

Plan B Assessment for Atlantic Halibut

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December 14, 2017

Outline of this Presentation

- Follows the material in “Halibut Assessment for 2017”, Draft, December 1, 2017.
- Consideration of available data
- De-emphasizes the DCAC analyses
- Focuses on methodology used to project catch in 2018
 - Ratio methods and randomization tests to estimate magnitude and significance of changes in relative abundance.
 - Simulation tests of Ratio method
 - Proposed catch adjustment method based on rates of change in indices
 - Simulation tests of FSD method
 - Estimation of uncertainty of forecast
 - Application of method to DFO 3N0Ps4VWX5Zc Atlantic halibut and IPHC Pacific halibut

The Plan B Dilemma

- Restrictions on introductions of new data and analytical models
- Rebuilding considerations
- No revisions of stock structure
- Accountability measures
- *How should catch be adjusted without measures of biomass and fishing mortality, and their respective reference points?*

Some Plan B Options

1. Use some function of recent catch
 1. Last year
 2. Some arbitrary average
 3. Some arbitrary scalar applied to some arbitrary average
2. Apply a method that relies entirely on the assumed state of the stock.
3. Apply a biologically based rate to a swept area estimate
4. Piggy back the US control rule on the management decisions applied to the adjoining Canadian stock
5. Develop an updating function that adjusts catches based on trends in one or more indices.
 - First 4 options are either hard to justify or cause knife fights

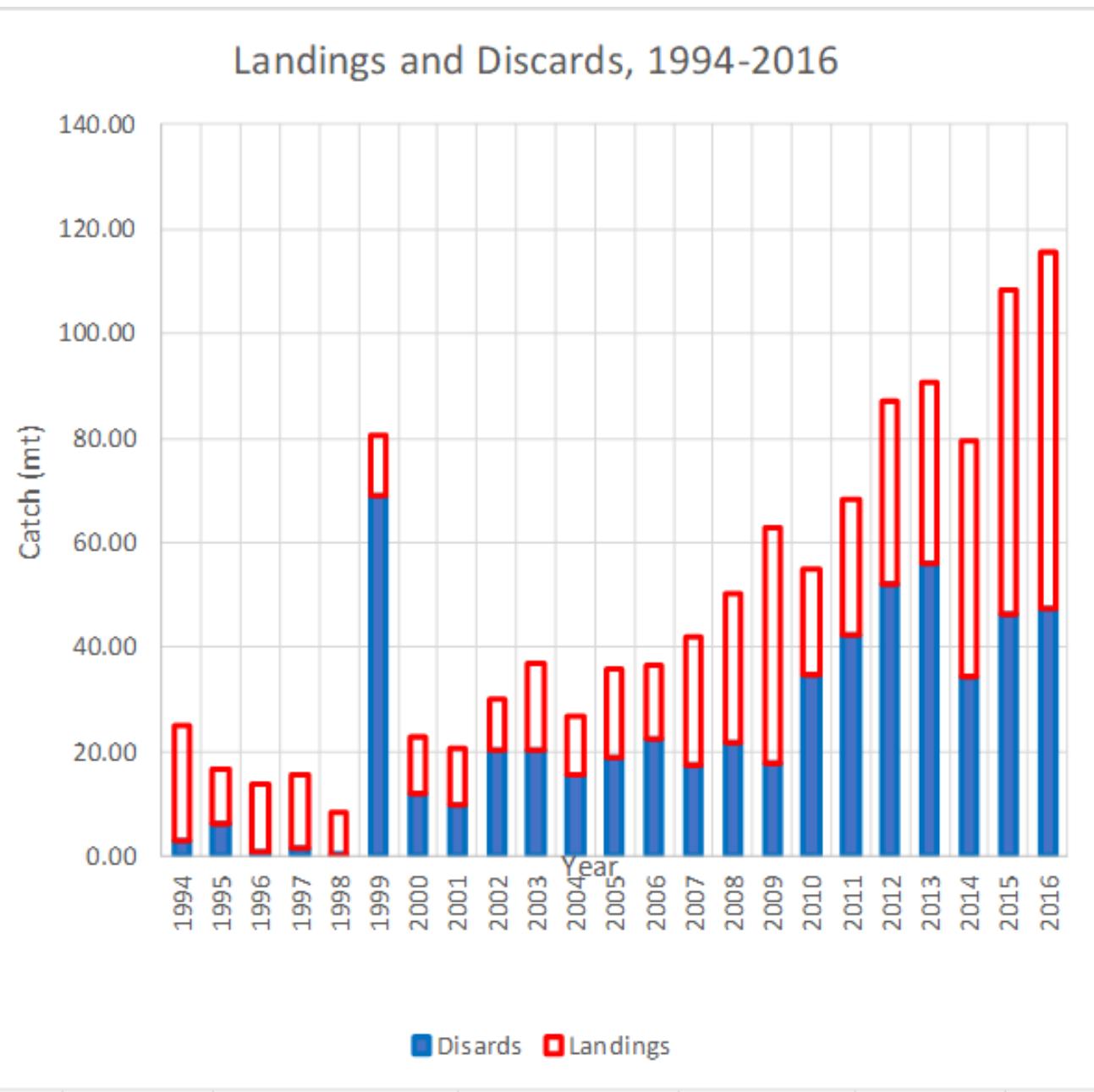
Perspectives

- Has the population changed in recent years?
- Is the change significant?
- Is the observed change supported by multiple indices?
- How does the proposed data poor method perform in simulation?
- Are there adverse effects for rebuilding, catches, and accountability measures?

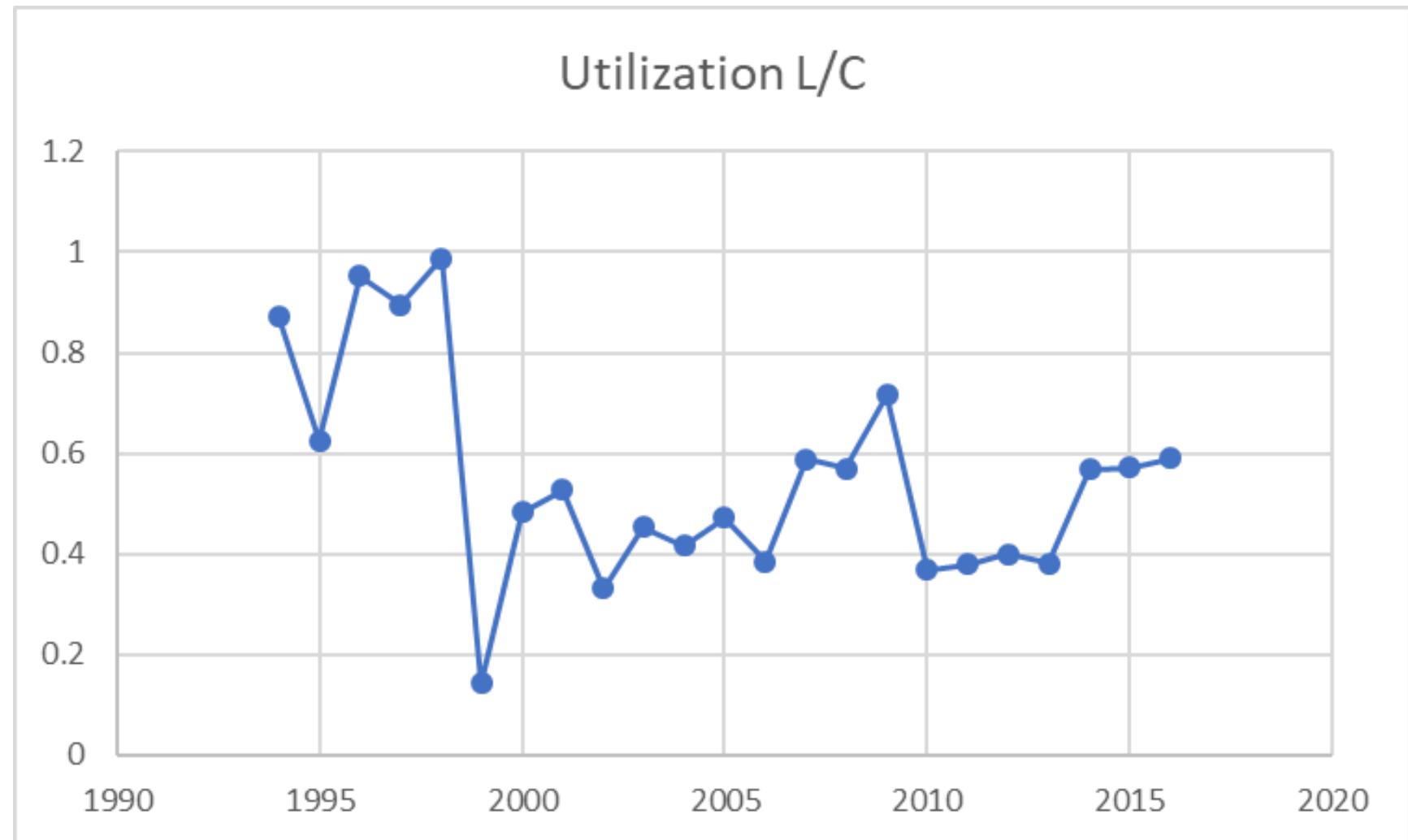
Data Sources Considered (Table 1)

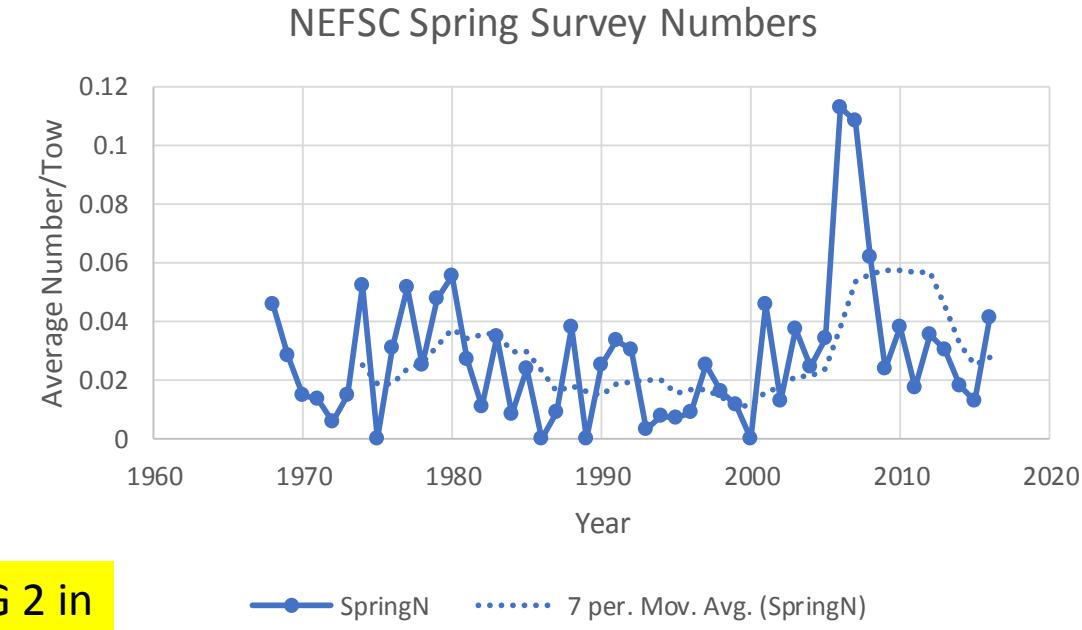
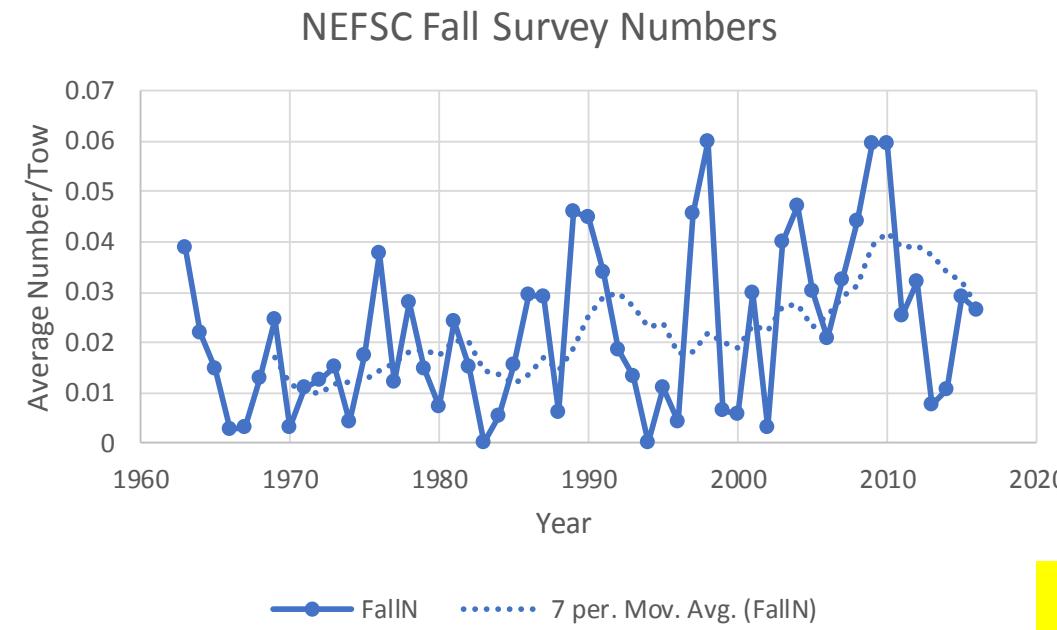
- Standard NEFSC survey update
- Landings and Discard update
- Abundance Indices
 - d/k ratio gill net
 - d/k ratio trawl
 - Maine Standardized CPUE—Hansell et al.
 - Maine Survey indices
 - Maine Commercial Indices from logbooks
- Comparisons with Canada

Year	Disards	Landings	Catch
1994	3.16	21.77	24.93
1995	6.34	10.54	16.88
1996	0.65	13.32	13.97
1997	1.64	14.01	15.65
1998	0.10	8.41	8.51
1999	69.08	11.51	80.59
2000	11.87	11.07	22.94
2001	9.68	10.82	20.50
2002	20.20	10.01	30.21
2003	20.15	16.68	36.83
2004	15.71	11.22	26.93
2005	18.89	16.81	35.70
2006	22.45	14.08	36.53
2007	17.27	24.61	41.88
2008	21.66	28.69	50.35
2009	17.85	45.05	62.90
2010	34.68	20.20	54.88
2011	42.34	25.79	68.13
2012	52.18	34.80	86.98
2013	56.16	34.67	90.83
2014	34.33	44.99	79.32
2015	46.28	62.00	108.28
2016	47.39	68.20	115.59

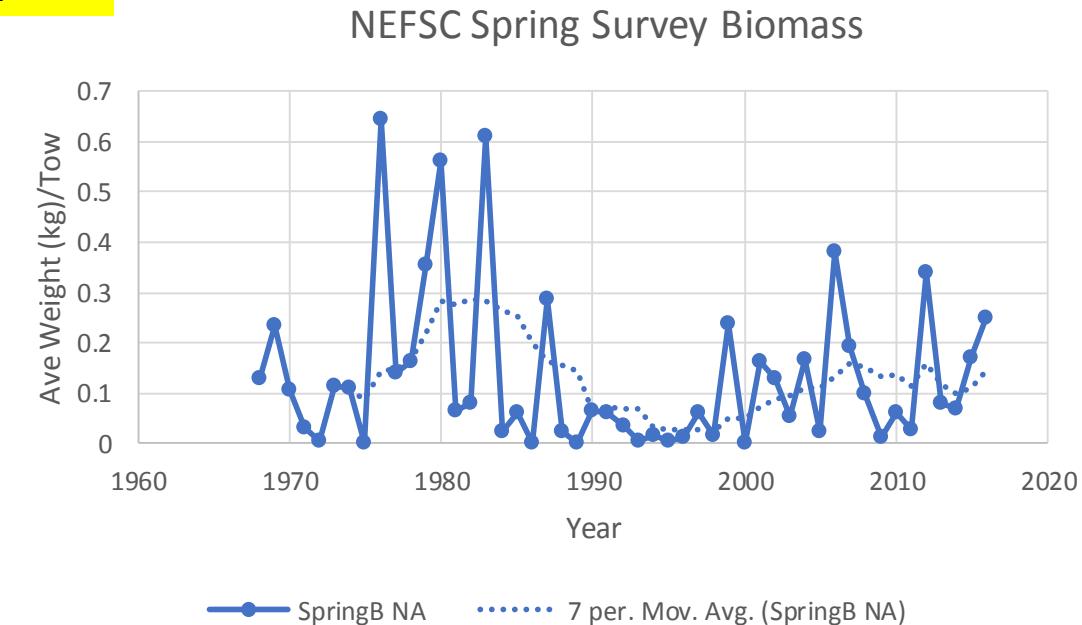
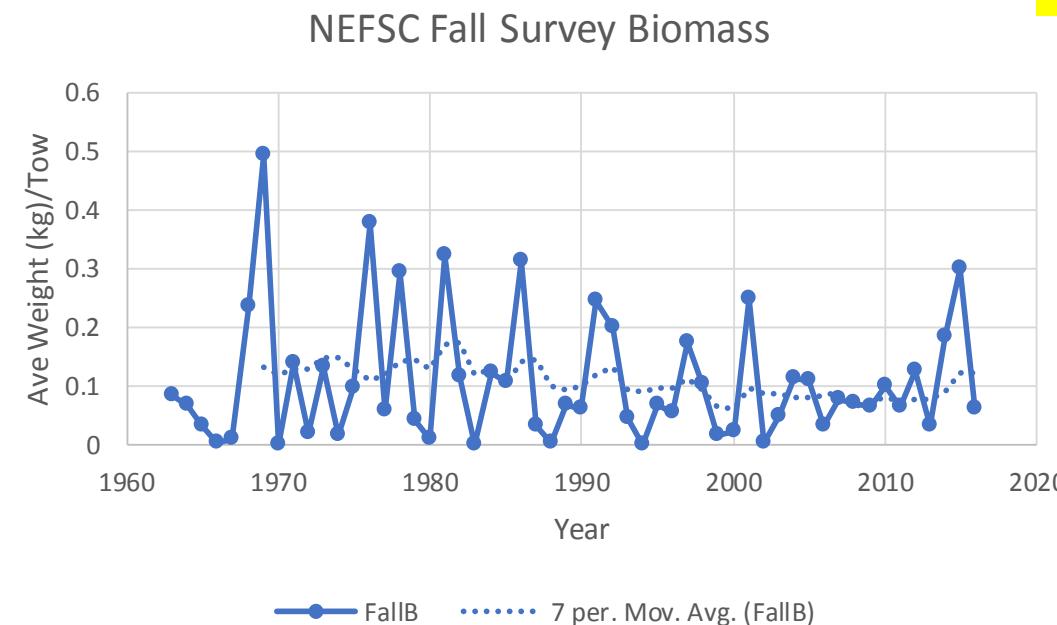


Trends in Utilization Ratio (Landings/Catch), 2002-2016

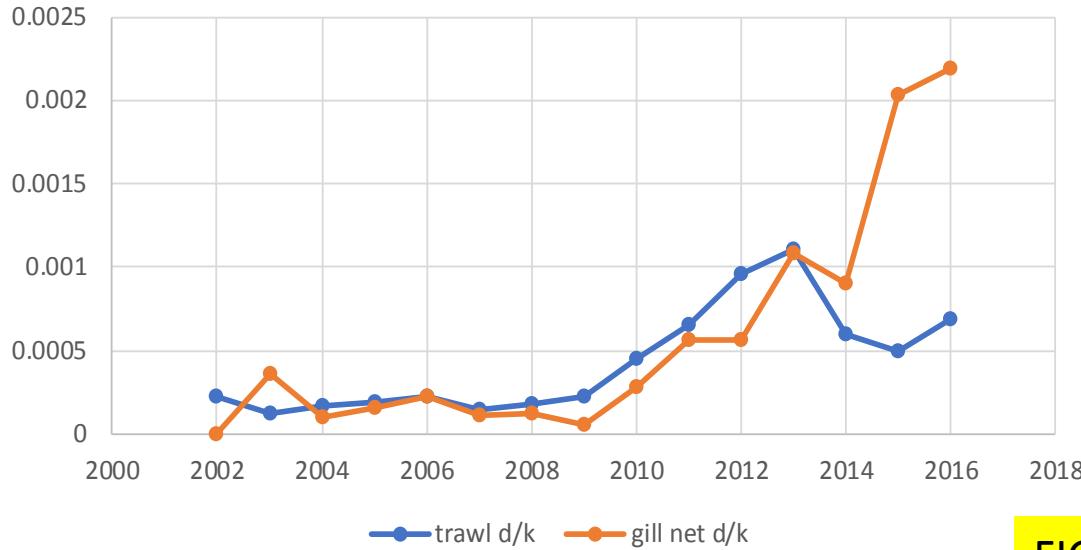




**FIG 2 in
Report**



d/k ratios for NEFSC obsr (trawl, gill net)



Maine CPUE Longline

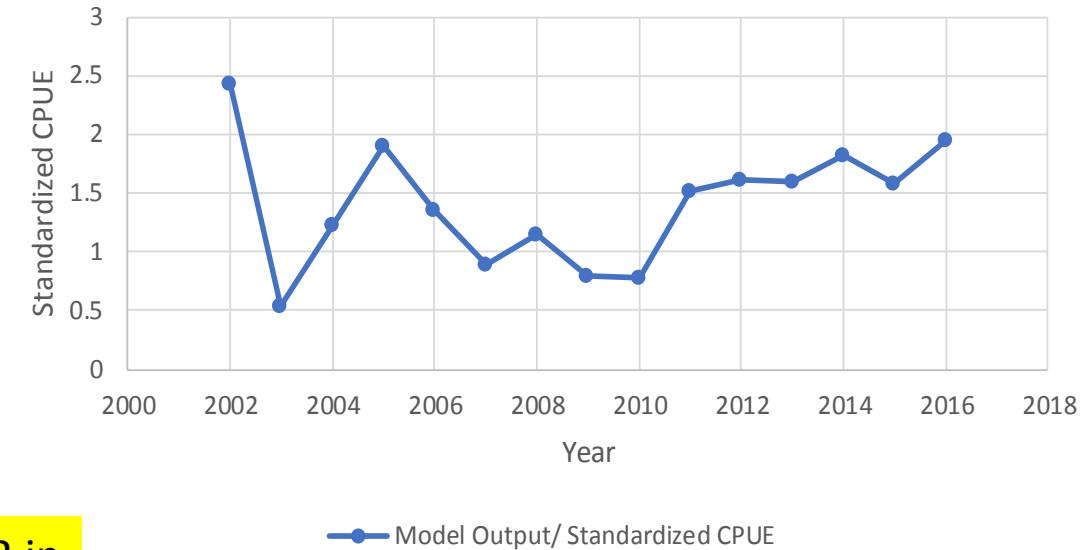
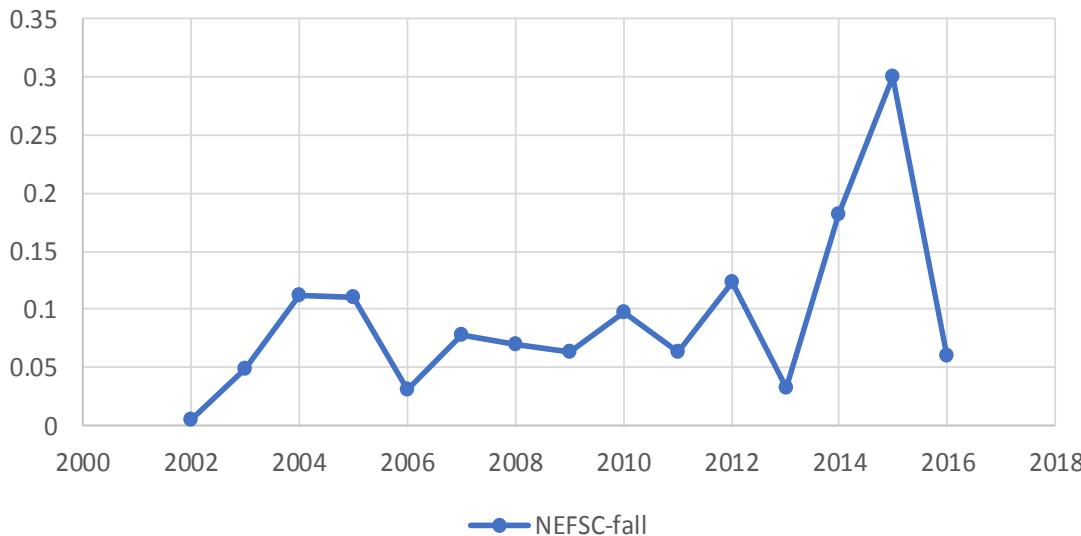
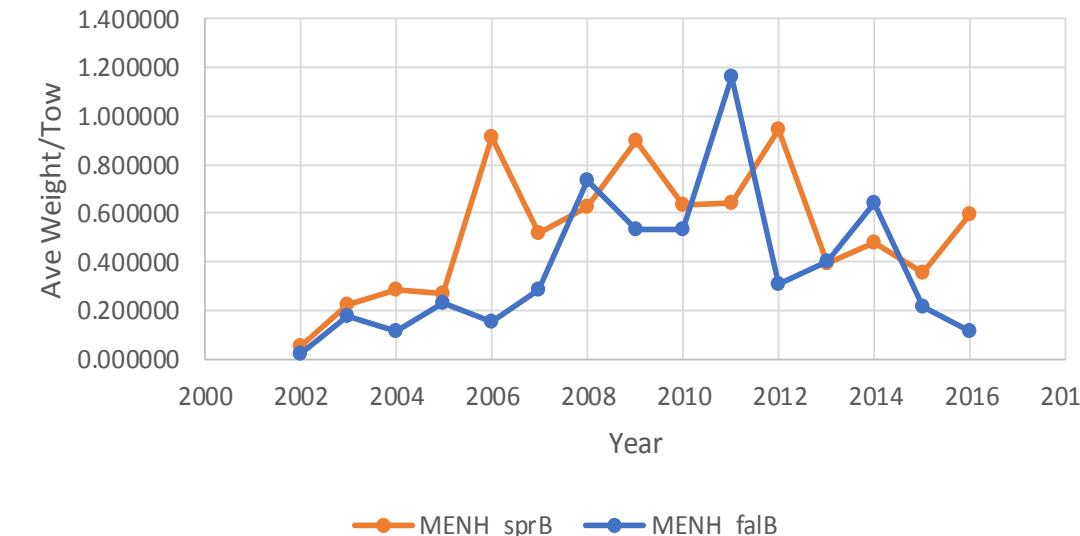


