Harvest rules for stocks with changing recruitment, like Blue whiting

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for

Pelagic AC

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Task

... to develop harvest rules that can work well with large unpredictable recruitment fluctuations, rather than to attempt to make predictions based on presumably realistic scenarios for the future.
Therefore, the suggestion is to set up a test-bench with a range of recruitment scenarios and transitions between scenarios, and to use that to explore the performance of harvest rules when recruitment fluctuates like it has done for blue whiting.

In brief:

Outline harvest rules that can work for a stock like Blue whiting,

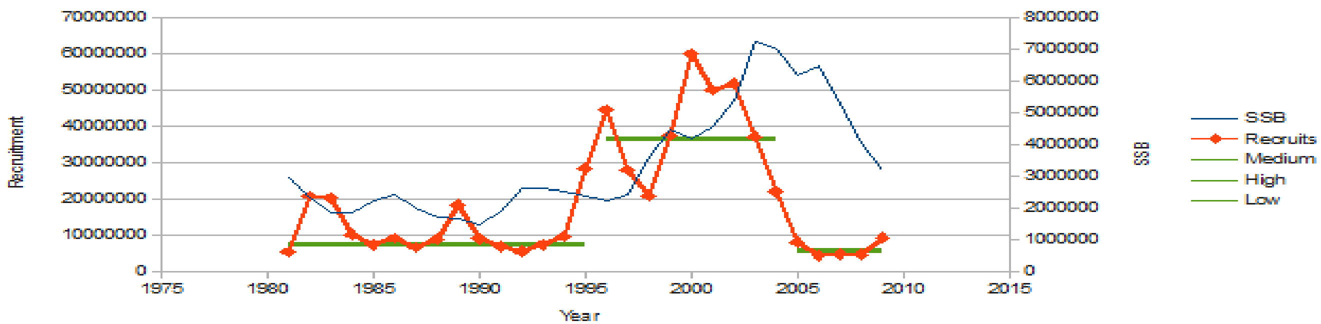
with

- Large and unpredictable variations in recruitment,
- Noisy assessments.

Harvest rules for Blue whiting have never survived very long.

This slide is from the study in 2012.
Still true!

The major challenge:
Shifts in recruitment regimes:



Most harvest rules assume a stable recruitment regime
(variations around a stable relation between recruitment and SSB)

Limited experience with designing rules for regime shifts.

Why is this so difficult?

- Variable recruitment
- Uncertain assessments
- Many interested parties, including scientists.

What can we do?

- Look for rules that can handle shifts in recruitment and 'strange' levels of recruitment
- Reduce sensitivity to noise but keep sensitivity to changing production capacity
- Start with conventional plan designs, and work from there.

A rational approach:

We are used to assume stationarity in dynamics and reference points.
We cannot just assume that when recruitment changes.
Clarify what becomes different.

Some key issues:

- Reference points may not be universally valid, safe values ain’t so safe.
- The timing of management action should be adapted to timing of change in stock dynamics and abundance

Reference points:

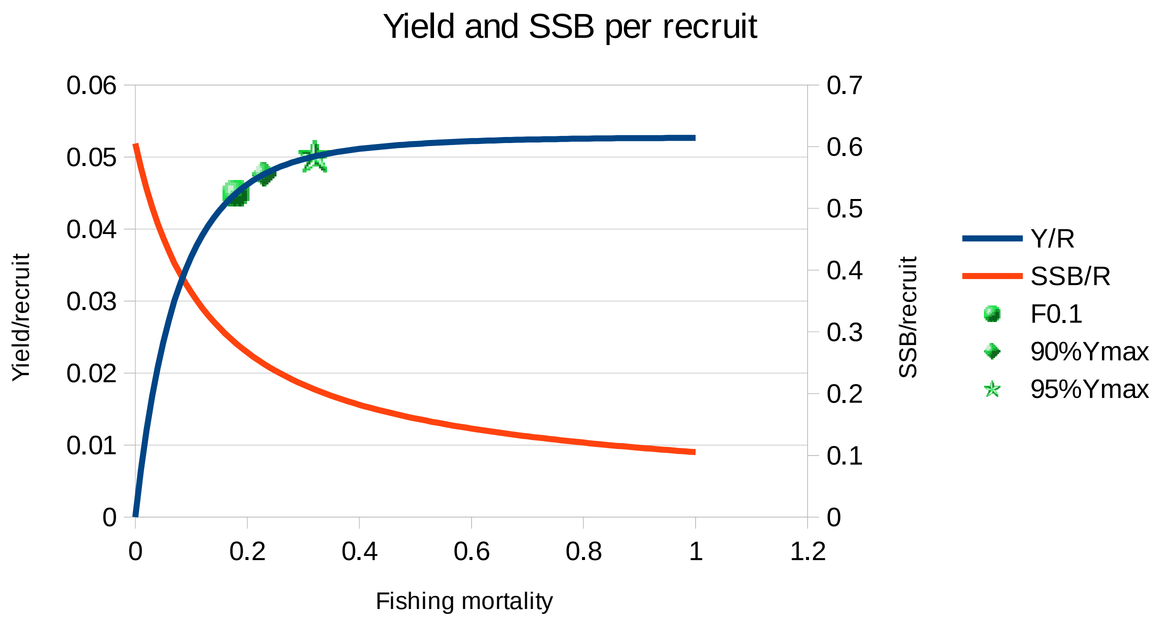
Yield and SSB per recruit

Depends on:

- Growth
- Maturation
- Selectivity in fishery
- Natural mortality.

Values from Blue whiting assessment 2016, but modified selectivity at age

Actual catch and SSB is Y/R and SSB/R times the recruitment.



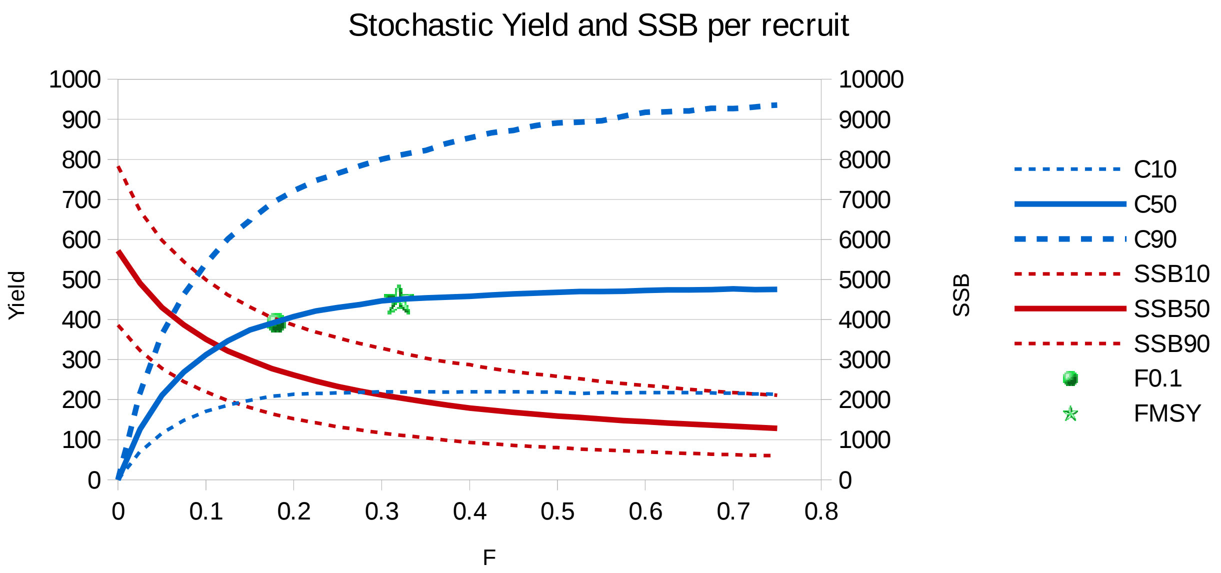
Two key values:

F=0.18: $F_{0.1}$

F=0.32:

Where Y/R is 95% of the maximum and ICES $F_{MSY.}$

When recruitment (and growth and maturity) is has random variations, that translates into variation in catches and SSB:



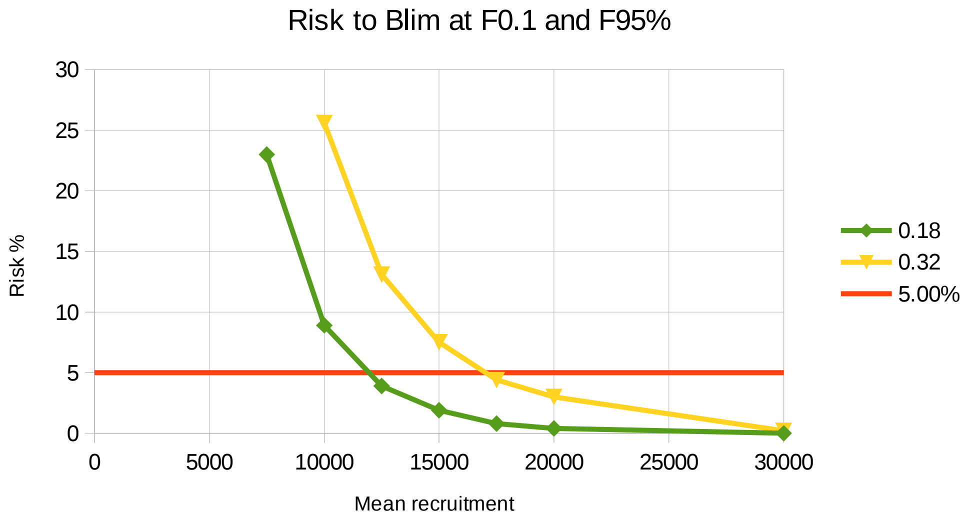
Here, we have assumed a constant mean recruitment at 10000 (arbitrary example!) and the variability used elsewhere in this study.

