Update on AIGKC state harvest strategy development: forecast simulations

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Crab Plan Team Meeting

September 10-13, 2018

Seattle, WA

Stock Status

- 2017/18 total catch = 2,942 t (6.487 million lb)
- 2017/18 OFL = 6,048 t (13.333 million lb)
- “Overfishing” did not occur in the Aleutian Islands golden king crab fishery in 2017/18.

Status and catch specifications (million lb) of Aleutian Islands golden king crab

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2016/17	N/A	N/A	5.545	5.716	6.497	12.53	9.40
2017/18	13.325	31.315	5.545	5.699	6.487	13.333	10.000

Current ADF&G harvest strategy

The annual TAC is set by state regulation, 5 AAC 34.612 (Harvest Levels for Golden King Crab in Registration Area O), as approved by the BOF in March 2012:

(a) Until the Aleutian Islands golden king crab stock assessment model and a state regulatory harvest strategy are established, the harvest levels for the Registration Area O golden king crab fishery are as follows:

(1) east of 174° W long. (EAG): 3.31 million pounds; and

(2) west of 174° W long. (WAG): 2.98 million pounds;

(b) The department may modify the harvest levels based on the best scientific information available and considering the reliability of estimates and performance measures, sources of uncertainty as necessary to avoid overfishing, and any other factors necessary to be consistent with sustained yield principles.

*Prior to 2018, the word “reduce” was used

Harvest Strategy Update

- Update state harvest strategy so that TAC responds to population fluctuations
  - Use model estimated abundance in TAC calculation
- Develop draft harvest strategy scenarios
  - Presented at Jan 2018 CPT meeting
- Compare harvest strategy effects on stock sustainability and productivity via forecast simulations
  - Discuss today
- Submit recommended harvest strategy to the Board of Fisheries in March 2019
- Implement updated harvest strategy for 2019/20 fishery

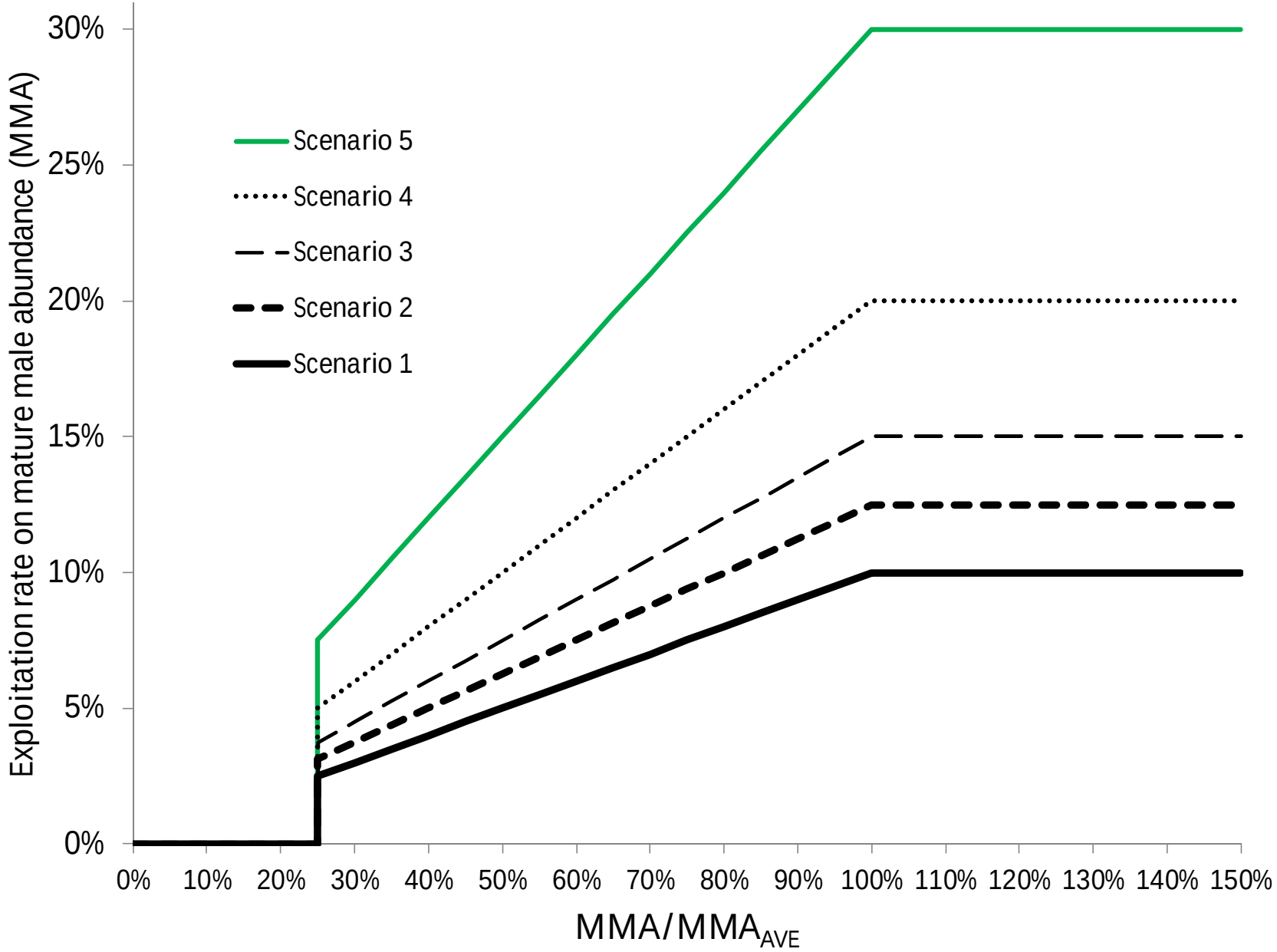
Harvest Strategy Core Elements

1. Threshold for opening/closing fishery
2. Exploitation rate on mature male abundance
3. Maximum allowable exploitation rate on legal male abundance

Threshold for opening fishery

- Current year point estimate relative to long-term average
  - $MMA/MMA_{ave} = 25\%$
  - Follows federal assessment F_{OFL} control rule: “critical biomass threshold”
  - Separate for EAG and WAG
- What years should be used for the long-term average (MMA_{ave})?
  - Used 1985-2017 for simulations

Exploitation rate on MMA



Maximum exploitation on legal male abundance

- Because TAC is based on mature male abundance, this measure provides a level of protection against over harvesting legal males when legal males are in relatively low abundance compared to mature males
  - Other BSAI crab harvest strategies: BBRKC: 50%, StMatt BKC: 25%, PIBKC: 20%, Tanner: 50%, snow: 58% “exploited” legals
- Evaluated 25%, 30%

Proposed State Harvest Strategy Scenarios

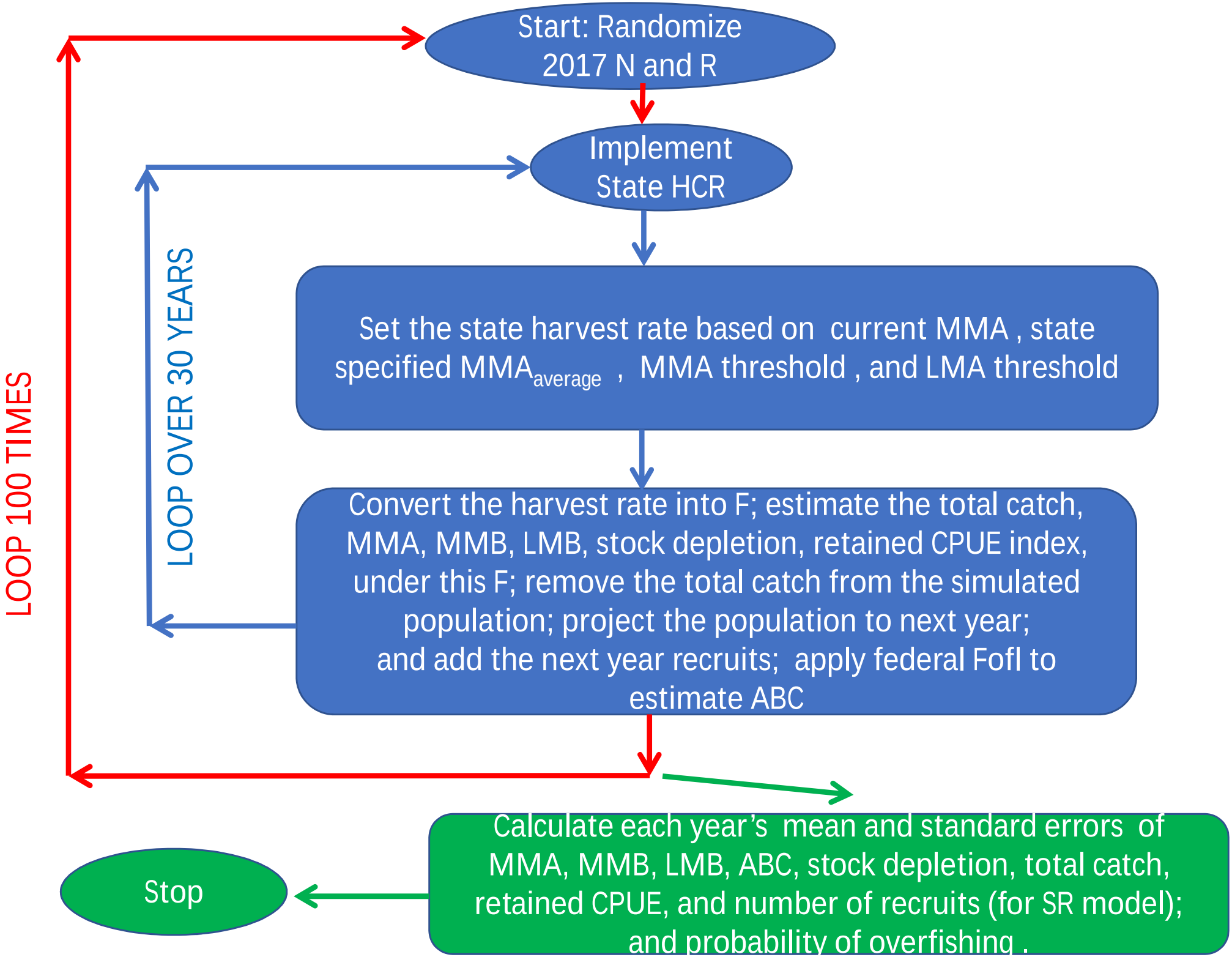
	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	Sc7	Sc8	Sc9	Sc10
Time period for mean MMA[1] (MMA_{ave})	1985–2017	1985–2017	1985–2017	1985–2017	1985–2017	1985–2017	1985–2017	1985–2017	1985–2017	1985– 2017
Threshold for opening/closing $\frac{???}{???_{???}}$%	25%	25%$_e$	25%	25%	25%	25%	25%	25%	25%	25%
Exploitation rate on MMA when $\frac{???}{???_{???}}$%< 100%	$\frac{???}{???_{???}} \times 0.1$	$\frac{???}{???_{???}} \times 0.125$	$\frac{???}{???_{???}} \times 0.15$	$\frac{???}{???_{???}} \times 0.20$	$\frac{???}{???_{???}} \times 0.3$	$\frac{???}{???_{???}} \times 0.1$	$\frac{???}{???_{???}} \times 0.125$	$\frac{???}{???_{???}} \times 0.15$	$\frac{???}{???_{??}} \times 0.20$	$\frac{???}{???_{???}} \times 0.30$
Max Exploitation rate on MMA when $\frac{???}{???_{???}}$% ≥ 100%	10%	12.5%	15%	20%	30%	10%	12.5%	15%	20%	30%
Max exploitation rate on legal male abundance	25%	25%	25%	25%	25%	30%	30%	30%	30%	30%