FIG 3 in Report

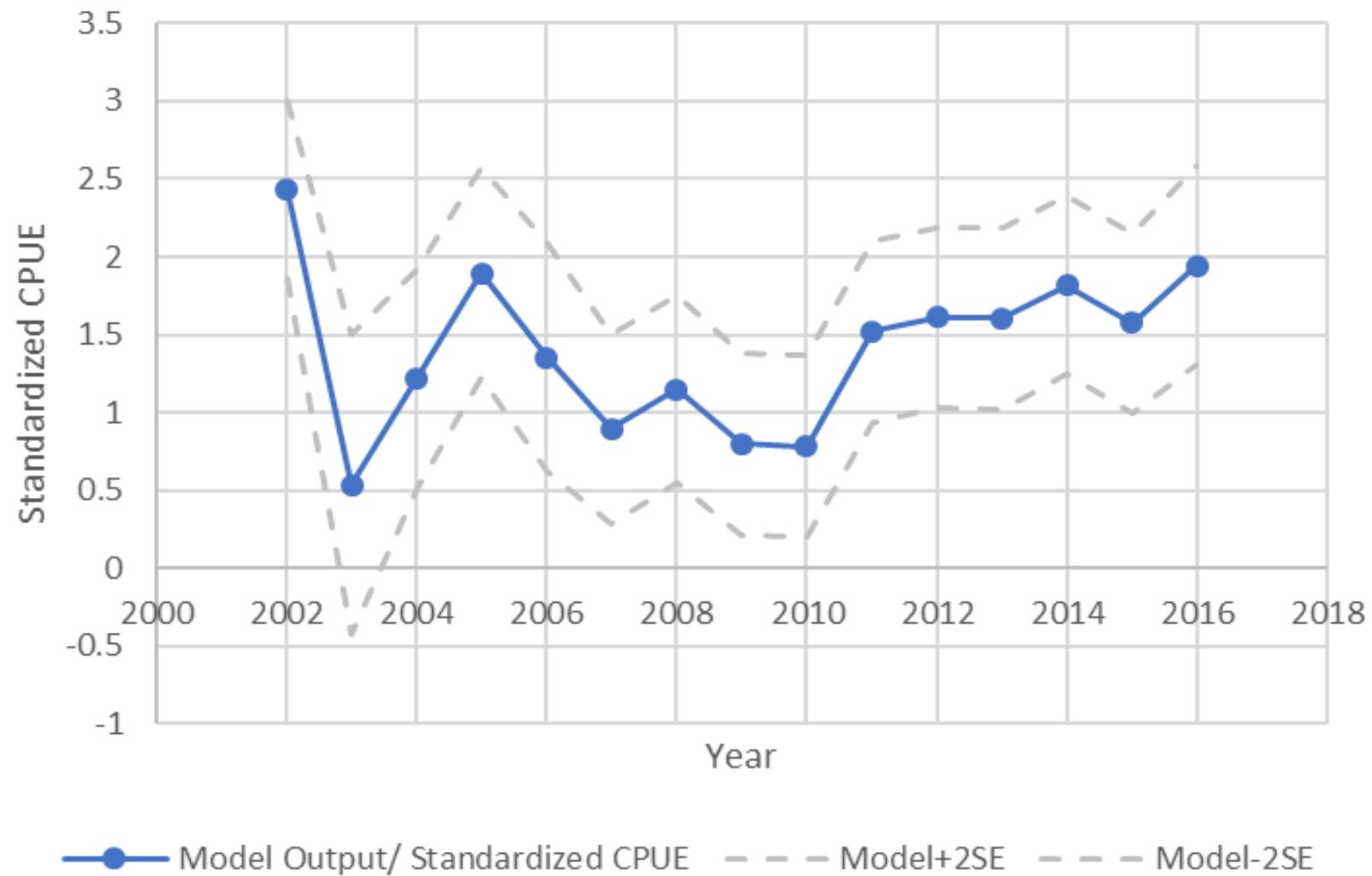
NEFSC fall survey(raw)



Maine_NH Survey metrics

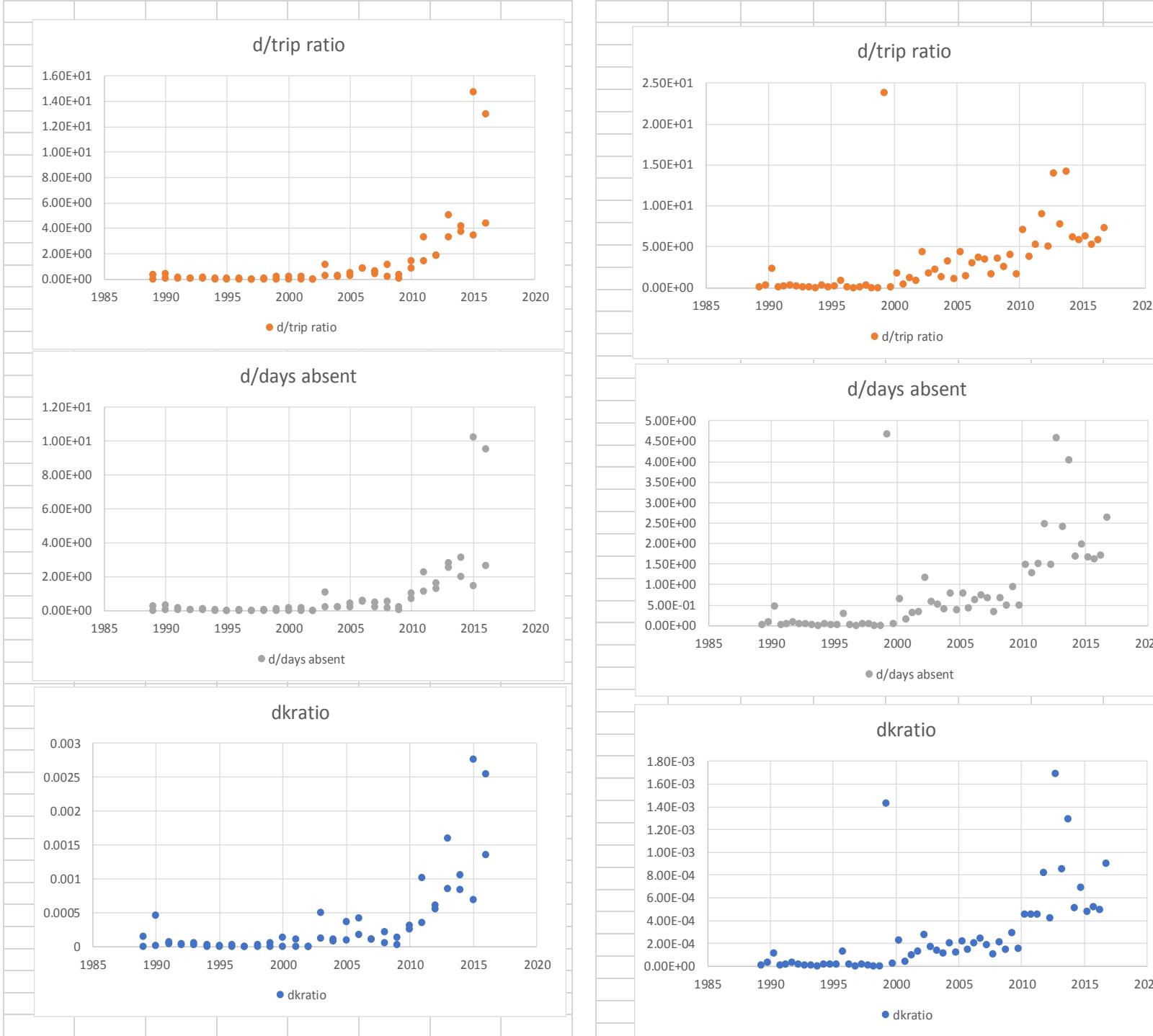


Standardized CPUE for Maine Commercial Longline Fishery



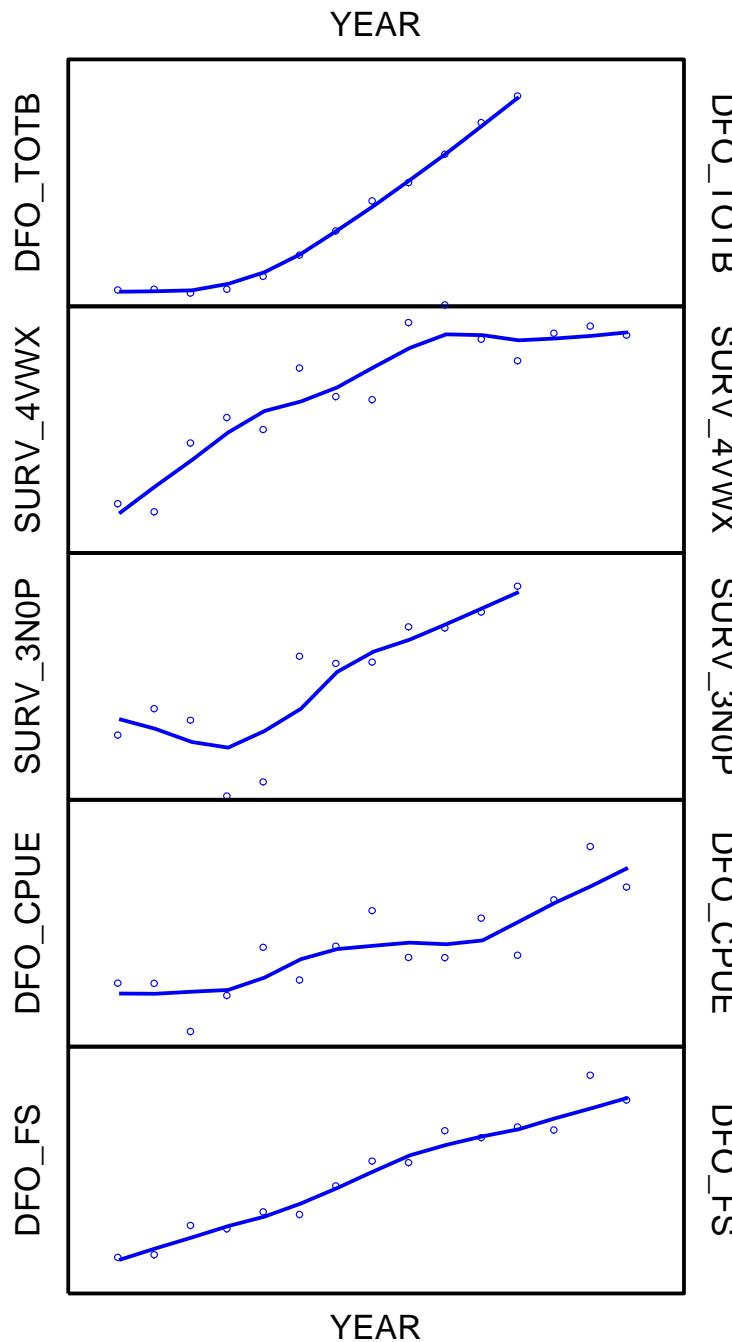
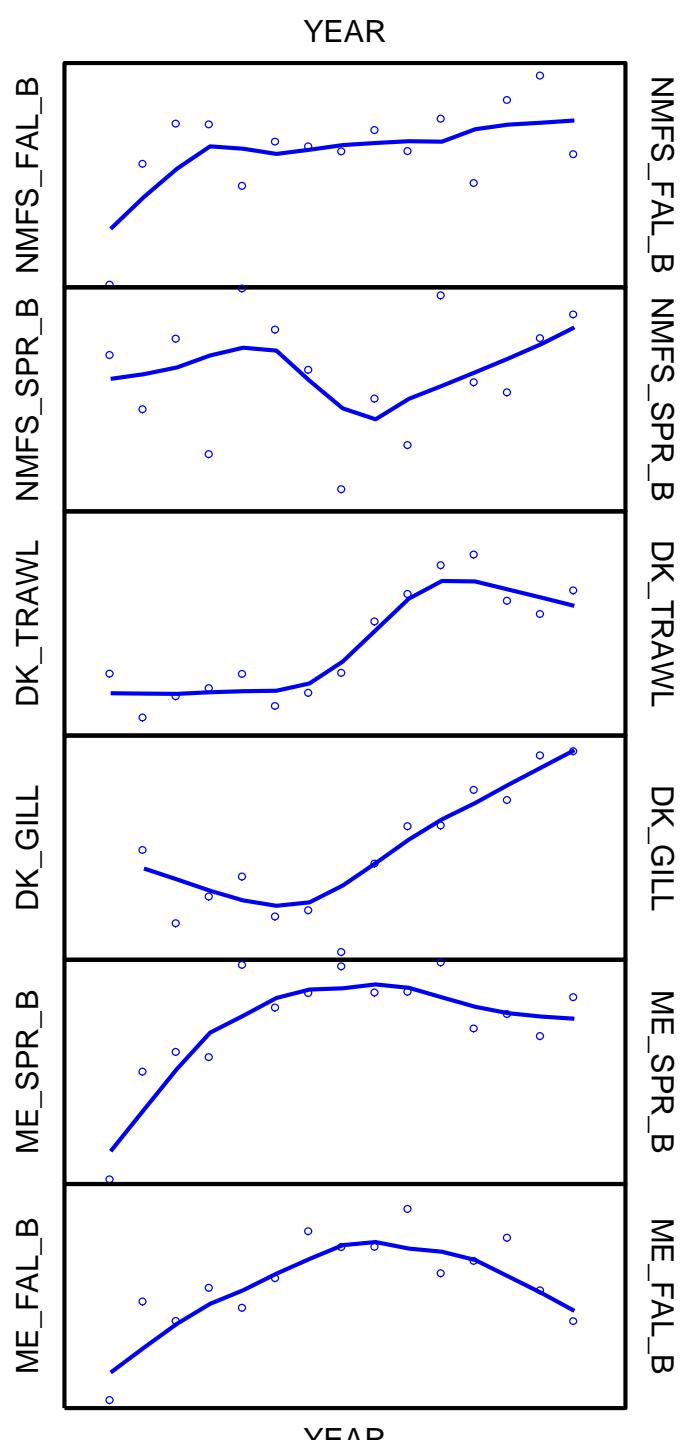
Analyses
courtesy
of Hansell
et al.
2017

FIG 4 in
Report



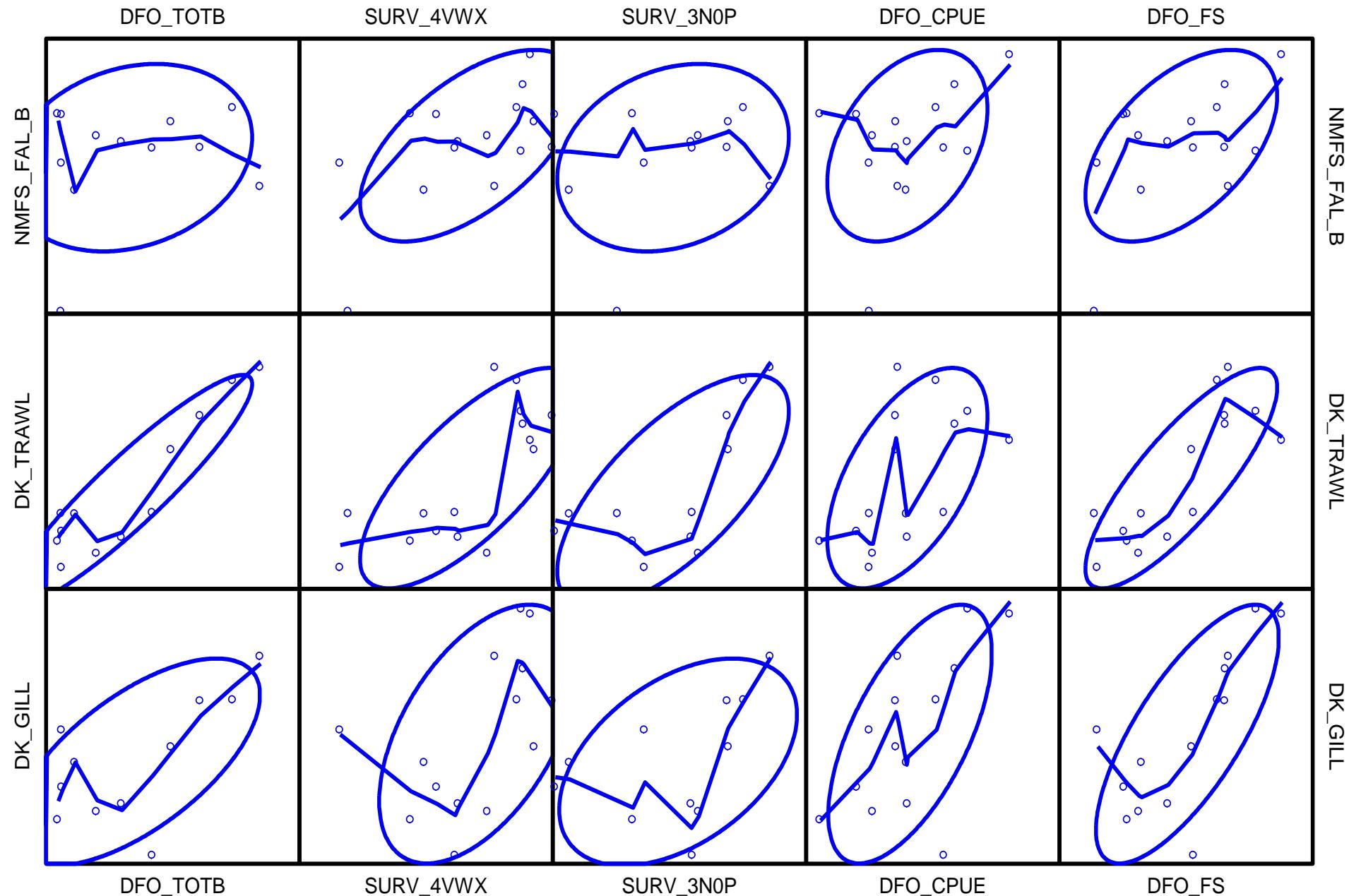
NEFSC observer
program d/k ratios for
gill nets (left) and trawls
(right) for half-year
intervals, 1989-2016

FIG 5 and
6 in Report



Comparison of time trends in US and Canada relative abundance indices for Atlantic Halibut, 2002-2016. DFO_TOTB is total abundance for Canada stock derived from assessment model.

FIG 7 (LEFT) and 8 (RIGHT) in Report



Comparison of core abundance indices for US and Canada, including results of model SSB for Canada

FIG 9 in Report

The Panoply of Data Poor Methods

- Methods that rely some arbitrary scalar adjustment to recent average catches with no rigorous analyses of population consequences.
 - ORCS
- Methods that rely on strong assumptions about current stock status
 - DCAC, DB-SRA etc.
- Methods that apply a biologically based harvest rate to a swept area estimate of abundance
 - Eg GOM winter flounder, GB yellowtail flounder, etc.
- Methods that adjust current catches based on measures of current trends or trends.
 - GB cod
 - MPA etc. Butterworth type, also Hillary, Apostolaki et al. etc.

DCAC = Plan C—served as a useful starting point

- Basic Equation

- $C_{sustainable} = \frac{\sum_{t=1}^n C_t}{n + \frac{Delta}{0.2 M}} \quad [3]$

- $Delta = \frac{B_t - B_{t+n}}{B_{MSY}} \quad [4]$

- $C_t = C_{sustainable} \frac{B_t}{B_{MSY}} \quad [5]$

- **Finding DELTA ?**

- Ratio Increase

- Percentage increase with respect to current stock abundance

Rcrit and Randomization—is the observed trend in one or more indices significant?

- Definition:

$$\bullet R_{crit,j} = \frac{\sum_{t=T-m+1}^T \frac{I_{j,t}}{m}}{\sum_{t=1}^n I_{j,t} \frac{1}{n}} \quad [6]$$

- Standardize the indices with respect to means (multiple indices)

$$\bullet R_{crit,.} = \frac{\sum_{j=1}^J \sum_{t=T-m+1}^T \frac{s(I_{j,t})}{m}}{\sum_{j=1}^J \sum_{t=1}^n \frac{s(I_{j,t})}{n}} \quad [7]$$

- Create the sampling distribution of Rcrit.

$$\bullet R_{crit,k} = \frac{\sum_{j=1}^J \sum_{t=T-m+1}^T R_k\left(\frac{s(I_{j,t})}{m}\right)}{\sum_{j=1}^J \sum_{t=1}^n R_k\left(\frac{s(I_{j,t})}{n}\right)} \quad [9]$$

Rcrit and Randomization (2)

- Significance Level of Rcrit
- $P(R_{crit,k} > R_{crit,obs}) = \frac{\sum_k^{N_{rand}} g(R_{crit,k} \geq R_{crit,obs})}{N_{rand}}$ [10]

Rcrit Simulation tests

- Key factors to consider
 - True underlying rate of change
 - Observation error of the indices
 - Number of variables available

Results of Simulation Tests for Rcrit model

Table xx. Summary of ratio test simulations for estimation of bias in mean and median of Rcrit as a function of the magnitude of true rate of change (Rcrit_true), the variation of the observation error (CV) and the number of relative abundance indices (Nvar). All simulations were based on a time series of length 10, and the ratio of the average of the last 3 to the first 3 observations for 2000 randomizations of each of 1000 stochastic realizations.

Relative Bias in Estimated Rcrit vs True Rcrit									
		Nvar=1		Nvar=2		Nvar=3		Nvar=5	
Rcrit_true	CV	Rel Bias (mean)	Rel Bias (median)						
2.014	0.1	0.3%	0.2%	0.1%	-0.1%	0.0%	0.1%	0.2%	0.0%
2.014	0.15	0.4%	-0.3%	0.6%	0.1%	0.0%	-0.5%	0.2%	-0.1%
2.014	0.2	0.6%	-1.4%	0.1%	-0.5%	0.4%	0.1%	0.1%	0.1%
2.014	0.25	3.1%	1.2%	1.5%	0.5%	1.2%	0.5%	0.5%	-0.1%
2.014	0.3	2.5%	-0.9%	1.0%	0.4%	1.8%	0.6%	0.7%	-0.1%
2.014	0.35	3.5%	-0.8%	2.5%	0.9%	1.1%	-0.5%	0.7%	0.0%
2.014	0.4	4.9%	-0.9%	3.3%	0.4%	1.8%	0.3%	0.8%	-0.4%
2.014	0.45	10.1%	-0.9%	2.8%	-0.5%	1.9%	0.3%	1.6%	0.5%
2.014	0.5	9.8%	-1.3%	6.1%	0.5%	3.8%	0.2%	1.9%	0.1%
2.014	0.6	-51.9%	-3.0%	6.8%	-1.6%	4.8%	0.2%	2.8%	0.1%
2.014	0.65	18.4%	-1.4%	9.0%	-0.5%	5.1%	0.2%	2.8%	-1.1%
2.014	0.7	7.8%	-5.1%	12.9%	0.7%	3.8%	0.2%	4.1%	0.8%
1.419	0.1	0.1%	-0.1%	0.3%	0.2%	0.2%	0.0%	-0.1%	0.0%
1.419	0.15	1.2%	0.5%	0.8%	0.9%	0.5%	0.5%	0.0%	-0.3%
1.419	0.2	1.5%	1.1%	1.0%	0.1%	0.1%	-0.4%	-0.5%	0.2%
1.419	0.25	0.7%	-1.8%	0.5%	-0.2%	0.8%	-0.1%	1.2%	1.1%
1.419	0.3	4.3%	0.1%	2.1%	0.9%	0.6%	-0.4%	0.5%	-0.8%
1.419	0.35	4.5%	0.4%	0.4%	-1.9%	1.0%	-0.1%	0.7%	-0.1%
1.419	0.4	5.9%	1.1%	3.7%	0.7%	1.9%	0.3%	1.0%	-0.3%
1.419	0.45	9.2%	-0.4%	2.0%	-1.2%	2.4%	0.0%	1.3%	-0.1%
1.419	0.5	8.5%	1.8%	5.1%	-0.6%	3.0%	0.5%	2.2%	0.2%
1.419	0.6	24.1%	-0.4%	6.8%	-0.6%	3.2%	-0.5%	2.4%	1.1%
1.419	0.65	17.5%	-0.6%	16.9%	2.1%	4.8%	-1.0%	3.1%	0.5%
1.419	0.7	23.5%	-3.0%	12.1%	3.1%	3.5%	-2.1%	1.6%	-2.1%
1.191	0.1	0.3%	0.5%	0.1%	0.1%	0.2%	-0.1%	-0.1%	-0.2%
1.191	0.15	0.4%	0.0%	0.3%	0.1%	0.2%	0.0%	0.2%	0.0%
1.191	0.2	1.7%	0.2%	0.4%	-0.4%	0.5%	0.1%	0.2%	-0.4%
1.191	0.25	1.5%	-0.4%	1.4%	0.5%	1.3%	1.3%	0.2%	-0.4%
1.191	0.3	2.8%	-0.2%	1.5%	0.7%	0.6%	-0.7%	-0.2%	-0.7%
1.191	0.35	4.6%	1.8%	2.8%	0.9%	2.1%	1.1%	0.6%	-0.9%
1.191	0.4	5.3%	0.1%	2.7%	-0.4%	1.9%	0.5%	1.1%	0.7%
1.191	0.45	8.3%	-0.2%	3.7%	1.7%	2.5%	1.4%	0.8%	-1.1%
1.191	0.5	20.9%	3.8%	3.8%	-1.0%	2.8%	-0.6%	2.1%	0.0%
1.191	0.6	14.8%	1.1%	7.3%	1.7%	3.5%	-0.5%	2.4%	-0.1%
1.191	0.65	26.4%	1.8%	11.9%	0.9%	4.9%	-1.1%	2.3%	-0.9%
1.191	0.7	0.3%	-2.6%	9.7%	-0.6%	8.1%	3.7%	3.1%	-1.8%

Table 2. Relative bias in estimates as function of true Rcrit, CV and number of indices considered.

		Nvar=1	
Rcrit_true	CV	Rel Bias (mean)	Rel Bias (median)
2.014	0.1	0.3%	0.2%
2.014	0.15	0.4%	-0.3%
2.014	0.2	0.6%	-1.4%
2.014	0.25	3.1%	1.2%
2.014	0.3	2.5%	-0.9%
2.014	0.35	3.5%	-0.8%
2.014	0.4	4.9%	-0.9%
2.014	0.45	10.1%	-0.9%
2.014	0.5	9.8%	-1.3%
2.014	0.6	-51.9%	-3.0%
2.014	0.65	18.4%	-1.4%
2.014	0.7	7.8%	-5.1%

Average Probability Value for Rcrit					
Rcrit_true	CV	Nvar=1	Nvar=2	Nvar=3	Nvar=5
2.014	0.1	0.000	0.000	0.000	0.000
2.014	0.15	0.002	0.000	0.000	0.000
2.014	0.2	0.010	0.000	0.000	0.000
2.014	0.25	0.021	0.002	0.000	0.000
2.014	0.3	0.042	0.008	0.001	0.000
2.014	0.35	0.066	0.015	0.003	0.000
2.014	0.4	0.095	0.027	0.005	0.001
2.014	0.45	0.115	0.047	0.012	0.001
2.014	0.5	0.148	0.058	0.020	0.005
2.014	0.6	0.199	0.103	0.040	0.013
2.014	0.65	0.214	0.120	0.052	0.019
2.014	0.7	0.241	0.136	0.070	0.025
1.419	0.1	0.008	0.000	0.000	0.000
1.419	0.15	0.036	0.005	0.001	0.000
1.419	0.2	0.085	0.022	0.006	0.001
1.419	0.25	0.132	0.054	0.020	0.004
1.419	0.3	0.163	0.083	0.046	0.013
1.419	0.35	0.202	0.130	0.076	0.029
1.419	0.4	0.234	0.149	0.098	0.044
1.419	0.45	0.263	0.200	0.123	0.065
1.419	0.5	0.278	0.204	0.143	0.085
1.419	0.6	0.316	0.253	0.192	0.128
1.419	0.65	0.335	0.249	0.205	0.148
1.419	0.7	0.353	0.271	0.229	0.178
1.191	0.1	0.084	0.022	0.005	0.001
1.191	0.15	0.171	0.086	0.044	0.013
1.191	0.2	0.224	0.151	0.094	0.046
1.191	0.25	0.284	0.190	0.145	0.093
1.191	0.3	0.317	0.234	0.198	0.139
1.191	0.35	0.339	0.269	0.218	0.166
1.191	0.4	0.354	0.302	0.250	0.205
1.191	0.45	0.372	0.314	0.270	0.235
1.191	0.5	0.368	0.338	0.304	0.244
1.191	0.6	0.403	0.361	0.330	0.281
1.191	0.65	0.406	0.366	0.342	0.305
1.191	0.7	0.419	0.392	0.328	0.317

Table 3. Average Probability value of Rcrit estimates as function of true Rcrit, CV and number of indices considered.