If recruitment changes over time, beyond random variations, each recruitment regime will have its own set of such curves.

A new dimension! - reference points depend on recruitment.

Normally, we assume that recruitment varies around a stationary mean.
We look at the yield and SSB as a function of F and
the probability that SSB is below Blim (risk) as a function of F
under that condition.

But when recruitment is variable, we also have to consider how the risk depends on mean recruitment.



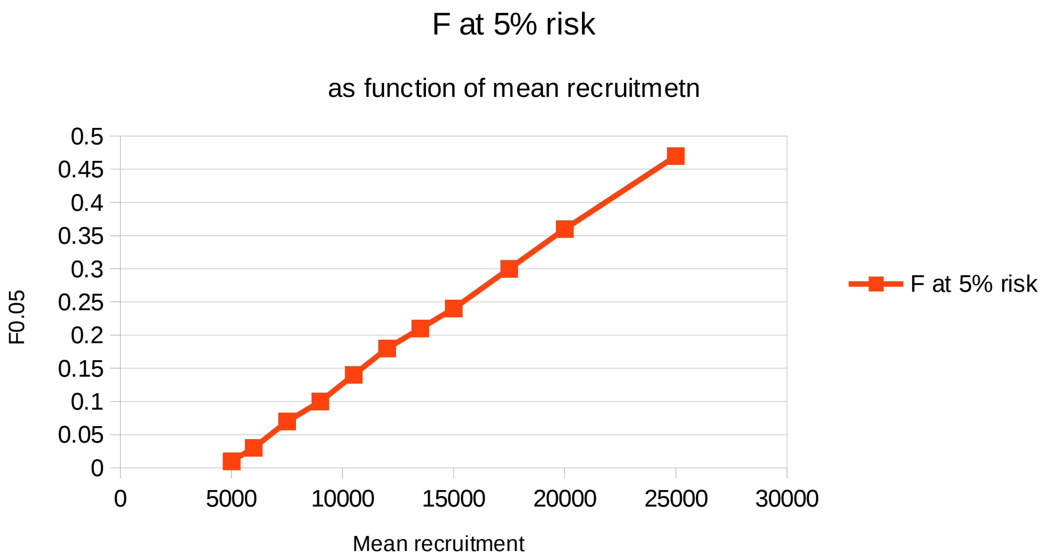
One way to see this:

For the two key F-values:

How the risk to Blim depends on mean recruitment

Another way to see this:

The F leading to 5% risk as a function of the mean recruitment.

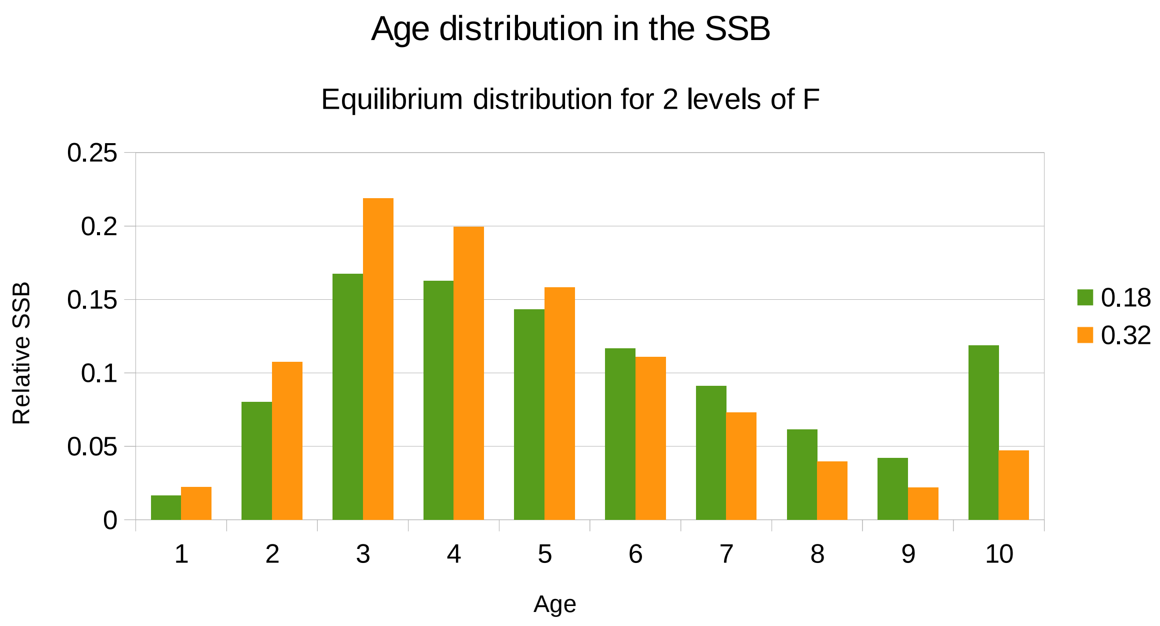


This is a straight line!

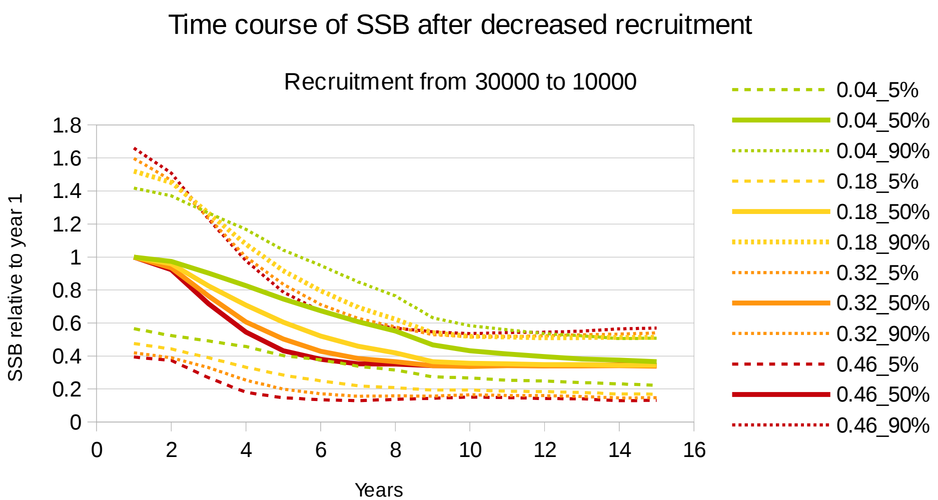
- Guidance for a rule where F depends on recruitment
- There is no specific F-value that is 'safe', even $F_{0.1}$ is only safe if there is enough recruits.

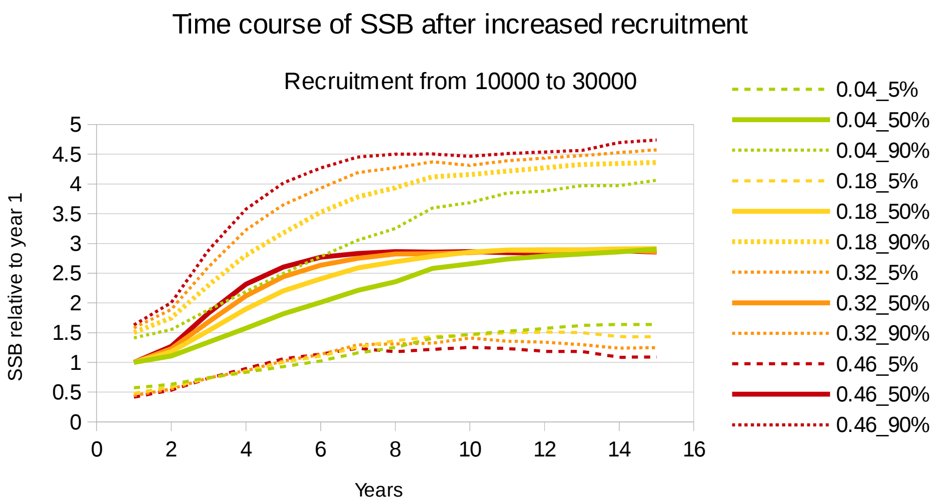
Timing of response

1. Spawning biomass is mostly ages 3-5.



2. Change in SSB is delayed and gradual





Two implications:

1. There is time to confirm a change in recruitment, but don't wait for too long
2. Using SSB as guidance means late and gradual response.

