Including quantitative ecosystem objectives in Management Strategy Evaluation with examples from South Africa's small pelagic fishery

Small Pelagic Fish: New Frontiers in Science for Sustainable Management
9th November 2022

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Management (MARAM) Group
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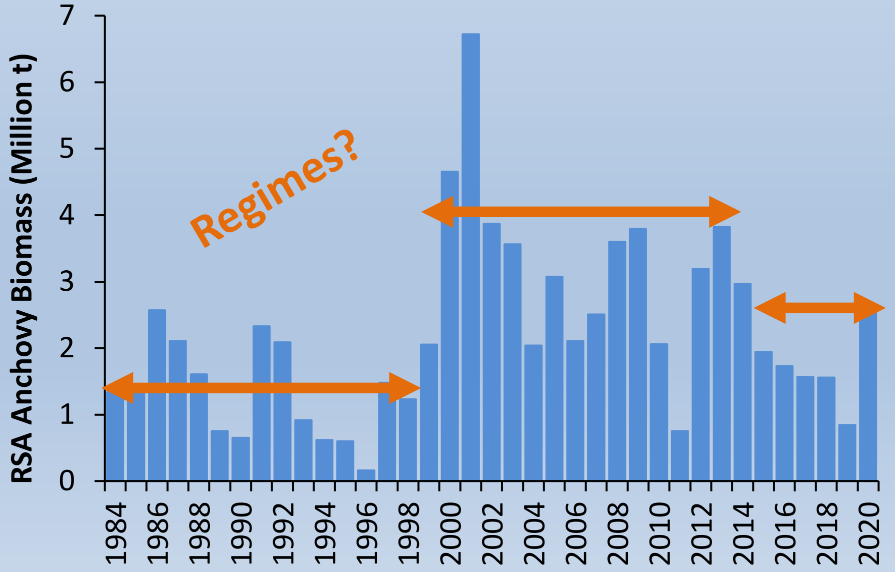
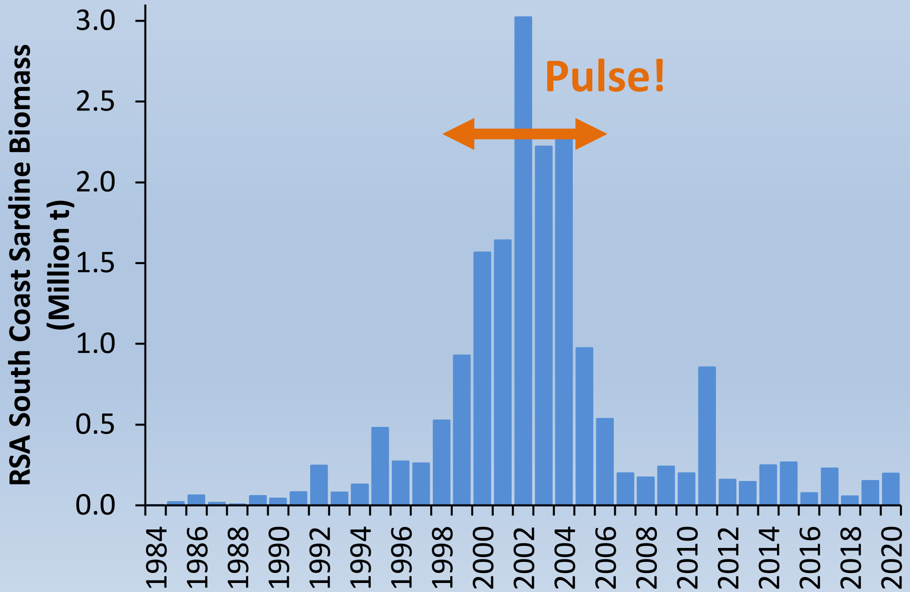
Outline