*MMA: mature male abundance (number of crab)

*Zero exploitation rate used as a control (Sc0)

Forecast simulations

- 2018 base model (scenario 18_1)
- Projected abundances for 30 years
- 100 random replicates
- Estimated:
  - Mature males biomass (MMB)
  - Mature male abundance (MMA)
  - Legal male biomass (LMB)
  - Overfishing level (OFL)
  - Acceptable biological catch (ABC)
  - Total catch (TOTC)
  - Retained catch (RETC)
  - Retained catch per unit effort (CPUE) index
  - Number of annual recruits
    - 2 different recruitment scenarios
  - Probability of exceeding ABC (25% buffer on OFL)


Start: Randomize 2017 N and R
Implement State HCR
Set the state harvest rate based on current MMA , state specified $MMA_{average}$, MMA threshold , and LMA threshold
Convert the harvest rate into F; estimate the total catch, MMA, MMB, LMB, stock depletion, retained CPUE index, under this F; remove the total catch from the simulated population; project the population to next year; and add the next year recruits; apply federal Fofl to estimate ABC
LOOP OVER 30 YEARS
LOOP 100 TIMES
Calculate each year's mean and standard errors of MMA, MMB, LMB, ABC, stock depletion, total catch, retained CPUE, and number of recruits (for SR model); and probability of overfishing .
Stop

Initial conditions and recruitment

- Future production depends on recruitment and total mortality.
- Two recruitment scenarios:
  1. Random draw from 1987-2012 (period vetted by CPT and SSC)
     - Selected via uniform random distribution
     - + lognormal annual deviate
  2. Established Ricker stock-recruitment model
- Initial numbers-at-length in 2018:
  - Numbers based on terminal estimates in 2017 + error
  - Size-distribution based on terminal numbers-at-length

Recruitment random selection

1. Randomly select the estimated 1987 to 2012 recruits:

$$?_{?} = ?^{[??\,?\,?\;\;??\,?\,?\,??\;\;?\;\;??\,??\,??\,(??)?\,?.?\times???\,?\,?\,?\,??\;\;?\,?\,??\;\;??\;\;?\,??\,??\,??\;\;(?,?)]}$$

- where i = 2 to 30 years;

$$?? = 1987 + ??\,??\,???\;\;??\,??\,??\;\;?\,??\,??\,(?,?) * (2012 - 1987);$$ and

j = number of simulations.

Ricker S-R

2. Ricker stock-recruitment relationship:

- $? _{?} = ? ?_{?? \, ?} \, ?^{? \, ? \, ?_{?? \, ?}} \, ?^{\varepsilon_{?}? \, \frac{\sigma^{?}_{\epsilon_{?}}}{?}}$

Which was transformed into a linear form for fitting:

$?? \left(\frac{? _{?}}{? _{?? \, ?}}\right) = \left(\ln(?) - \frac{? \, ?^{?}_{?}}{?}\right) - ? ?_{?? \, ?} + ?_{?}$

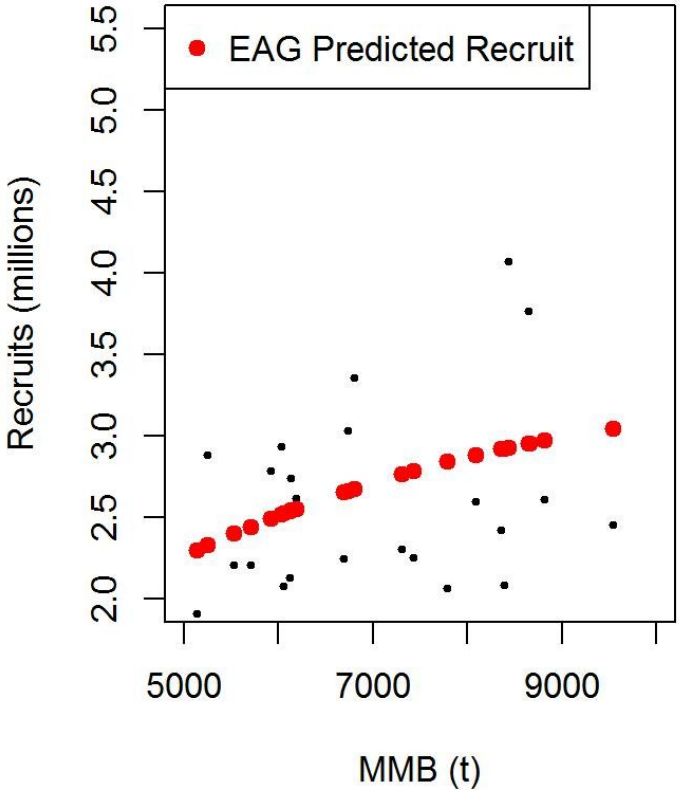
where

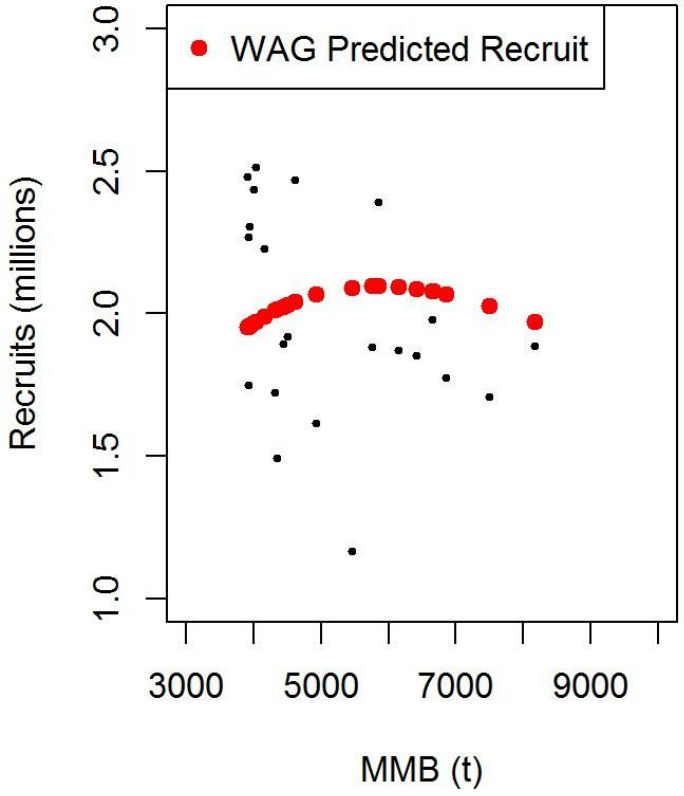
- $?_{?} = ? \, ?_{?? \, ?} + ?_{?} \qquad ?_{?} \sim ? \, (0, ? ^{?})$
- $?^{?}_{?_{?}} = \frac{? ^{?}}{?? \;\; ? ^{?}}$

where i is the year and k is the time lag

Procedure: Fit the SR model with (model M1) and without (model M2) the first order autocorrelation to the estimated MMB lagged by 8 years and number of annual recruits R (i.e., 1986-2009 MMB vs 1994-2017 R).

Fitted Ricker stock-recruitment (SR) model to EAG (left) and WAG (right) assessment estimated MMB (t) and annual number of recruits (millions of crab). Fitted SR model for EAG did not consider first order autocorrelation whereas fitted model for WAG did consider first order autocorrelation.



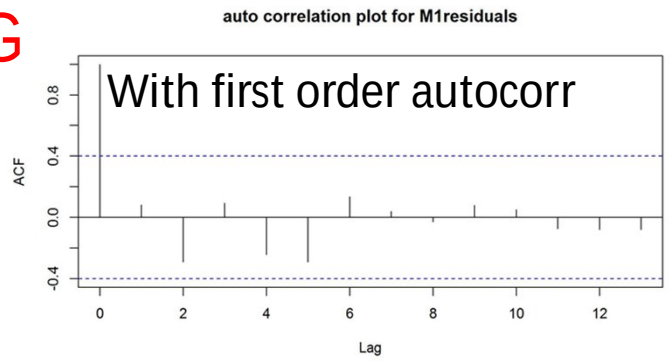


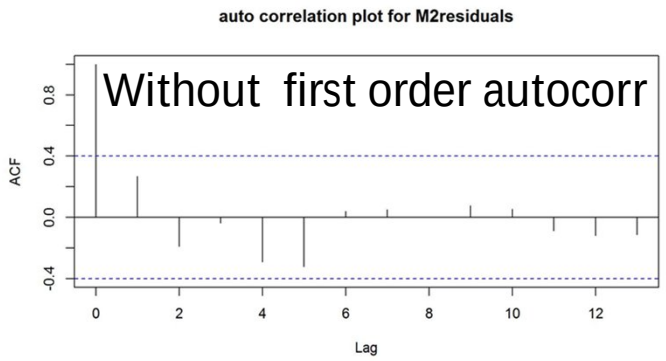
Ricker S-R Fit

Used generalized least square (GLS) with maximum likelihood option (R version 3.5.1, 2018) to fit linear form of Ricker model both with (model M1) and without (model M2) first order autocorrelation to estimated MMB (lagged by 8 years) and annual recruits (i.e., 1986-2009 MMB vs 1994-2017 R).