HCS: Workbench for testing harvest rules

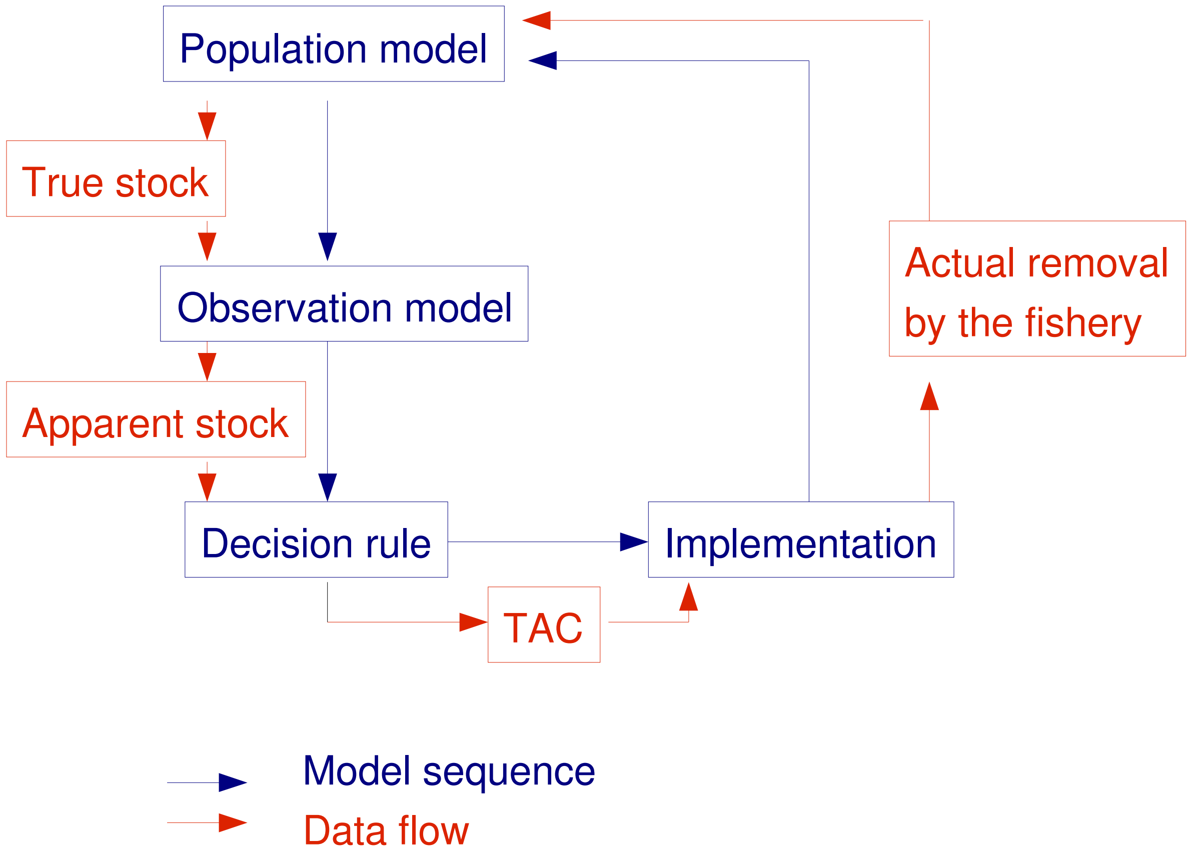
Brief tutorial on bootstrap simulation tools, like HCS.

Many elements are uncertain: Recruitment, growth, observations.
These are represented by statistical distributions rather than exact numbers.

We make many (1000) examples (iterations) with values for the uncertain elements drawn from their assumed statistical distributions. That translates these distributions into distributions of our performance parameters. We can then state the probability of outcomes of interest.
For example, we want to know the 'risk to Blim', which is the probability that SSB falls below the limit.

We get that by counting the number out of the 1000 iterations where this happens - if it happens in 50 out of 1000 iterations, the risk is 5%.

This way of accounting for uncertainty is called bootstrap or Monte Carlo methods.



HCS - how it works

An artificial stock that is updated every year. It is managed by TACs that are set according to a harvest rule and removed from the stock. A new year class recruits each year.

Decisions are made according to 'observed' values for stock abundance. The 'observed' numbers have error that imitates a real assessment

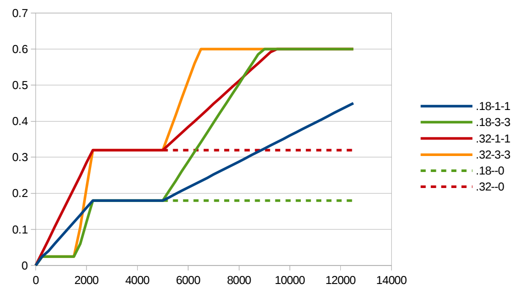
The anatomy of a harvest rule.

Basis:
Anything that informs about the state of the stock:
SSB, TSB, Recruitment, something else.One or more.

Rule:
A formula that derives a *measure of exploitation* from the basis:

If Basis(1) < Btrig1: *v = vstd*(1.0-alpha1*(btrig1-Basis(1))/btrig1)*.
If that leads to *v<0*, set *v = 0*
If Basis(1) > Btrig1 and Basis(2) < Btrig2: *v = vstd*
If Basis(1) > Btrig1 and Basis(2) > Btrig2: *v=vstd*(1.0+alpha2*(Basis(2)-btrig2)/btrig2).*
If v<vmin so far, set v=vmin
If v>vmax so far, set v=vmax

Measure of exploitation: F, harvest rate (HR=TAC/TSB)



Translation:
Derive TAC from measure of exploitation,
typically using 'observed' stock numbers.
Gives a primary TAC.

Stabilizers:
50-50 rule: TAC = 0.5*TAC(y-1)+(1-0.5)*primary TAC)
Percentage rule: TAC-change constrained if SSB > a trigger

Maximum or minimum TAC

Model conditioning:

- Weights, maturities natural mortalities: As used by WGWIDE 2016.
- Selection in the fishery: Almost flat above age, different from most recent year.
- Initial numbers: Observation model applied to stock numbers at start of 2016.

- Recruitment:
  Sequence of recruitment models with different means.
  Hockey stick with break-point at SSB = 1500,
  - Lognormal ditribution with CV= 0.45,
  - Autocorrelation 0.75,
  - No truncation,
  - No exceptional year classes (spikes)

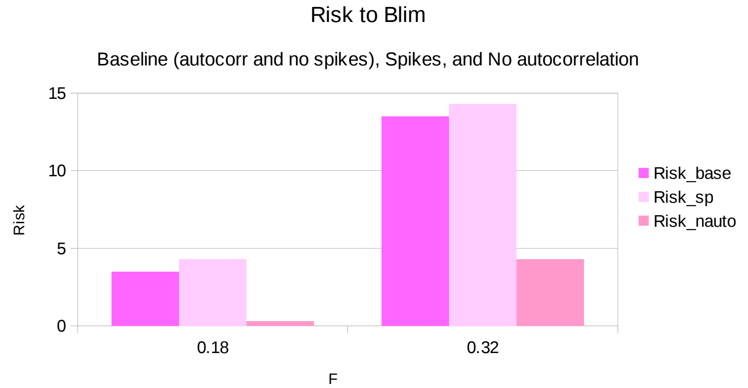
  Probably somewhat more variable than the historical series.

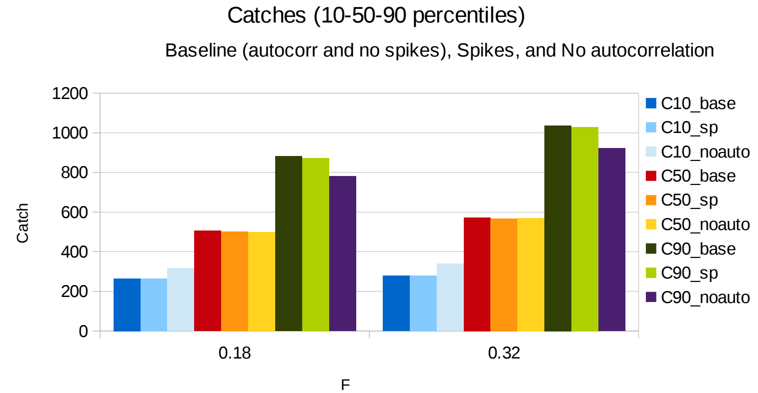
- Observation model:
  Random noise is a product: Year factor * Age factor.
  - Age factor from assessment - CV of stock numbers at age.
  - Year factor: Autocorrelation 0.6 (a bit arbitrary) and CV scaled to give
  - a confidence interval of SSB in the initial year equal to that in the assessment.

  This imitates a quite noisy assessment.

Spikes and autocorrelations

Tested including spikes and removing autocorrelation for two levels of fishing mortality



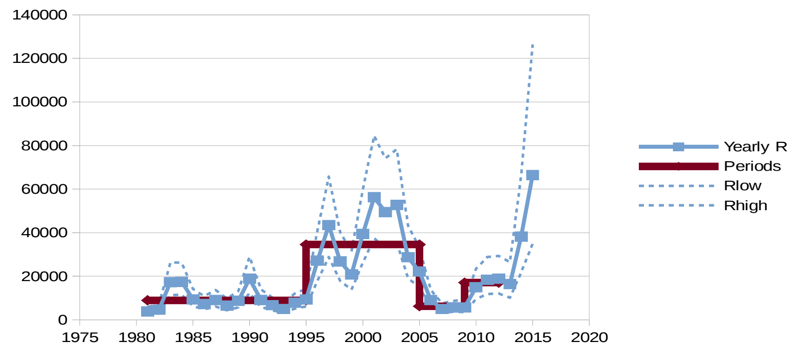


Autocorrelation (here with ρ=0.75) broadens the distribution of catches (and biomasses) leading to higher risks. The median catch is almost unchanged.

