 0.0 | 0.0 |
| $NB_{10}$ | | 23.3 | 19.1 | 29.6 | 13.2 | 27.1 | 16.7 | 25.6 | 144.4 |
| $NB_A$ | | | | | | | | | 5084.6 |
| $NB_B$ | | | | | | | | | 4956.5 |
| $NB_C$ | | | | | | | | | 135.5 |
| $NB_D$ | | | | | | | | | 144.2 |

Table 6, Page 12

# Analysis of survey data

## Night/day ratios

| Year | NEFSC fall ($NB_9$) | NEFSC spring ($NB_8$) | DFO ($NB_9$) |
|---|---|---|---|
| 2009 | 2.30 (0.40, 22.37) | | |
| 2010 | 3.80 (1.23, 11.79) | 2.33 (0.92, 6.04) | 1.02 (0.17, 6.91) |
| 2011 | 8.35 (2.93, 28.43) | 0.74 (0.28, 2.59) | 3.11 (0.99, 11.22) |
| 2012 | 9.57 (1.56, 55.89) | 5.02 (1.75, 12.30) | 1.37 (0.36, 5.50) |
| 2013 | 13.07 (2.39, 47.27) | 1.25 (0.61, 2.39) | 1.93 (0.57, 4.86) |
| 2014 | 0.51 (0.02, 8.04) | 1.30 (0.39, 4.12) | 5.64 (1.37, 23.12) |
| 2015 | 0.92 (0.22, 3.63) | 1.64 (0.72, 4.65) | 2.37 (0.89, 6.32) |
| 2016 | 2.01 (0.30, 10.47) | 2.49 (0.95, 13.35) | 2.91 (0.69, 18.12) |
| 2017 | | 1.54 (0.49, 4.84) | 4.66 (1.71, 34.32) |

Table 7, Page 13

# Abundance/biomass estimation: Method 1 of 3

- All methods account for differences in chain sweep/rockhopper ratio with size
- Numbers (at length) in each tow in terms of chain sweep instead of rockhopper (no day/night effects)
  - Bigelow Catch (chainsweep) = Bigelow Catch (rockhopper) * ratio (chain sweep/rockhopper)

$$\tilde{N}_{1,h,i}(L) = N_{h,i}(L)\hat{\rho}(L)$$

# Abundance/biomass estimation: Method 2 of 3

- Numbers (at length) in each tow in terms of chain sweep accounting for differences in ratio by day and night
  - Bigelow catch (chainsweep, day or night) =

Bigelow Catch (day or night,rockhopper) * ratio (chain sweep/rockhopper, day or night)

$$\tilde{N}_{2,h,i}(L) = N_{h,i}(L)\hat{\rho}(L,D)^{I_{h,i}(D)}\hat{\rho}(L,N)^{1-I_{h,i}(D)}$$

# Abundance/biomass estimation: Method 3 of 3

- Numbers (at length) in each tow in terms of chain sweep at night
  - Bigelow catch (night, rockhopper) = Bigelow catch (day, rockhopper) * ratio (night/day, rockhopper)
  - Bigelow catch (night, chain sweep) = Bigelow catch (night, rockhopper) * ratio (chain sweep/rockhopper, night)

$$\tilde{N}_{3,h,i}(L) = N_{h,i}(L)\hat{\kappa}^{I_{h,i}(D)}\hat{\rho}(L,N)$$

# Abundance/biomass estimation

- Biomass is estimated using Abundance (at length) and weight at length
  - Design-based estimates of abundance at length from one of the tow-specific numbers at length methods

$$\hat{N}_g(L) = \sum_{h=1}^{H} \frac{W_h}{n_h} \sum_{i=1}^{n_h} \tilde{N}_{g,h,i}(L)$$