- Compared fits via ANOVA to assess if autocorrelation parameter needed

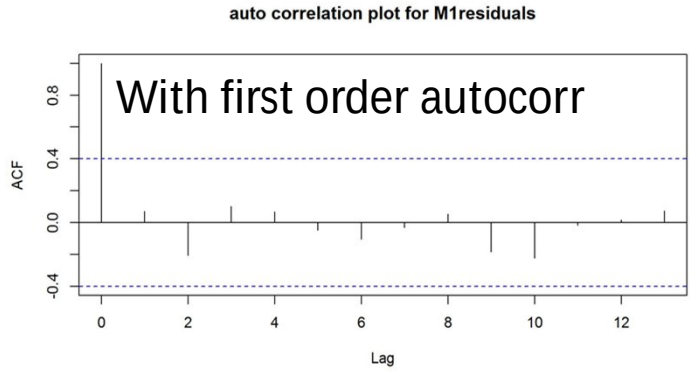
EAG

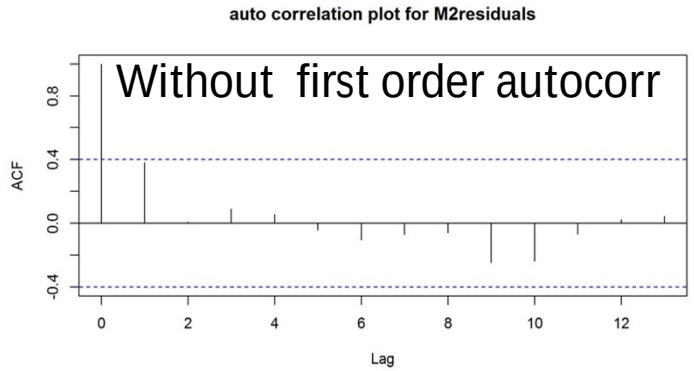




*Including autocorrelation parameter did not remove autocorrelation. Used M2 for EAG

WAG





*Including autocorrelation parameter did remove autocorrelation. Used M1 for WAG

ANOVA to select the Ricker stock-recruitment model

EAG: model 2 without AR1 selected

Model	Model Code	Df	AIC	BIC	Loglik	Test	Likelihood Ratio	p-value
AR1 model	M1	4	2.1644	6.8766	2.9178			
Without AR1 model	M2	3	1.9948	5.5289	2.0026	1 vs 2	1.8304	0.1761

WAG: model 1 with AR1 selected

Model	Model Code	Df	AIC	BIC	Loglik	Test	Likelihood Ratio	p-value
AR1 model	M1	4	-7.0092	-2.2969	7.5046			
Without AR1 model	M2	3	-4.8077	-1.2736	5.4039	1 vs 2	4.2014	0.0404

Randomizing initial abundance

- $? _{?,?} = ? _{?,?} ? ^{\varepsilon_? ?} \frac{\sigma_\varepsilon^?}{?}$
- where σ_ε = $\frac{??? .? ???? ?? ???? ?? ? ? ? ?? ? ? ? ?}{???? ?? ? ? ? ?? ? ? ?}$
- $?_? = ??? .? ??? ??(?) * \sigma_\varepsilon$
- $? _{?,?}$= initial abundance to be randomized for jth replication

Depletion Stat:

- $? ??? ?? ?? ? = \frac{? ? ?}{? ? ? _{???}}$

Overfishing Reference Point

- Used ABC (=0.75*OFL) to assess if total harvest exceeds overfishing
  - State uses the above Reference Point for setting TAC
  - State also must consider bycatch mortality in non-directed crab fisheries and groundfish fisheries

Results: EAG

- Random recruitment: Probability of total catch exceeding ABC higher than 0.5 for 20% and 30% HR
  - Applies for both 25% and 30% legal cap
- Ricker S-R: Probability of total catch exceeding ABC higher than 0.5 for 15%, 20%, and 30% HR
  - Applies for 25% legal cap only
  - Above 0.5 probability for only 20% and 30% HR when legal cap was 30%
- MMB and MMA below long term average for 30% HR, nearing this threshold for 20% HR
- LMB, CPUE lower and F (fishery mortality) higher as HR increased
- Recruitment trends reduced with 30% HR

Results: WAG

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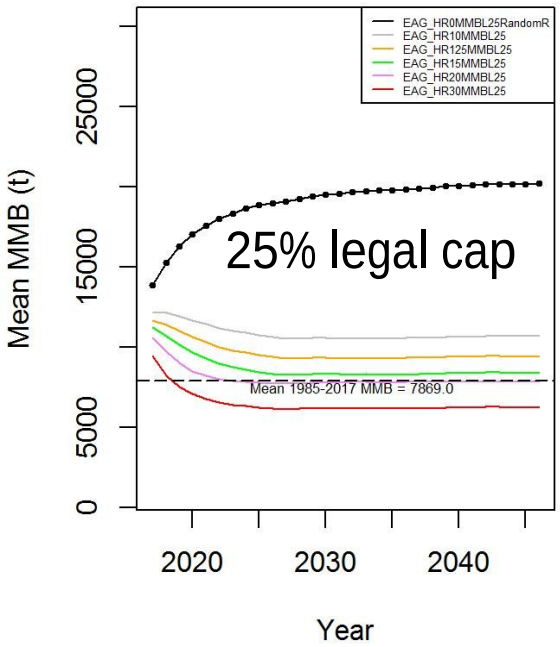
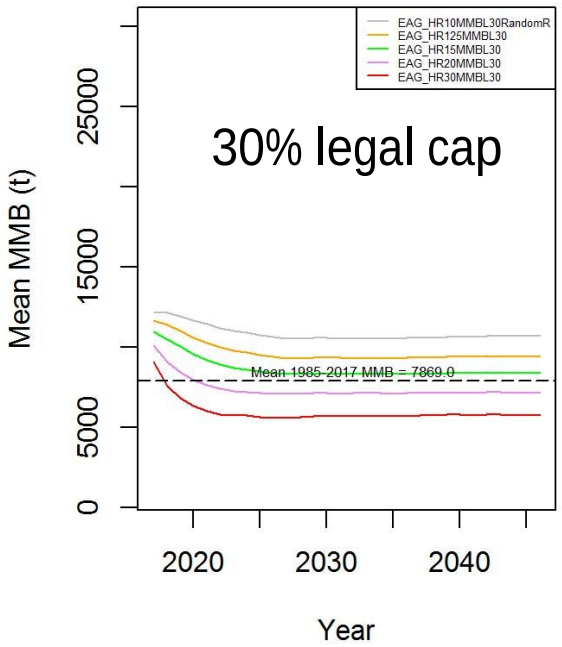
  - Above 0.5 probability for only 20% and 30% HR when legal cap was 30%
- MMB and MMA below long term average for 30% HR, nearing this threshold for 20% HR
- LMB, CPUE lower and F higher as HR increased
- Recruitment trends:
  - With 25% legal cap: horizontal mean, fluctuated with HR
  - With 30% legal cap: reduced with 30% HR, similar trends as EAG