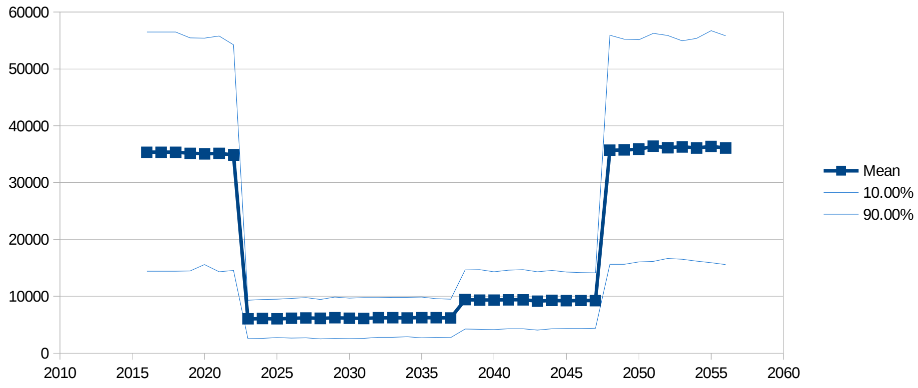
Spikes make little difference when the mean recruitment is adjusted accordingly.

Sequence of recruitments:

History:

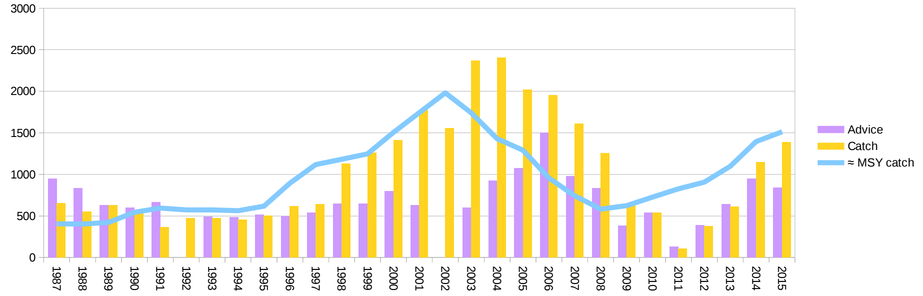


Standard test bench:
4 periods, shift in fixed years.
Levels similar to the historical ones, but set up to test how rules can handle such recruitments and recruitment shifts.

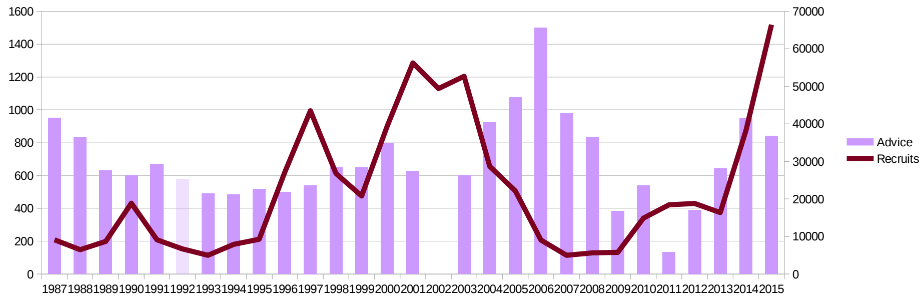


Designing harvest rules for changing recruitment

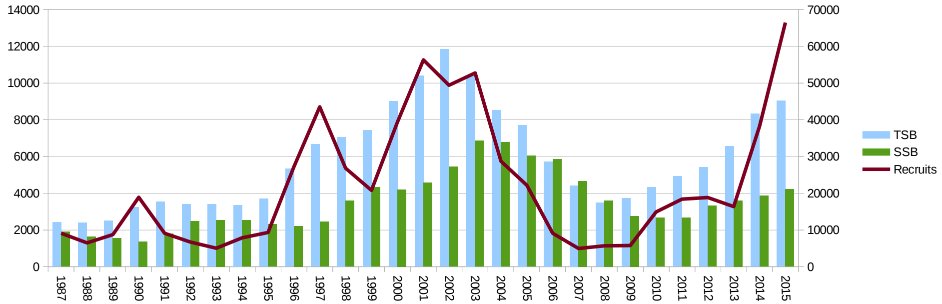
Blue whiting experience



Catch vs advice
and 'MSY catch'



Advice and recruits



TSB, SSB and recruits

Tested several types of rules.
Started with the conventional and moved towards slightly more innovative.

The more innovative have different timing and strength of the response to changing productivity.

Rules that have been examined:

1. The ICES standard MSY rule
2. Extensions of the standard rule
3. Using TSB and HR instead of SSB and F
4. Let F in the an extended standard rule be a linear function of recruitment
5. Escapement at high SSB: Leave enough behind, take the rest.

Performance criteria

What do we want to know about?

Just catches and SSB is not meaningful here, they are just scaled with the recruitment, which is arbitrary here.

We want rules that can handle the large changes in recruitment that we test. Generally, we would like to see:

- Low risk and rapid recovery if the stock gets low.
- High yield and timely response to changes in recruitment
- Low year - to -year variation.

Two measures that need explanation

IAV: Change in TAC as percentage of the mean of the two years:
IAV(y) = (TAC(y) - TAC(y-1))/(TAC(y) + TAC(y-1))

MSY proxy catch: Approximately the catch you would get by applying FMSY
TSB times the Yield/TSB ratio at $F = F_{MSY}$.

For each harvest rule type, we present

In the low recruitment period:

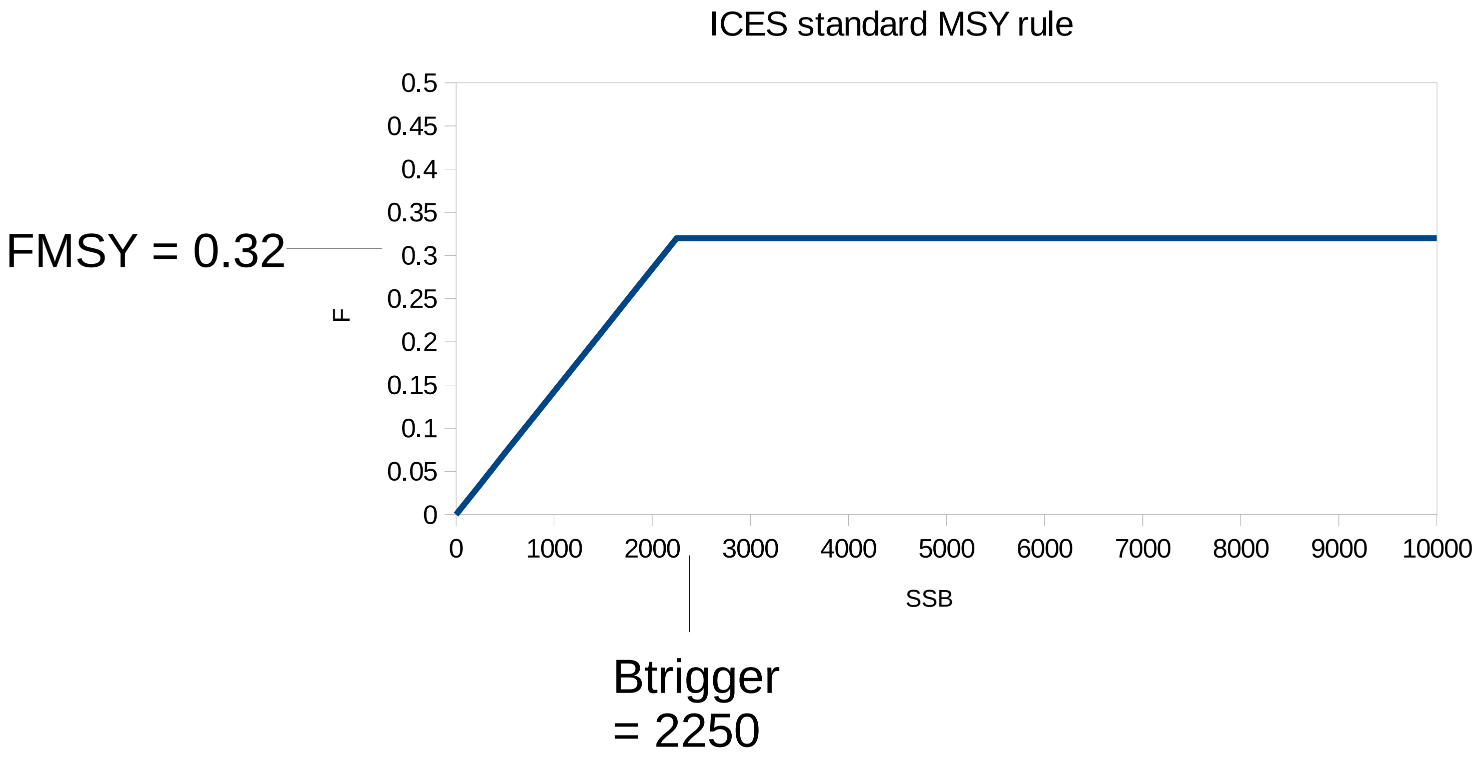
- How long it takes before the 5% limit is passed after the recruitment dropped
- The maximum percentage risk
- The minimum SSB (lowest value of 5 percentile)
- The time needed for 95% of those trajectories that have been below B_{lim} to recover above B_{lim} after the recruitment returned to 'normal'.