Performance improves as CV decreases, as the number of indices increases and as the true underlying rate of increase increases.

lambda	Rcrit_true	CV	P0.005	P0.01	P0.025	P0.05	P0.1	P0.15	P0.2	P0.25
0.1	2.014	0.1	0.994	0.998	1	1	1	1	1	1
0.1	2.014	0.15	0.868	0.951	0.989	0.999	1	1	1	1
0.1	2.014	0.2	0.634	0.771	0.914	0.958	0.993	0.994	0.998	0.998
0.1	2.014	0.25	0.426	0.578	0.769	0.891	0.959	0.98	0.99	0.993
0.1	2.014	0.3	0.278	0.41	0.619	0.773	0.883	0.937	0.96	0.973
0.1	2.014	0.35	0.209	0.303	0.475	0.643	0.799	0.869	0.915	0.936
0.1	2.014	0.4	0.142	0.217	0.378	0.527	0.701	0.802	0.864	0.907
0.1	2.014	0.45	0.123	0.181	0.309	0.463	0.642	0.753	0.819	0.863
0.1	2.014	0.5	0.076	0.135	0.248	0.394	0.575	0.679	0.76	0.811
0.1	2.014	0.6	0.06	0.1	0.18	0.288	0.458	0.559	0.645	0.699
0.1	2.014	0.65	0.052	0.086	0.171	0.275	0.44	0.543	0.624	0.685
0.1	2.014	0.7	0.043	0.067	0.142	0.251	0.379	0.487	0.573	0.635
0.05	1.419	0.1	0.644	0.807	0.926	0.969	0.995	0.998	1	1
0.05	1.419	0.15	0.319	0.462	0.641	0.786	0.908	0.949	0.968	0.984
0.05	1.419	0.2	0.177	0.271	0.45	0.6	0.752	0.815	0.87	0.914
0.05	1.419	0.25	0.084	0.132	0.257	0.388	0.6	0.7	0.769	0.817
0.05	1.419	0.3	0.094	0.137	0.231	0.347	0.511	0.624	0.704	0.773
0.05	1.419	0.35	0.051	0.087	0.169	0.283	0.432	0.558	0.643	0.706
0.05	1.419	0.4	0.028	0.061	0.151	0.253	0.374	0.486	0.575	0.646
0.05	1.419	0.45	0.035	0.058	0.114	0.203	0.34	0.432	0.522	0.593
0.05	1.419	0.5	0.021	0.043	0.093	0.16	0.292	0.408	0.504	0.579
0.05	1.419	0.6	0.018	0.031	0.075	0.146	0.253	0.346	0.428	0.502
0.05	1.419	0.65	0.013	0.023	0.062	0.118	0.237	0.322	0.401	0.469
0.05	1.419	0.7	0.016	0.027	0.049	0.112	0.218	0.304	0.368	0.448
0.025	1.191	0.1	0.182	0.268	0.438	0.603	0.75	0.815	0.867	0.9
0.025	1.191	0.15	0.061	0.111	0.227	0.356	0.501	0.609	0.696	0.756
0.025	1.191	0.2	0.037	0.078	0.156	0.26	0.396	0.501	0.589	0.661
0.025	1.191	0.25	0.027	0.047	0.109	0.187	0.318	0.42	0.491	0.556
0.025	1.191	0.3	0.015	0.028	0.075	0.141	0.26	0.352	0.438	0.512
0.025	1.191	0.35	0.02	0.033	0.075	0.138	0.246	0.336	0.412	0.473
0.025	1.191	0.4	0.018	0.029	0.057	0.114	0.199	0.282	0.372	0.435
0.025	1.191	0.45	0.008	0.02	0.047	0.093	0.189	0.27	0.355	0.42
0.025	1.191	0.5	0.011	0.031	0.064	0.109	0.191	0.268	0.352	0.431
0.025	1.191	0.6	0.014	0.02	0.049	0.088	0.172	0.243	0.313	0.382
0.025	1.191	0.65	0.008	0.02	0.045	0.092	0.163	0.229	0.298	0.362
0.025	1.191	0.7	0.005	0.017	0.049	0.085	0.151	0.211	0.287	0.34

Table 4. Fraction of simulations with significance probabilities less than or equal to the value in the column header. Color coding is consistent across Tables 4-7.

Results in this table are for ONE index of relative abundance.

lambda	Rcrit_true	CV	P0.005	P0.01	P0.025	P0.05	P0.1	P0.15	P0.2	P0.25
0.1	2.014	0.1	1	1	1	1	1	1	1	1
0.1	2.014	0.15	1	1	1	1	1	1	1	1
0.1	2.014	0.2	1	1	1	1	1	1	1	1
0.1	2.014	0.25	1	1	1	1	1	1	1	1
0.1	2.014	0.3	1	1	1	1	1	1	1	1
0.1	2.014	0.35	0.996	0.998	1	1	1	1	1	1
0.1	2.014	0.4	0.981	0.991	0.996	0.999	0.999	1	1	1
0.1	2.014	0.45	0.93	0.968	0.986	0.996	1	1	1	1
0.1	2.014	0.5	0.849	0.912	0.956	0.977	0.993	0.998	0.998	0.999
0.1	2.014	0.6	0.709	0.81	0.889	0.934	0.962	0.983	0.991	0.994
0.1	2.014	0.65	0.598	0.697	0.821	0.9	0.956	0.973	0.984	0.989
0.1	2.014	0.7	0.541	0.657	0.797	0.863	0.922	0.958	0.974	0.987
0.05	1.419	0.1	1	1	1	1	1	1	1	1
0.05	1.419	0.15	1	1	1	1	1	1	1	1
0.05	1.419	0.2	0.973	0.992	0.999	0.999	1	1	1	1
0.05	1.419	0.25	0.869	0.921	0.965	0.982	0.994	0.998	0.999	1
0.05	1.419	0.3	0.647	0.747	0.856	0.931	0.976	0.986	0.993	0.997
0.05	1.419	0.35	0.53	0.627	0.761	0.85	0.929	0.953	0.971	0.977
0.05	1.419	0.4	0.382	0.497	0.647	0.765	0.862	0.912	0.943	0.967
0.05	1.419	0.45	0.3	0.413	0.554	0.674	0.819	0.863	0.898	0.927
0.05	1.419	0.5	0.247	0.321	0.473	0.599	0.749	0.818	0.87	0.899
0.05	1.419	0.6	0.151	0.221	0.356	0.496	0.64	0.722	0.775	0.824
0.05	1.419	0.65	0.132	0.199	0.322	0.447	0.591	0.674	0.738	0.782
0.05	1.419	0.7	0.101	0.159	0.262	0.354	0.51	0.599	0.682	0.741
0.025	1.191	0.1	0.964	0.981	0.995	1	1	1	1	1
0.025	1.191	0.15	0.664	0.767	0.869	0.938	0.971	0.988	0.994	0.997
0.025	1.191	0.2	0.381	0.482	0.632	0.745	0.855	0.909	0.936	0.961
0.025	1.191	0.25	0.22	0.308	0.452	0.579	0.719	0.801	0.857	0.893
0.025	1.191	0.3	0.121	0.18	0.314	0.453	0.608	0.699	0.766	0.809
0.025	1.191	0.35	0.103	0.161	0.253	0.363	0.498	0.619	0.693	0.749
0.025	1.191	0.4	0.079	0.14	0.236	0.334	0.481	0.572	0.638	0.692
0.025	1.191	0.45	0.061	0.098	0.18	0.268	0.396	0.498	0.566	0.629
0.025	1.191	0.5	0.055	0.085	0.164	0.263	0.385	0.468	0.551	0.617
0.025	1.191	0.6	0.031	0.056	0.126	0.194	0.323	0.416	0.489	0.554
0.025	1.191	0.65	0.036	0.054	0.119	0.197	0.295	0.379	0.45	0.529
0.025	1.191	0.7	0.035	0.068	0.115	0.181	0.281	0.356	0.423	0.484

Table 7. Fraction of simulations with significance probabilities less than or equal to the value in the column header. Color coding is consistent across Tables 4-7.

Results in this table are for FIVE indices of relative abundance.

Rcrit Applications

- US—6 candidate indices
- DFO—3 indices AND SSB from an analytical model

Finding the best estimate of Rcrit for multiple indices?

- Often a difficult problem in stock assessments—lots of group discussion
- Therefore-- Consider all possible models
- Combination of all possible models of n indices taken m at a time summed over m=1,..., n
- $\text{Comb}(6,6) + \text{Comb}(6,5) + \text{Comb}(6,4) + \text{Comb}(6,3) + \text{Comb}(6,2) + \text{Comb}(6,1)$
- $1 + 6 + 15 + 20 + 15 + 6 = 63$
- Can now compare alternative models and compute average Rcrit and Pvalue of Rcrit across all possible models.

50000 replicates
ratio 2014/2016 to 2002-2004

USA Data (2002-2016)										
Model #	Nvars	Combinati	Rcrit	Pvalue	Var 1	Var 2	Var 3	Var 4	Var 5	Var 6
1	6	1	3.231	0.0000	ME_sprB	ME_falB	LLcpueStd	DK_trawl	DK_gillnet	FallSurvB
2	5	1	3.216	0.0000	ME_sprB	ME_falB	LLcpueStd	DK_trawl	DK_gillnet	
3	5	2	2.436	0.0000	ME_sprB	ME_falB	LLcpueStd	DK_trawl	FallSurvB	
4	5	3	3.196	0.0000	ME_sprB	ME_falB	LLcpueStd	DK_gillnet	FallSurvB	
5	5	4	4.254	0.0000	ME_sprB	ME_falB	DK_trawl	DK_gillnet	FallSurvB	
6	5	5	3.242	0.0000	ME_sprB	LLcpueStd	DK_trawl	DK_gillnet	FallSurvB	
7	5	6	3.327	0.0000	ME_falB	LLcpueStd	DK_trawl	DK_gillnet	FallSurvB	
8	4	1	2.184	0.0011	ME_sprB	ME_falB	LLcpueStd	DK_trawl		
9	4	2	3.166	0.0001	ME_sprB	ME_falB	LLcpueStd	DK_gillnet		
10	4	3	2.253	0.0006	ME_sprB	ME_falB	LLcpueStd	FallSurvB		
11	4	4	4.088	0.0000	ME_sprB	ME_falB	DK_trawl	DK_gillnet		
12	4	5	3.140	0.0000	ME_sprB	ME_falB	DK_trawl	FallSurvB		
13	4	6	4.471	0.0000	ME_sprB	ME_falB	DK_gillnet	FallSurvB		
14	4	7	3.228	0.0000	ME_sprB	LLcpueStd	DK_trawl	DK_gillnet		
15	4	8	2.354	0.0003	ME_sprB	LLcpueStd	DK_trawl	FallSurvB		
16	4	9	3.205	0.0000	ME_sprB	LLcpueStd	DK_gillnet	FallSurvB		
17	4	10	4.447	0.0000	ME_sprB	DK_trawl	DK_gillnet	FallSurvB		
18	4	11	3.339	0.0001	ME_falB	LLcpueStd	DK_trawl	DK_gillnet		
19	4	12	2.418	0.0007	ME_falB	LLcpueStd	DK_trawl	FallSurvB		
20	4	13	3.305	0.0001	ME_falB	LLcpueStd	DK_gillnet	FallSurvB		
21	4	14	4.649	0.0000	ME_falB	DK_trawl	DK_gillnet	FallSurvB		
22	4	15	3.352	0.0001	LLcpueStd	DK_trawl	DK_gillnet	FallSurvB		
23	3	1	1.871	0.0122	ME_sprB	ME_falB	LLcpueStd			
24	3	2	3.053	0.0003	ME_sprB	ME_falB	DK_trawl			
25	3	3	5.259	0.0000	ME_sprB	ME_falB	DK_gillnet			
26	3	4	3.040	0.0002	ME_sprB	ME_falB	FallSurvB			
27	3	5	2.033	0.0037	ME_sprB	LLcpueStd	DK_trawl			
28	3	6	3.173	0.0004	ME_sprB	LLcpueStd	DK_gillnet			
29	3	7	2.128	0.0024	ME_sprB	LLcpueStd	FallSurvB			
30	3	8	5.125	0.0000	ME_sprB	DK_trawl	DK_gillnet			
31	3	9	3.142	0.0001	ME_sprB	DK_trawl	FallSurvB			
32	3	10	4.778	0.0000	ME_sprB	DK_gillnet	FallSurvB			
33	3	11	2.106	0.0091	ME_falB	LLcpueStd	DK_trawl			
34	3	12	3.310	0.0009	ME_falB	LLcpueStd	DK_gillnet			
35	3	13	2.196	0.0051	ME_falB	LLcpueStd	FallSurvB			
36	3	14	5.511	0.0000	ME_falB	DK_trawl	DK_gillnet			
37	3	15	3.305	0.0004	ME_falB	DK_trawl	FallSurvB			
38	3	16	5.074	0.0000	ME_falB	DK_gillnet	FallSurvB			
39	3	17	3.374	0.0003	LLcpueStd	DK_trawl	DK_gillnet			
40	3	18	2.319	0.0025	LLcpueStd	DK_trawl	FallSurvB			
41	3	19	3.331	0.0005	LLcpueStd	DK_gillnet	FallSurvB			
42	3	20	4.984	0.0000	DK_trawl	DK_gillnet	FallSurvB			
43	2	1	2.803	0.0042	ME_sprB	ME_falB				
44	2	2	1.611	0.0353	ME_sprB	LLcpueStd				
45	2	3	3.025	0.0014	ME_sprB	DK_trawl				
46	2	4	6.216	0.0000	ME_sprB	DK_gillnet				
47	2	5	3.014	0.0016	ME_sprB	FallSurvB				
48	2	6	1.680	0.0792	ME_falB	LLcpueStd				
49	2	7	3.317	0.0041	ME_falB	DK_trawl				
50	2	8	7.050	0.0003	ME_falB	DK_gillnet				
51	2	9	3.240	0.0045	ME_falB	FallSurvB				
52	2	10	1.901	0.0276	LLcpueStd	DK_trawl				
53	2	11	3.351	0.0046	LLcpueStd	DK_gillnet				
54	2	12	2.023	0.0180	LLcpueStd	FallSurvB				
55	2	13	6.509	0.0003	DK_trawl	DK_gillnet				
56	2	14	3.354	0.0028	DK_trawl	FallSurvB				
57	2	15	5.703	0.0009	DK_gillnet	FallSurvB				
58	1	1	2.550	0.0205	ME_sprB					
59	1	2	3.129	0.0520	ME_falB					
60	1	3	1.274	0.2200	LLcpueStd					
61	1	4	3.447	0.0256	DK_trawl					
62	1	5	11.217	0.0131	DK_gillnet					
63	1	6	3.291	0.0267	FallSurvB					

Average Rcrit value overall models=

3.522825

fraction of models with significance probability <0.05

0.952381

ratio 2014/2016 to 2002-2004

USA Data (2002-2016)

Model #	Nvars	Combinati	Rcrit	Pvalue	Var 1	Var 2	Var 3	Var 4	Var 5	Var 6
1	6	1	3.231	0.0000	ME_sprB	ME_falB	LLcpueStd	DK_trawl	DK_gillnet	FallSurvB
2	5	1	3.216	0.0000	ME_sprB	ME_falB	LLcpueStd	DK_trawl	DK_gillnet	
3	5	2	2.436	0.0000	ME_sprB	ME_falB	LLcpueStd	DK_trawl	FallSurvB	
4	5	3	3.196	0.0000	ME_sprB	ME_falB	LLcpueStd	DK_gillnet	FallSurvB	
5	5	4	4.254	0.0000	ME_sprB	ME_falB	DK_trawl	DK_gillnet	FallSurvB	
6	5	5	3.242	0.0000	ME_sprB	LLcpueStd	DK_trawl	DK_gillnet	FallSurvB	
7	5	6	3.327	0.0000	ME_falB	LLcpueStd	DK_trawl	DK_gillnet	FallSurvB	
8	4	1	2.184	0.0011	ME_sprB	ME_falB	LLcpueStd	DK_trawl		
9	4	2	3.166	0.0001	ME_sprB	ME_falB	DK_trawl	DK_gillnet		
10	4	3	2.253	0.0006	ME_sprB	ME_falB	LLcpueStd	FallSurvB		
11	4	4	4.088	0.0000	ME_sprB	ME_falB	DK_trawl	DK_gillnet		
12	4	5	3.140	0.0000	ME_sprB	ME_falB	DK_trawl	FallSurvB		
13	4	6	4.471	0.0000	ME_sprB	ME_falB	DK_gillnet	FallSurvB		
14	4	7	3.228	0.0000	ME_sprB	LLcpueStd	DK_trawl	DK_gillnet		
15	4	8	2.354	0.0003	ME_sprB	LLcpueStd	DK_trawl	FallSurvB		
16	4	9	3.205	0.0000	ME_sprB	LLcpueStd	DK_gillnet	FallSurvB		
17	4	10	4.447	0.0000	ME_sprB	DK_trawl	DK_gillnet	FallSurvB		
18	4	11	3.339	0.0001	ME_falB	LLcpueStd	DK_trawl	DK_gillnet		
19	4	12	2.418	0.0007	ME_falB	LLcpueStd	DK_trawl	FallSurvB		
20	4	13	3.305	0.0001	ME_falB	LLcpueStd	DK_gillnet	FallSurvB		
21	4	14	4.649	0.0000	ME_falB	DK_trawl	DK_gillnet	FallSurvB		
22	4	15	3.352	0.0001	LLcpueStd	DK_trawl	DK_gillnet	FallSurvB		
23	3	1	1.871	0.0122	ME_sprB	ME_falB	LLcpueStd			
24	3	2	3.053	0.0003	ME_sprB	ME_falB	DK_trawl			
25	3	3	5.259	0.0000	ME_sprB	ME_falB	DK_gillnet			
26	3	4	3.040	0.0002	ME_sprB	ME_falB	FallSurvB			
27	3	5	2.033	0.0037	ME_sprB	LLcpueStd	DK_trawl			
28	3	6	3.173	0.0004	ME_sprB	LLcpueStd	DK_gillnet			
29	3	7	2.128	0.0024	ME_sprB	LLcpueStd	FallSurvB			
30	3	8	5.125	0.0000	ME_sprB	DK_trawl	DK_gillnet			
31	3	9	3.142	0.0001	ME_sprB	DK_trawl	FallSurvB			
32	3	10	4.778	0.0000	ME_sprB	DK_gillnet	FallSurvB			
33	3	11	2.106	0.0091	ME_falB	LLcpueStd	DK_trawl			
34	3	12	3.310	0.0009	ME_falB	LLcpueStd	DK_gillnet			
35	3	13	2.196	0.0051	ME_falB	LLcpueStd	FallSurvB			
36	3	14	5.511	0.0000	ME_falB	DK_trawl	DK_gillnet			
37	3	15	3.305	0.0004	ME_falB	DK_trawl	FallSurvB			
38	3	16	5.074	0.0000	ME_falB	DK_gillnet	FallSurvB			
39	3	17	3.374	0.0003	LLcpueStd	DK_trawl	DK_gillnet			
40	3	18	2.319	0.0025	LLcpueStd	DK_trawl	FallSurvB			
41	3	19	3.331	0.0005	LLcpueStd	DK_gillnet	FallSurvB			
42	3	20	4.984	0.0000	DK_trawl	DK_gillnet	FallSurvB			
43	2	1	2.803	0.0042	ME_sprB	ME_falB				
44	2	2	1.611	0.0353	ME_sprB	LLcpueStd				
45	2	3	3.025	0.0014	ME_sprB	DK_trawl				
46	2	4	6.216	0.0000	ME_sprB	DK_gillnet				
47	2	5	3.014	0.0016	ME_sprB	FallSurvB				
48	2	6	1.680	0.0792	ME_falB	LLcpueStd				
49	2	7	3.317	0.0041	ME_falB	DK_trawl				
50	2	8	7.050	0.0003	ME_falB	DK_gillnet				
51	2	9	3.240	0.0045	ME_falB	FallSurvB				
52	2	10	1.901	0.0276	LLcpueStd	DK_trawl				
53	2	11	3.351	0.0046	LLcpueStd	DK_gillnet				
54	2	12	2.023	0.0180	LLcpueStd	FallSurvB				
55	2	13	6.509	0.0003	DK_trawl	DK_gillnet				
56	2	14	3.354							

Canadian Data								
Model #	Nvars	Combination	Rcrit	Pvalue	Var 1	Var 2	Var 3	Var 4
1	4	1	2.719	0.00000	Can.RV.Summer	Can.CRV.Spr	Can.CPUE	Can.SSB.Mod
2	3	1	2.703	0.00000	Can.RV.Summer	Can.CRV.Spr	Can.CPUE	
3	3	2	3.476	0.00000	Can.RV.Summer	Can.CRV.Spr	Can.SSB.Mod	
4	3	3	2.317	0.00000	Can.RV.Summer	Can.CPUE	Can.SSB.Mod	
5	3	4	2.532	0.00000	Can.CRV.Spr	Can.CPUE	Can.SSB.Mod	
6	2	1	3.967	0.00002	Can.RV.Summer	Can.CRV.Spr		
7	2	2	2.101	0.00004	Can.RV.Summer	Can.CPUE		
8	2	3	3.079	0.00000	Can.RV.Summer	Can.SSB.Mod		
9	2	4	2.420	0.00040	Can.CRV.Spr	Can.CPUE		
10	2	5	3.458	0.00004	Can.CRV.Spr	Can.SSB.Mod		
11	2	6	1.948	0.00000	Can.CPUE	Can.SSB.Mod		
12	1	1	3.519	0.00026	Can.RV.Summer			
13	1	2	4.410	0.01296	Can.CRV.Spr			
14	1	3	1.344	0.01606	Can.CPUE			
15	1	4	2.763	0.00000	Can.SSB.Mod			

[1] Average Rcrit value overall models=

[1] 2.850295

[1] fraction of models with significance probability <0.05

[1] 1

Rcrit average for models that do NOT include Can.SSB.Mod

2.923448

Changes in catches and indices for US and Canada. See Text table, p.16

		Changes in catches			Change in indices				
Ratio Definition		Statistic	Rcrit	%/yr	Statistic	Rcrit	%/yr	Model	
US		'02-04:'14-'16	Rcrit(Catch)	3.227	9.4%	Rcrit(Indices)	3.23	9.4%	(all six indices)
						4.98	13.1%	(DK_g, DK_t, Survey)	
						3.52	10.2%	average over 63 models	
		'05-07:'14-'16	Rcrit(Catch)	2.657	13.0%	Rcrit(Indices)	2.20	10.4%	(all six indices)
						4.11	19.3%	DK_g, DK_t, Survey	
						2.44	11.8%	average over 63 models	
		'02-04:'11-'13	Rcrit(Catch)	2.617	10.1%	Rcrit(indices)	2.893	11.2%	(all six indices)
						5.033	17.5%	(DK_g, DK_t, Survey)	
						3.144	12.1%	average over 63 models	
Canada	2002-04: 2014-2016	Rcrit(Catch)	2.259	6.5%	Rcrit(Indices)	2.703	7.9%	(two surveys , one CPUE average over 6 models Analytical model results)	

Replacement Yield Model (RYM)

- Used in past assessment but unstable results when updated in 2015
(concluded to be REBUILT in 2014)

$$B_t = B_{t-1} + R_{t-1} - C_{t-1} \quad [1]$$

$$R_t = rB_t \left(1 - \frac{B_t}{K}\right) \quad [2]$$

- Basically a Surplus production model with constraints
 - Fixed $r=2$ F0.1
 - Fixed $q=0.5$ for fall survey
 - Assumptions about catch history
- Review panel “the updated assessment was not acceptable as a scientific basis for management advice. The updated assessment produced an unstable and unrealistic solution”

Revised model for stock dynamics

- Assume linear model BUT r and h vary with time

- $B_{t+1} = B_t + r_t B_t - h_t B_t \quad [17]$

- $C_t = h_t B_t \quad [18]$

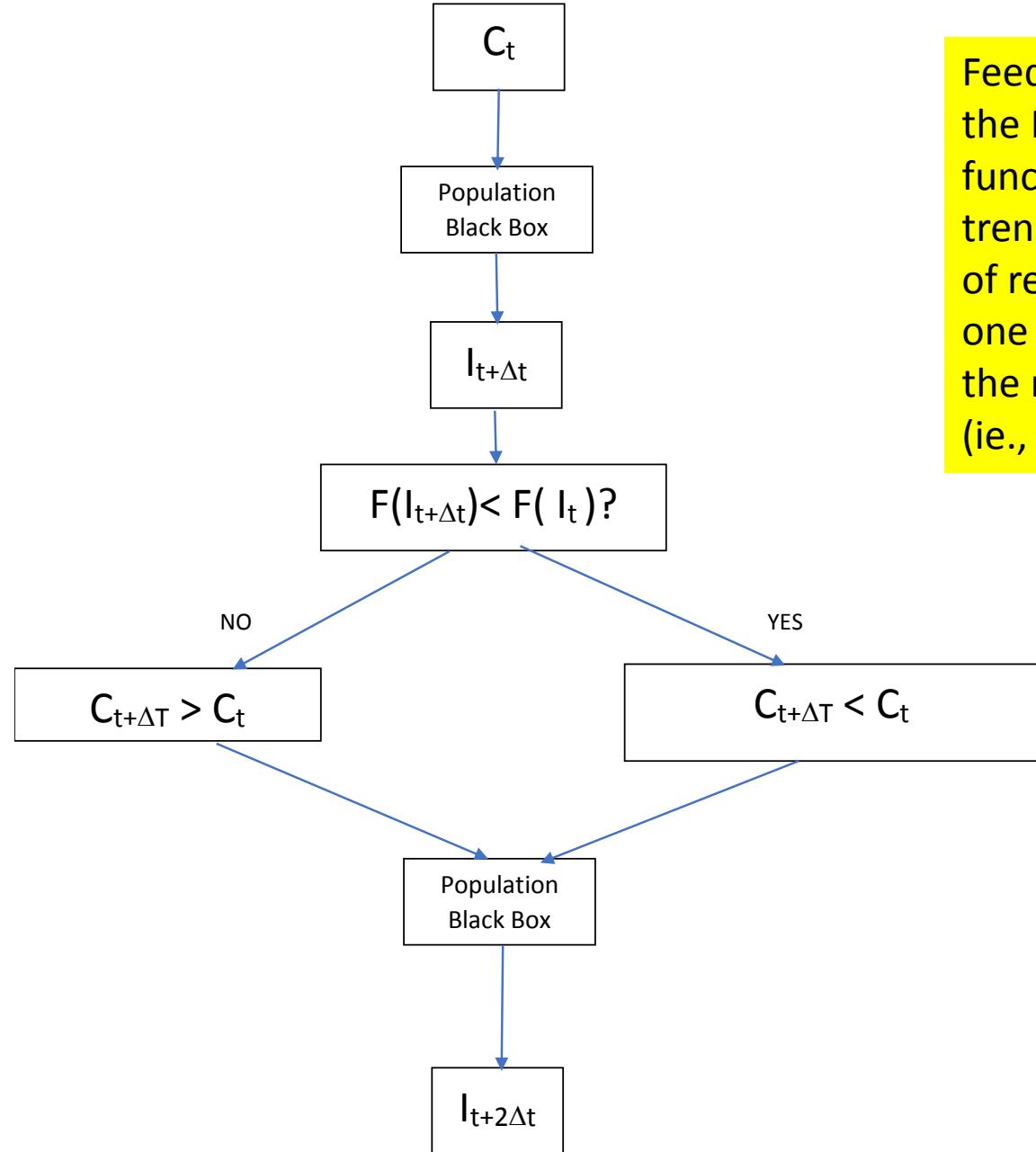
- $\frac{C_{t+1}}{C_t} = \frac{h_{t+1} B_{t+1}}{h_t B_t} \quad [22] \quad C_{t+1} = \frac{h_{t+1}}{h_t} \frac{I_{t+1}}{I_t} C_t \quad [24]$

- $\frac{B_{t+1}}{B_t} = \frac{q I_{t+1}}{q I_t} = \frac{I_{t+1}}{I_t} = 1 + r_t - h_t \quad [26]$

- $\ln(I_{t+p}) = (p \ln(1 + r - h) + \ln(I_t)) \quad [29]$

- $slope_t = \ln(1 + r_t - h_t)$

FIG 15 in
Report



Feedback Process used in the FSD model. The $F()$ function estimates the trend (ie., first derivative of relative abundance) in one or more indices AND the rate of change in trend (ie., the second derivative)

The magnitude of the change in C is determined by the values of the first and second derivatives and the gain parameters(K_p , K_d) applied.