EAG

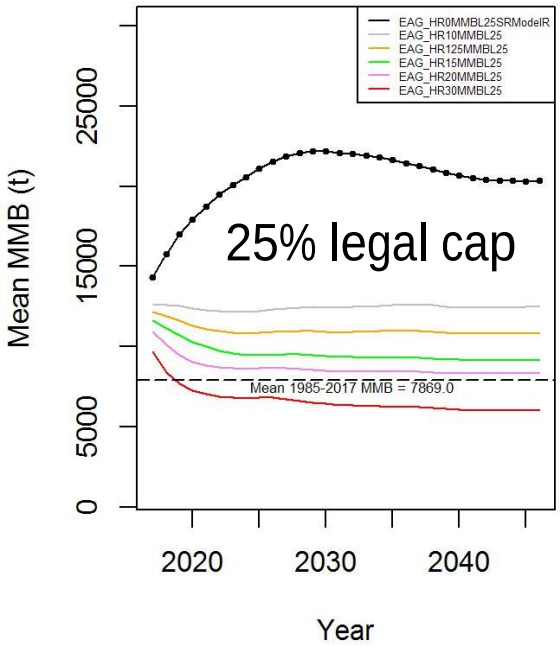
Mean MMB

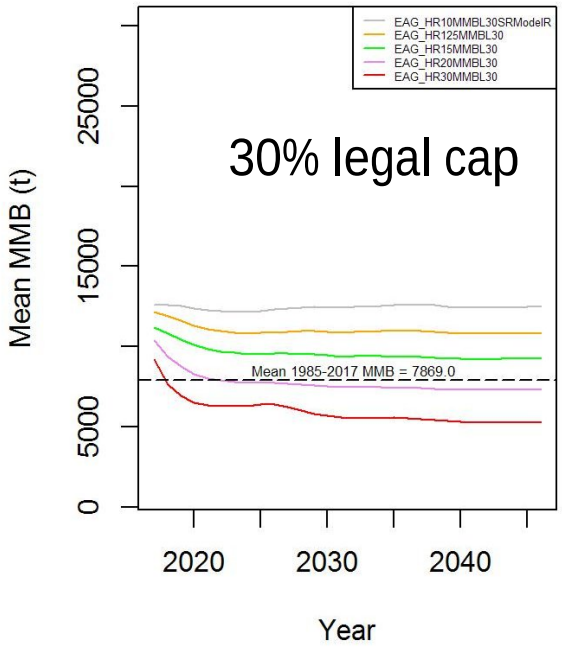
Randomly generated recruitment





Ricker S-R generated recruitment

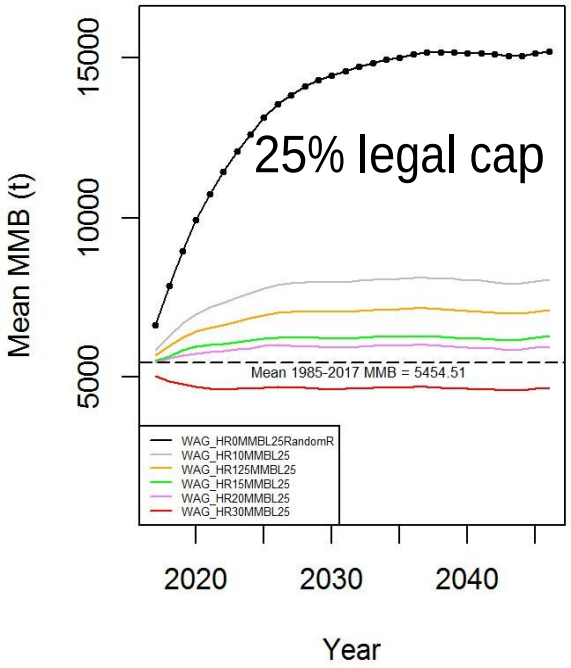


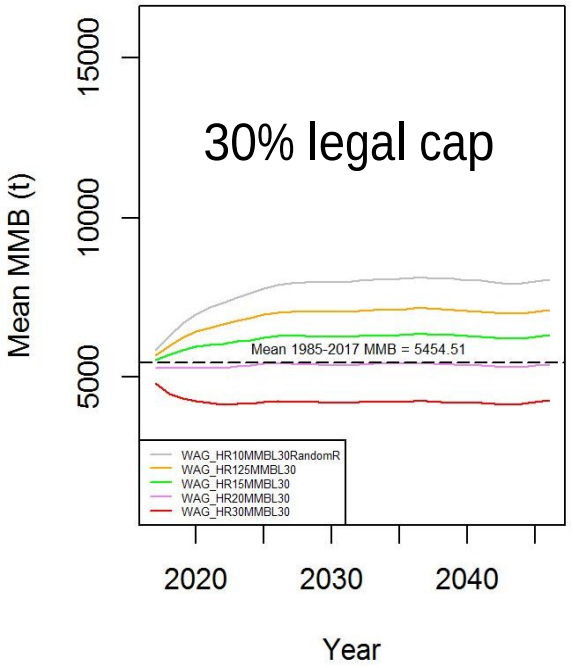


WAG

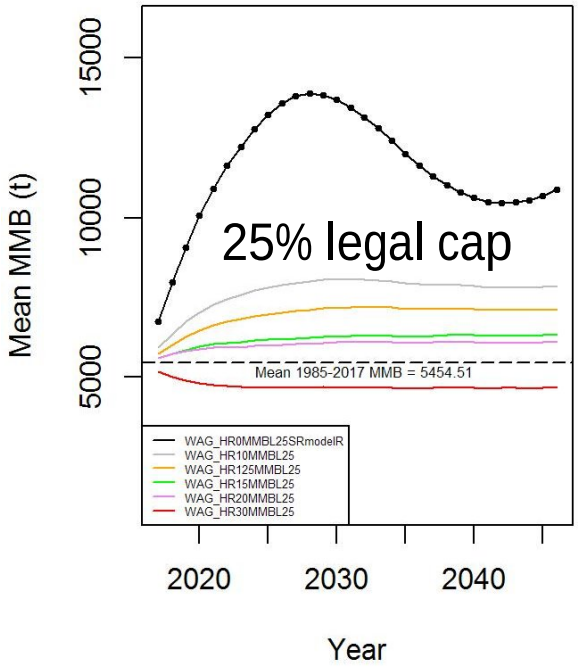
Mean MMB

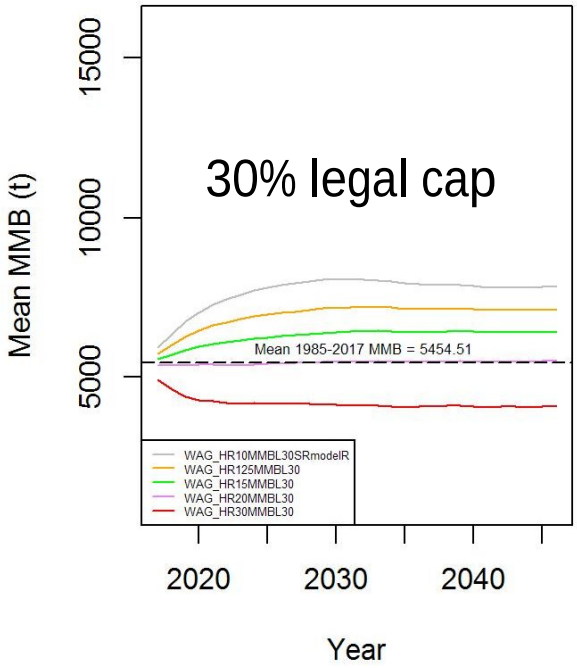
Randomly generated recruitment





Ricker S-R generated recruitment

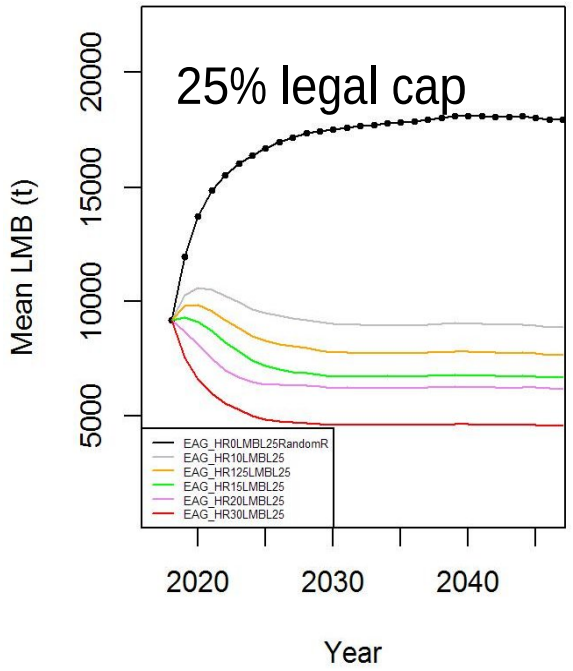


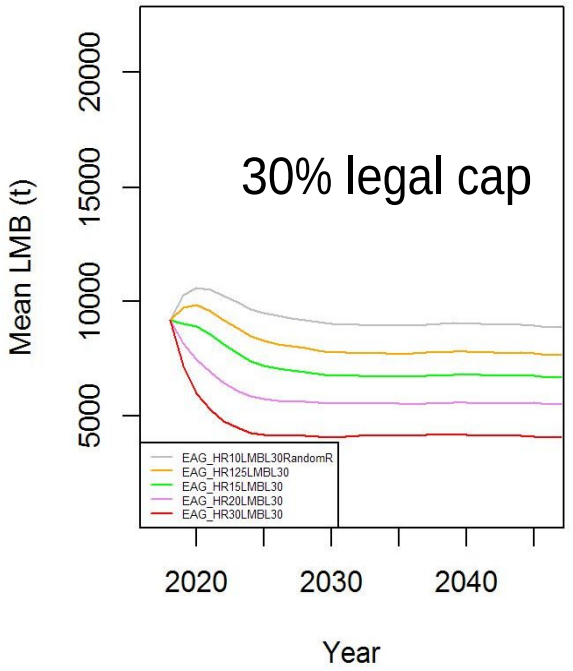


EAG

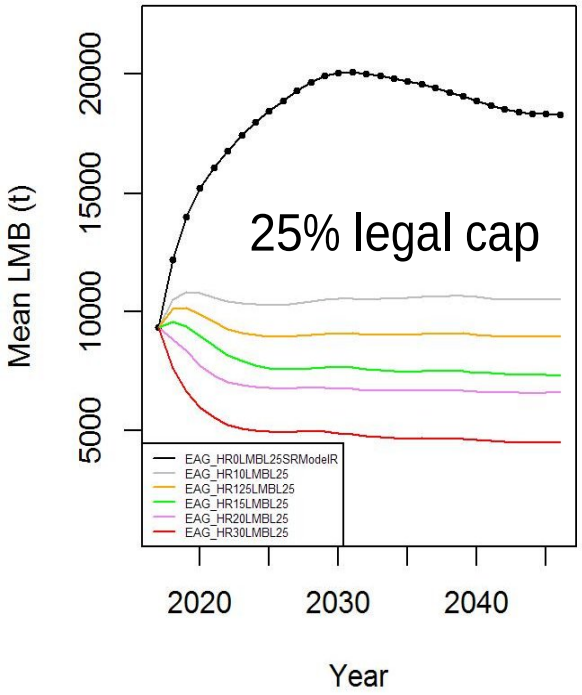
Mean LMB

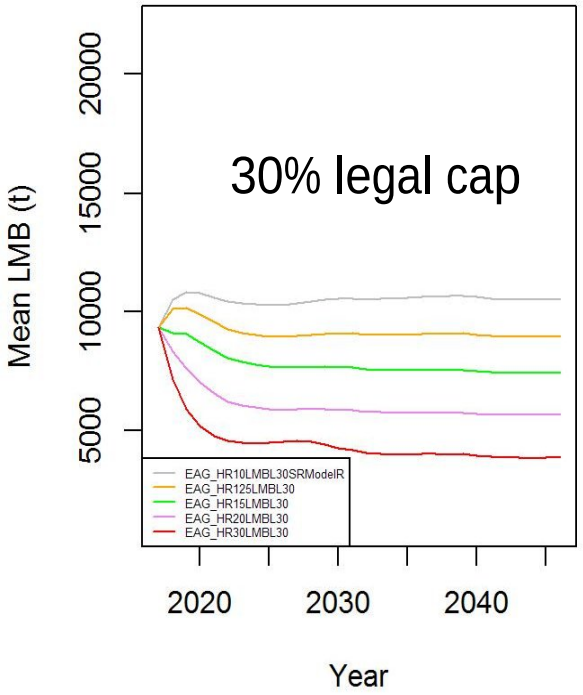