Eq 5, Page 3

- Biomass estimated by converting abundance at length to biomass at length

$$\hat{B}_g = \sum_{l=1}^{n_L} \hat{N}_g(L = l)\hat{w}(L = l)$$

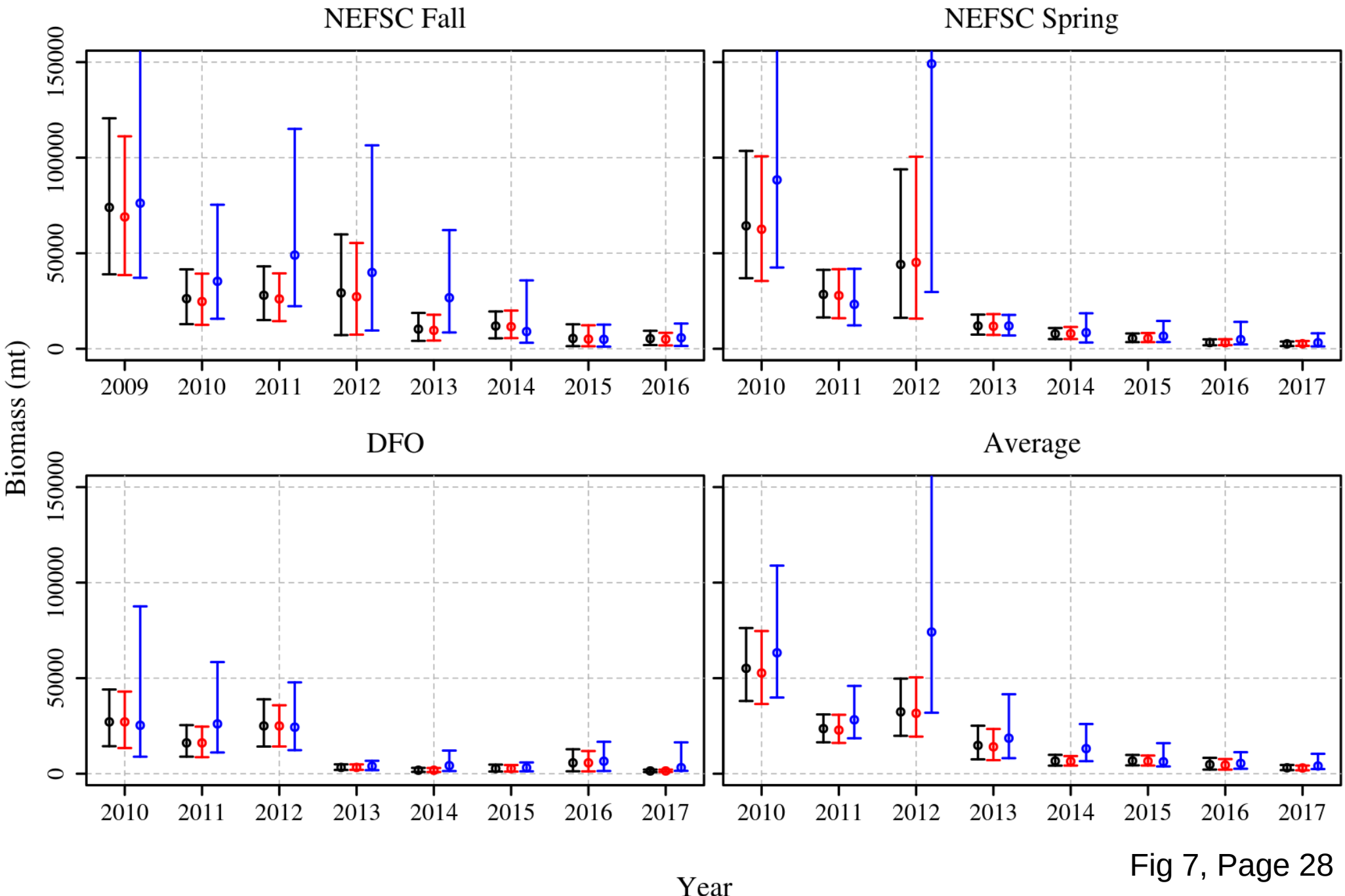
Eq 6, Page 3

- Weight at length is estimated for each annual survey from length weight observations