Building the First and Second Derivative Model

- Recursive equation for updating catch
- $C_{t+1} \cong \frac{h_{t+1}}{h_t} e^{slope_t} C_t$ [31]
- This can be extended to multiple indices
- BUT also interested in ability to detect changes in the slope.
- Need to extend model
- $\beta(t, n) = slope(x_{t-n+1}, x_{t-n}, \dots, x_{t-1}, x_t)$
- $\Delta\beta(t, n) = \beta(t, n) - \beta(t - 1, n)$ [34]

Controllability

- Do we want to take all of the increase in relative abundance and translate it to an equivalent increase in catch?
- Why not, it's only fair
 - Concerns about lag in signal—based on 5 year window of index observations
 - Possibly bad signal, observation error is high.
 - Longevity suggest that under harvest of halibut will be in the water next year to capture. Therefore can balance tradeoff.
 - Examples from control theory literature (eg. Thermostats) suggest potential instability in process if gain is set too high.
- Many MPA examples consider “slow up, fast down” policies
- One way to quantify is to consider rate of change in slope in terminal year, an approximation of the second derivative of abundance.
- Important because of potential changes in productivity over time ($r(t)$). Especially important if stock productivity is declining via slower growth or reduced recruitment

Weighting the slope and delta slope components

- Gain factors
 - Kp Gain on proportional rate of change
 - Kd Gain on derivative of change
- $C_{t+1} = e^{(K_p\beta(t,n)+K_d\Delta\beta(t,n))} C_t$ [35]
- Equation 35 is the recursive updating equation for catch. Note that when Kp=Kd=0 this becomes a constant status quo catch model.

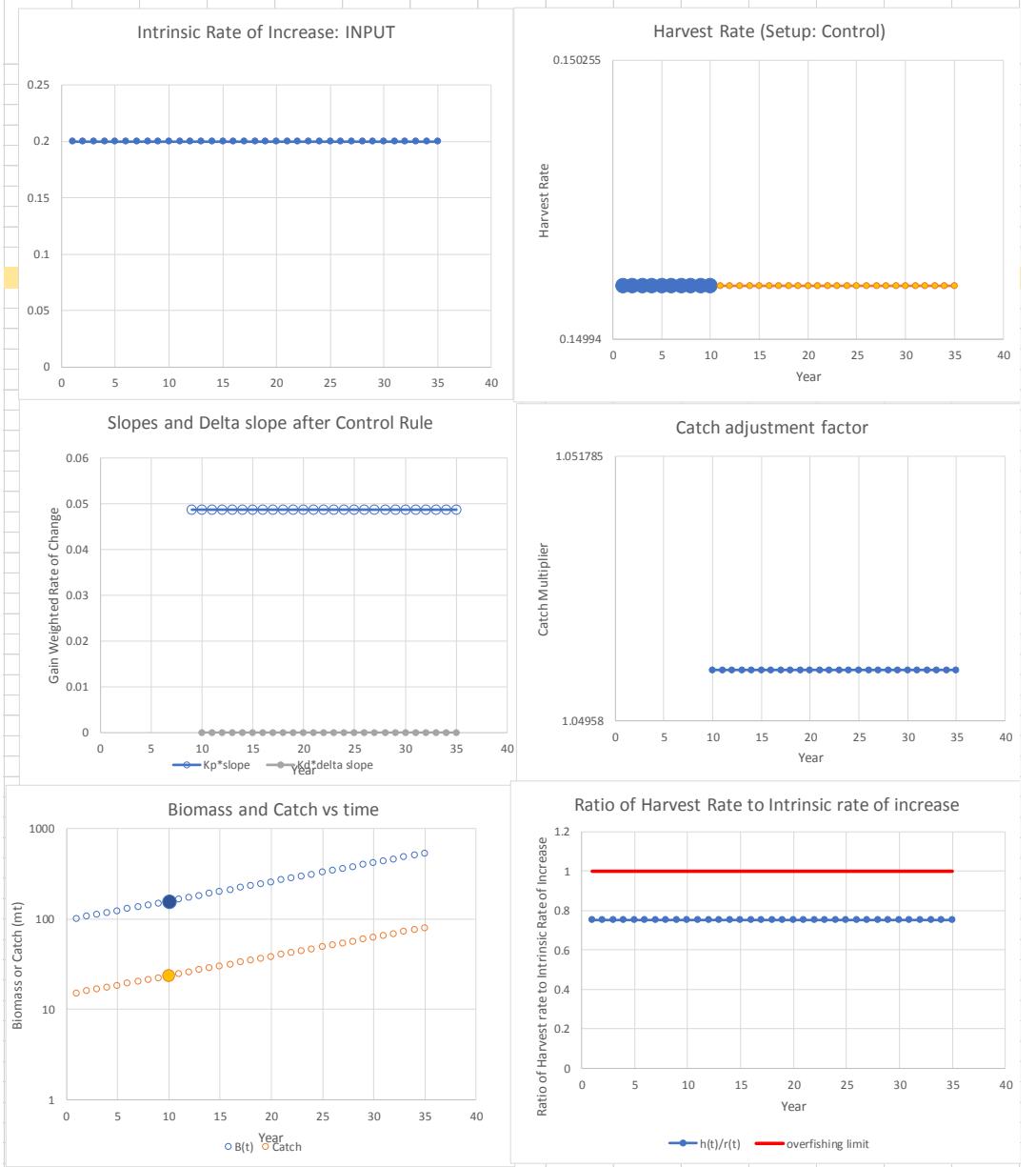
Simulation Tests on FSD model

- Observation error for the relative abundance indices $CV=\{0.005, 0.2\}$
- Number of abundance indices available $Nvar=\{2, 6\}$
- Number of years to consider for estimating average slope.
 $Ntrend=\{3, 5\}$
- Effects of alternative values of K_p and K_d
- The underlying rate of population increase ($r(t)$) during the period before and after the control rule is applied.
- The pattern of harvesting ($h(t)$) prior to the application of the control rule.

What is expected behavior of population controlled by FSD?

- Depends on:
 - True rate of change in productivity
 - Initial conditions prior to implementation of controls
 - Harvest rates
 - Intrinsic rate of increase
 - Weighting factors applied to slope and Delta slope
 - Ability to track changes in relative abundance
- Any control system that relies on past information to forecast future conditions will have problems when
 - Lags in information—slope is based on n years, reflecting a balance between sensitivity and estimability—the Signal:Noise ratio.
 - The population biology changes—growth declines, recruitment fails etc (e.g., IPHC Pacific Halibut)
 - The fishery changes—fishing activity becomes more targeted resulting in stable CPUE while stock declines

Initial Harvest $h(t)$ Scenario	Intrinsic rate of increase $r(t)$ scenario	Number of years used for slope estimation	Kp Gain on slope derivative	Kd Gain on slope derivative	Total Catch	CV of Catch	Max Cmult	Min Cmult	Fraction of Overfishing Events
1	1	5	1	0	1166	0.355	1.050	1.050	0.00

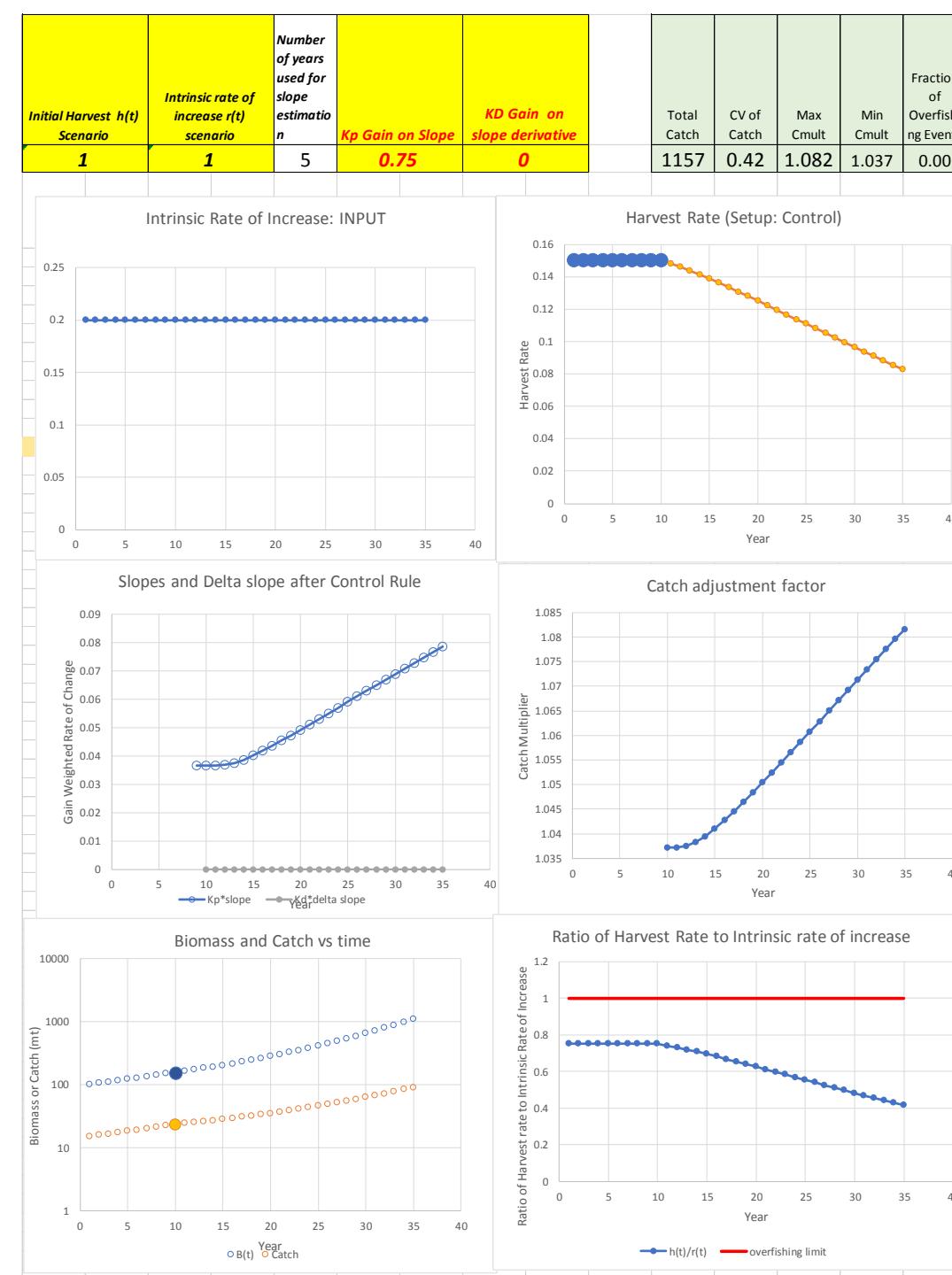


Example 1—the boring equilibrium:

- Intrinsic rate of increase is constant =0.2
- Initial Harvest rate is below intrinsic rate during initial period $h(t)=0.15$
- Assume $Kp=1.0$ for proportional and $Kd=0$ for derivative controls

Key Results

- High cumulative catch 1166 mt
- No Overfishing
- Multiplier is same over entire period= 1.05
- Stock size AND catch continuously increase.
- Rate of population growth during control period is same as in period of no direct control.



Example 2— Don't take it all policy:

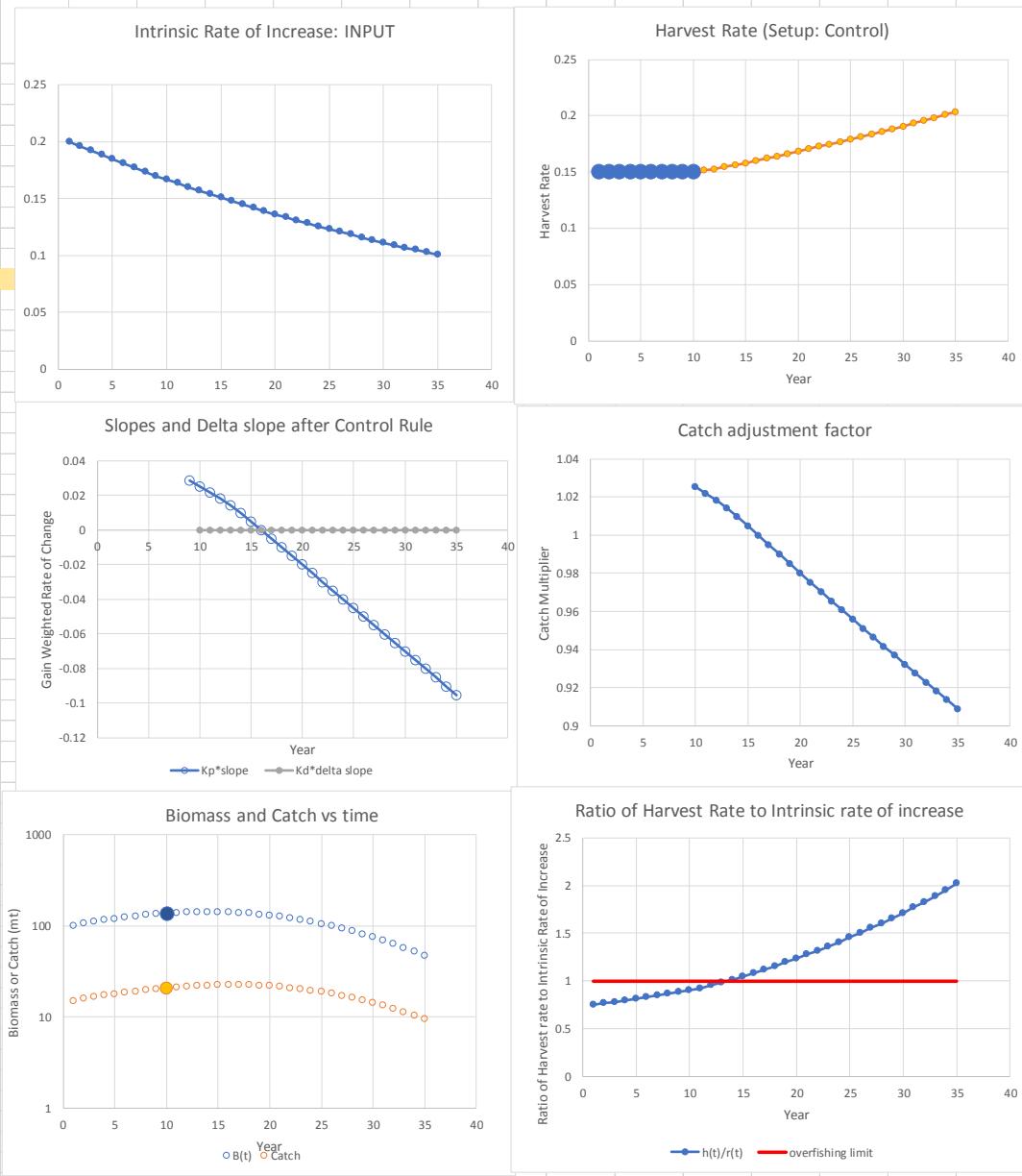
- Intrinsic rate of increase is constant =0.2
- Initial Harvest rate is below intrinsic rate during initial period $h(t)=0.15$
- **Assume Kp=0.75** for proportional and Kd=0 for derivative controls

Key Results

- High cumulative catch 1157 mt but much of this comes in the out years as population continues to increase
- No Overfishing AND Harvest Rate continues to decrease
- Multiplier increases over entire period= 1.05
- Stock size AND catch increases slightly.
- Rate of population growth increases continuously over the control period.

Initial Harvest $h(t)$ Scenario	Intrinsic rate of increase $r(t)$ scenario	Number of years used for slope estimation	Kp Gain on slope derivative	Kd Gain on slope derivative	Total Catch	CV of Catch	Max Cmult	Min Cmult	Fraction of Overfishing Events
1	4	5	1	0	456.7	0.233	1.025	0.909	0.63

More challenging Control Problems: Stock productivity declines continuously



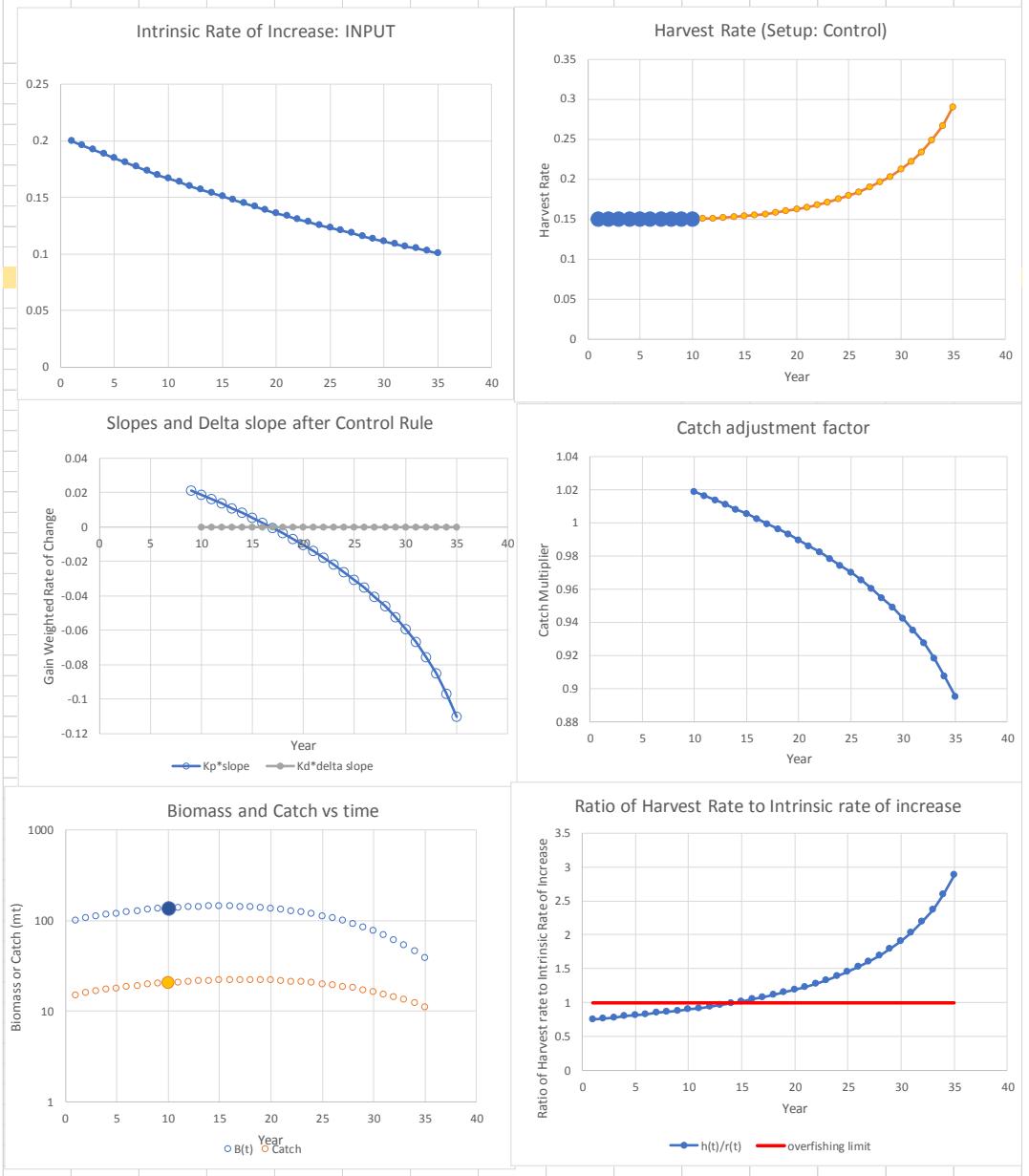
Example 3:

- Intrinsic rate of increase is DECLINING
- Initial Harvest rate is below intrinsic rate during initial period
- Set **Kp=1** (take it all). Don't consider derivative. (Kd=0)

Key Results

- Moderate cumulative catch 457 mt
- Overfishing commences about year 10. Frequency of overfishing years is 63%
- Minimum catch multiplier is 0.91 or 9% decrease
- Stock size gradually declines as do catches as the stock declines

Initial Harvest $h(t)$ Scenario	Intrinsic rate of increase $r(t)$ scenario	Number of years used for slope estimation	Kp Gain on slope derivative	Kd Gain on slope derivative
1	4	5	0.75	0



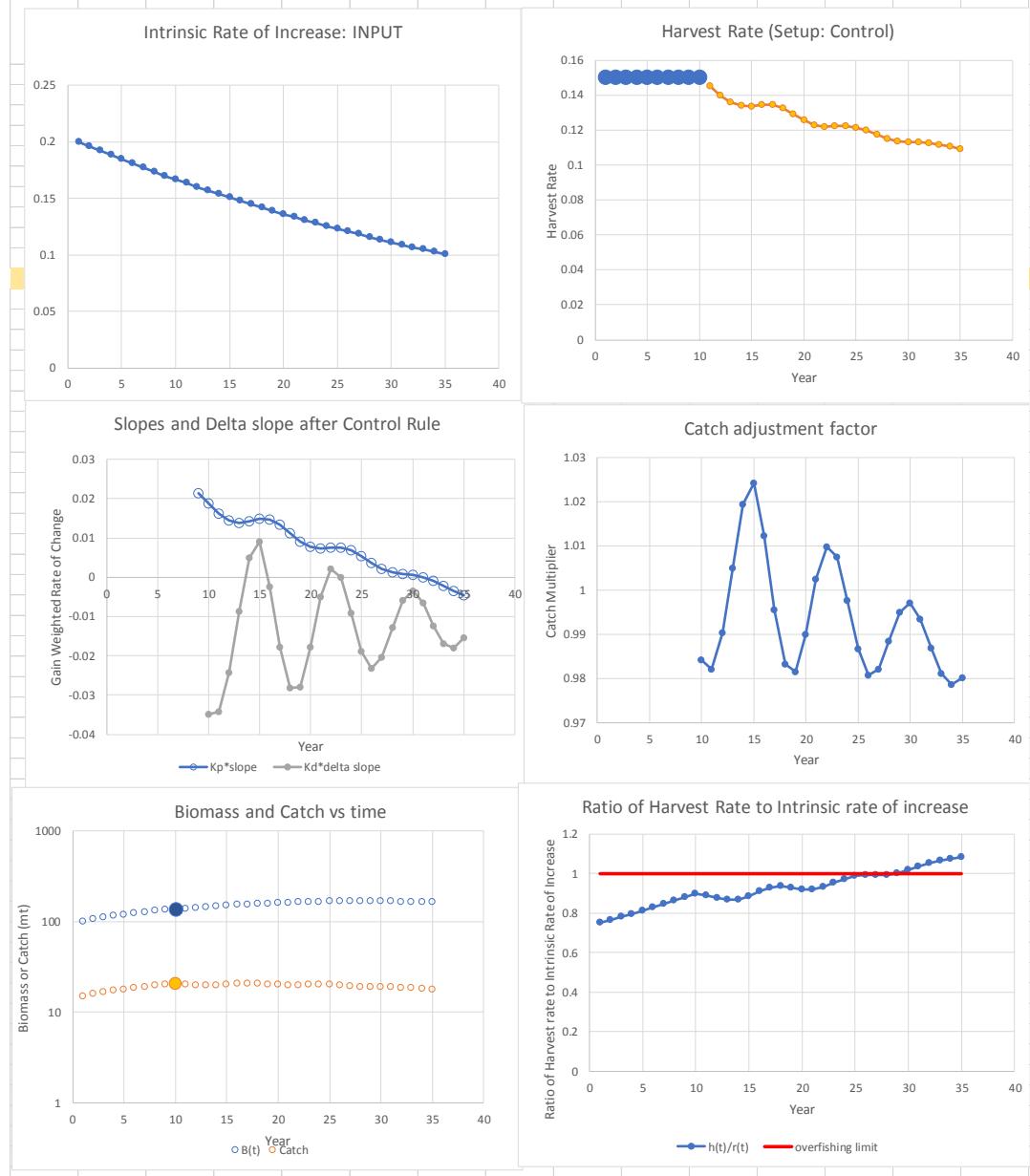
Example 4:

- Intrinsic rate of increase is DECLINING
- Initial Harvest rate is below intrinsic rate during initial period
- Set **Kp=0.75** (hold back). Don't consider derivative. (Kd=0)

Key Results

- Moderate cumulative catch 475 mt
- **Overfishing commences about year 15**. Frequency of overfishing years is 60%
- Minimum catch multiplier is 0.89 or 11% decrease
- Stock size gradually declines as do catches as the stock declines

Initial Harvest $h(t)$ Scenario	Intrinsic rate of increase $r(t)$ scenario	Number of years used for slope estimation	Kp Gain on slope derivative	KD Gain on slope derivative	Total Catch	CV of Catch	Max Cmult	Min Cmult	Fraction of Overfishing Events
1	4	5	0.75	10	487.4	0.042	1.024	0.979	0.20



Using the gain on the second derivative $K_d > 0$

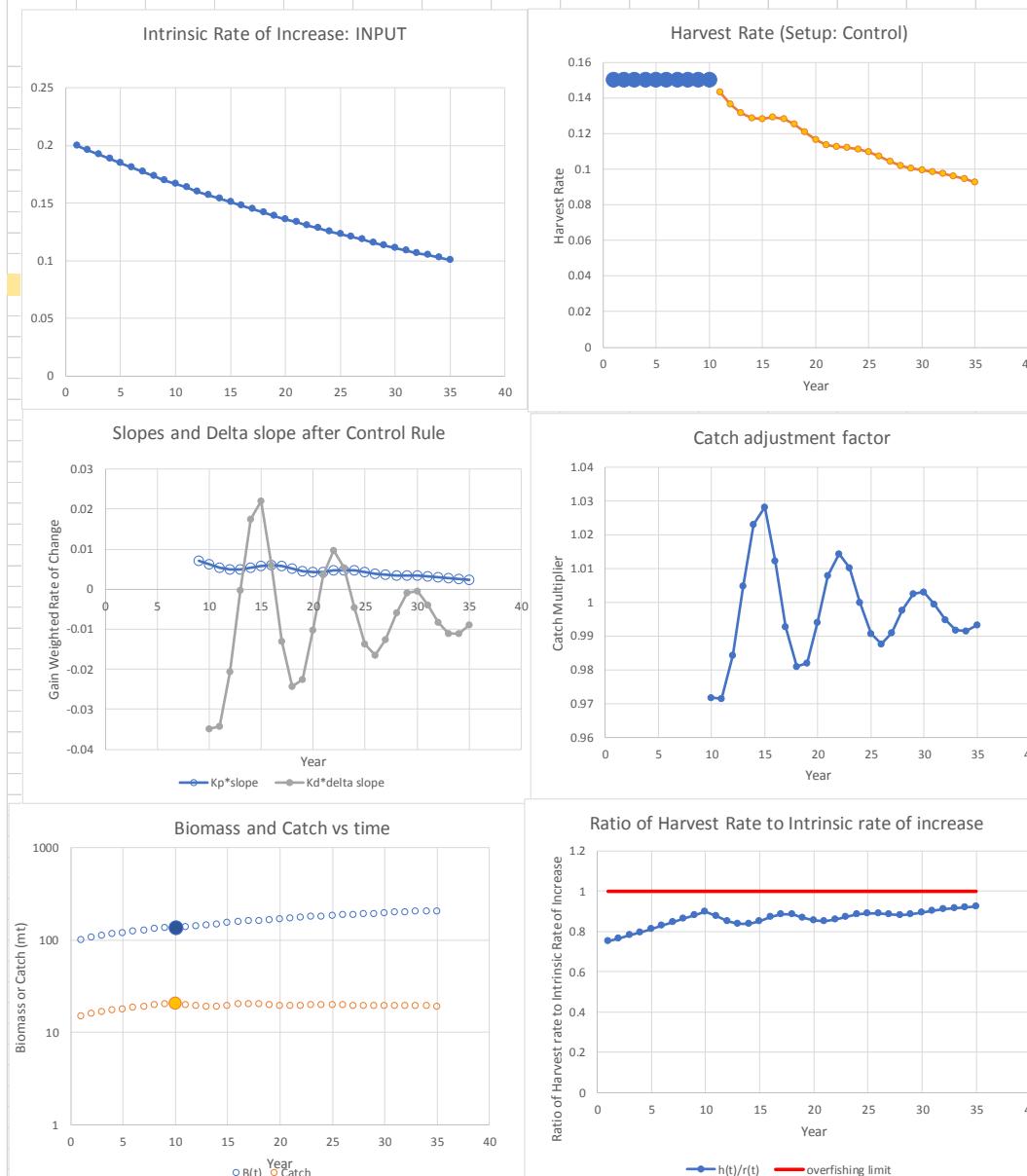
Example 5:

- Intrinsic rate of increase is DECLINING
- Initial Harvest rate is below intrinsic rate during initial period
- Differential weights on proportional and derivative controls:
 - $K_p=0.75$
 - $K_d=10$

Key Results

- Slightly higher cumulative catch 488 mt
- Overfishing commences about year 30. Frequency of overfishing years is 20%
- Minimum catch multiplier is 0.98 or 2% decrease
- Catch multiplier oscillates but within a narrow range. +/- 2%.
- Stock size remains stable despite decreasing trend in productivity as do catches

<i>Initial Harvest $h(t)$ Scenario</i>	<i>Intrinsic rate of increase $r(t)$ scenario</i>	<i>Number of years used for slope estimation</i>	<i>Kp Gain on Slope</i>	<i>Kd Gain on slope derivative</i>
1	4	5	0.25	10



Fine tuning. Set Kp to a low value and rely more on gain on the second derivative Kd>0

Example 6:

- Intrinsic rate of increase is DECLINING
- Initial Harvest rate is below intrinsic rate during initial period
- Differential weights on proportional and derivative controls:
 - $Kp=0.25$ (less weight on proportional change)
 - $Kd=10$

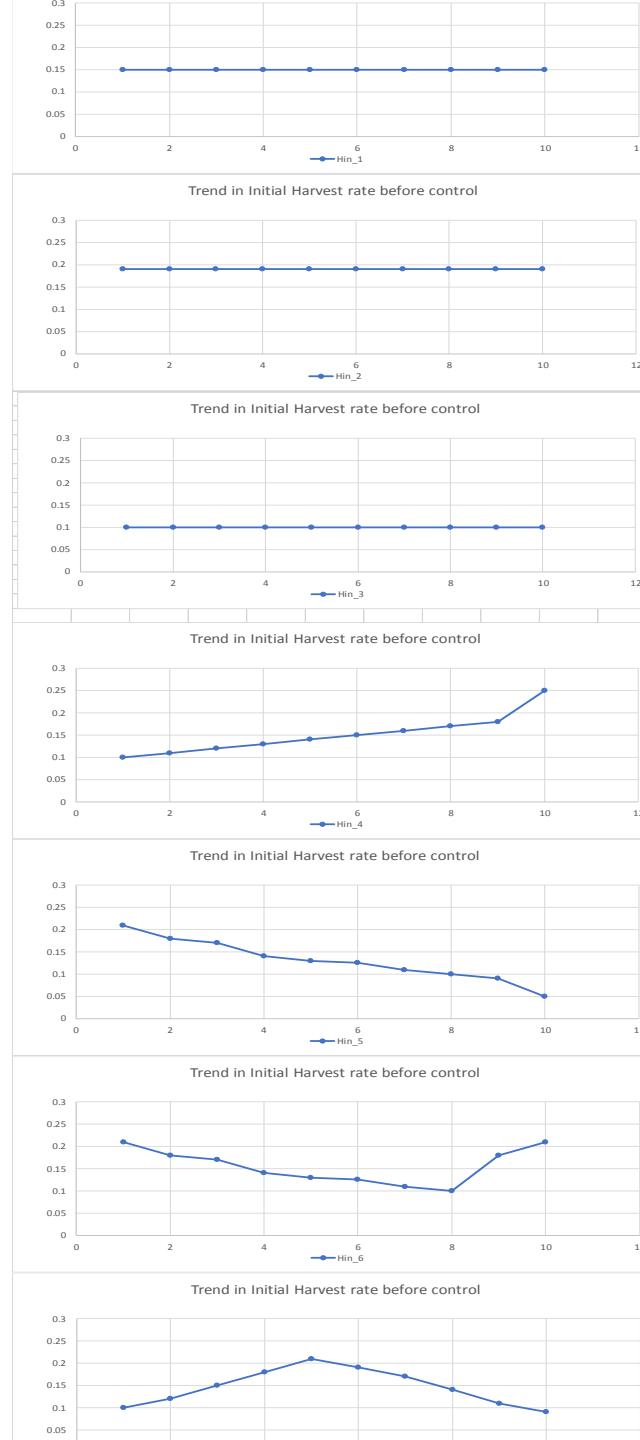
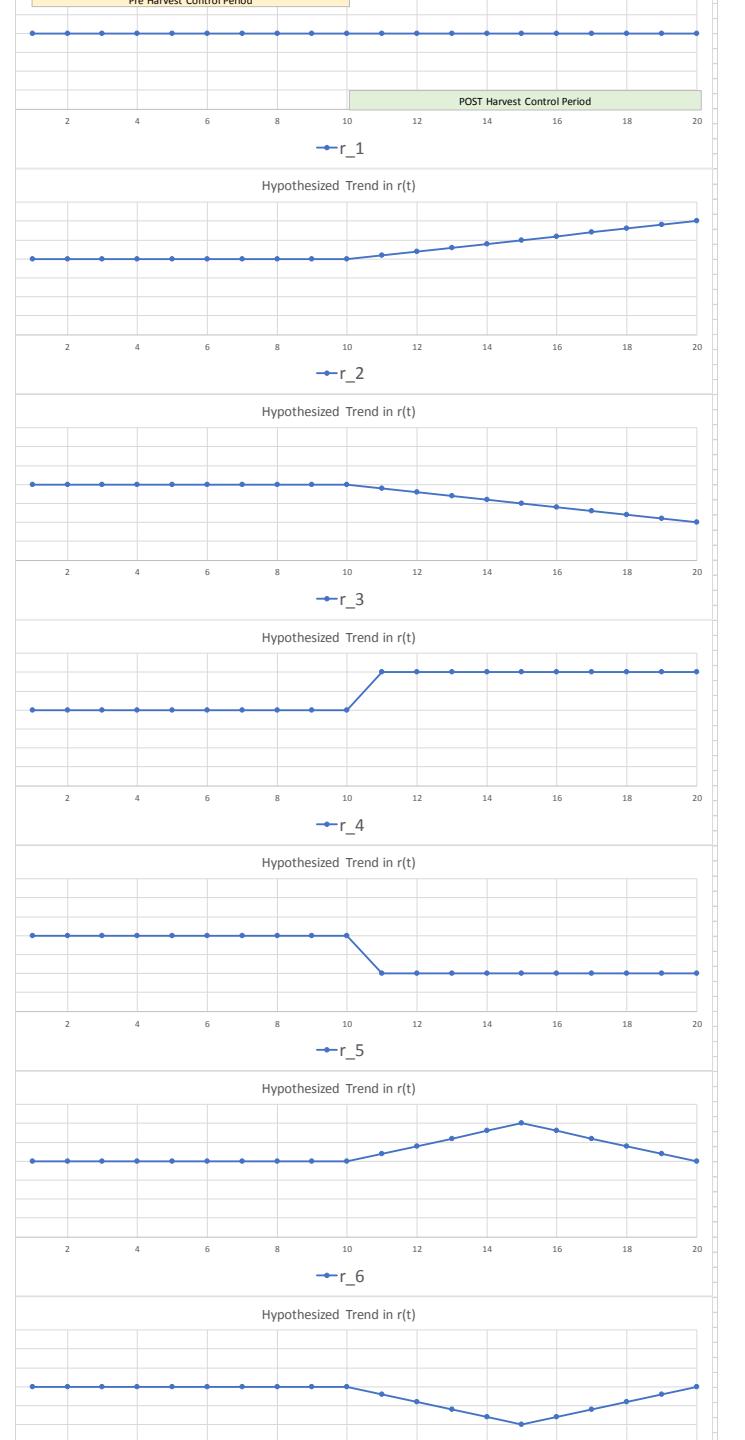
Key Results

- About the same cumulative catch 487 mt
- NO overfishing over the entire period
- Minimum catch multiplier is 0.97 or 3% decrease
- Catch multiplier oscillates but within a narrow range. +/- 3%.
- Stock size remains stable despite decreasing trend in productivity as do catches

But of course, we don't know what the future holds and only have modest information about the initial conditions.

- So it is helpful to simulate various control strategies for different assumptions about the:
 - Intrinsic rate of increase
 - Harvest rate in the initial (pre-control) period
 - Variability of observations
 - Number of indices available
 - Number of years used to estimate slope
 - Alternative weighting factors for proportional and derivative gain (K_p, K_d)

Temporal
Change in
intrinsic rate
of growth $r(t)$.
See Fig. 16



Temporal
Change in initial
harvest rate $h(t)$
prior to
implementation
of the control
rule governed
by FSD.

See Fig. 17

FSD Simulation Results

- Consider effects of
 - Multiple set up conditions $r(t)$ and $h(t)$.
 - Multiple number of relative abundance indices
 - Varying levels of observation error
 - Varying number of years used to estimate slope.
 - Different gain factors applied to slope indices
- Need to consider multiple objectives as metrics for choosing a control strategy.
 - Average # of overfishing events
 - Average catch
 - CV of catch
 - Simulation failures—overshoots on catch
 - Net rate of population growth during the period where the FSD control is applied

Average % of overfishing events						Fraction of simulation failures					
CV	Kd	Kp=0.25	Kp=0.5	Kp=0.75	Kp=1	CV	Kd	Kp=0.25	Kp=0.5	Kp=0.75	Kp=1
0.005	0	0.171	0.201	0.229	0.282	0.005	0	0.163	0.163	0.153	0.134
	1	0.197	0.228	0.249	0.314		1	0.122	0.112	0.111	0.071
	5	0.244	0.254	0.269	0.280		5	0.000	0.000	0.000	0.000
	10	0.217	0.237	0.255	0.281		10	0.000	0.004	0.010	0.022
0.2	0	0.171	0.201	0.234	0.275	0.2	0	0.166	0.164	0.157	0.151
	1	0.196	0.231	0.271	0.309		1	0.126	0.114	0.097	0.082
	5	0.247	0.253	0.274	0.292		5	0.034	0.035	0.029	0.028
	10	0.226	0.241	0.258	0.279		10	0.147	0.162	0.182	0.194
Average Catch						Net rate of population change during control period					
CV	Kd	Kp=0.25	Kp=0.5	Kp=0.75	Kp=1	CV	Kd	Kp=0.25	Kp=0.5	Kp=0.75	Kp=1
0.005	0	228.6	248.9	270.6	296.5	0.005	0	0.078	0.071	0.061	0.047
	1	236.0	254.8	275.3	298.9		1	0.071	0.063	0.056	0.038
	5	256.6	276.3	297.6	320.1		5	0.058	0.054	0.049	0.043
	10	294.4	313.5	332.1	348.2		10	0.054	0.048	0.041	0.033
0.2	0	227.8	248.3	270.6	295.6	0.2	0	0.078	0.071	0.062	0.052
	1	235.0	254.5	276.3	298.8		1	0.072	0.062	0.050	0.038
	5	256.6	277.2	297.1	319.4		5	0.055	0.050	0.042	0.035
	10	292.7	314.0	332.2	346.4		10	0.050	0.044	0.036	0.027
Average CV of Catch											
CV	Kd	Kp=0.25	Kp=0.5	Kp=0.75	Kp=1						
0.005	0	0.068	0.135	0.199	0.259						
	1	0.097	0.159	0.219	0.283						
	5	0.239	0.281	0.322	0.361						
	10	0.401	0.430	0.458	0.483						
0.2	0	0.070	0.137	0.203	0.266						
	1	0.115	0.176	0.239	0.304						
	5	0.368	0.410	0.457	0.503						
	10	0.675	0.712	0.737	0.769						

Summary of simulation results by Kp and Kd gain factors. Results are averaged over 7 different scenarios for population productivity and 7 scenarios for pre-control harvest rates.

Response variables are:

- Ave % overfishing events
- Average Catch
- Ave CV of Catch
- Fraction of Sim Failures
- Net of increase during control period

See Table 14 in report

Average % of overfishing events						Average Catch					
<i>CV</i>	<i>Kd</i>	<i>Kp=0.25</i>	<i>Kp=0.5</i>	<i>Kp=0.75</i>	<i>Kp=1</i>	<i>CV</i>	<i>Kd</i>	<i>Kp=0.25</i>	<i>Kp=0.5</i>	<i>Kp=0.75</i>	<i>Kp=1</i>
0.005	0	0.171	0.201	0.229	0.282	0.005	0	228.6	248.9	270.6	296.5
	1	0.197	0.228	0.249	0.314		1	236.0	254.8	275.3	298.9
	5	0.244	0.254	0.269	0.280		5	256.6	276.3	297.6	320.1
	10	0.217	0.237	0.255	0.281		10	294.4	313.5	332.1	348.2
						0.2	0	227.8	248.3	270.6	295.6
							1	235.0	254.5	276.3	298.8
							5	256.6	277.2	297.1	319.4
							10	292.7	314.0	332.2	346.4
0.2	0	0.171	0.201	0.234	0.275						
	1	0.196	0.231	0.271	0.309						
	5	0.247	0.253	0.274	0.292						
	10	0.226	0.241	0.258	0.279						
						Average CV of Catch					
						<i>CV</i>	<i>Kd</i>	<i>Kp=0.25</i>	<i>Kp=0.5</i>	<i>Kp=0.75</i>	<i>Kp=1</i>
						0.005	0	0.068	0.135	0.199	0.259
						1	0.097	0.159	0.219	0.283	
						5	0.239	0.281	0.322	0.361	
						10	0.401	0.430	0.458	0.483	
0.2	0	0.070	0.137	0.203	0.266						
	1	0.115	0.176	0.239	0.304						
	5	0.368	0.410	0.457	0.503						
	10	0.675	0.712	0.737	0.769						

Text table—Page 26. Effect of scenarios on frequency of simulation failures, averaged over all gain factors (K_p, K_d).

		R scenario							
		r=0.2	r_up	r_down	r_step_up	r_step_dn	r_up_dn	r_dn_up	
Description	Harvest Scenario	1	2	3	4	5	6	7	average
<i>h=0.15</i>	1	0.0159	0.0241	0.0178	0.0256	0.0191	0.0225	0.0181	0.020
<i>h=0.19</i>	2	0.0394	0.0375	0.0363	0.0525	0.3281	0.0456	0.0419	0.083
<i>h=0.10</i>	3	0.0053	0.0078	0.0091	0.0078	0.0078	0.0094	0.0053	0.008
<i>h_up</i>	4	0.3722	0.0816	0.5066	0.0691	0.5500	0.1044	0.5113	0.314
<i>h_down</i>	5	0.0016	0.0016	0.0013	0.0028	0.0013	0.0025	0.0019	0.002
<i>h_dn_up</i>	6	0.0469	0.0363	0.3153	0.0316	0.5028	0.0534	0.4019	0.198
<i>h_up_dn</i>	7	0.0119	0.0188	0.0156	0.0231	0.0184	0.0203	0.0141	0.017
	average	0.070	0.030	0.129	0.030	0.204	0.037	0.142	0.092

Application of FSD to US stock

- Used 3 core indices:
 - NEFSC fall survey weight per tow
 - d/k ratio for gill nets
 - d/k ratio for trawls
- Examined fit over a range of Kp and Kd gain factors

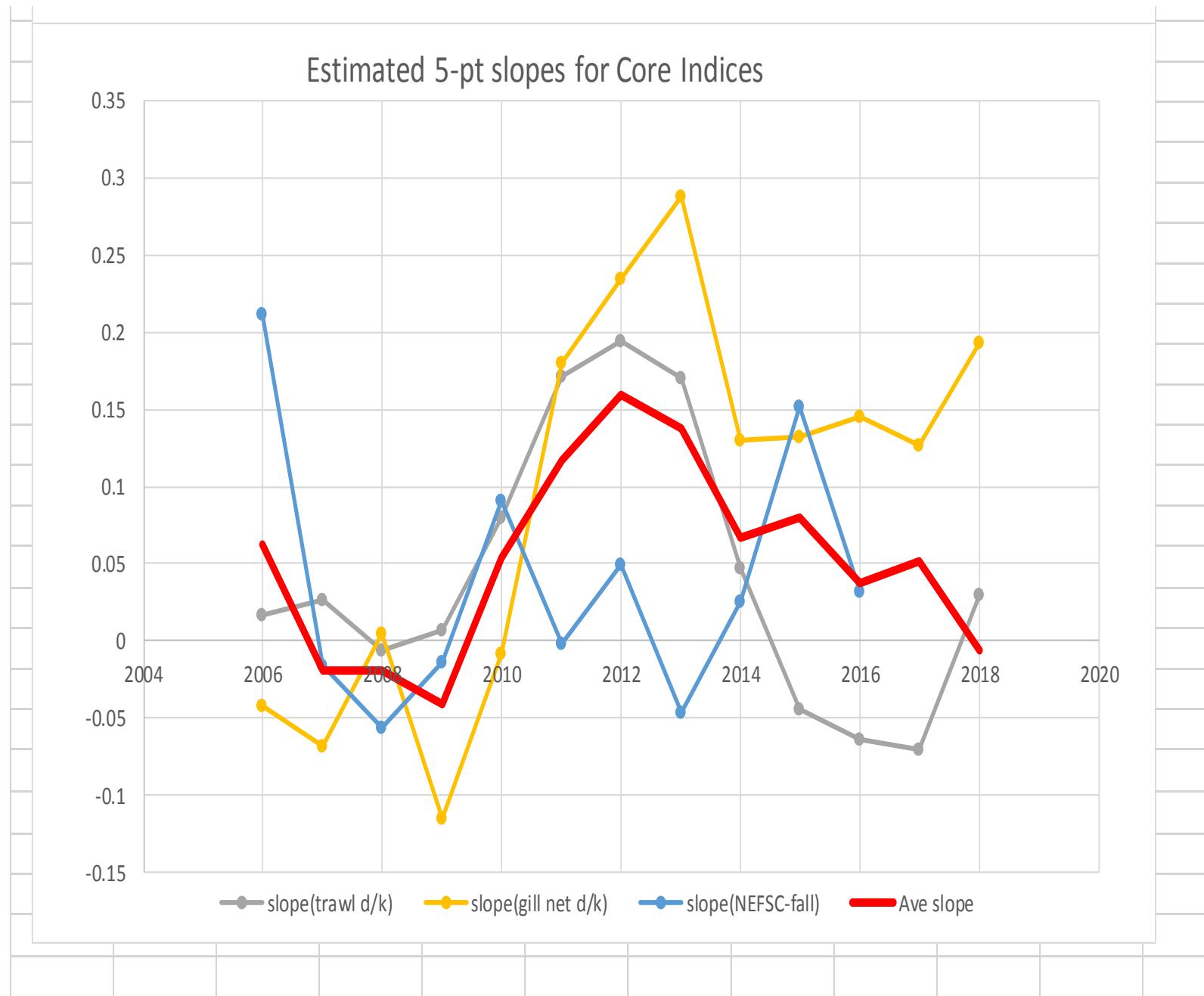


Figure 18 in Report
(bottom)

Three Core Indices

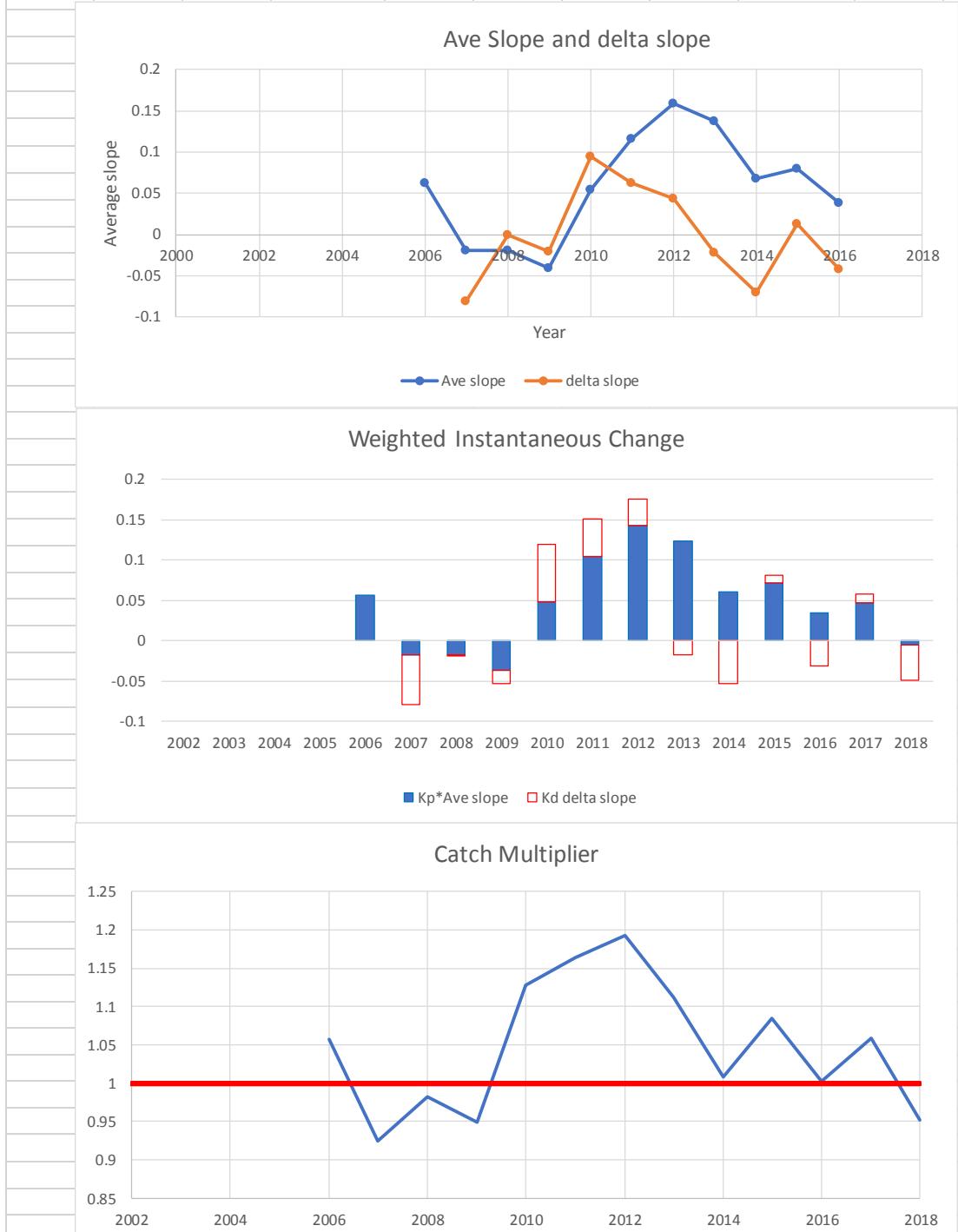


Figure 19 in Report

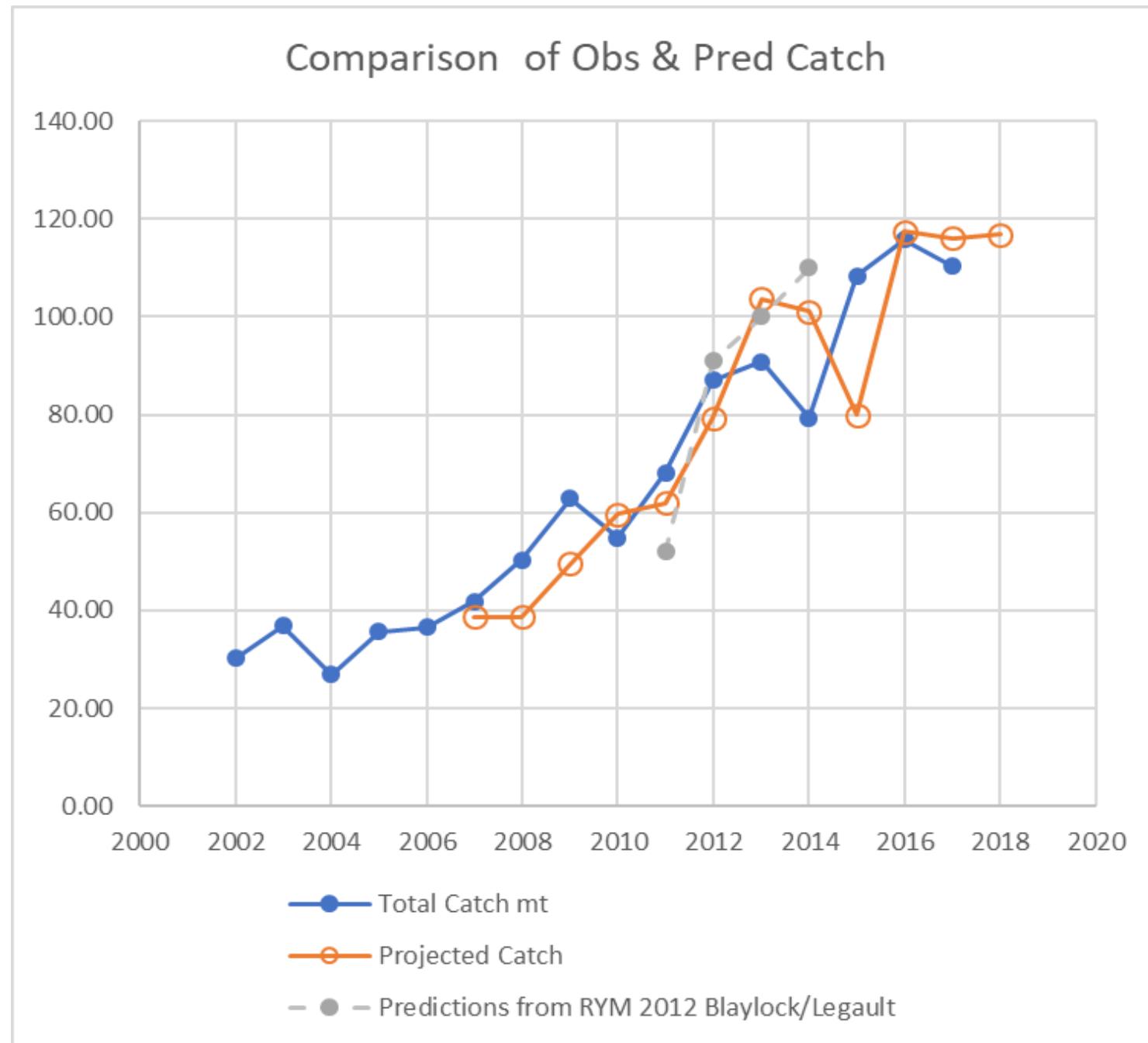


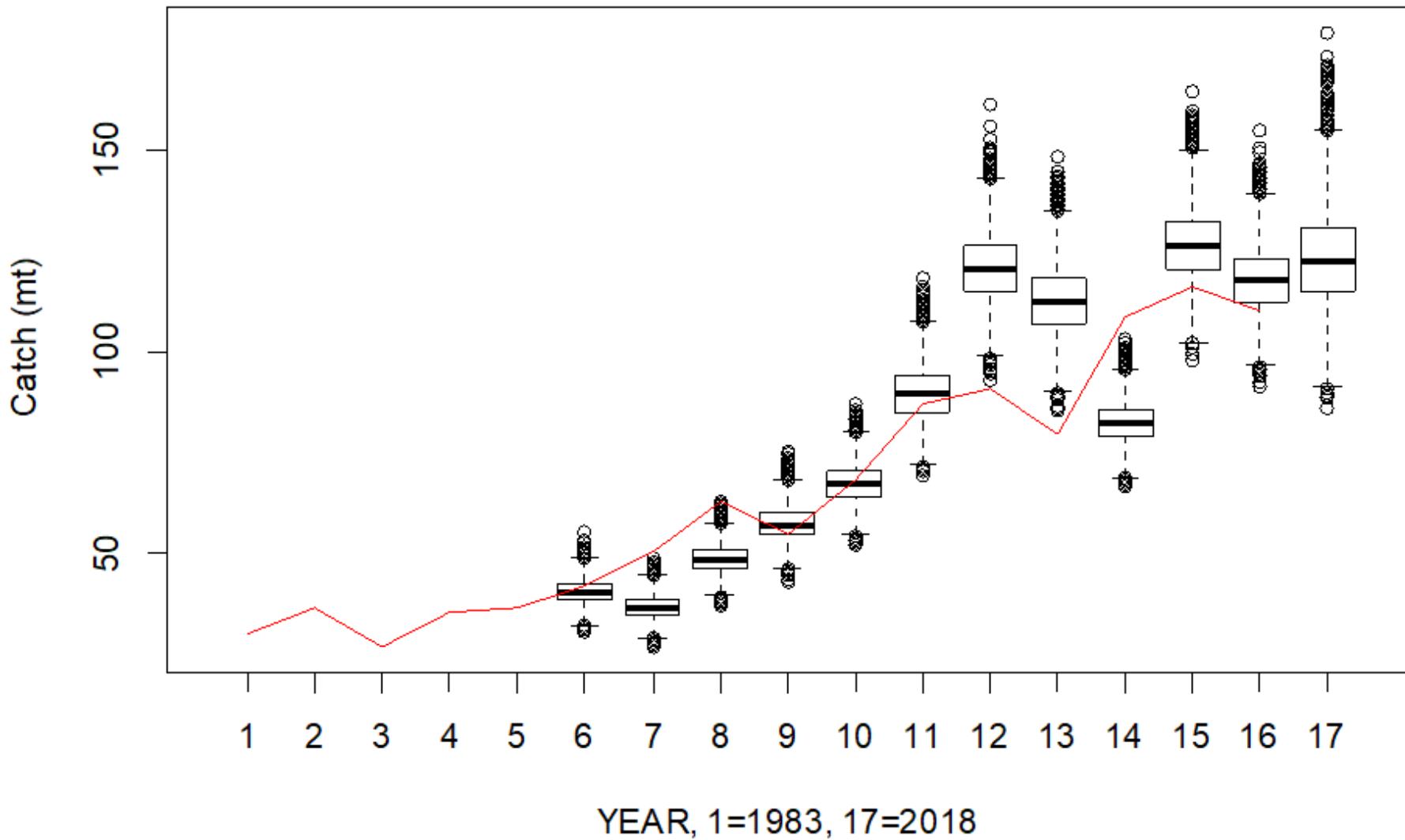
Figure 20 in Report

Bootstrap Method for Projections

- $Irand_{k,j,t} \sim LogNormal(Iobs_{j,t}, \sqrt{CV_{j,t}^2 + 1})$
- Apply to 3 core indices
 - d/k gill net
 - d/k trawl
 - NEFSC Fall Survey weight per tow
- Replicate 5000 times
- Compute sampling distribution of forecasts at each step