Randomly generated recruitment





Ricker S-R generated recruitment

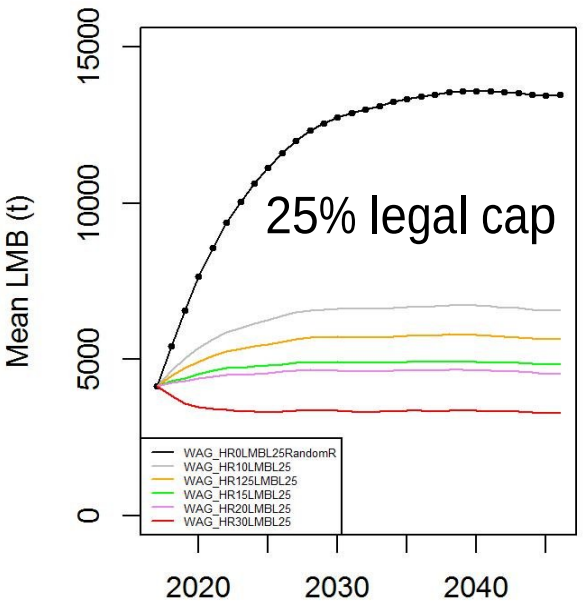


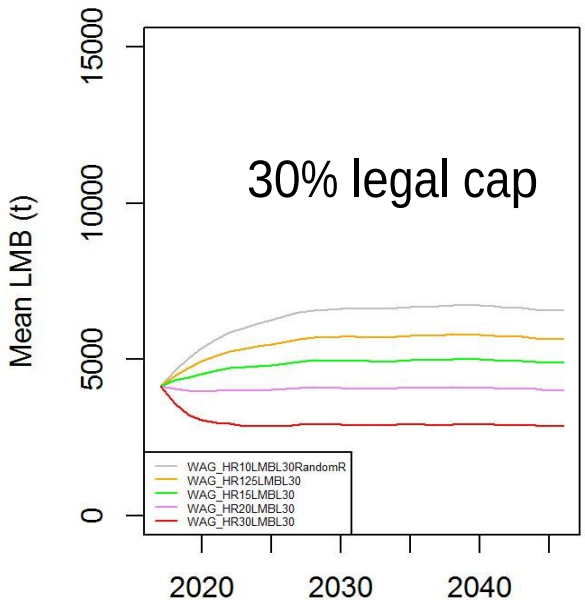


WAG

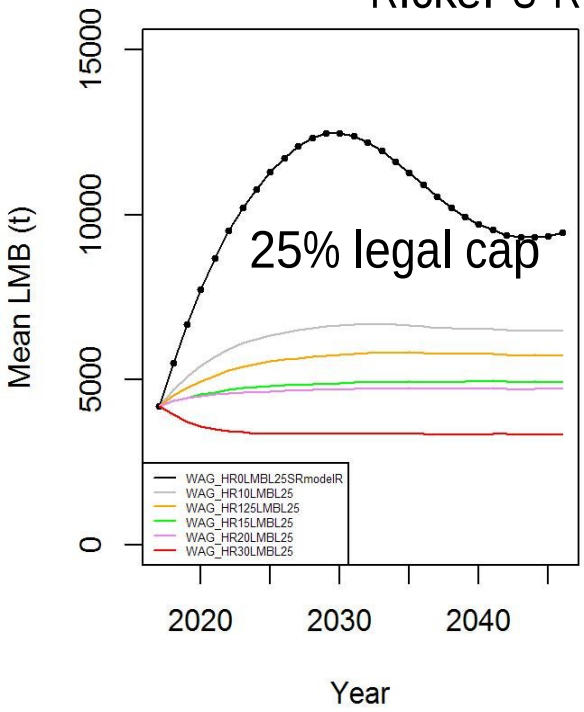
Mean LMB

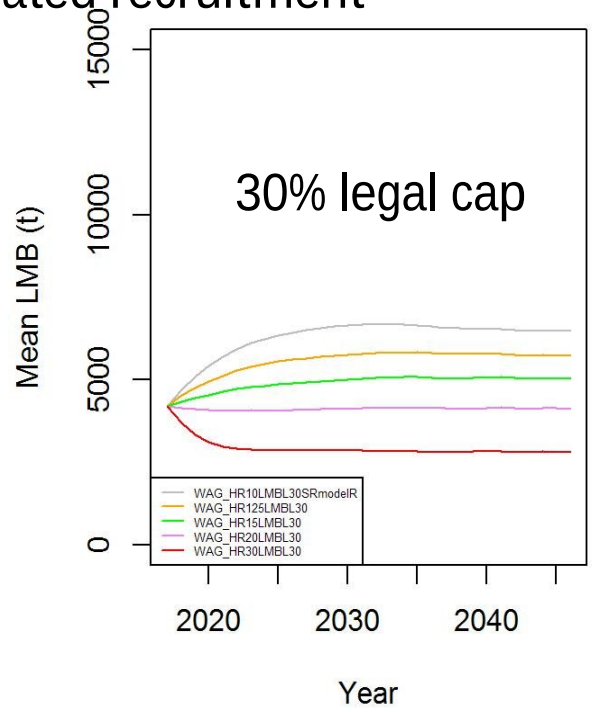
Randomly generated recruitment





Ricker S-R generated recruitment



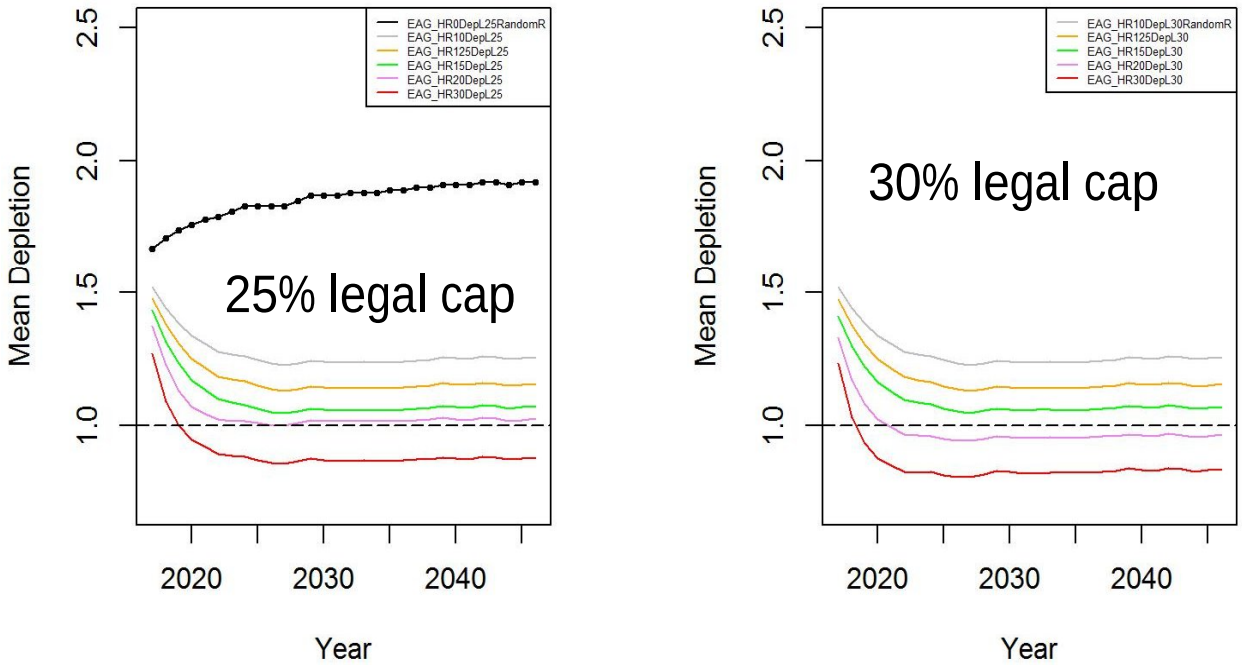


EAG

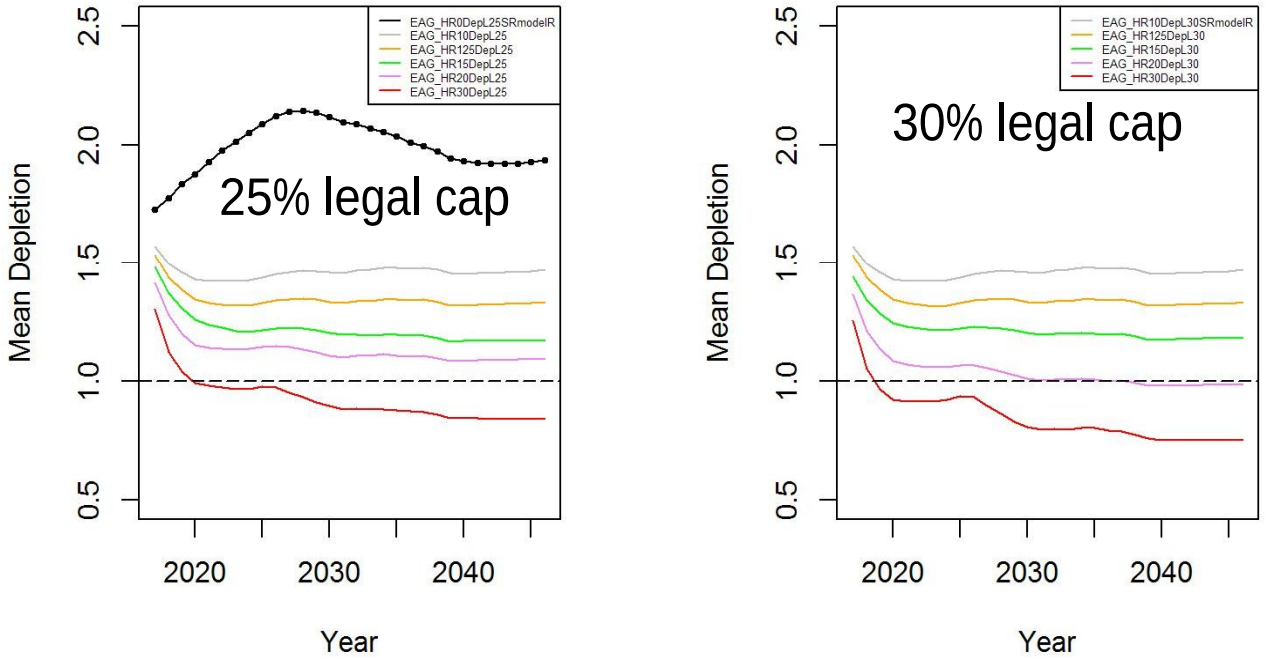
Stock depletion

$$???????? = \frac{???}{???\,???}$$

Randomly generated recruitment



Ricker S-R generated recruitment

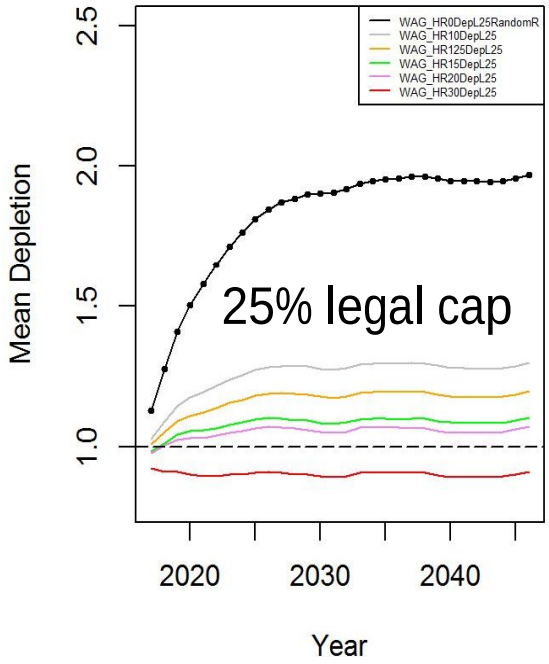