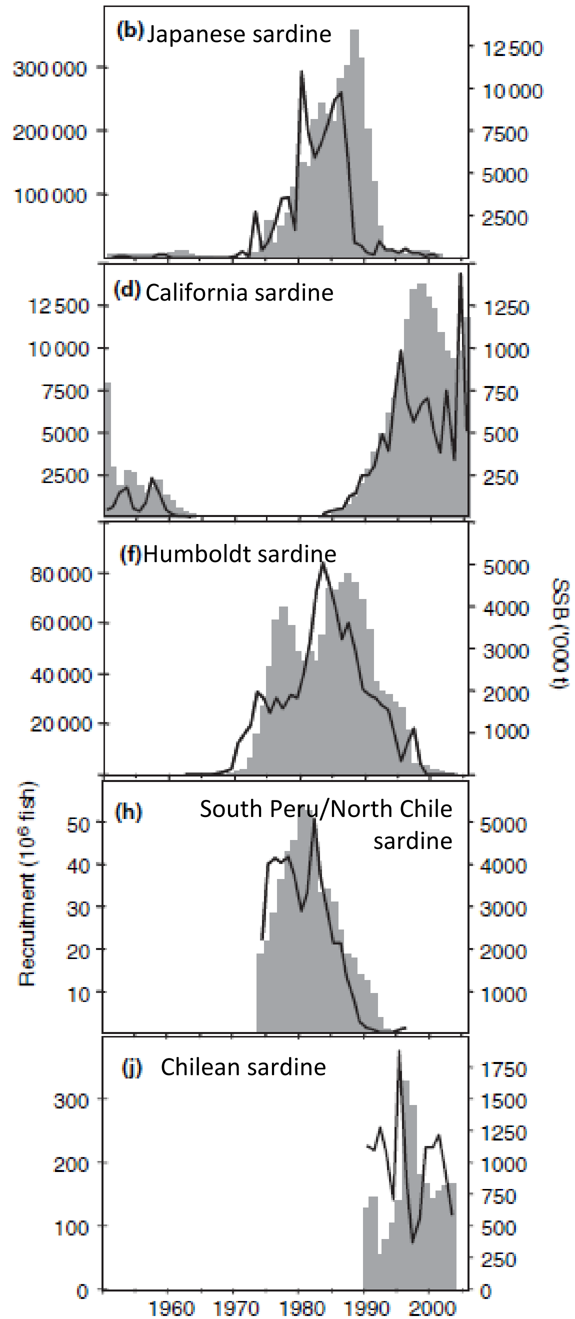
- Why is managing Small Pelagic (SP) fisheries especially difficult?
- Why is Management Strategy Evaluation (MSE) useful and can it be used for SPF?
- How can we explicitly consider an Ecosystem Approach to Fisheries (EAF) within an MSE?
- Some examples of explicitly considering EAF in making management decisions for South Africa’s small pelagic fishery
- Summary

Managing Small Pelagic Fish

- Why is managing SP fisheries especially difficult?
- Short life spans
- Highly variable recruitment
- Rapid changes in biomass levels, with ‘regimes’ or ‘pulses’
- Difficult space in which management needs to operate
- Objectives can include relatively stable catches