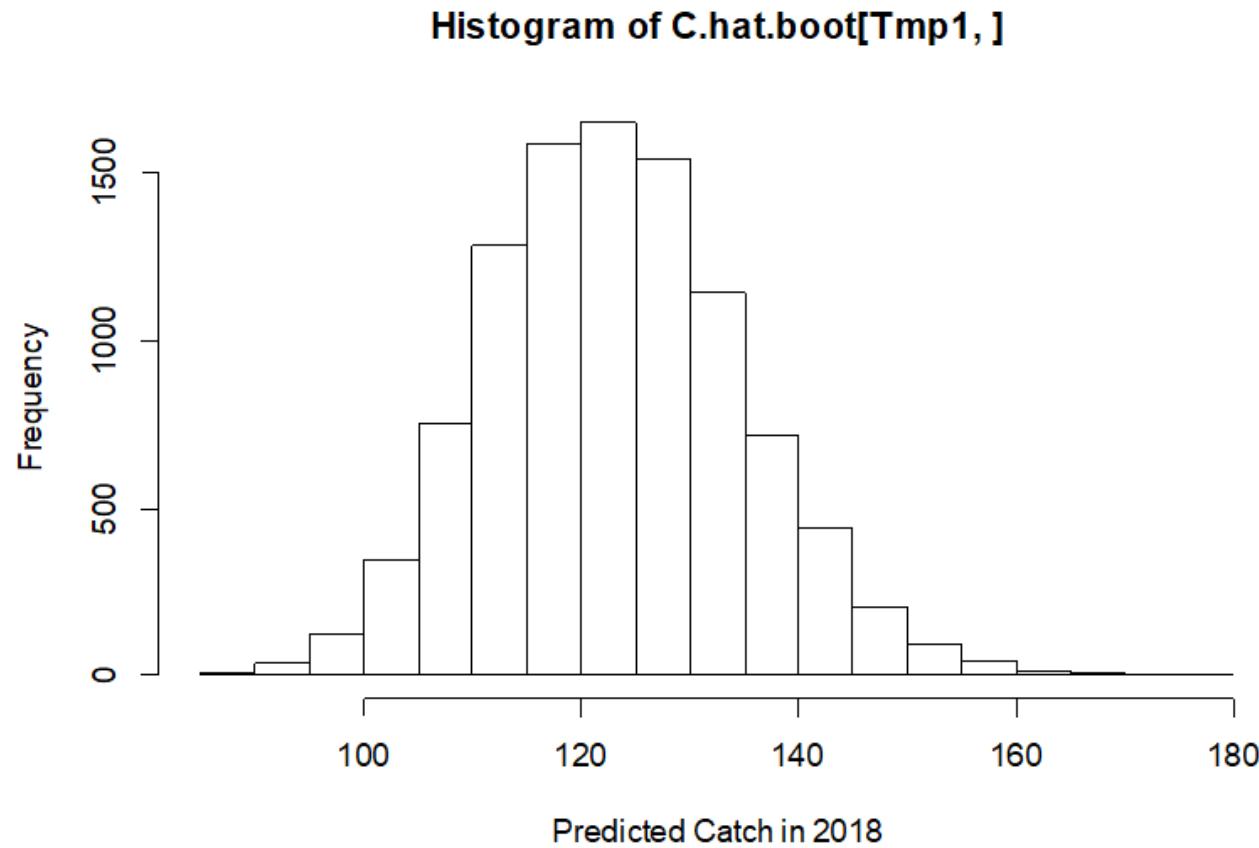
Uncertainty estimates for FSD projections

Figure 21 in Report



Projected Catch (mt) distribution for 2018

Figure 22 in Report



1%	5%	10%	25%	50%	75%	90%	95%	99%
98.24	104.98	108.61	114.88	122.65	130.69	138.34	143.16	152.26

The bootstrap mean of projected catch is 123.10 mt with a CV equal to 0.095.

Range of Possible Catch Estimates

- Examine implications of different weightings of Kp and Kd gain factors.
- How much weight for the proportional gain—how much of the population rate of increase translates into an increase in Catch?
- How much weight for the rate of change in population increase (ie the second derivative)?
 - IF second derivative has same sign as first then veracity of the population trend supported.
 - If second derivative has a different sign, then population may be going through an inflection --*Caveat coerator “Let the manager beware”*
- *If both* Kp and Kd are set to zero, the update function reverts to 1.0—NO change in catch in following year.

Data table for 2018 Catch give range of Kp and Kd gain factors

Estimated catch
in 2018 for
varying values
of Kp and Kd.

		Kp									
	122.67	0	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1	
Kd	0	110.3	114.3	115.7	117.1	118.5	120.0	121.4	122.9	124.4	
	0.25	111.2	115.3	116.7	118.1	119.5	120.9	122.4	123.9	125.4	
	0.5	112.1	116.2	117.6	119.0	120.5	121.9	123.4	124.9	126.4	
	0.75	113.0	117.2	118.6	120.0	121.5	122.9	124.4	125.9	127.4	
	1	114.0	118.1	119.6	121.0	122.5	123.9	125.4	127.0	128.5	
	1.25	114.9	119.1	120.5	122.0	123.5	125.0	126.5	128.0	129.5	
	1.5	115.8	120.1	121.5	123.0	124.5	126.0	127.5	129.0	130.6	
	1.75	116.8	121.1	122.5	124.0	125.5	127.0	128.6	130.1	131.7	
	2	117.8	122.1	123.5	125.0	126.5	128.1	129.6	131.2	132.8	
	2.25	118.7	123.1	124.6	126.1	127.6	129.1	130.7	132.3	133.8	
	2.5	119.7	124.1	125.6	127.1	128.6	130.2	131.7	133.3	134.9	
	2.75	120.7	125.1	126.6	128.1	129.7	131.2	132.8	134.4	136.1	
	3	121.7	126.1	127.6	129.2	130.7	132.3	133.9	135.5	137.2	
	3.25	122.7	127.2	128.7	130.2	131.8	133.4	135.0	136.6	138.3	
	3.5	123.7	128.2	129.8	131.3	132.9	134.5	136.1	137.8	139.4	
	3.75	124.7	129.3	130.8	132.4	134.0	135.6	137.2	138.9	140.6	
	4	125.7	130.3	131.9	133.5	135.1	136.7	138.4	140.0	141.7	

min (C(2018))=

111.2 max(C(2018))=

141.7

Relative
Goodness of Fit:
Quantities
expressed in
terms of
difference in
SSQ to min SSQ

	Ratio of (SSQ-Min(SSQ)) to Minimum SSQ									
	Kp									
	0	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1	
Kd	0	0.12	0.13	0.14	0.16	0.19	0.22	0.25	0.30	0.34
	0.25	0.00	0.04	0.07	0.10	0.14	0.19	0.24	0.30	0.37
	0.5	0.13	0.22	0.26	0.31	0.37	0.44	0.51	0.59	0.69
	0.75	0.58	0.71	0.78	0.85	0.93	1.02	1.12	1.23	1.35
	1	1.40	1.61	1.69	1.79	1.90	2.02	2.15	2.30	2.45
	1.25	2.70	2.98	3.10	3.23	3.38	3.53	3.70	3.88	4.08
	1.5	4.56	4.95	5.11	5.28	5.46	5.66	5.88	6.11	6.36
	1.75	7.13	7.64	7.84	8.06	8.29	8.55	8.82	9.11	9.42
	2	10.54	11.20	11.46	11.73	12.03	12.35	12.69	13.05	13.43
	2.25	14.97	15.81	16.14	16.49	16.86	17.26	17.68	18.13	18.60
	2.5	20.63	21.70	22.11	22.55	23.02	23.51	24.03	24.58	25.16
	2.75	27.78	29.13	29.64	30.19	30.76	31.37	32.01	32.69	33.40
	3	36.71	38.40	39.04	39.71	40.42	41.17	41.96	42.79	43.65
	3.25	47.80	49.90	50.69	51.51	52.39	53.30	54.27	55.27	56.33
	3.5	61.46	64.06	65.03	66.04	67.11	68.23	69.41	70.63	71.92
	3.75	78.20	81.41	82.60	83.84	85.15	86.52	87.94	89.44	90.99
	4	98.65	102.60	104.05	105.57	107.16	108.82	110.55	112.36	114.25

Data table for 2018 Catch give range of Kp and Kd gain factors

		Kp									
		0	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1	
Kd	122.67	110.3	114.3	115.7	117.1	118.5	120.0	121.4	122.9	124.4	
	0	111.2	115.3	116.7	118.1	119.5	120.9	122.4	123.9	125.4	
	0.25	112.1	116.2	117.6	119.0	120.5	121.9	123.4	124.9	126.4	
	0.5	113.0	117.2	118.6	120.0	121.5	122.9	124.4	125.9	127.4	
	0.75	114.0	118.1	119.6	121.0	122.5	123.9	125.4	127.0	128.5	
	1	114.9	119.1	120.5	122.0	123.5	125.0	126.5	128.0	129.5	
	1.25	115.8	120.1	121.5	123.0	124.5	126.0	127.5	129.0	130.6	
	1.5	116.8	121.1	122.5	124.0	125.5	127.0	128.6	130.1	131.7	
	1.75	117.8	122.1	123.5	125.0	126.5	128.1	129.6	131.2	132.8	
	2	118.7	123.1	124.6	126.1	127.6	129.1	130.7	132.3	133.8	
	2.25	119.7	124.1	125.6	127.1	128.6	130.2	131.7	133.3	134.9	
	2.5	120.7	125.1	126.6	128.1	129.7	131.2	132.8	134.4	136.1	
	2.75	121.7	126.1	127.6	129.2	130.7	132.3	133.9	135.5	137.2	
	3	122.7	127.2	128.7	130.2	131.8	133.4	135.0	136.6	138.3	
	3.25	123.7	128.2	129.8	131.3	132.9	134.5	136.1	137.8	139.4	
	3.5	124.7	129.3	130.8	132.4	134.0	135.6	137.2	138.9	140.6	
	3.75	125.7	130.3	131.9	133.5	135.1	136.7	138.4	140.0	141.7	

min (C(2018))=

111.2

max(C(2018))=

141.7

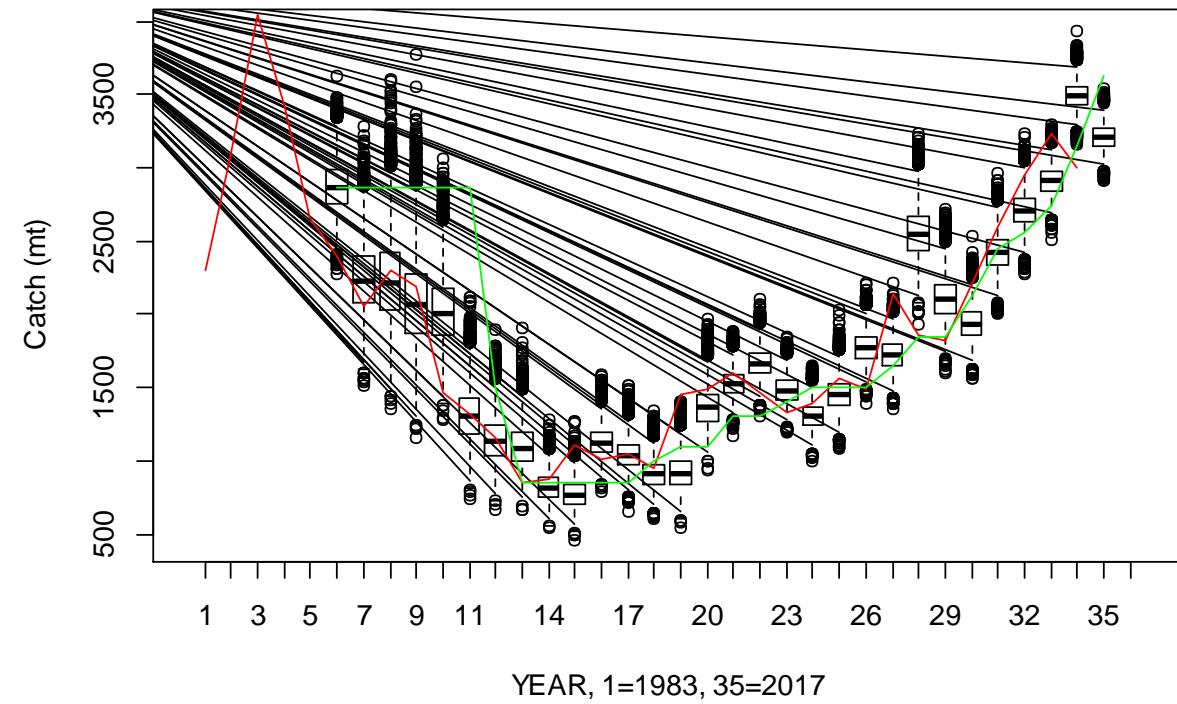
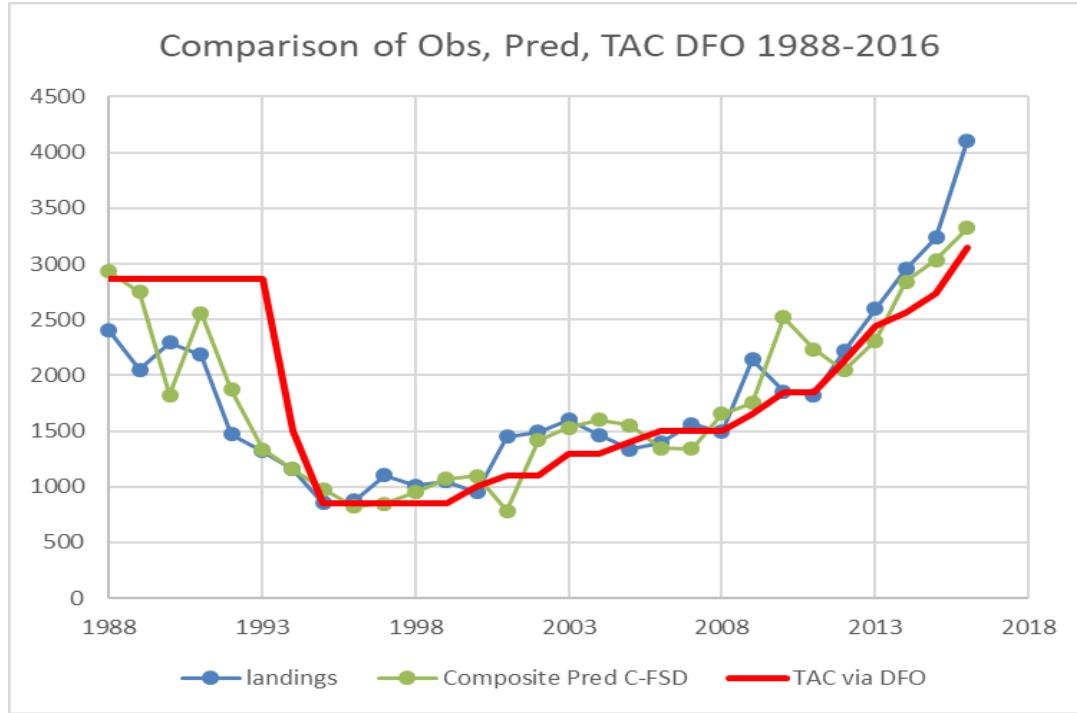
		Ratio of (SSQ-Min(SSQ)) to Minimum SSQ									
		0	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1	
Kd	0	0.12	0.13	0.14	0.16	0.19	0.22	0.25	0.30	0.34	
	0.25	0.00	0.04	0.07	0.10	0.14	0.19	0.24	0.30	0.37	
	0.5	0.13	0.22	0.26	0.31	0.37	0.44	0.51	0.59	0.69	
	0.75	0.58	0.71	0.78	0.85	0.93	1.02	1.12	1.23	1.35	
	1	1.40	1.61	1.69	1.79	1.90	2.02	2.15	2.30	2.45	
	1.25	2.70	2.98	3.10	3.23	3.38	3.53	3.70	3.88	4.08	
	1.5	4.56	4.95	5.11	5.28	5.46	5.66	5.88	6.11	6.36	
	1.75	7.13	7.64	7.84	8.06	8.29	8.55	8.82	9.11	9.42	
	2	10.54	11.20	11.46	11.73	12.03	12.35	12.69	13.05	13.43	
	2.25	14.97	15.81	16.14	16.49	16.86	17.26	17.68	18.13	18.60	
	2.5	20.63	21.70	22.11	22.55	23.02	23.51	24.03	24.58	25.16	
	2.75	27.78	29.13	29.64	30.19	30.76	31.37	32.01	32.69	33.40	
	3	36.71	38.40	39.04	39.71	40.42	41.17	41.96	42.79	43.65	
	3.25	47.80	49.90	50.69	51.51	52.39	53.30	54.27	55.27	56.33	
	3.5	61.46	64.06	65.03	66.04	67.11	68.23	69.41	70.63	71.92	
	3.75	78.20	81.41	82.60	83.84	85.15	86.52	87.94	89.44	90.99	
	4	98.65	102.60	104.05	105.57	107.16	108.82	110.55	112.36	114.25	

Rough boundaries on 2018 catch for solutions that are within 10% of the solution that minimizes differences between observed and projected catch for 2007 onward.

Application to DFO 3N0Ps4WX5Zc halibut stock

- Utilized same abundance indices used in the statistical catch at age model used by DFO.
- Comparisons with TAC

Figure 23 in Report

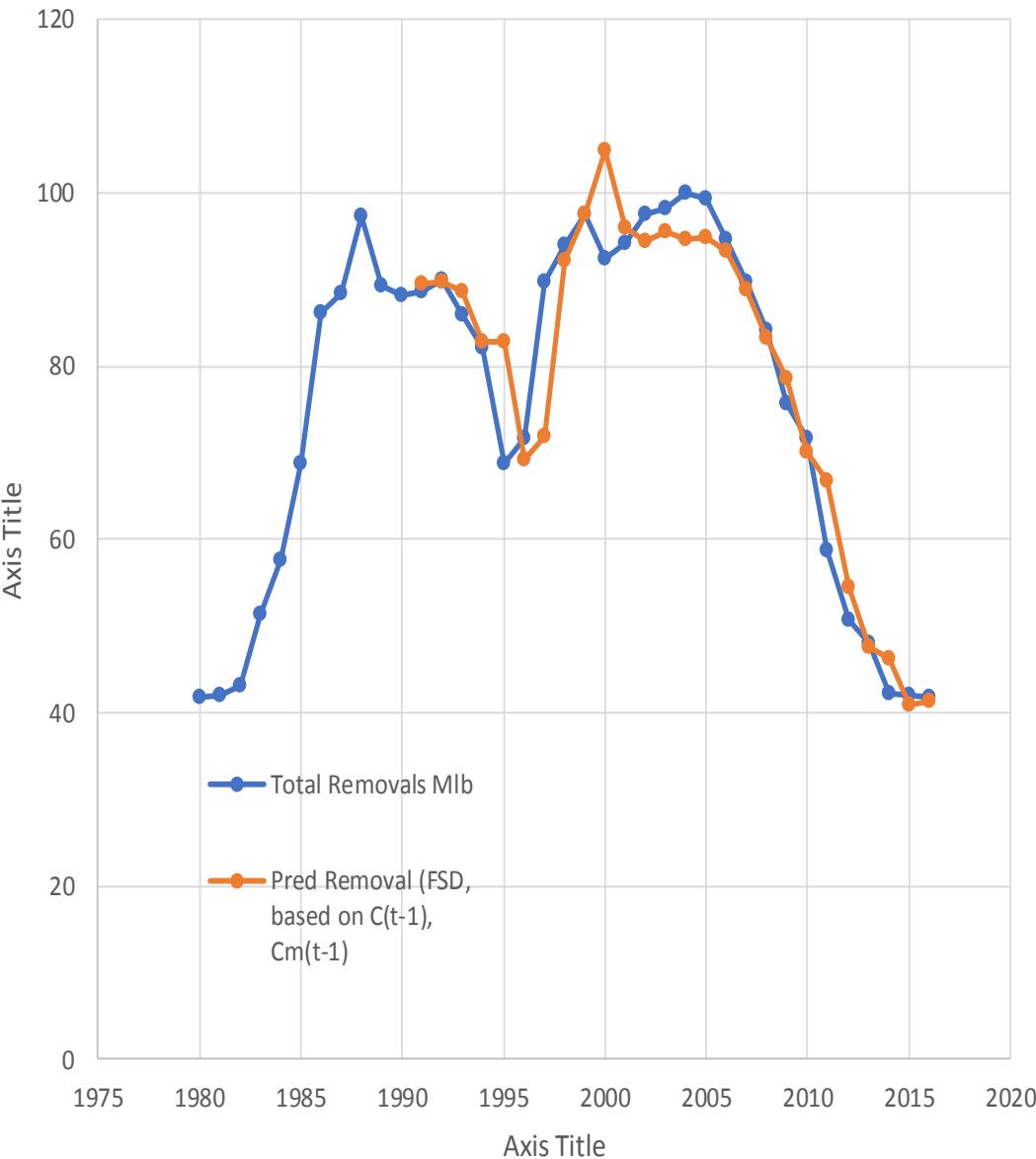


Appendix 2. Figure 2.1 in Report

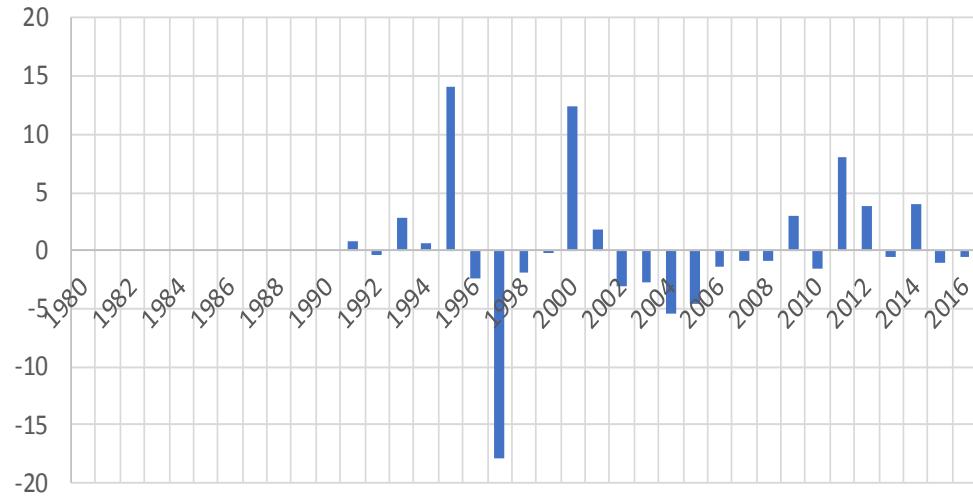
*Application to IPHC Pacific **Halibut***

- Used same indices as used in IPHC assessment
- Assumed that observed catches were very close to TAC
- Residuals tend to be small in recent years, less than 10% of actual catch

Pacific Halibut: Observed vs Pred Catch (5y ave slope)