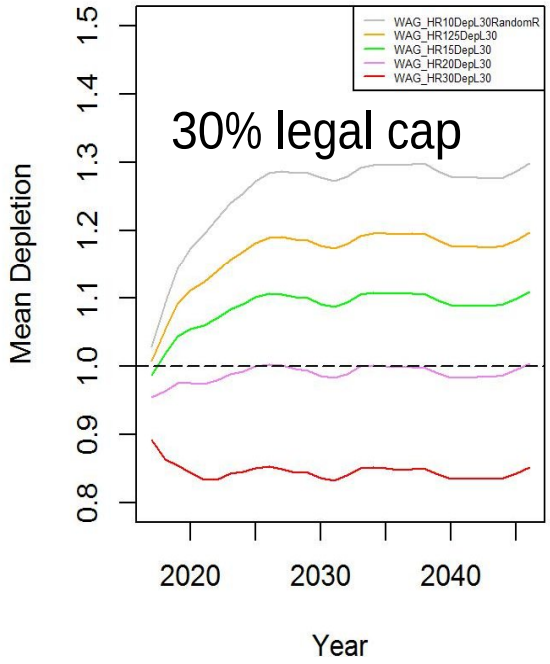
WAG

Stock depletion

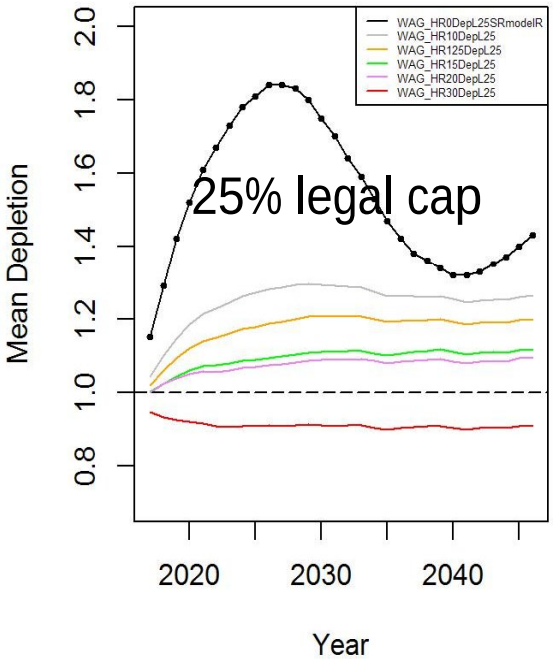
$$??????? = \frac{???}{???_{???}}$$

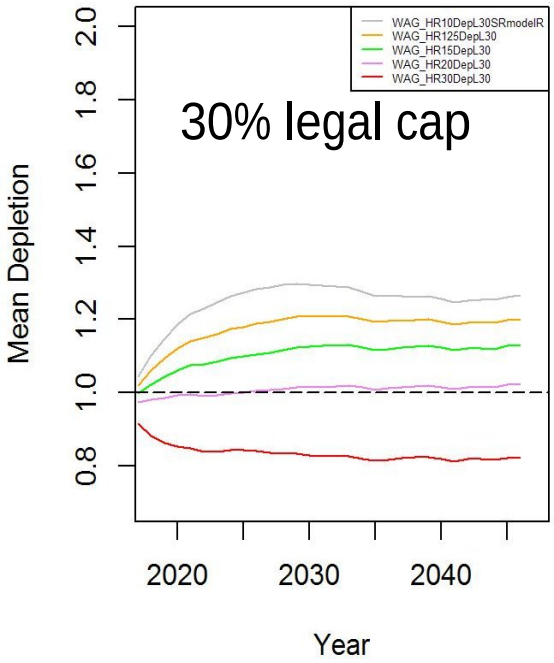
Randomly generated recruitment





Ricker S-R generated recruitment

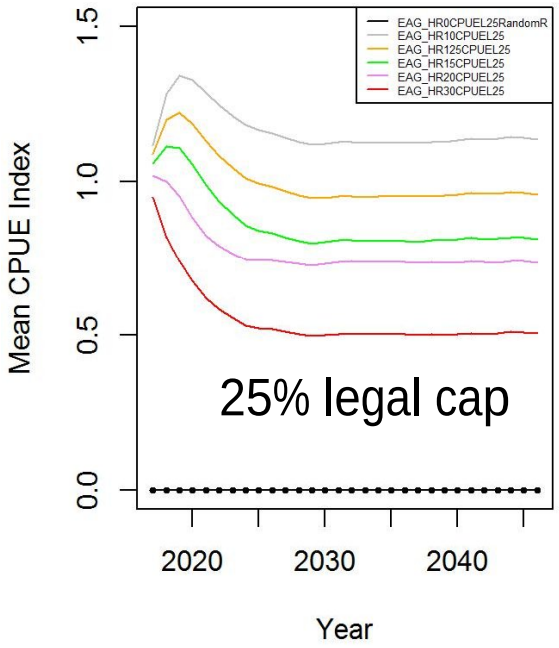


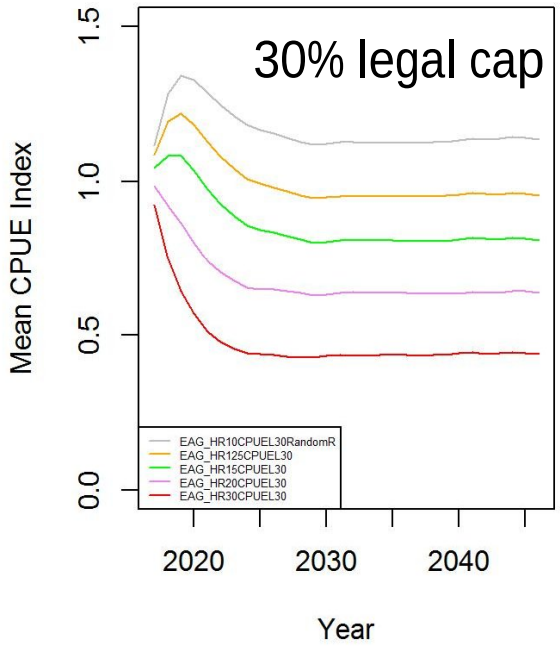


EAG

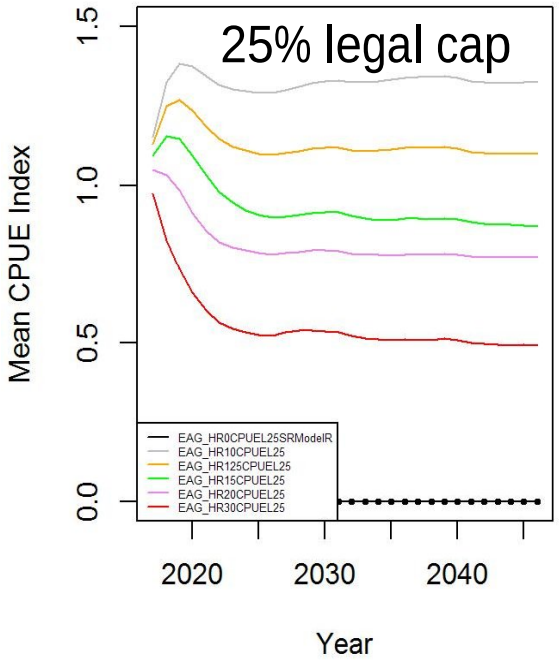
CPUE index

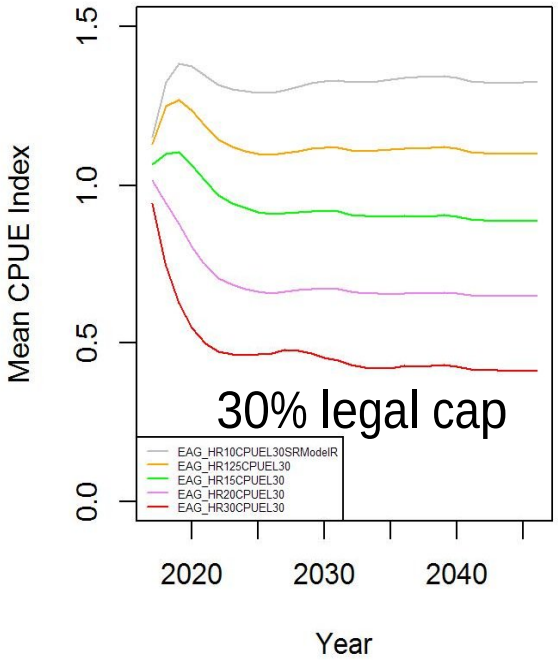
Randomly generated recruitment





Ricker S-R generated recruitment

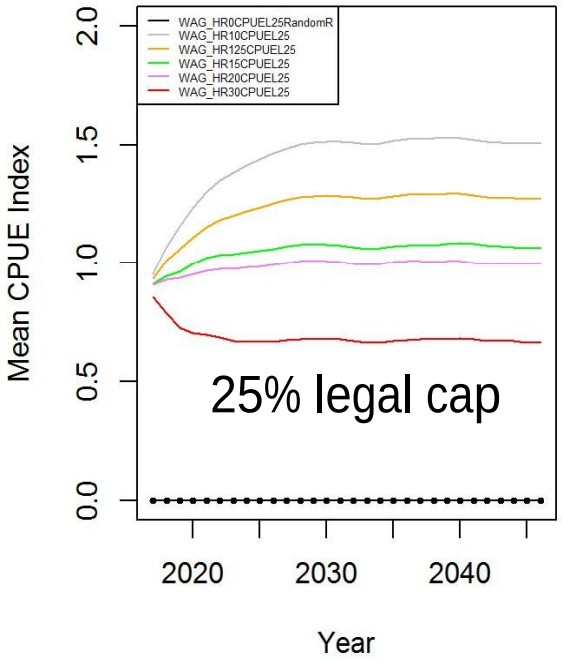


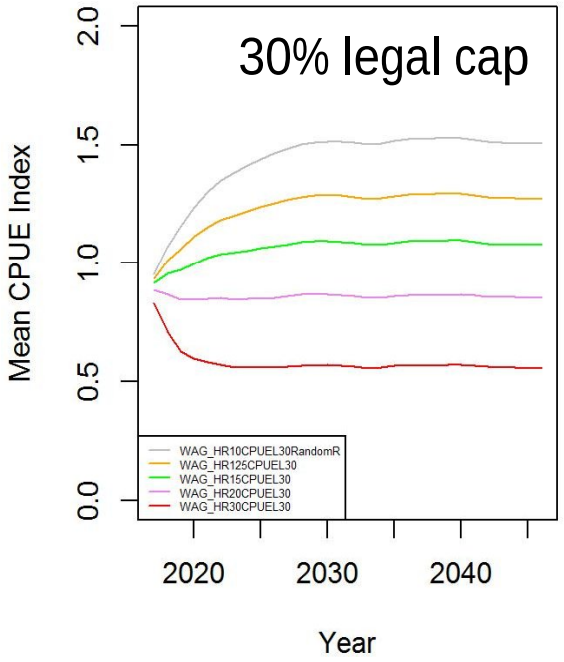