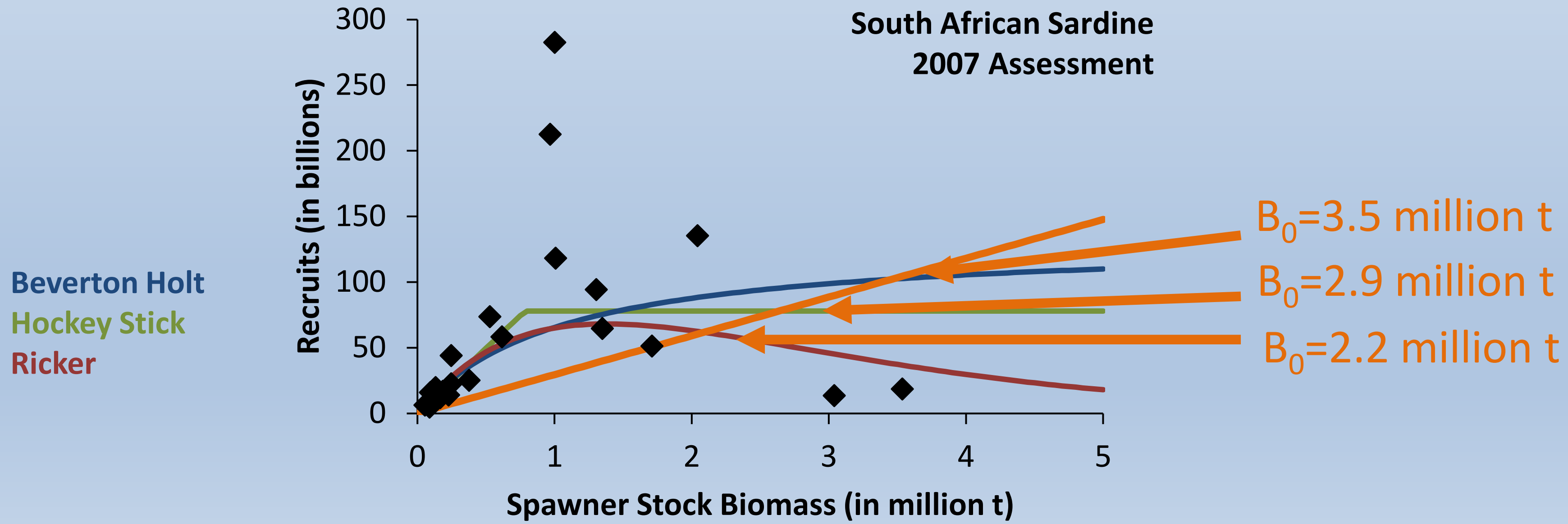




Barange *et al.* (2009) Current trends in the assessment and management of stocks

Managing Small Pelagic Fish

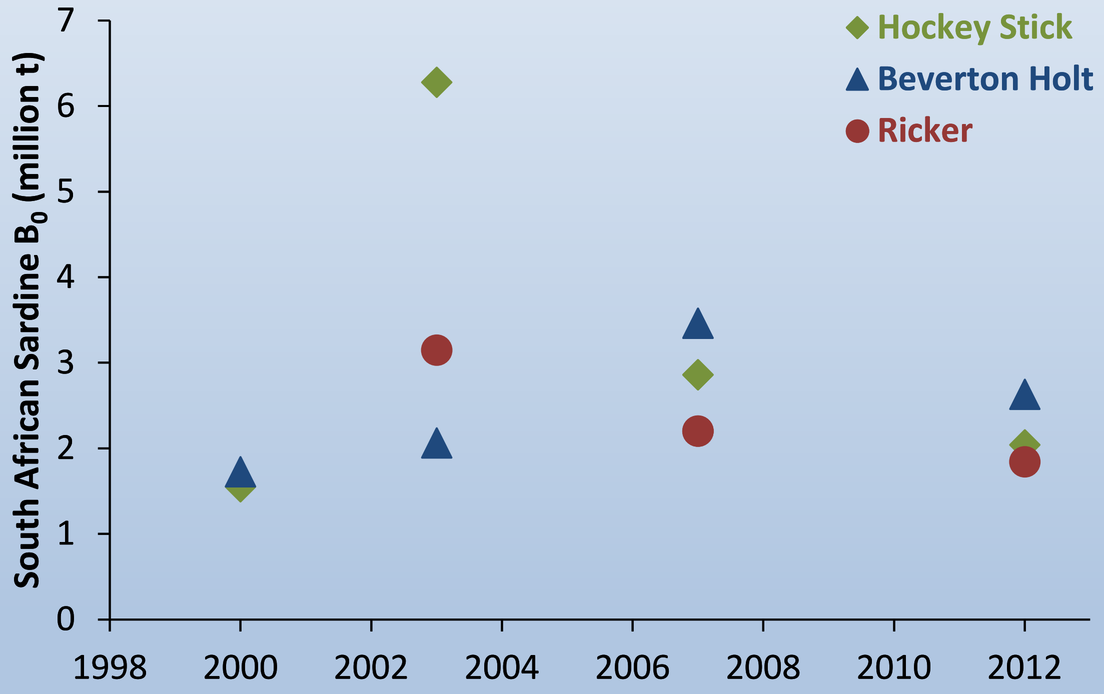
- Traditional fisheries management
- Target Reference Points implicitly assume that B_0 can be estimated (e.g. $B_{MSY}=0.4B_0$)
- But for SPF, B_0 isn't always well estimated
- B_0 can differ considerably for alternative stock recruit relationships, all of which fit the data near equally well