ALL DATA: obs- pred removals FSD method



2003-2016: obs- pred removals FSD method

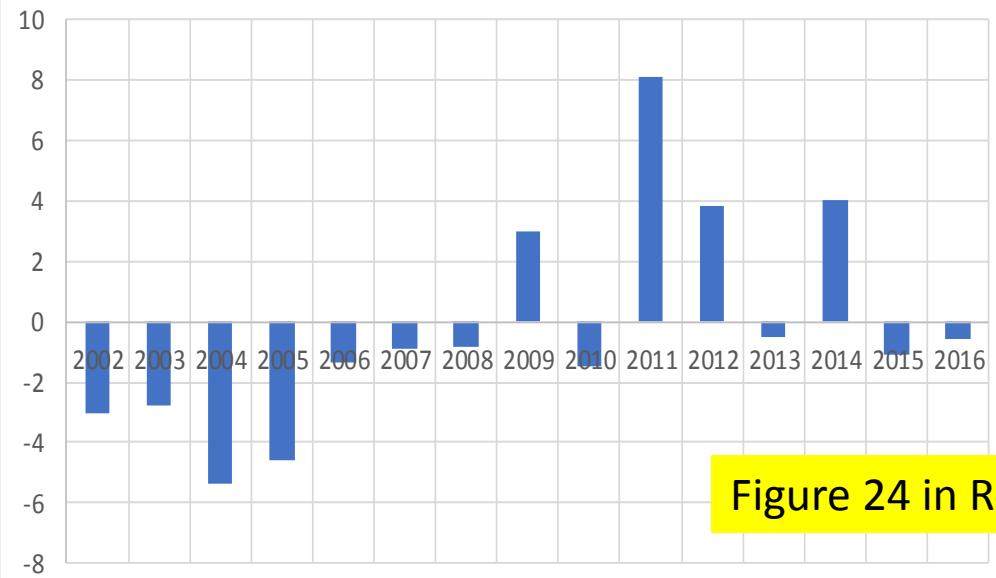


Figure 24 in Report

Add bootstrap for IPHC stock

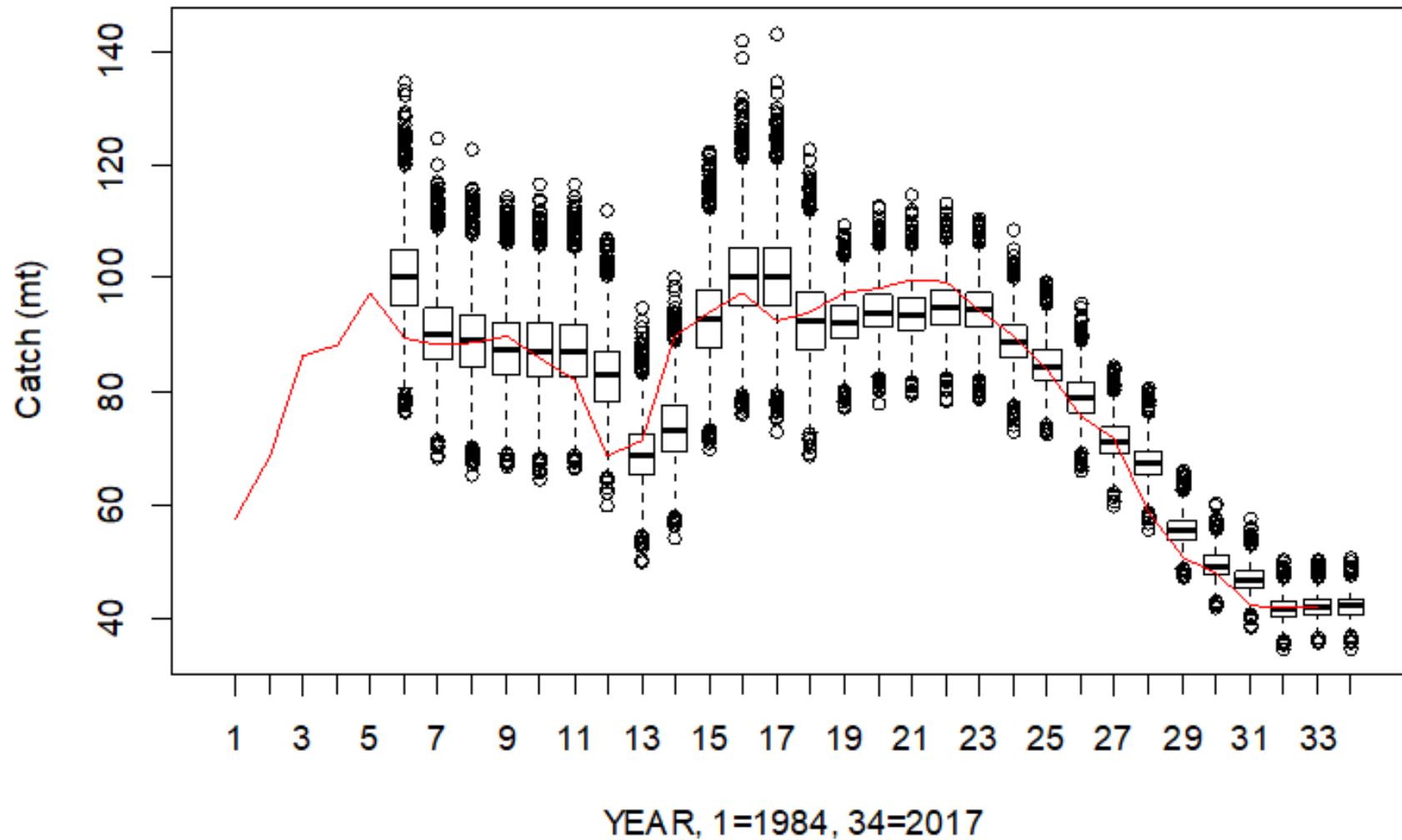


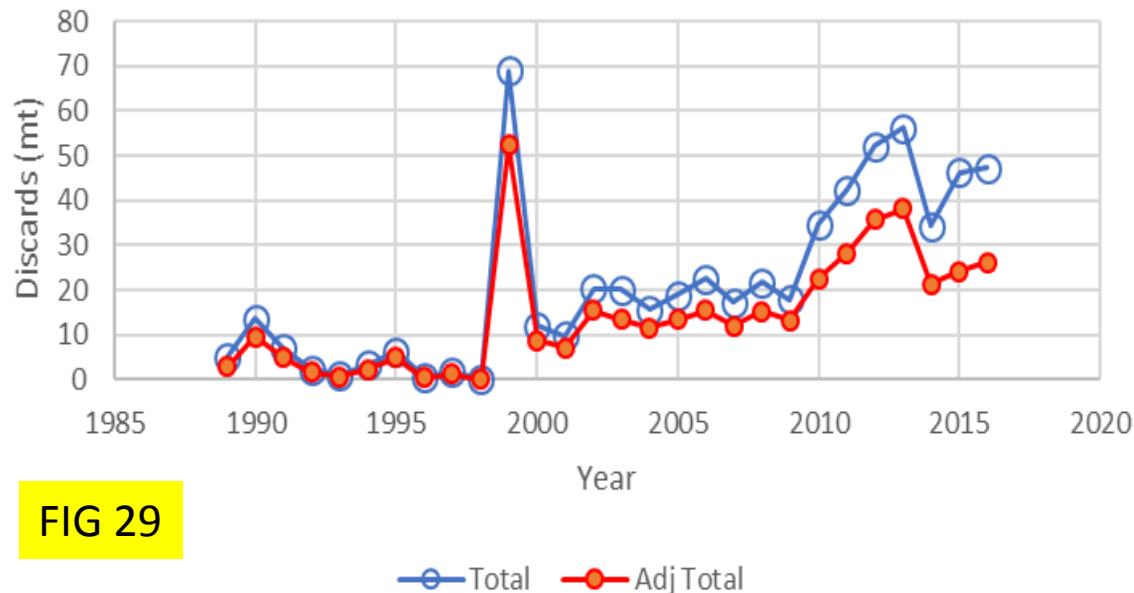
Figure 25 in Report

Odds and Ends—Discard Mortality and Alternative measure of relative abundance from Observed Trips

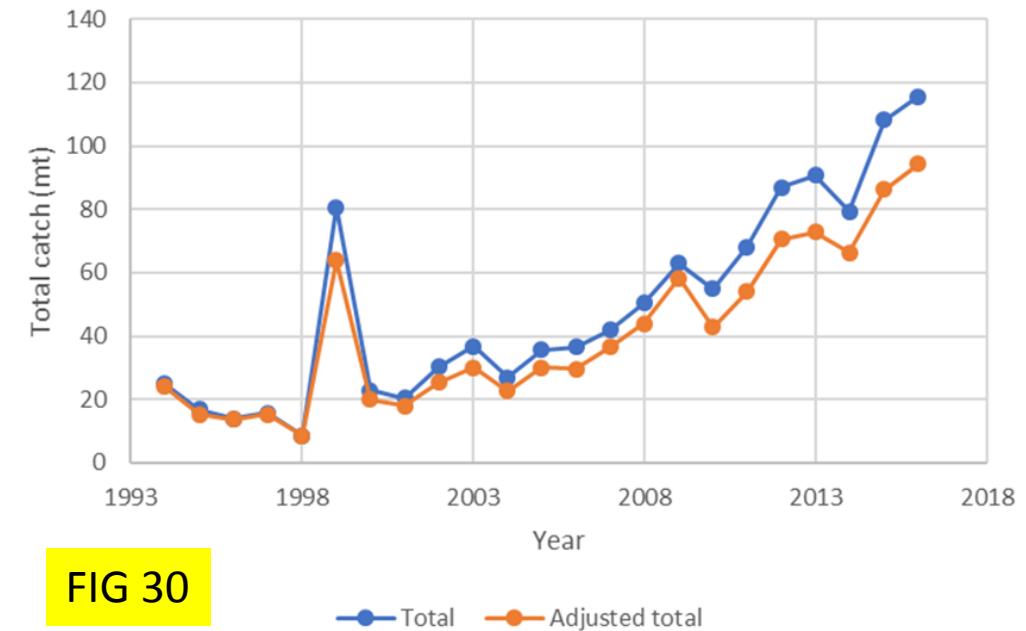
- Discard mortality
 - Concerns from harvesters and managers about effects of decreased mortality of captured halibut. See page 28-29 in report.
- d/k vs t/k revision
 - PDT suggested that ratio of total encounters to kept all (i.e., t/k) was a better measure of relative abundance than discards to kept all (i.e., d/k).
 - d/k ratio may be more influenced by regulations (min size, trip limits)

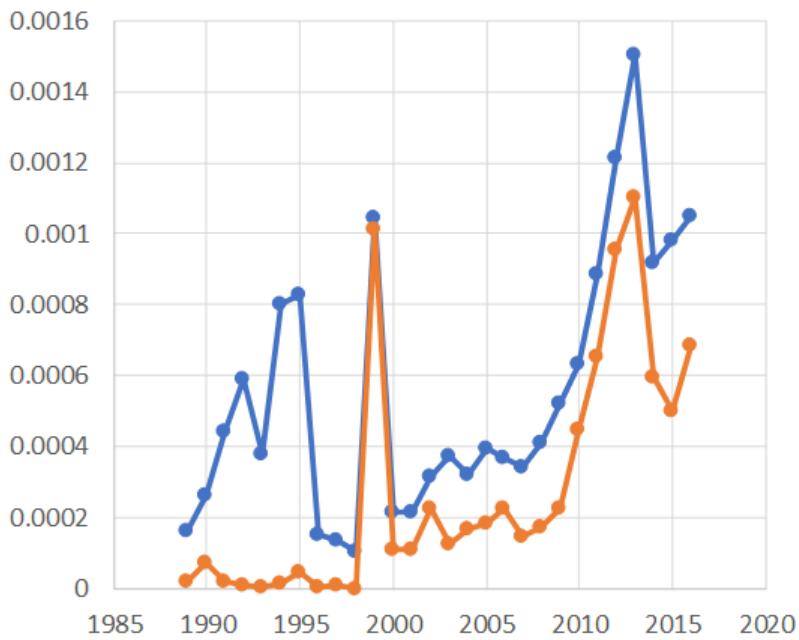
Effect of discard mortality on estimated discards and catch: 76% Trawl, 30% gill net, 10% hook

Comparison of Total Discard Estimates with and without discard mortality adjustments

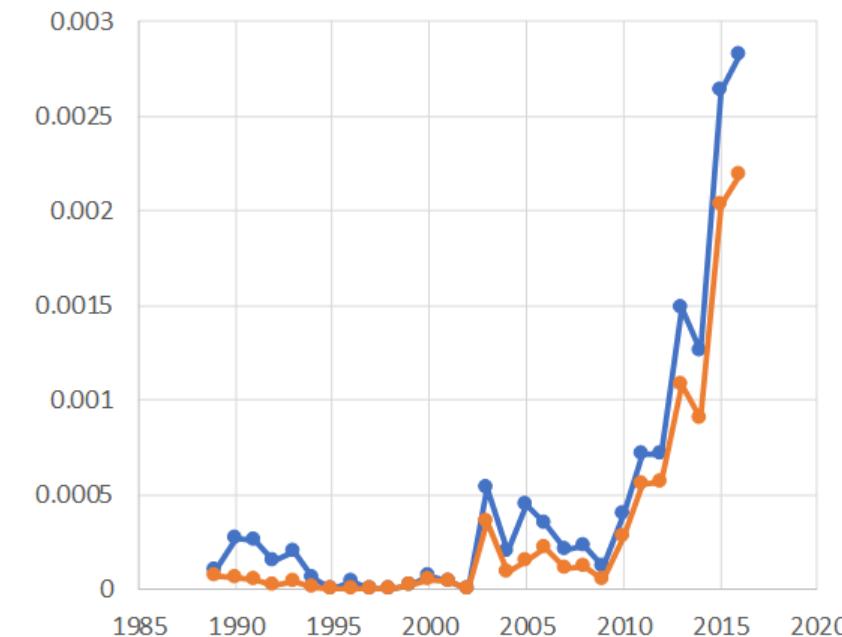


Effect of discard mortality rate on estimated total catch



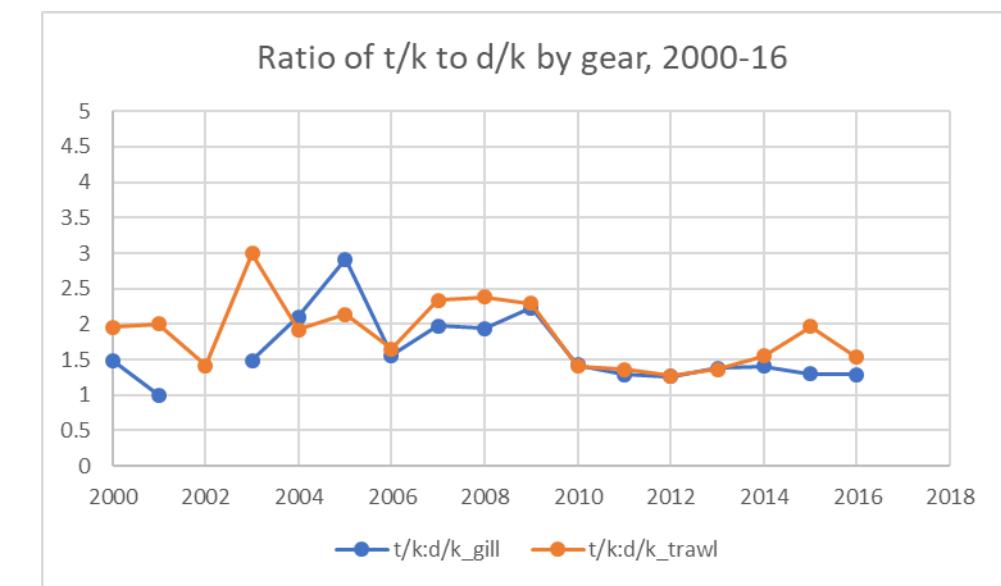


Trawl



Gill net

Hypothesis: total observed catch to kept all (t/k) is more representative of relative abundance than d/k ratio



Appendix 3. Figures 3.1 and 3.2

Application of discard mortality and use of t/k ratio have nominal effect on projected catch for 2018 UNLESS fraction of total discard by gear (ie trawl vs gill net vs hook) changes dramatically.

All models use Kp=0.75, Kd=0.5	Model based on d/k indices	Model Based on t/k indices
Assume 100% Mortality of discards	122.67 mt	122.82 mt
Assume discard Mortality varies by gear: 76% Trawl, 30% gill net, 10% hook	99.31 mt	99.44 mt

Summary

- Rcrit method may be useful for other stocks
- DCAC--a poor, assumption-driven, second choice
- Other methods require more assumptions, many of which would require “benchmark-level” discussions
- Proposed Model uses Management Procedure Approach for updating catches
- Does not introduce new data but uses d/k as measure of relative abundance.
- Method builds on the GB cod approach and examines the likely consequences for a population managed under such a policy.

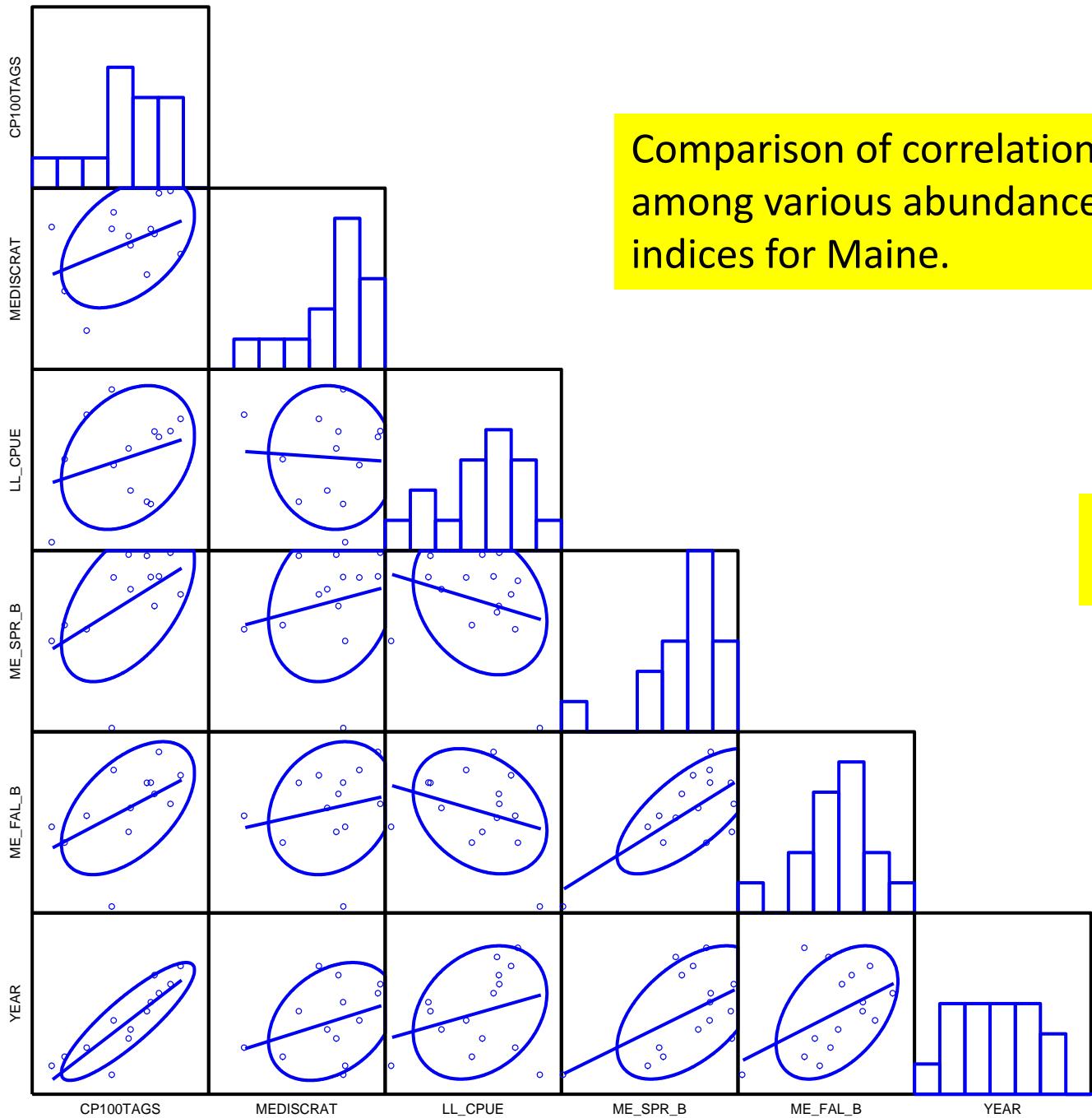
Proposed Model—Critique (1)

- Possible Advantages
 - Incorporates rate of change (slope) and CHANGES in rate of change (delta slope)
 - Does not assume equilibrium or constancy of model parameters
 - Does not assume density dependent regulation
 - Does not impose a causality model to observed patterns
 - Responds to what is rather than what we think it should be.
 - Recursively updates catch projections
 - Simulation experiments suggests that it is unlikely to cause overfishing during a rebuilding period
 - Can be used to examine trade-offs
 - Allows for evaluation of management options, e.g., max % TAC change/year
 - Can incorporate trends in multiple indices
 - Applications to other halibut stocks show some promise.

Proposed Model—Critique (2)

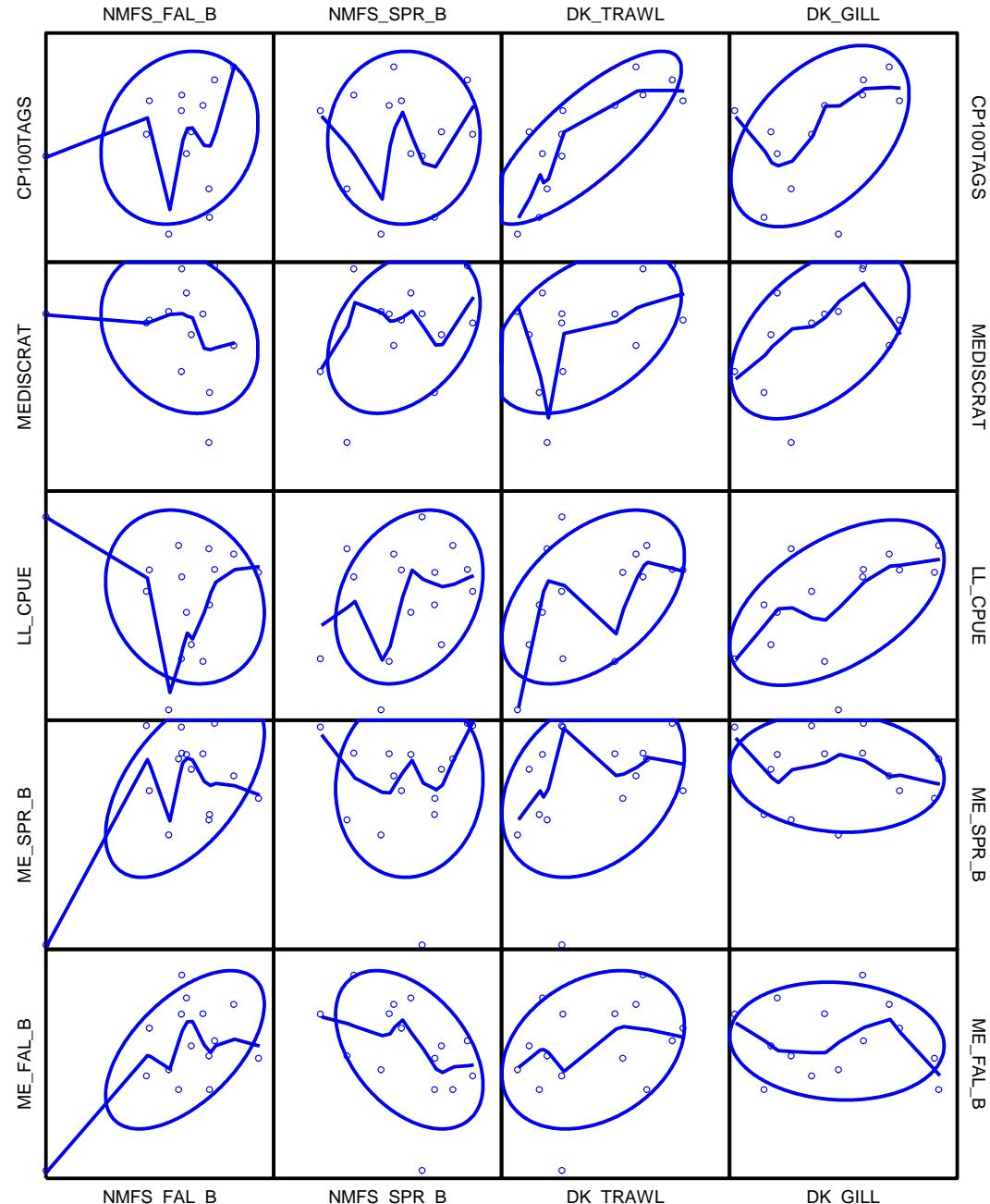
- Possible Disadvantages
 - A model too far—stretches the Plan B paradigm
 - Could follow false signals—e. g., makes unnecessary changes
 - Basis for selecting K_p and K_d is qualitative.
 - Potential for lags in signal identification—5 yr regression
 - Difficult to reduce catches quickly enough. Overshoots in catch can create long payback periods. (This is common to all models).
 - Observation error in indices may overwhelm ability to detect change
 - Effects of including indices without trend, (ie noise only) have not been evaluated. This is sometimes called the breakdown ratio—how much contaminated data can a model take?
 - Model is not designed to recalibrate for the effects of forgoing several years of potential increases. For example the model works only on the most recent year of catch, not the historical sequence.

MISC SLIDES



Comparison of correlations
among various abundance
indices for Maine.

FIG 10 in
Report



Comparison of NEFSC and
Maine abundance indices.
Fig. 11, with log-log axes.

FIG 11 in
Report

Q&D Executive Summary

- Alternative measures of abundance from Maine sources were considered.
- A review of data poor methods suggests that most have limited utility for Atlantic halibut, however the DCAC model was considered further.
- A ratio method (Rcrit) was developed and tested to determine robust measures of population change and the significance of these changes.
- ~~The Envelope Method was applied to estimate relative scale~~
- ~~Results of the Rcrit and Envelope method were combined to improve the DCAC model but its overall performance is unreliable and still governed by strong assumptions.~~
- An updating algorithm, called the FSD model was developed and tested via simulation. The approach allows use of short term information and multiple indices.
- FSD model results suggest that the 2018 Atlantic halibut catch would be in the range of 116-120 mt.
- Application of the FSD model to Atlantic halibut and Pacific halibut stocks assessed with advanced statistical catch-at-age models suggest reasonable agreement between Observed and predicted TACs.

Misc—DCAC Results

Envelope—finding a plausible range based on set of broad assumptions for q and F .