In the high recruitment period:

- The catch in the high recruitment period as percent of the MSY proxy.
- How long it takes to reach 90% of the maximum that is obtained in the long run This is the time it takes before the improved recruitment is picked up in the catches.
- IAV in the high recruitment period

The ICES standard MSY rule

Use F = F_{MSY} when the SSB is estimated above the trigger biomass, and reduce it linearly towards the origin when SSB is lower.



The ICES standard MSY rule

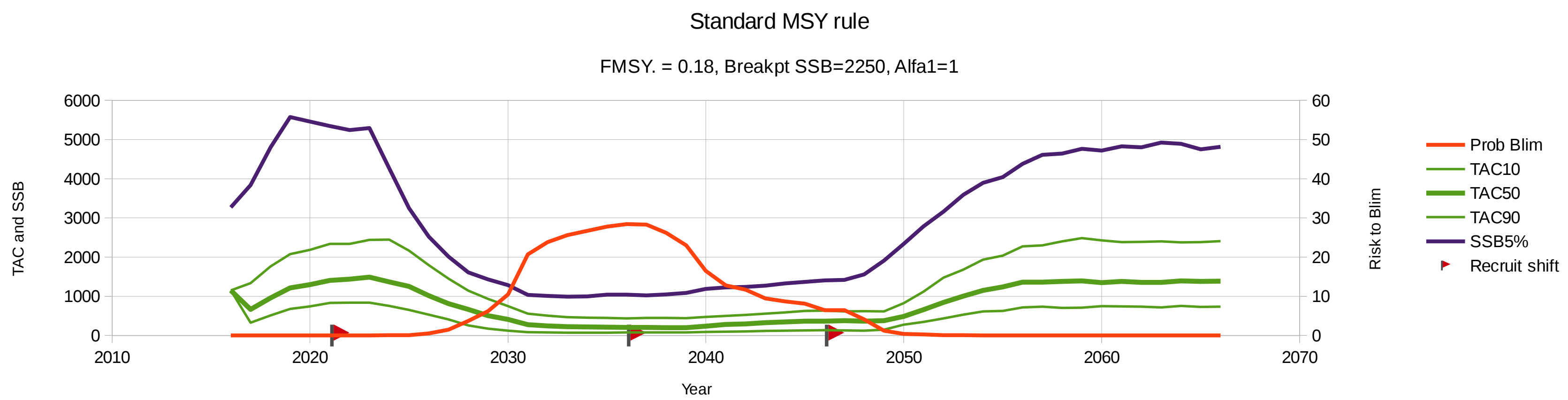
	Years to Blim	Max. risk (%)	Min of 5 percentile SSB	Time to prob recovery > 95%
F=0.18,Alfa1=1	8	28	1058	10
F=0.18,Alfa1=3	8	20	1064	7
F=0.32,Alfa1=1	5	52	689	10
F=0.32,Alfa1=3	5	39	865	9

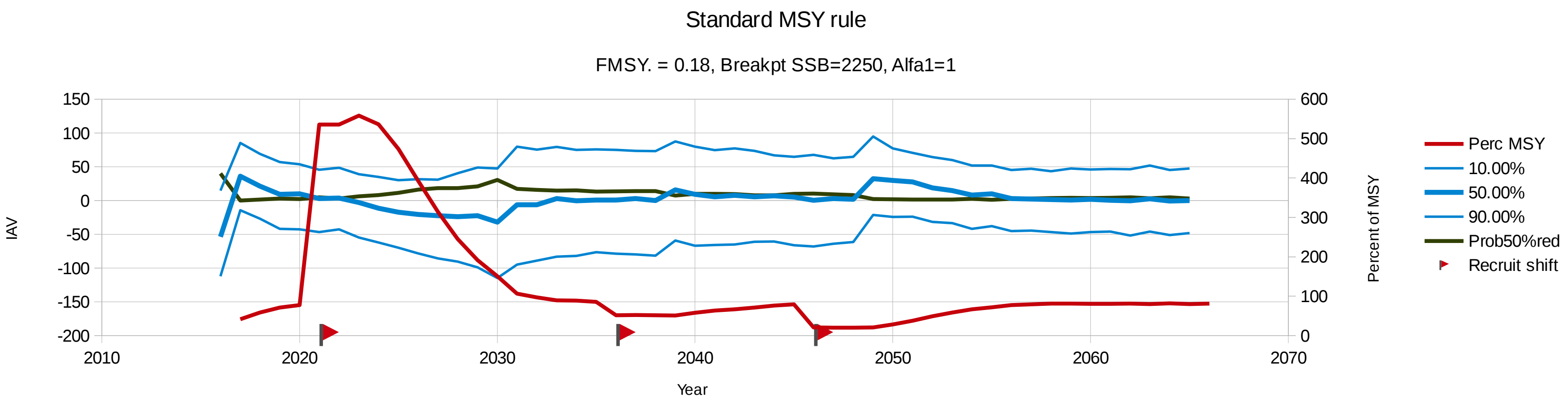
Low recruitment period

	Max in percent of MSY	Time to 90% of max
F=0.18,Alfa1=1	81	10
F=0.18,Alfa1=3	81	10
F=0.32,Alfa1=1	93	8
F=0.32,Alfa1=3	93	8

High recruitment period

The ICES standard MSY rule





ICES standard MSY rule.

Even at the low F = F0.1 = 0.18, there is
a substantial risk to Blim in the low recruitment phase
and a relatively low catch with high recruitment.

The response to improved recruitment is slow.

The FMSY = 0.32 gives very high risk to Blim in the low recruitment phase
and still relatively low catch with high recruitment.

The IAV is quite high, in particular in the low recruitment phase.

Extending the standard rule

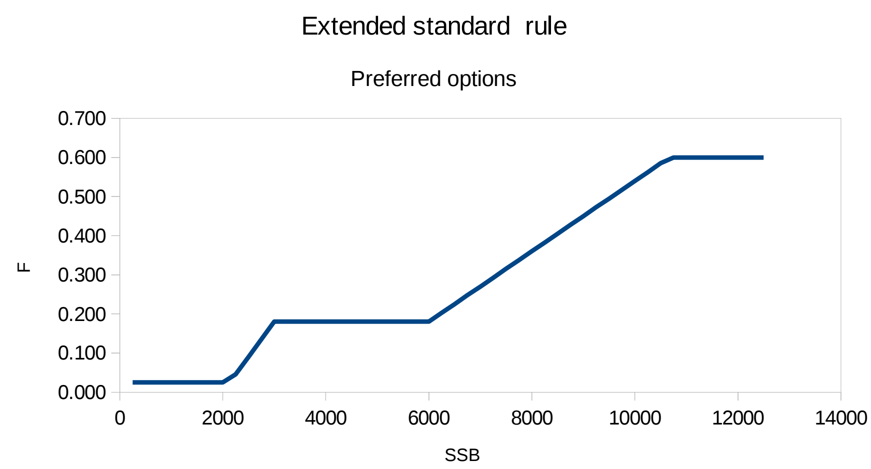
A wide range of options were tested.
Aim: Timely and adequate response to shifts in recruitment without un-necessary draconian actions.

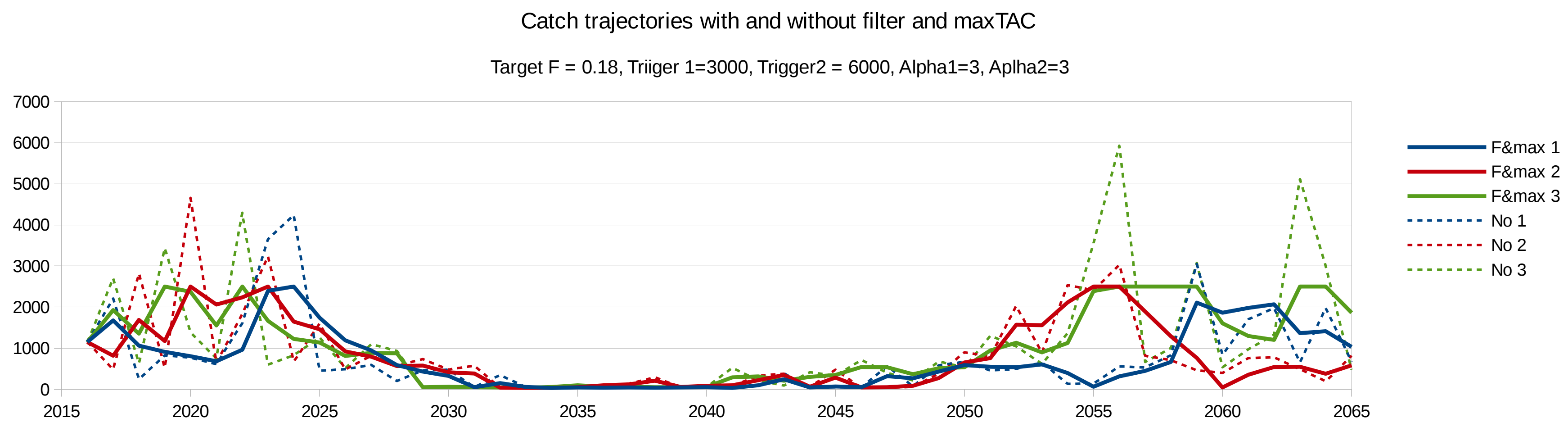
Options that were tested:

- Target F = 0.18 and 0.32
- Btrig1 (SSB below which F is reduced)
- Alpha1 (Slope of reduction towards low SSB)
- Btrig2 (SSB above which F is increased)
- Alpha2 (Slope of increase towards high SSB)
- Applying a filter (catch this year is the mean of the catch last year and the TAC first calculated for this year), applicable when SSB > 2250 kt (BMSYtrigger).
- Applying a maximum TAC at 2500 kt.
- A minimum F = 0.025 and a maximum F = 0.6 were always applied.