WAG

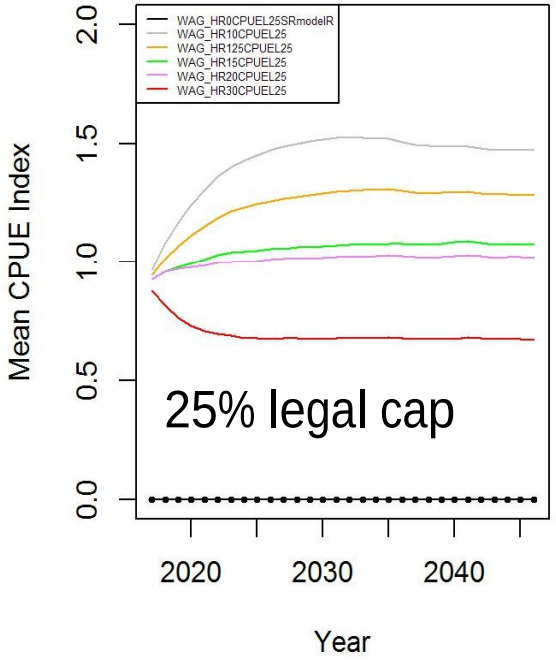
CPUE index

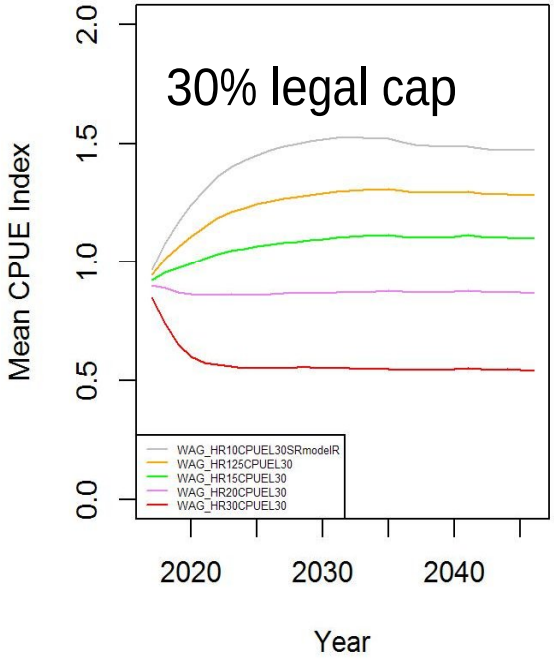
Randomly generated recruitment





Ricker S-R generated recruitment

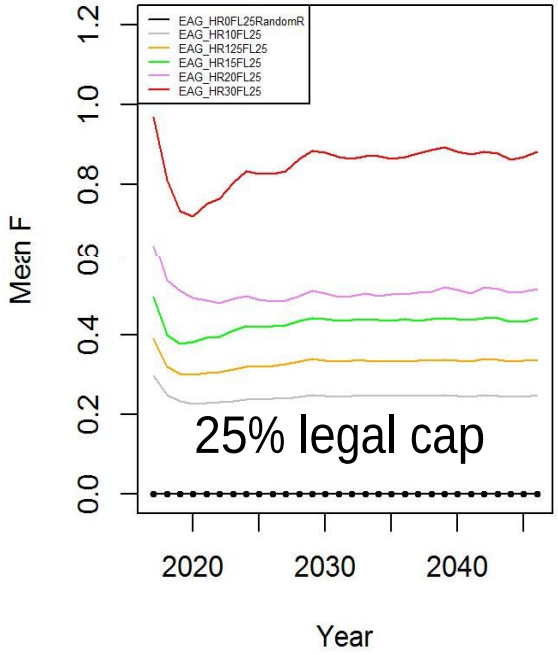


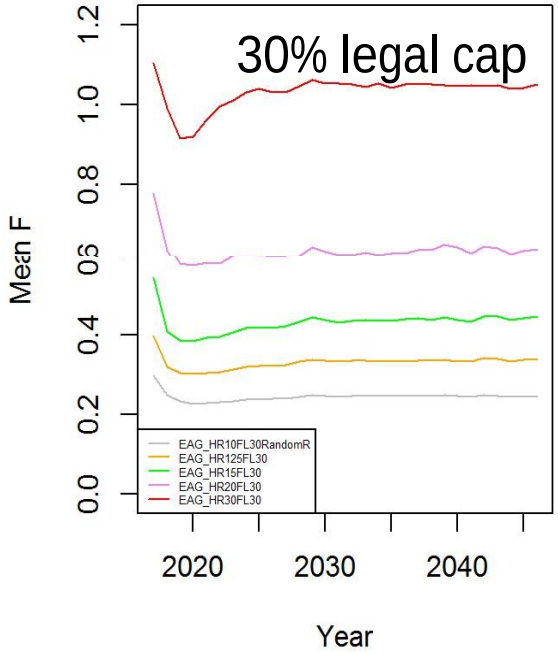


EAG

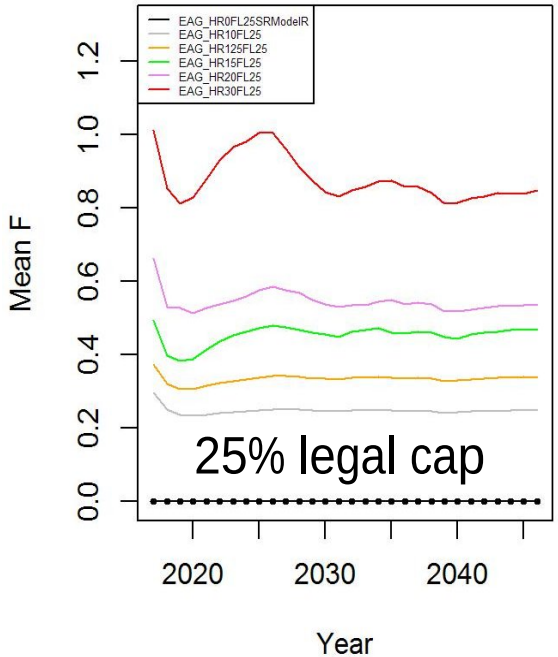
Fishery mortality (F)

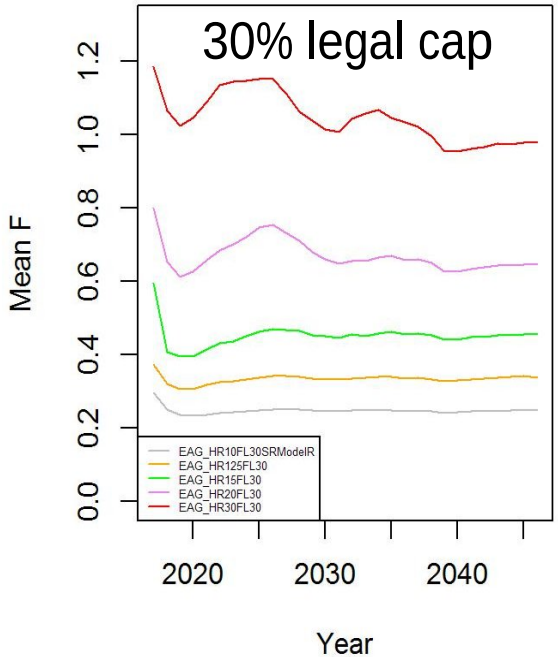
Randomly generated recruitment





Ricker S-R generated recruitment

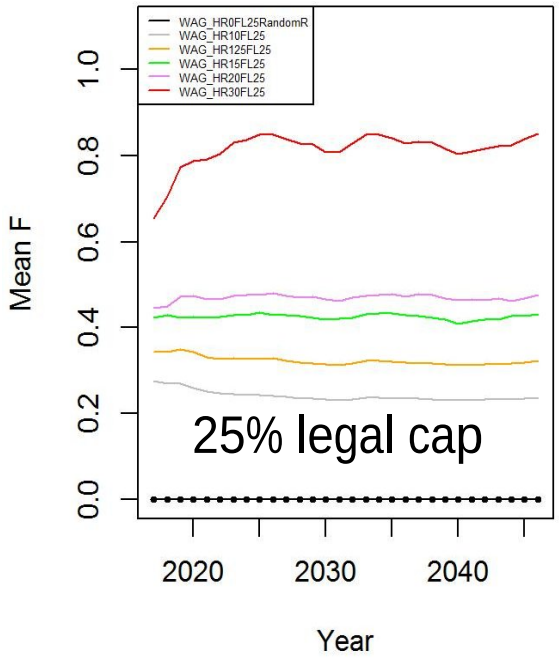


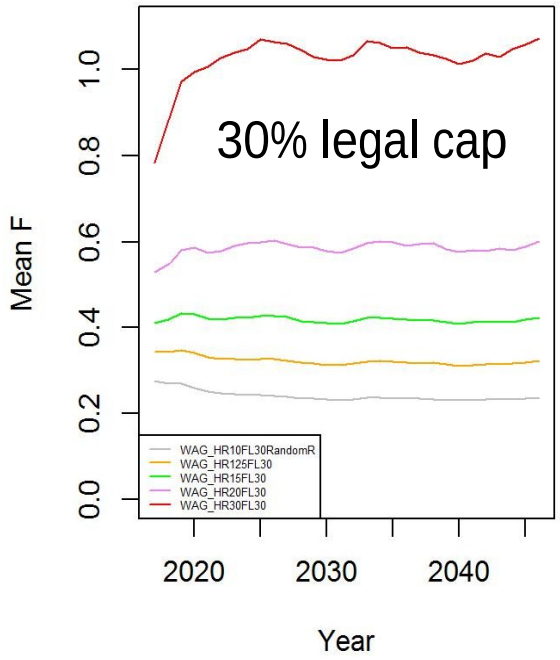


WAG

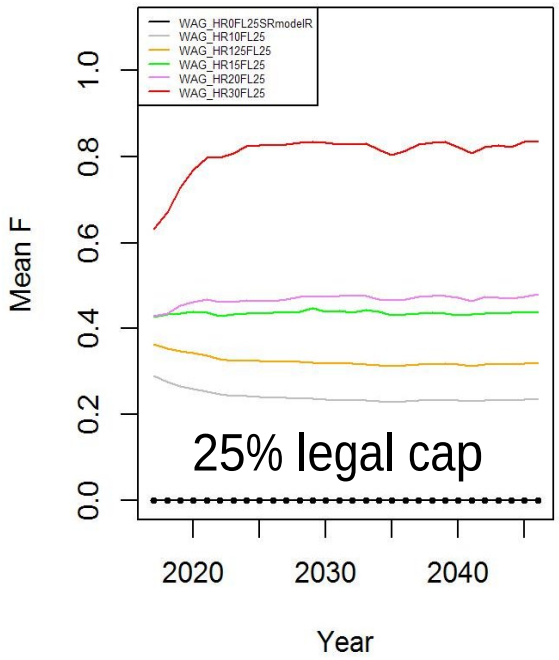
Fishery mortality (F)