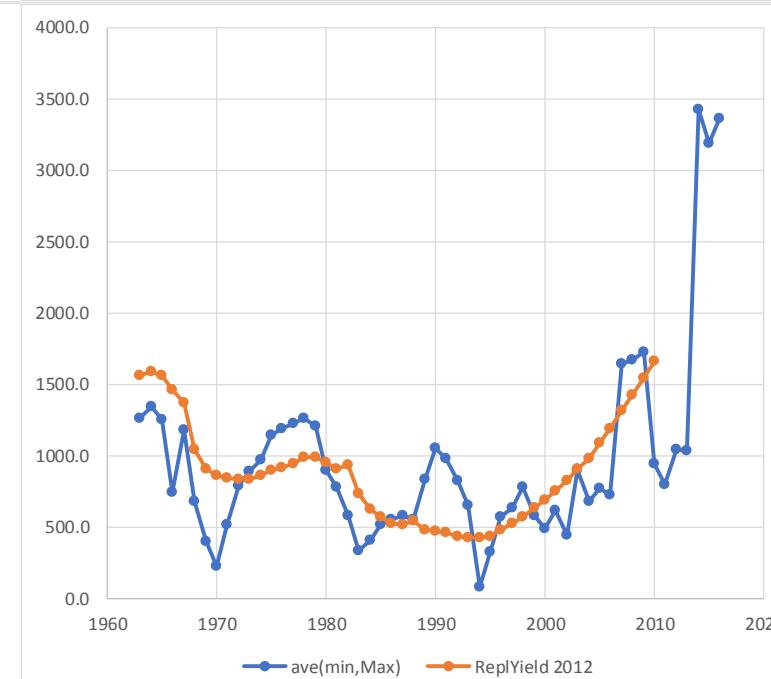
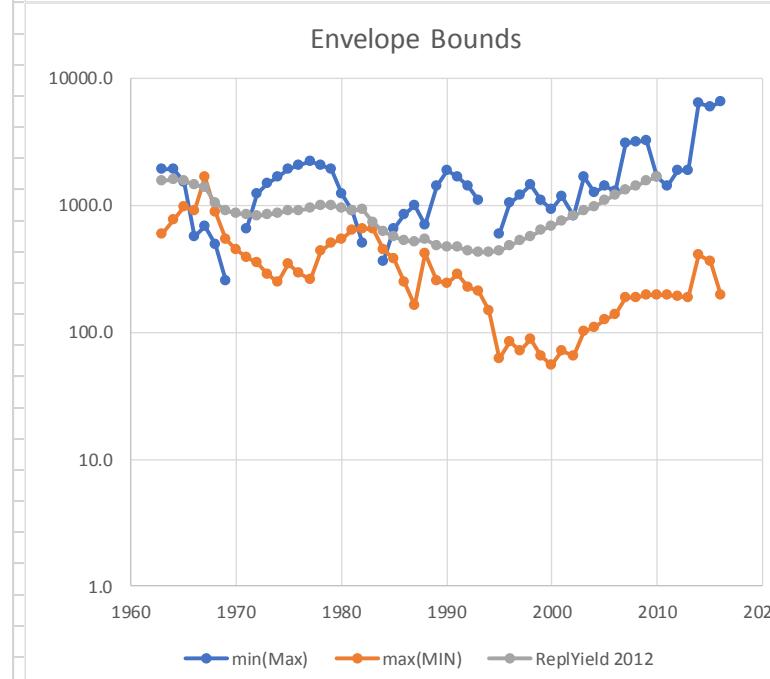
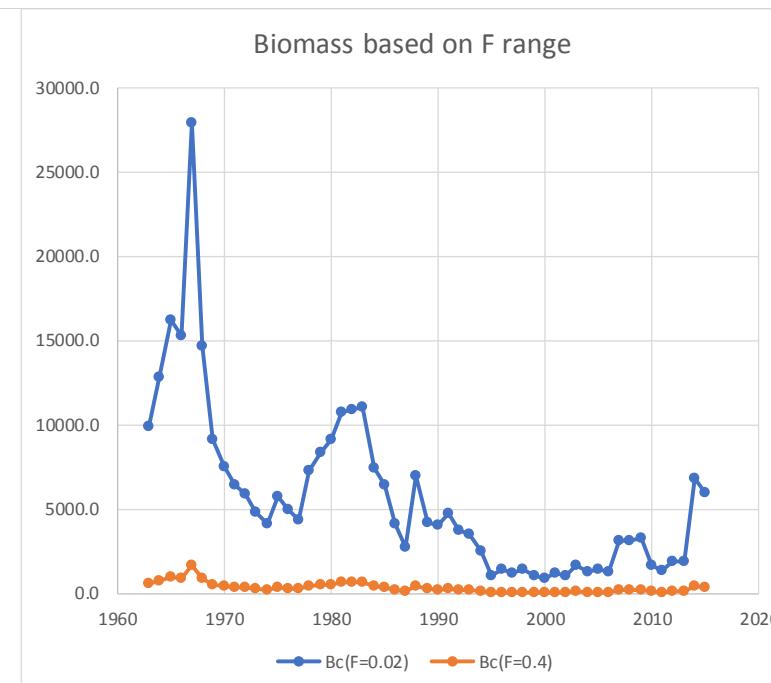
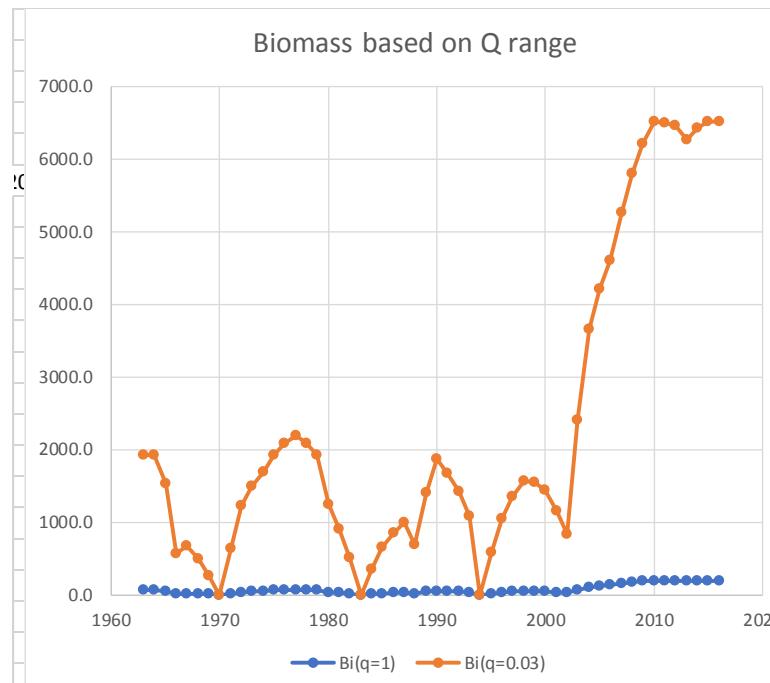
- *Biomass range based on q range*

- $$B_t = \frac{I_t}{q'} \frac{A}{a} \quad [13]$$

- Biomass range based on F range

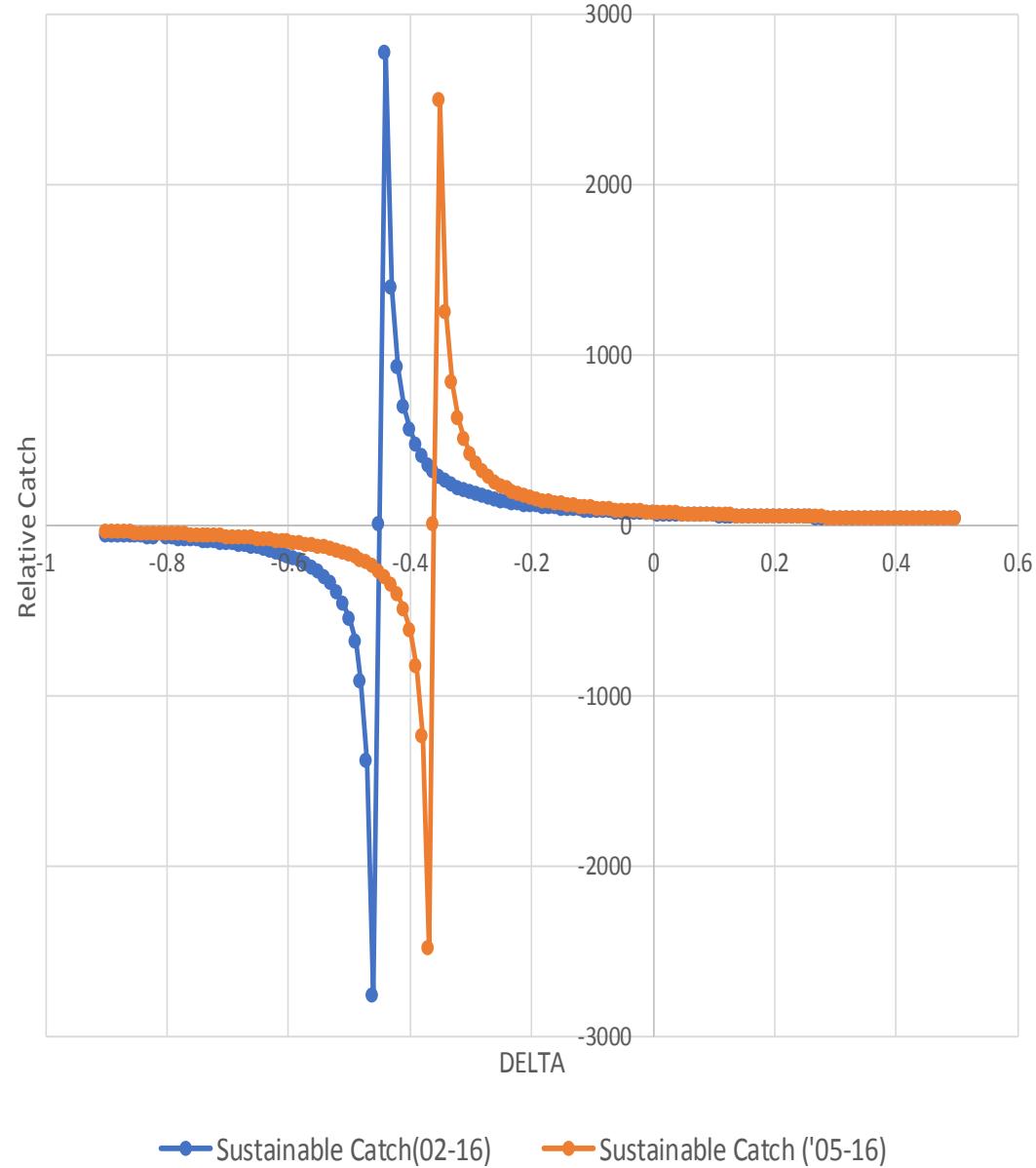
- $$B_{0,t} = \frac{C_t}{\frac{F}{F+M}(1-e^{-F-M})} \quad [14]$$

- Upper bound = min of Max values
- Lower bound = max of minimum values
- Envelope satisfies both constraints

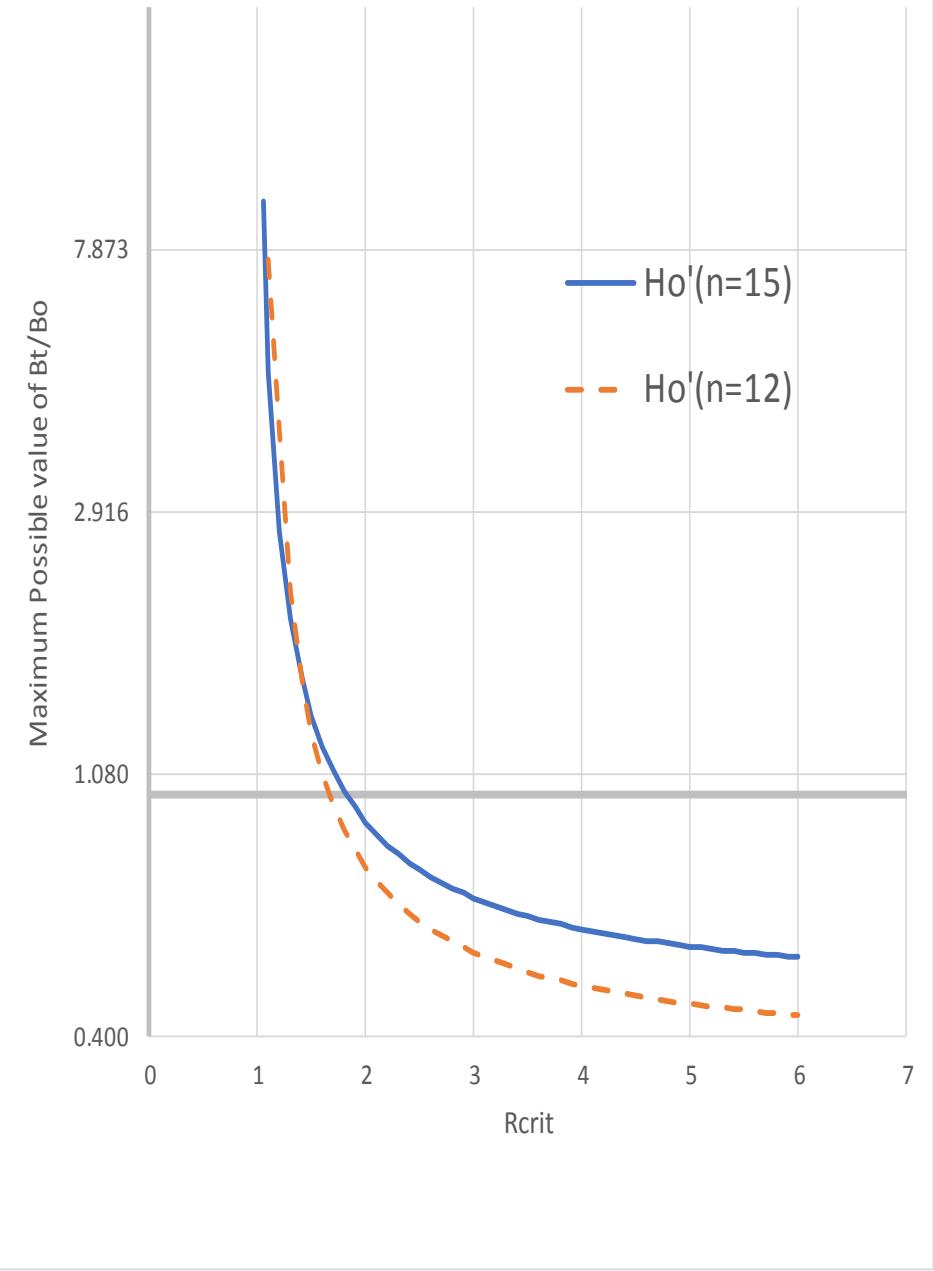


					<i>Biomass Estimates</i>				<i>Estimated B(2016)/K</i>		
<i>Survey Type</i>	<i>Basis for Estimating Max Biomass</i>		<i>Max Catch</i>	<i>max B(C,F)</i>	<i>min B(C,F)</i>	<i>Mid Range B(C,F)</i>	<i>Mid Range Biomass 2016</i>		<i>max B(C,F)</i>	<i>min B(C,F)</i>	<i>Mid Range B(C,F)</i>
Kalman	Max catch 1893-2016		4,908	266,850	15,952	141,401	3,363.2		0.013	0.211	0.024
Kalman	Max Catch since 1900		944	51,326	3,068	27,197	3,363.2		0.066	1.096	0.124
Kalman	Constrained range of B(1963-2016)			6,531	1,671	3,425	3,363.2		0.515	2.013	0.982
Raw	Max catch 1893-2016		4,908	266,850	15,952	141,401	3,407.4		0.013	0.214	0.024
Raw	Max Catch since 1900		944	51,326	3,068	27,197	3,407.4		0.066	1.111	0.125
Raw	Constrained range of B(1963-2016)		514	14,680	1,671	7,779	3,407.4		0.232	2.040	0.438

Instability of Catch estimate based on range of DELTA in
DCAC: 15 yr, 2002-2016, and 12 yr, 2005-2016



Maximum Feasible Value of $B(t)/B(0)$ vs R_{crit}



The pesky problems of singularities in DCAC when Delta is negative AND extreme sensitivity of B_t/B_0 as R_{crit} approaches one.

Putting Rcrit and Envelope Results back into DCAC

- Consider various values of potential increase based on Rcrit
- Consider various values of Bt/Bo based on Envelope
- Question
 - If Rcrit is 3.0 has the stock increased from 2% Bt/Bo to 6% Bt/Bo?
 - OR
 - Has the stock increased from 20% Bt/Bo to 60% Bt/Bo?
- Consequences for DELTA parameter in DCAC are different
 - Going from 2% to 6% means DELTA is -0.04
 - Going from 20% to 60% means DELTA is -0.40
 - There are an infinite range of possibilities in between!

Table hh. A. Summary of maximum fractional change in population abundance given alternative ranges of proportional stock increase for varying base period year ranges.

B. Derived Depletion corrected average catches of sustainable harvest alternative levels of rebuilding in 2016 and proportional increase in relative abundance.

Levels of rebuilding are based on envelope method. Natural mortality is assumed =

0.15

A

Maximum Fractional Change (DELTA) in DCAC for varying assumed values of B(t)/K

	Changes in catches		Change in indices			Assume 98.2% rebuilt in 2016	Assume 43.8% rebuilt in 2016	Assume 12.5% rebuilt in 2016	Assume 2.4% rebuilt in 2016	Total Catch
Ratio Definition	Statistics	Value	Statistic	Value	Model	0.982	0.438	0.125	0.024	
'02-04:'14-16	Rcrit(Catch)	3.227	Rcrit(Indices)	3.23	(all six indices)	-0.67798	-0.30240	-0.08630	-0.01657	925.3
				4.98	(DK_g, DK_t, Survey)	-0.78481	-0.35005	-0.09990	-0.01918	
				3.52	average over 120models	-0.70302	-0.31357	-0.08949	-0.01718	
'05-07:'14-16	Rcrit(Catch)	2.657	Rcrit(Indices)	2.44	average over 120models	-0.57954	-0.25849	-0.07377	-0.01416	831.4
				4.11	DK_g, DK_t, Survey	-0.74307	-0.33143	-0.09459	-0.01816	
				2.2	(all six indices)	-0.53564	-0.23891	-0.06818	-0.01309	
'02-04:'11-13	Rcrit(Catch)	2.617	Rcrit(indices)	2.893	(all six indices)	-0.64256	-0.28660	-0.08179	-0.01570	622.1
				5.033	(DK_g, DK_t, Survey)	-0.78689	-0.35097	-0.10016	-0.01923	
				3.144	average over 120models	-0.66966	-0.29869	-0.08524	-0.01637	

B

Nyears	Time Period	Total Catch	Derived Delta for Assumed Alpha				Derived Sustainable Average Catch for Assumed Alpha				Obs Ave Catch	Y Current --given assumed level of rebuilding			
			0.982	0.438	0.125	0.024	0.982	0.438	0.125	0.024		0.982	0.438	0.125	0.024
15	2002-2016	925.3	-0.678	-0.302	-0.086	-0.017	-121.8	188.1	76.3	64.0	61.7	-119.6	82.4	9.5	1.5
15		925.3	-0.785	-0.350	-0.100	-0.019	-82.9	277.7	79.3	64.4		-81.4	121.6	9.9	1.5
15		925.3	-0.703	-0.314	-0.089	-0.017	-109.7	203.5	77.0	64.1		-107.7	89.1	9.6	1.5
12	2005-2016	831.4	-0.580	-0.258	-0.074	-0.014	-113.6	245.7	87.1	72.1	69.3	-111.6	107.6	10.9	1.7
12		831.4	-0.743	-0.331	-0.095	-0.018	-65.1	873.0	94.0	73.0		-63.9	382.4	11.7	1.8
12		831.4	-0.536	-0.239	-0.068	-0.013	-142.0	206.0	85.5	71.9		-139.4	90.2	10.7	1.7
12	2002-2013	622.1	-0.643	-0.287	-0.082	-0.016	-66.1	254.3	67.1	54.2	51.8	-64.9	111.4	8.4	1.3
12		622.1	-0.787	-0.351	-0.100	-0.019	-43.7	2067.9	71.8	54.8		-42.9	905.7	9.0	1.3
12		622.1	-0.670	-0.299	-0.085	-0.016	-60.3	304.4	67.9	54.3		-59.2	133.3	8.5	1.3

See Table 13 in report.

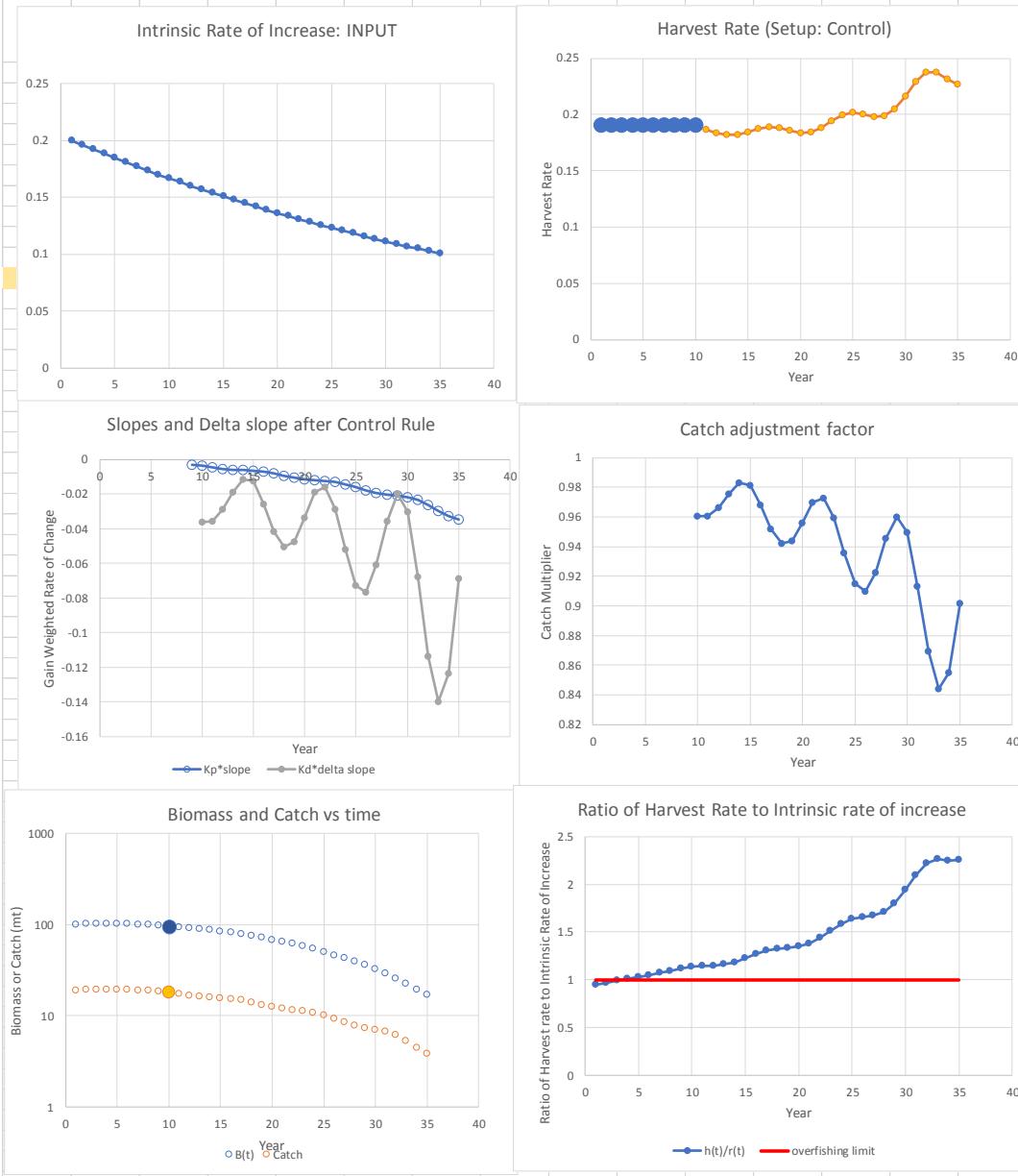
Assumed level of change in $B(2016)/K$ is obtained from Table 12.

Ignoring the negative values, the sustained average catch ranges from 64 to 2,067 mt.

Ignoring negative values, the current recommended yield ranges from 1.3 to 905.7 mt.

Initial Harvest $h(t)$ Scenario	Intrinsic rate of increase $r(t)$ scenario	Number of years used for slope estimation	Kp Gain on slope derivative	KD Gain on slope derivative
3	4	5	0.25	10

Total Catch	CV of Catch	Max Cmult	Min Cmult	Fraction of Overfishing Events
272.9	0.379	0.983	0.844	0.91



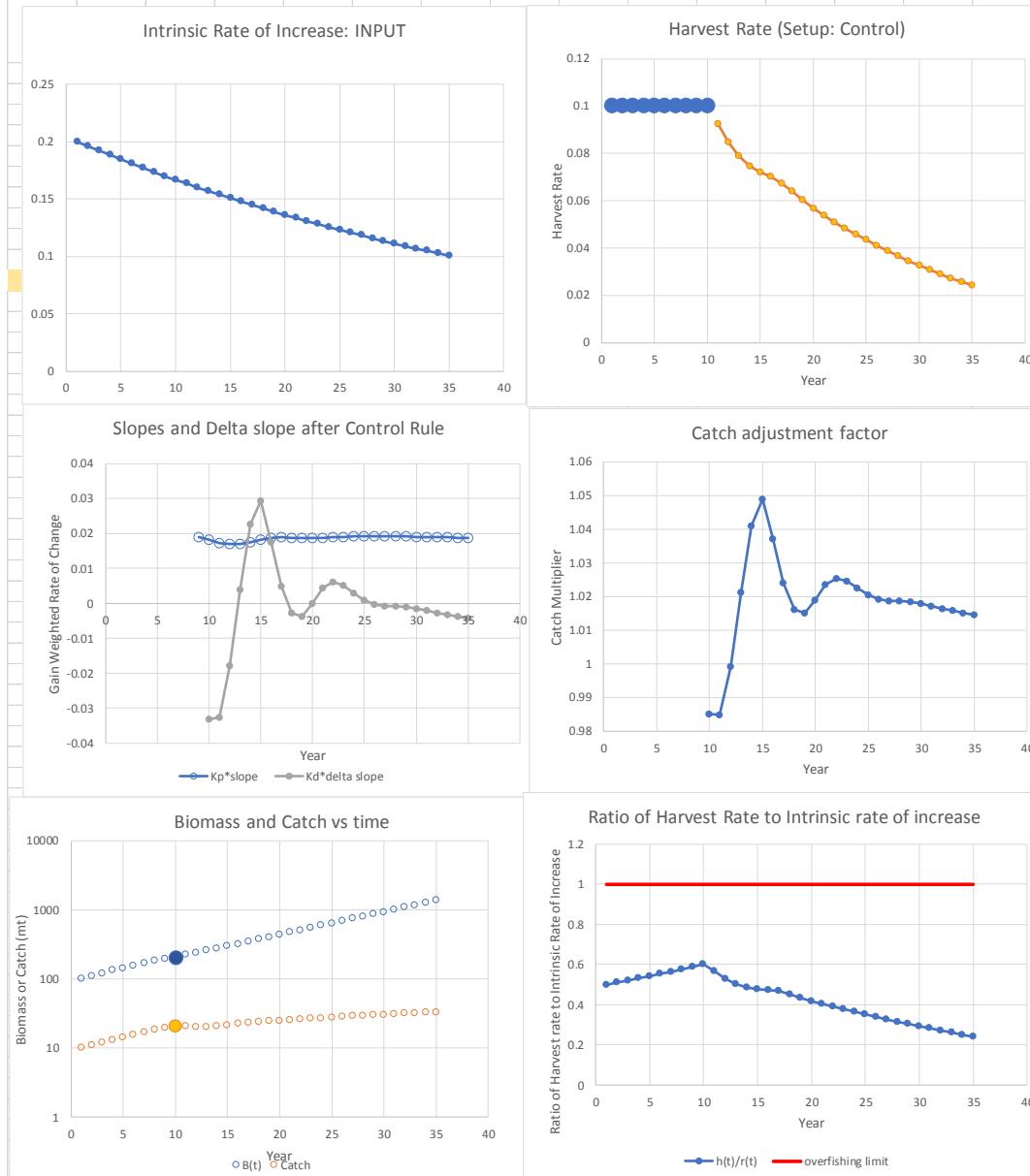
Example 4:

- Intrinsic rate of increase is DECLINING
- Initial Harvest rate is ABOVE intrinsic rate during much of the initial period
- Differential weights on proportional and derivative controls are SAME as Example 3:
 - $K_p=0.25$ (less weight on proportional change)
 - $K_d=10$

Key Results

- Much lower cumulative catch 272 mt
- Overfishing over 91% of the entire period
- Maximum catch multiplier is 0.98 or 2% decrease
- Catch multiplier is always less than 1.0 and oscillates over a wide range, to as low as 84%
- Stock size and catches declines after initial control period.

Initial Harvest $h(t)$ Scenario	Intrinsic rate of increase $r(t)$ scenario	Number of years used for slope estimation	Kp Gain on slope derivative	KD Gain on slope derivative
2	4	5	0.25	10



Example 5:

- Intrinsic rate of increase is DECLINING
- Initial Harvest rate is well BELOW intrinsic rate during the initial period
- Differential weights on proportional and derivative controls are SAME as Example 3 and 4:
 - $K_p=0.25$ (less weight on proportional change)
 - $K_d=10$

Key Results

- Much higher cumulative catch 658 mt
- NO Overfishing over the entire period
- Maximum catch multiplier is 1.05 or 5% decrease
- Catch multiplier is mostly above 1.0 and oscillates over a narrow range.
- Stock size and catches both increase at a steady pace but catch declines more slowly, thereby preserving the stock rebuilding program.
- Major difference is the lack of overfishing during the period prior to implementation of the control rule. This allows stock size to grow despite declines in productivity