Extending the standard rule - preferred option.

F=0.18,
Alfa1=3,
Alfa2=3,
Btrig1=3000
Btrig2=6000
Min F: 0.025
Max F: 0.6
Filter 0.5 above 2250,
MaxTAC = 2500





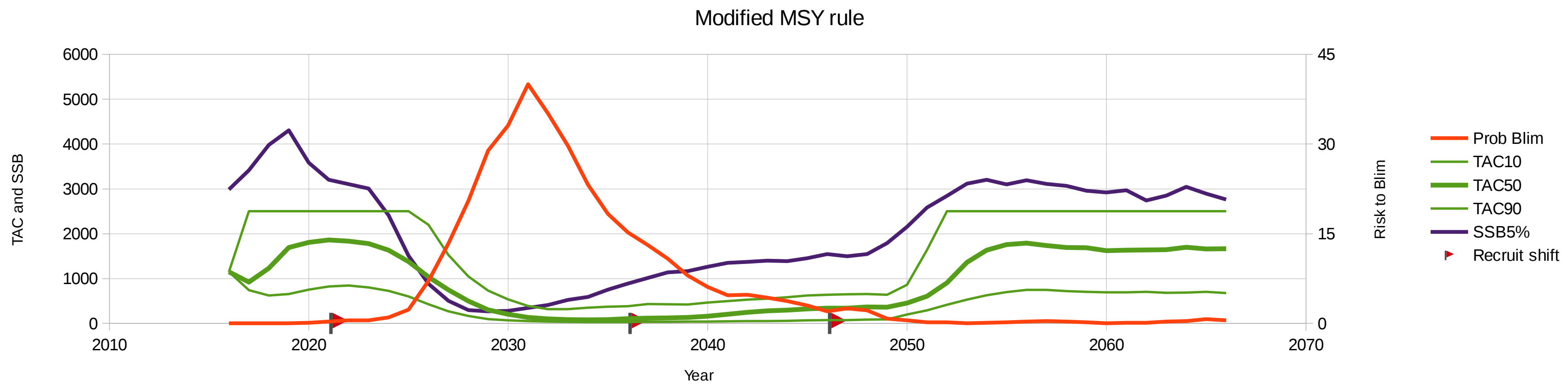
Extended standard rule
Low recruitment phase

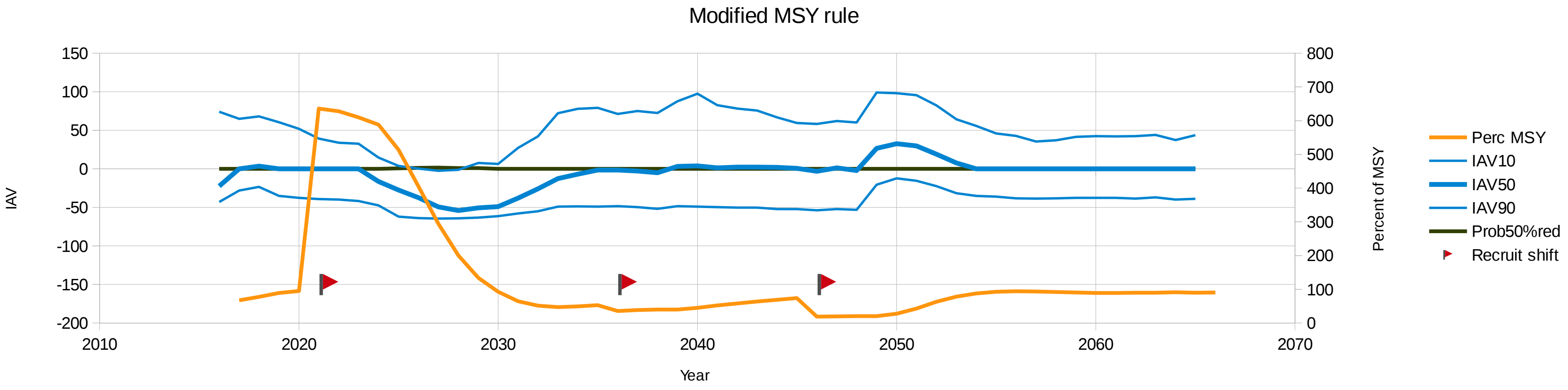
	Years to Blim	Max. risk (%)	Min of 5 percentile SSB	Time to prob recovery > 95%	Mean IAV Low (%)
F=0.18,Alfa1=3, Alfa2=3, Btrig1=3000 Btrig2=6000	5	13	781	7	72
Preferred: F=0.18,Alfa1=3, Alfa2=3, Btrig1=3000 Btrig2=6000 Filter 0.5 above 2250, MaxTAC = 2500	5	16	719	6	51
F=0.32,Alfa1=3, Alfa2=3, Btrig1=3750 Btrig2=6000	5	16	528	6	76

Extended standard rule
High recruitment phase

	Max in percent of MSY	Time to 90% of max	Mean IAV high R (%)
F=0.18,Alfa1=3, Alfa2=3, Btrig1=3000 Btrig2=6000	99	7	68
Preferred: F=0.18,Alfa1=3, Alfa2=3, Btrig1=3000 Btrig2=6000 Filter 0.5 above 2250, MaxTAC = 2500	90	9	33
F=0.32,Alfa1=3, Alfa2=3, Btrig1=3750 Btrig2=6000	102	6	75

Extended standard rule





Extended standard rule - lessons learned.

Large number of possible options.
Coarse screening here, but still 270 sets of options tested.

Improvements, but not quite satisfactory.

Quicker response to changes in recruitment,
but the Alphas and Btriggers need to be scaled quite carefully

Still quite high IAV
Filter and max. catch improve IAV, but cost something of catch.

The risk with low recruitment is bad, SSB can become very low.
Recovery looks ok,

TSB and harvest rate instead of SSB and F

Similar exploration as for extended standard rule.

HR: 0.11 or 0.17. corresponding roughly to F = 0.18 and 0.32.
Alph1: 1 or 3
Alpha2: 0 or 2.
Btrig1: TSB at 2500 or 4000
Btrig2: TSB at 8000 or no trigger
Min HR: 0.04
Max HR: 0.18 or 0.30
MaxTAC: 2500 or infinity
Filter: No filter or 50%, with derogation at SSB below 2250.

Results with the most promising choice are tabulated.