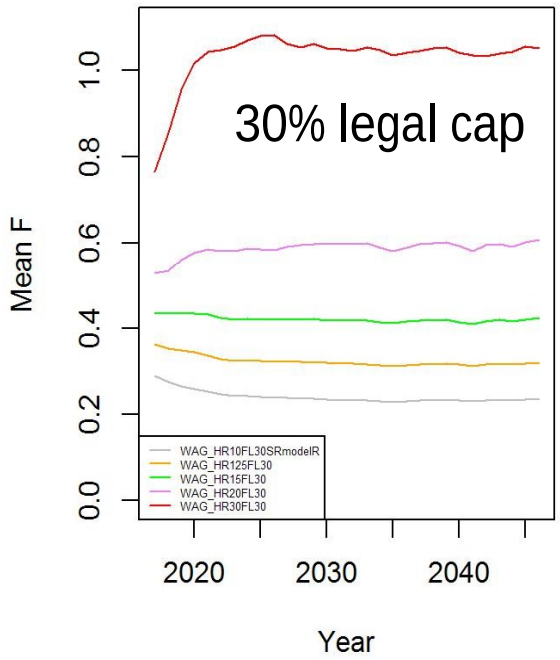
Randomly generated recruitment





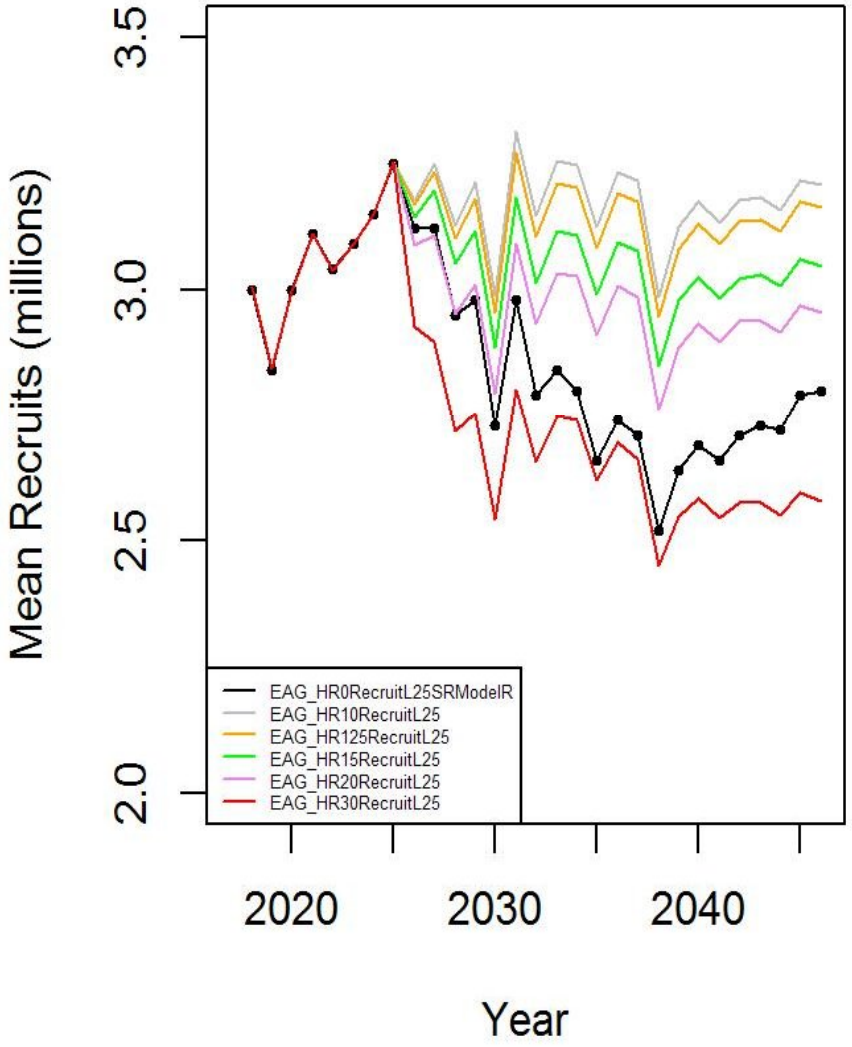
Ricker S-R generated recruitment



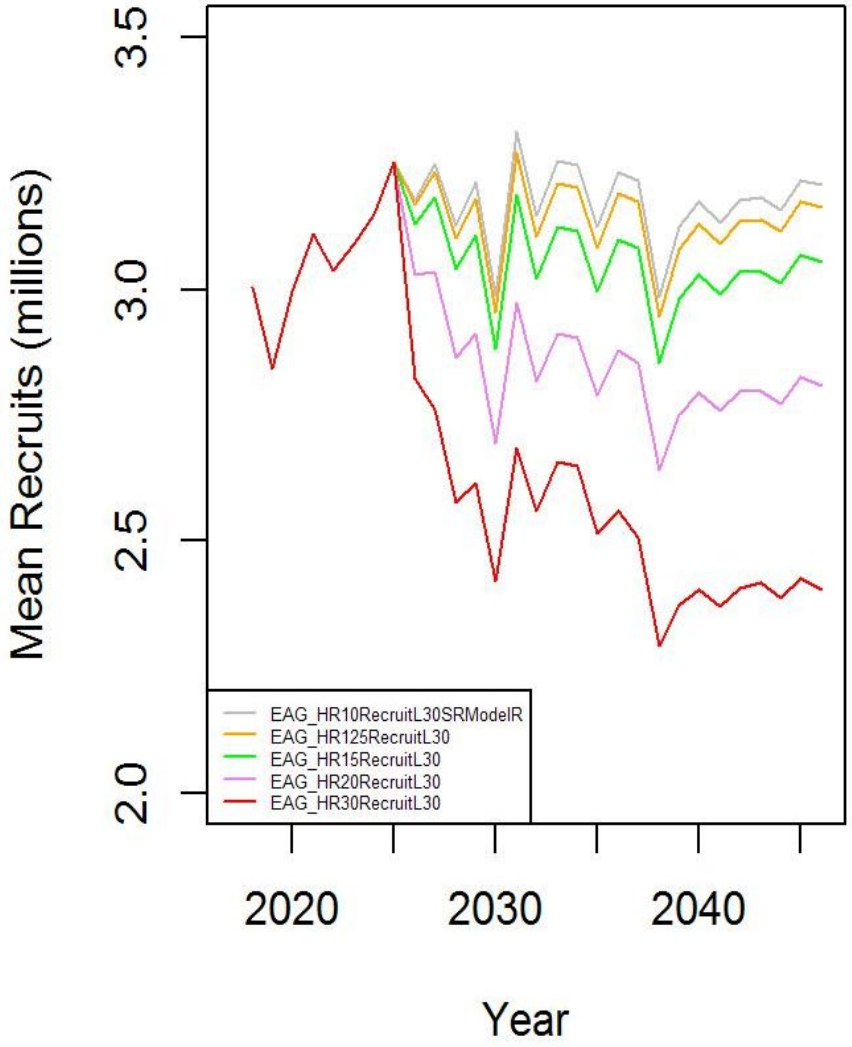


Recruits: EAG

25% legal cap



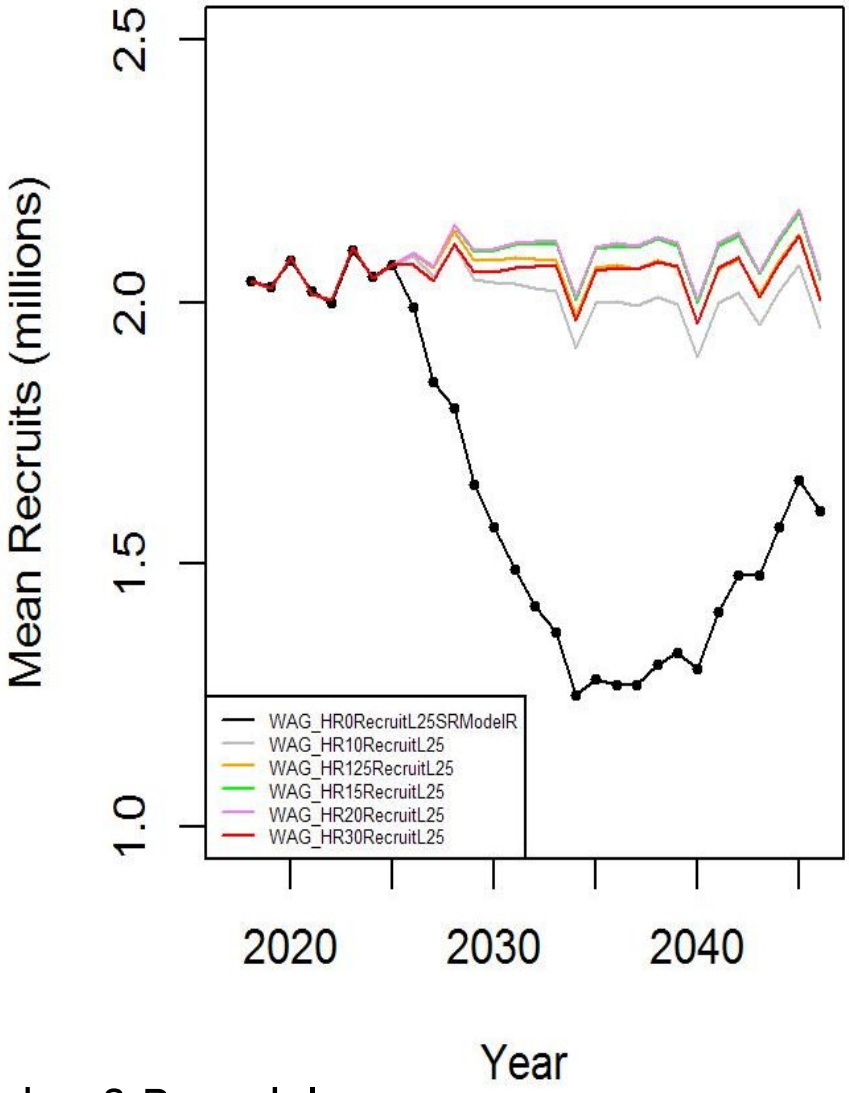
30% legal cap



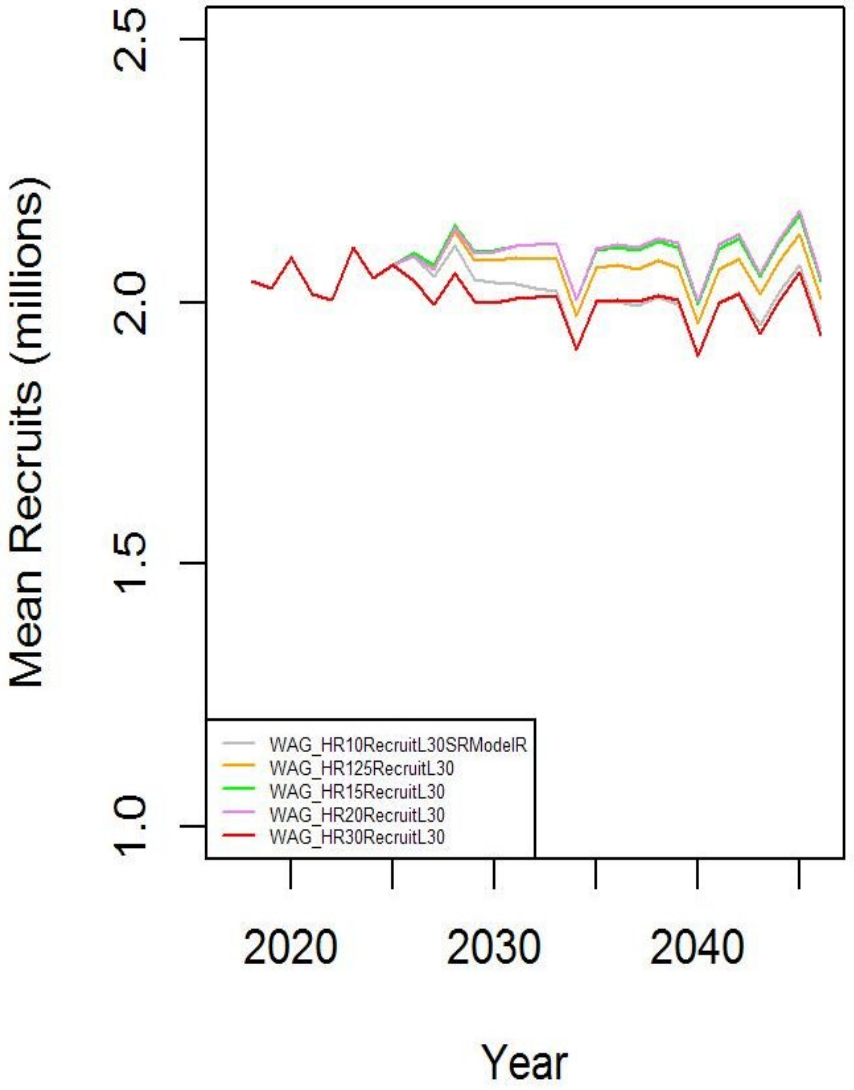
Ricker S-R model

Recruits: WAG

25% legal cap



30% legal cap



Ricker S-R model

Overall Conclusions

	Prob Total Catch >ABC			
	Sc. 1-2	Sc.3	Sc.4	Sc.5
EAG Random R	0	0.03	1.0	1.0
EAG S-R R	0	0.63	1.0	1.0
WAG Random R	0	0.57	1.0	1.0
WAG S-R R	0	0.97	1.0	1.0

Scenarios 1-5 are for the 25% legal male harvest limit . Scenarios 6-10 are for 30% legal male harvest limit-similar results (not shown above).

- 15% HR (Sc.3) is safe
- 20% HR (Sc.4) makes MMB and MMA trends approach their long term averages and likely to be risky
- 30% HR (Sc.5) is too high

**We compared total catch trends to ABC for determining probability of overfishing. If compared to OFL trends, probability of overfishing would be lower.*