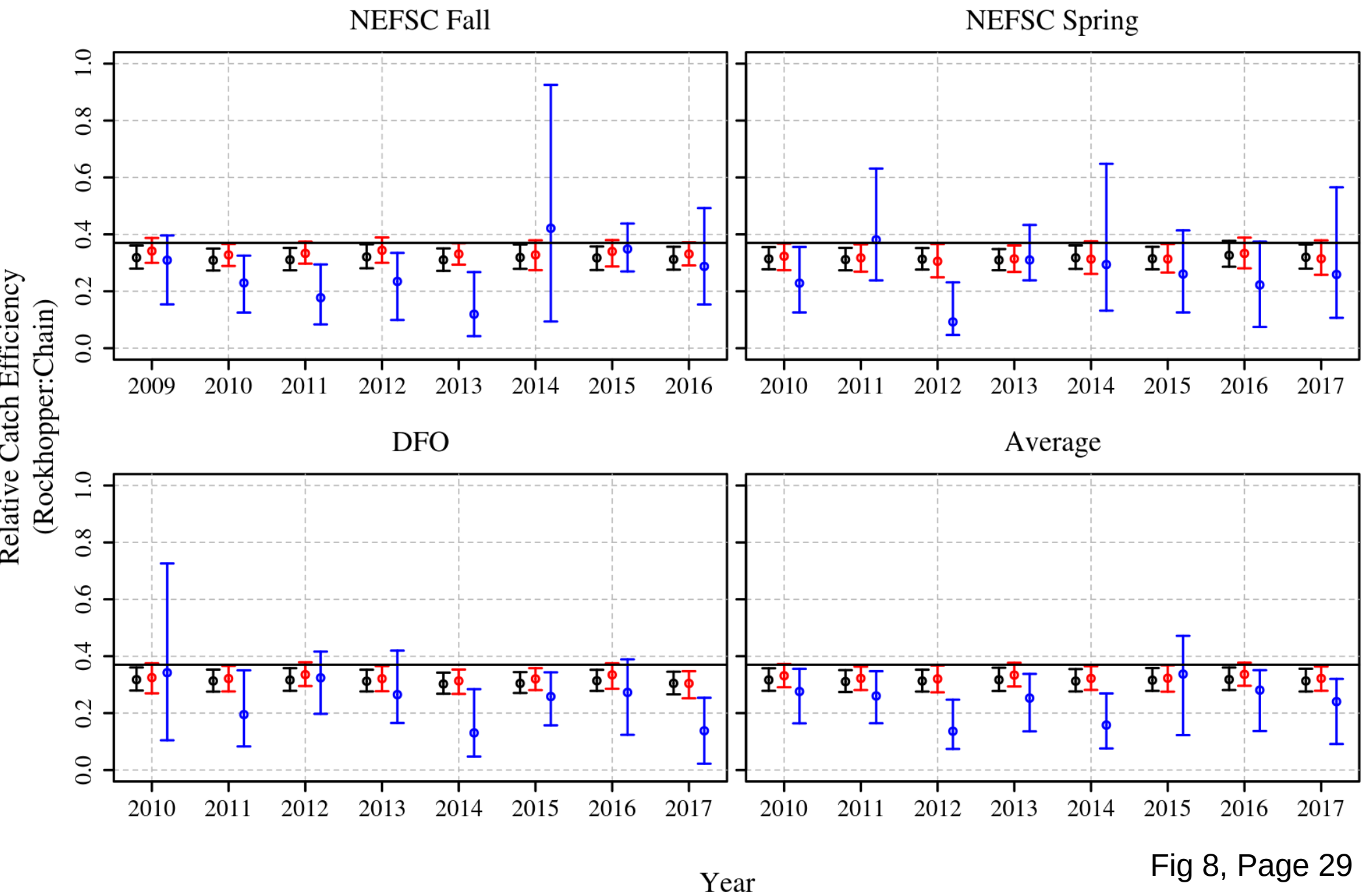
# 3 different types of abundance/biomass estimation

- Uncertainty in biomass estimates and confidence intervals are based on bootstrap procedures (1000 samples)
  - For twin-trawl observations the paired catches (at all sizes) are sampled with replacement
  - For analyses of survey data and abundance estimation bootstraps are resampled with replacement within each stratum.
    - The analysis of survey data and estimation of abundance are made from the same bootstrap to account for the correlation of these procedures performed with the same data.