TSB and harvest rate instead of SSB and F

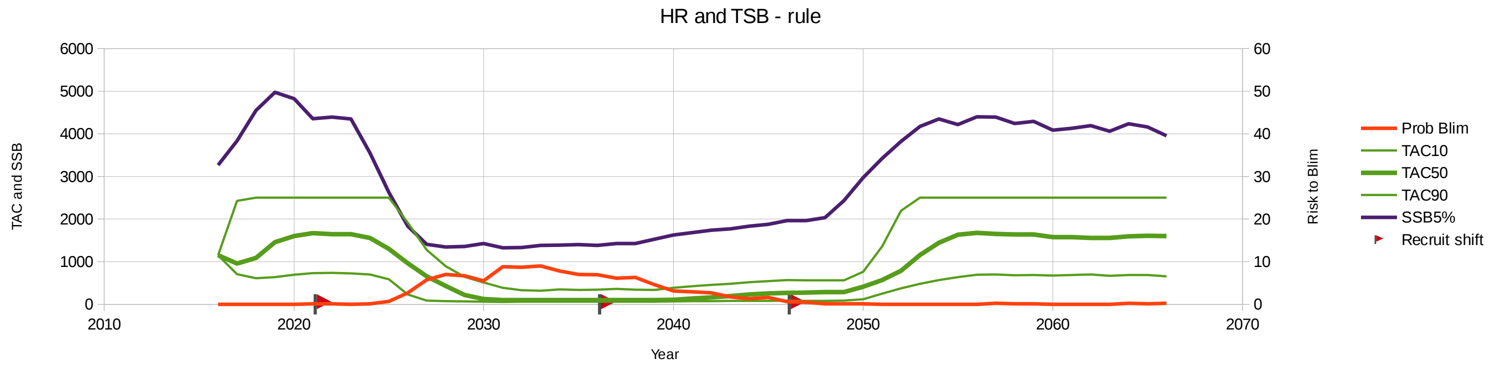
Low recruitment phase

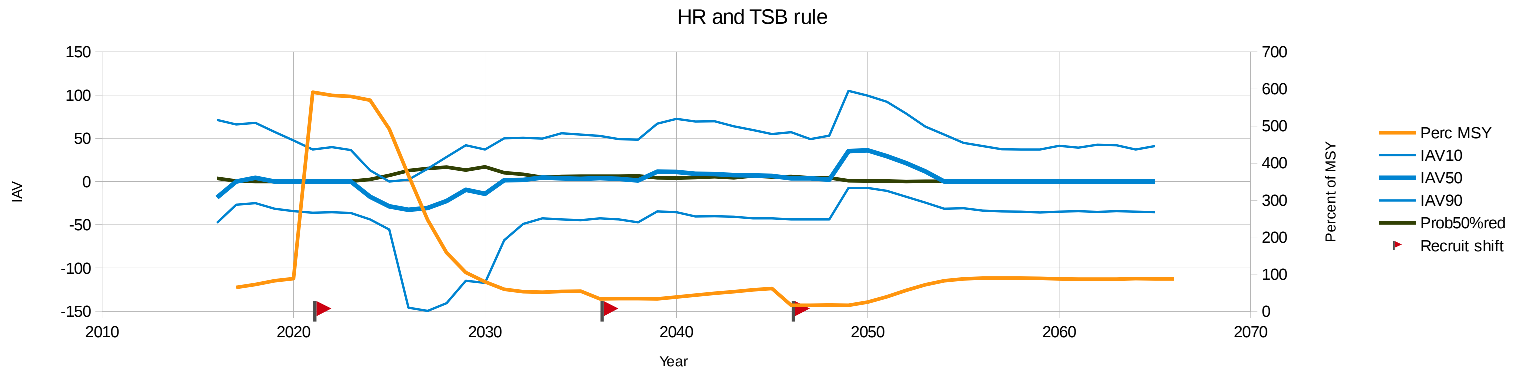
	Years to Blim	Max. risk (%)	Min of 5 percentile SSB	Time to prob recovery > 95%	Mean IAV Low (%)
HR=0.11, Btrig1=4000,Alfa1=3, Btrig2=8000, Alfa2=2, Max HR = 0.3 Min HR = 0.04 Filter 0.5 above 2250, MaxTAC = 2500	7	9	1324	7	35

High recruitment phase

	Max in percent of MSY	Time to 90% of max	Mean IAV high R (%)
HR=0.11, Btrig1=4000,Alfa1=3, Btrig2=8000,Alfa2=2, Max HR = 0.3 Min HR = 0.04 Filter 0.5 above 2250, MaxTAC = 2500	90	8	28

TSB and harvest rate instead of SSB and F





TSB and harvest rate instead of SSB and F
Lessons learned.

Performs better than the SSB-F rule.

- Lower risk, develops more slowly
- Lower IAV, in particular with low recruitment
- Similar average catch
- Similar recovery

R dependent F - rule

The general formula for the rule is:

- **vstd = v0 + gain*R**
- If Basis(1) < Btrig1: v = vstd*(1.0-alpha1*(btrig1-Basis(1))/btrig1). If that leads to v<0, set v = 0
- If Basis(1) > Btrig1 and/or Basis(2) < Btrig2: v = vstd
- If Basis(1) > Btrig1 and Basis(2) > Btrig2: v=vstd*(1.0+alpha2*(Basis(2)-btrig2)/btrig2).
- If v<vmin so far, set v = vmin
- If v>vmax so far, set v=vmax

Basis(1) and Basis(2) are both SSB, the v's are F's

The difference from the extended standard rule is that the standard exploitation measure (F) now depends on a measure of recruitment R

The relation between F and R is a straight line which crosses the y-axis at v0 and with a slope called gain.

For R we use the median of assessed recruitments for years -4 to -2 relative to the TAC year.

We skip the rise in F towards high SSB, since that is well enough covered by the high F at high recruitment.

R dependent F - rule

Scanned over a wide range of options, like it was done for previous rules.

A gain = 0.23 and a v0 = -0.10 is the relation between recruitment ant the F having a 5% risk in long term equilibrium, as seen earlier:

This seemed to be a good choice.

A filter and a maximum TAC improved the performance without reducing catch very much, but increased risk in the low phase somewhat.

R dependent F - rule

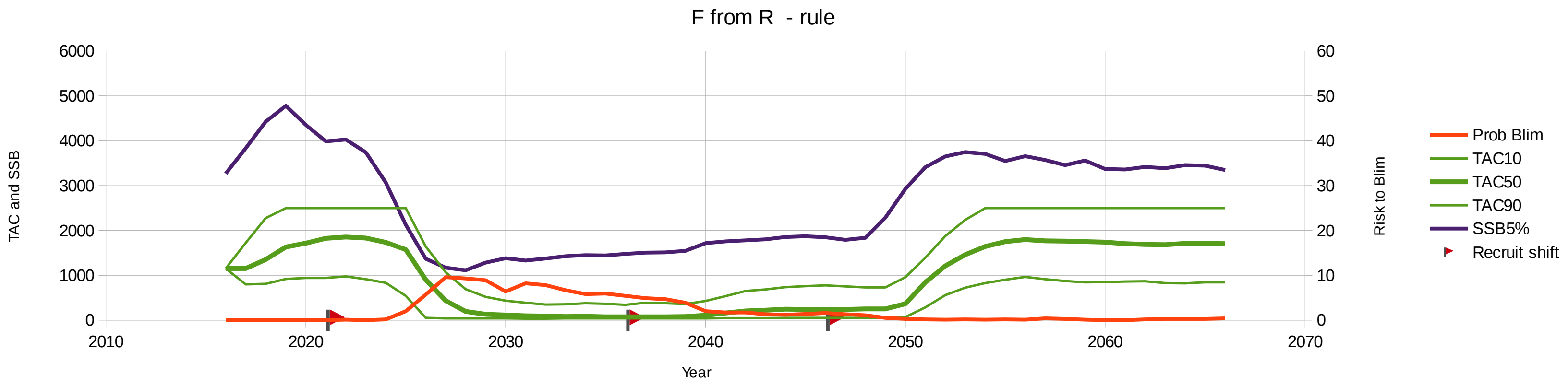
Low recruitment

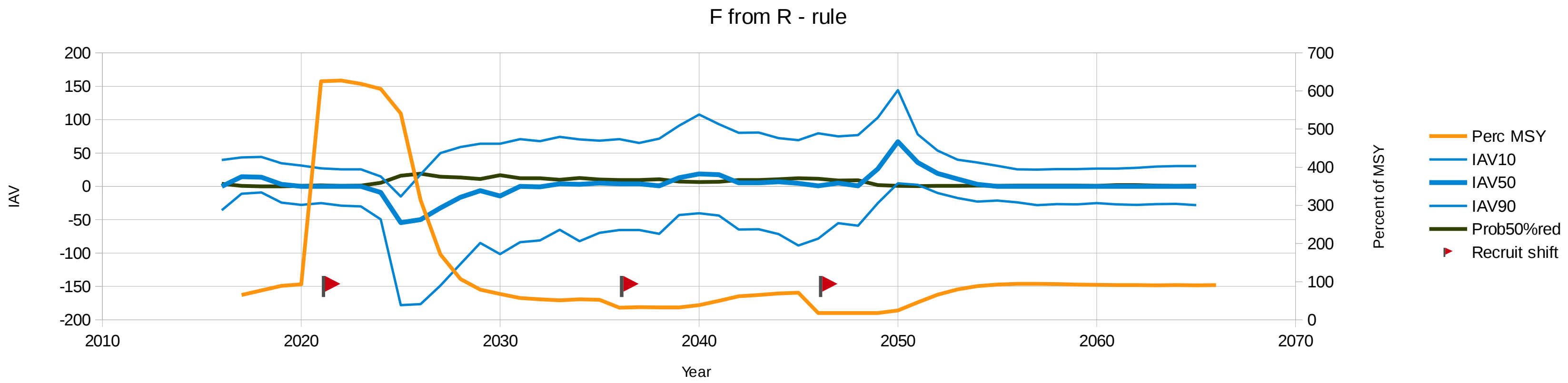
	Years to Blim	Max. risk (%)	Min of 5 percentile SSB	Time to prob recovery >95%	Mean IAV Low (%)
Gain=0.23, Vmax=0.32, Vmin=0.025, V0=-0.1 R is median for years -4 to -2, 50% filter above SSB = 2250	5	9.6	1110	7	42

High recruitment

	Max in percent of MSY	Time to 90% of max	Mean IAV High (%)
Gain=0.23, Vmax=0.32, Vmin=0.025, V0=-0.1 R is median for years -4 to -2, 50% filter above SSB = 2250	95	7	28

R dependent F - rule





Escapement rule

This is the standard type of rule, using F and SSB, but with an additional clause:

If SSB is above a treshold and the difference between the actual SSB and the treshold is bigger than the TAC calculated by the ordinary rule, then set the TAC equal to the difference.

“If there is plenty fish, why not take it.”

Explored only with the 'best' options for the extended standard rule.
but no increase of F above Btrigger2, no filter, but maximum TAC at 3000 kt.