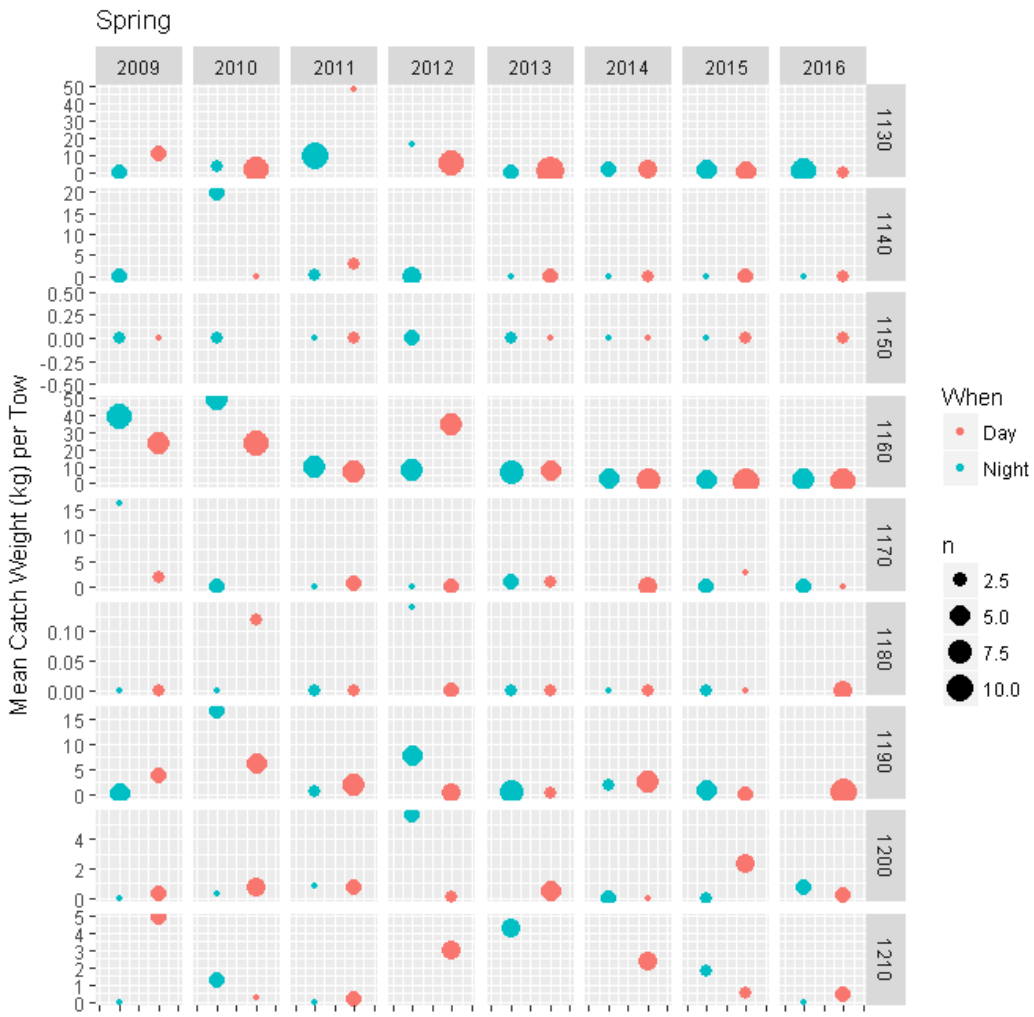
# GB YTF biomass

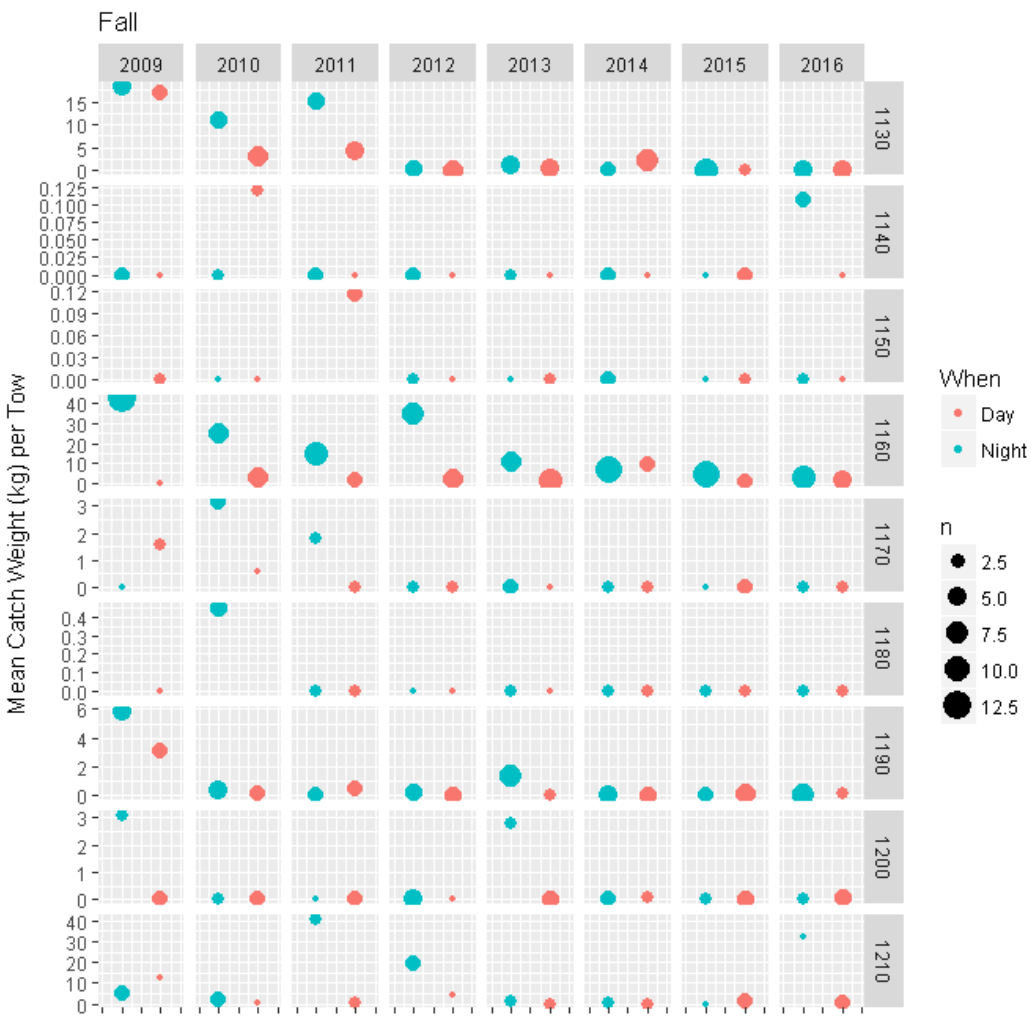


# GB YTF biomass efficiency

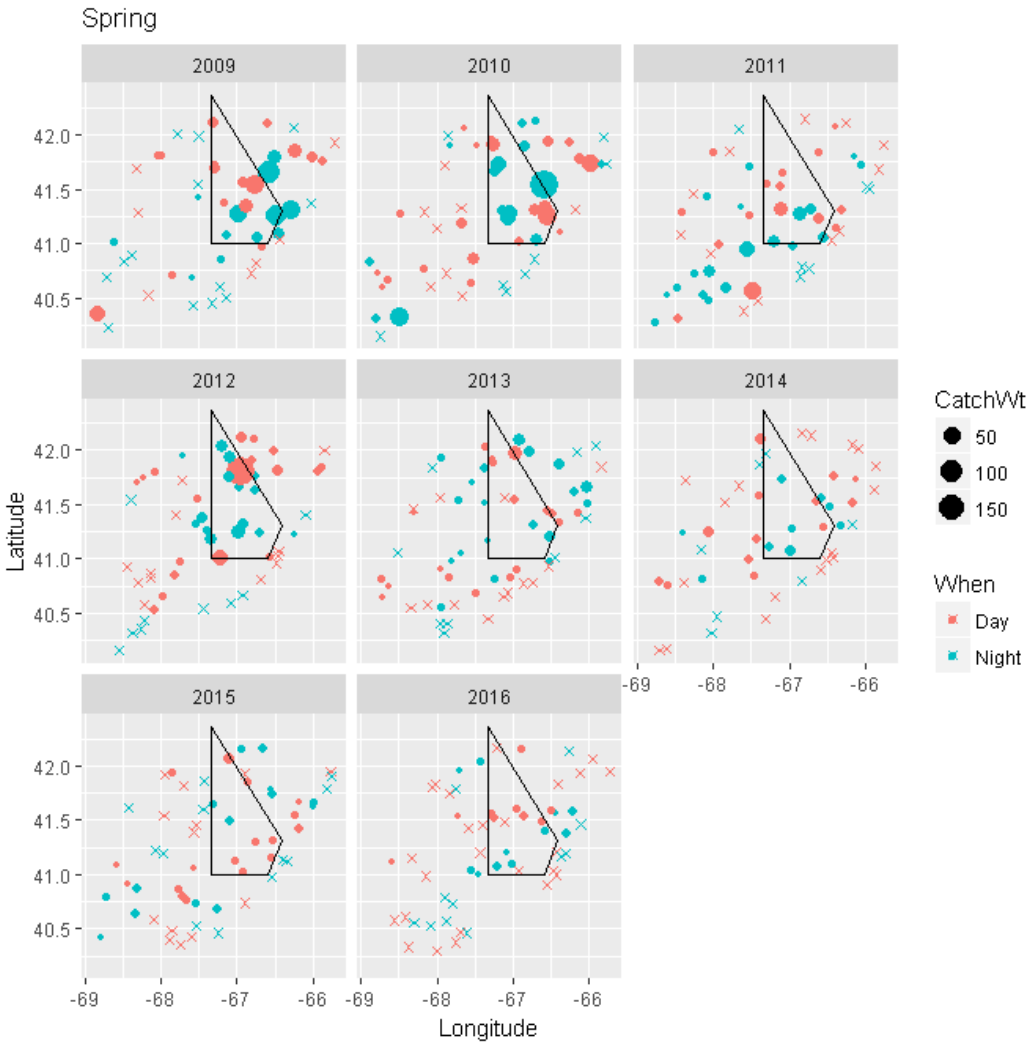


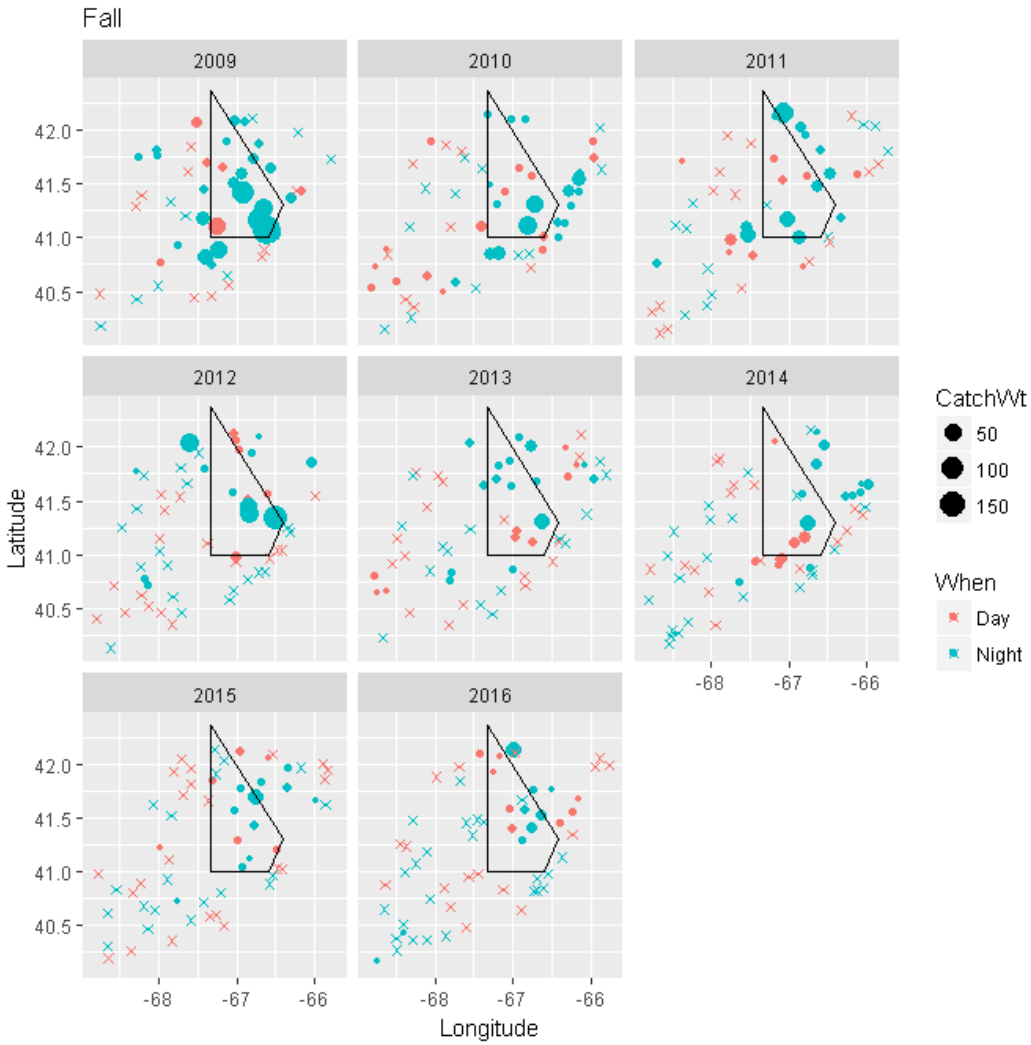
# NEFSC Survey catch/tow



# NEFSC Survey Spatial Locations



# Conclusions

- These analyses provide a statistical evaluation of effects on relative efficiency of rockhopper and chain sweep gear and effects on observable abundance for the surveys.
- Regardless of biomass method, the twin trawl study indicates a somewhat lower efficiency ~30-34% than what is currently used to scale surveys in TRAC (37%), but wing swept area was used here. Of course, the chain sweep is not fully efficient so true efficiency is likely even lower.
- The difference in efficiencies of the chain and rockhopper in terms of numbers depends on size and to a lesser extent on day/night. The first and second method did not provide notably different biomass estimates
- Day/night effects on survey gear efficiency varied annually and by survey and were not well estimated. The translation of the large uncertainty and annual inconsistency in the night/day ratios into biomass estimation seems problematic.

# Recommendation

- A better approach to understanding day/night effects is a controlled study with replicate tows in day and night (the same 24 hrs) in the same location.
- Recommend using one of the more precise biomass estimates that do not use estimates of day/night effects on rockhopper efficiency from survey data
- Recommend using method 1 given the similarity and consistency of the biomass estimates using methods 1 and 2 and the lesser complexity
  - Can use constant 0.31 to approximate results from methods 1 and 2