Escapement rule

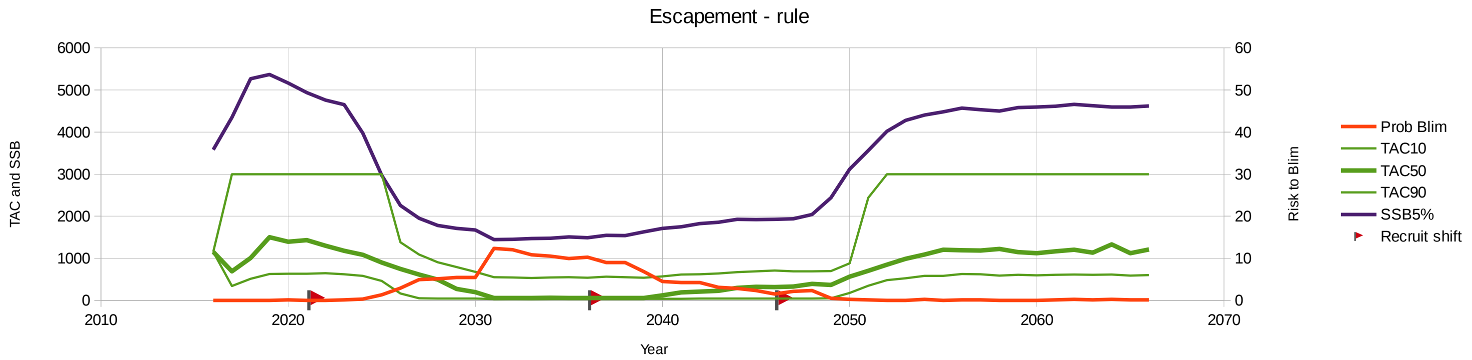
Low recruitment

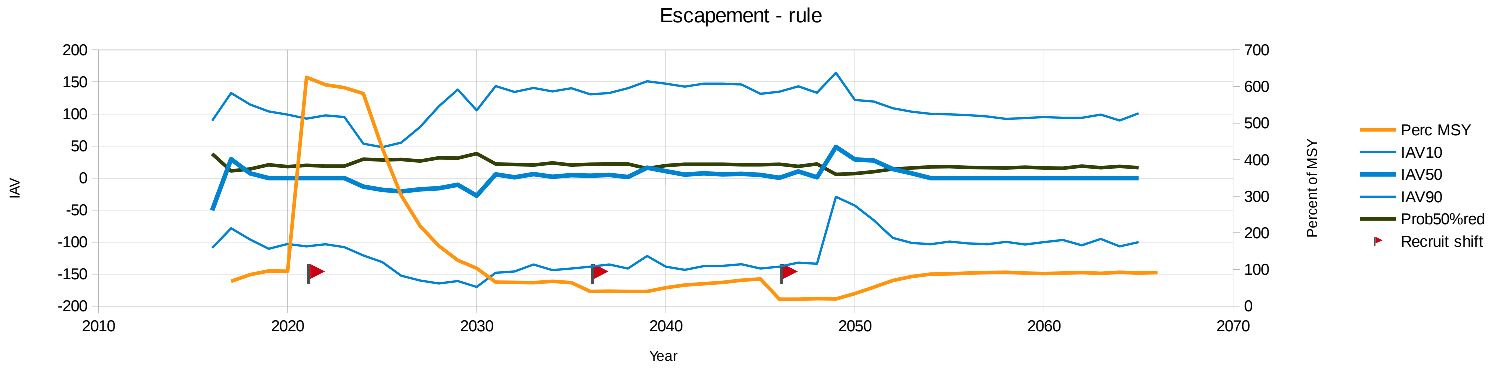
	Years to Blim	Max. risk (%)	Min of 5 percentile SSB	Time to prob recovery > 95%	Mean IAV Low (%)
F=0.18,Alfa1=3, Alfa2=0, Btrig1=3000 MaxTAC = 3000 Escapement biomass = 6000	7	12	1439	7	67

High recruitment

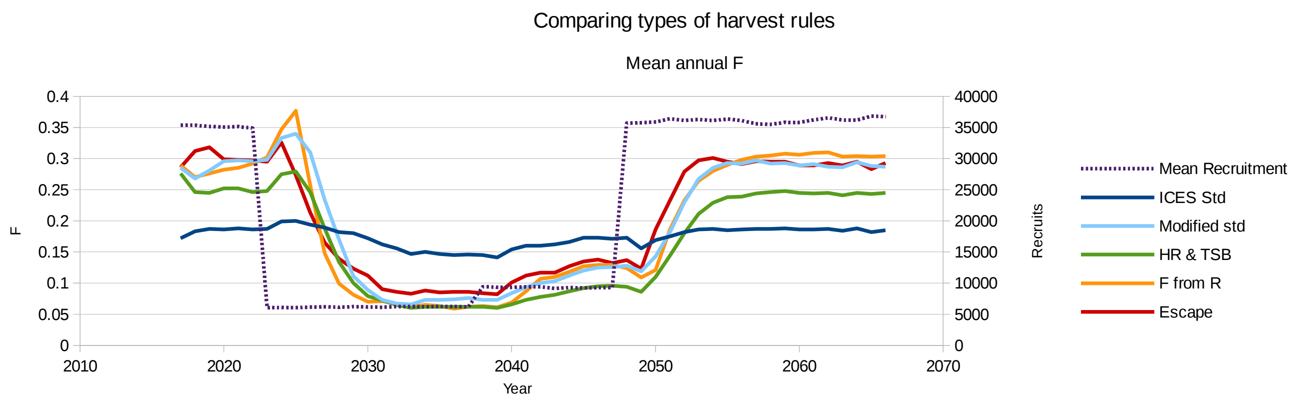
	Max in percent of MSY	Time to 90% of max	Mean IAV high R (%)
F=0.18,Alfa1=3, Alfa2=0, Btrig1=3000 MaxTAC = 3000 Escapement biomass = 6000	91	8	56

Escapement rule

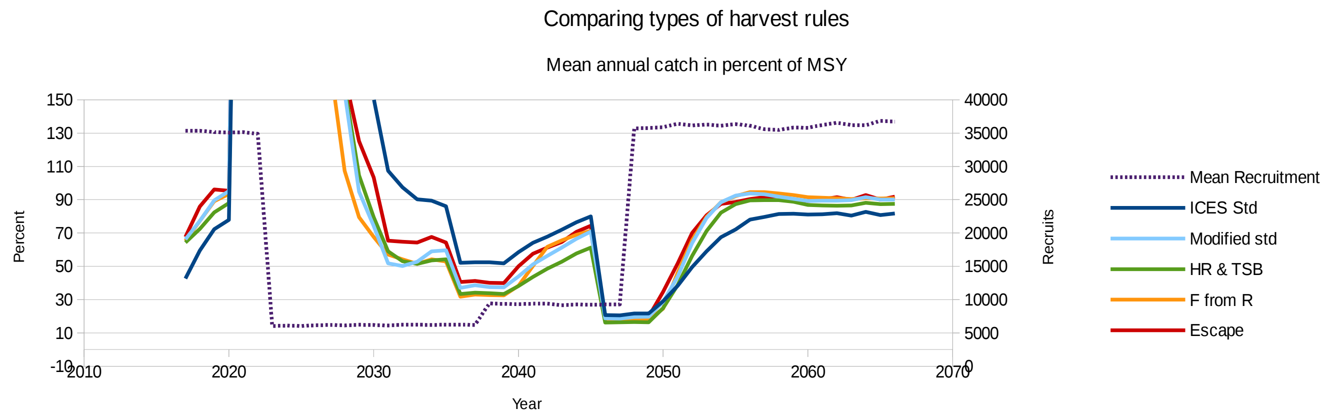




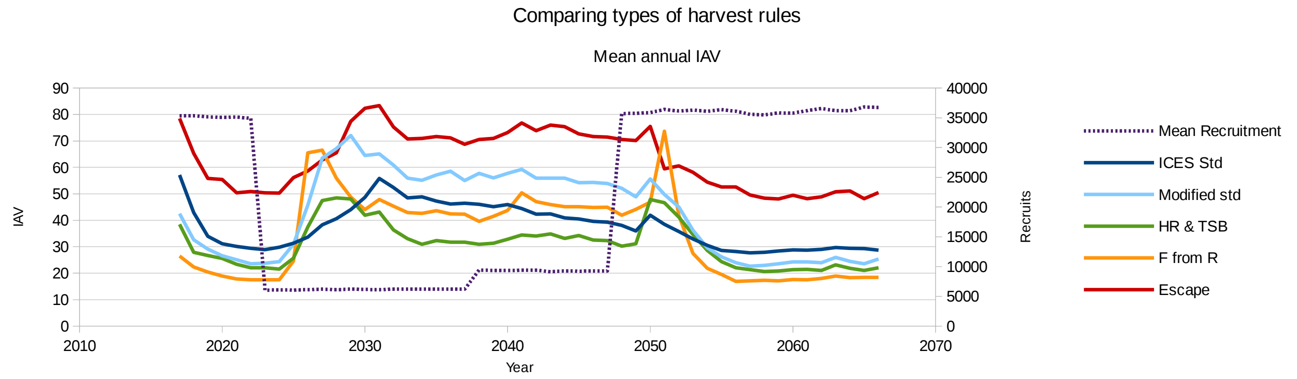
Comparing rules



Mean F



Mean catch relative to MSY proxy



IAV

T

The ICES standard MSY-rule is not the best
F does not adjust properly to changes in productivity.
Impossible trade-off between high catch when productivity is big
and low risk when productivity is low

Modifying it improves performance: Steeper and earlier reduction of F at low SSB
and incresded G at high SSB, applying a filter stabilizer and a maximum catch

Letting F depend on recruitment seems to work well,
low risk, satisfactory catches and low IAV

Using TSB as basis (here combined with using HR rather than F)
also works well.

Applying an escapement rule at high SSB does not improve mean catch but
increases IAV very much.

**The F depending on R and the TSB-HR rules seem most promising, and
are candidates (with some further refinement) for a better management
of the Blue whiting.**