Managing Small Pelagic Fish

- Estimates of B_0 can change over time

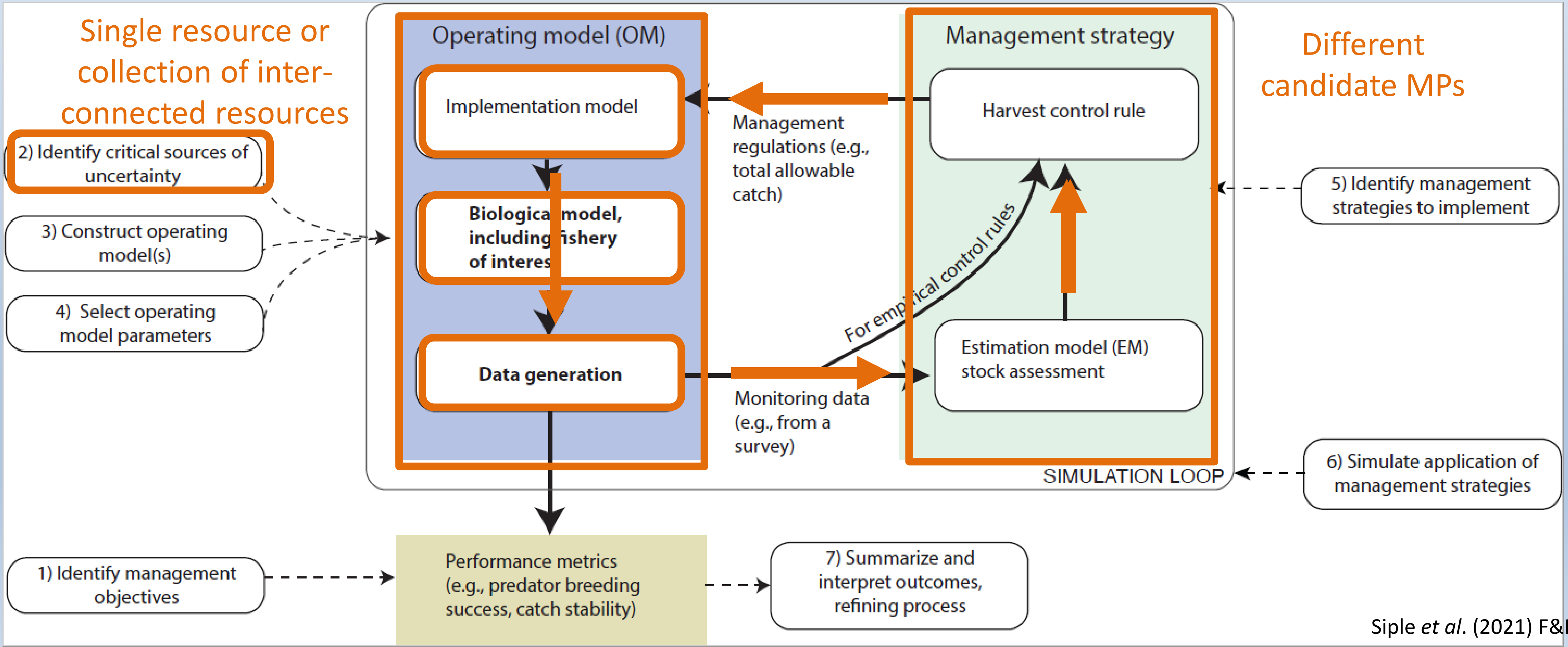
We don't know B_0 with confidence!



- This complicates the single-species management of these highly dynamic resources
- What about EAF…!

Management Strategy Evaluation

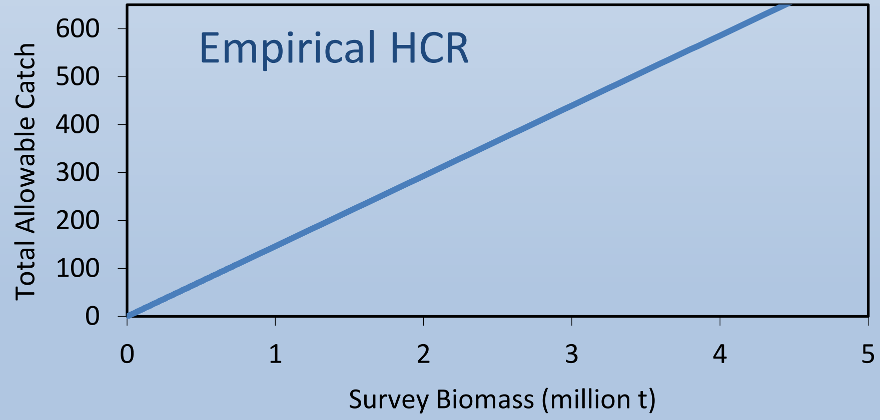
- What is MSE?
- State-of-the art method to simulation test Management Procedures (MPs)
- Takes uncertainty into account

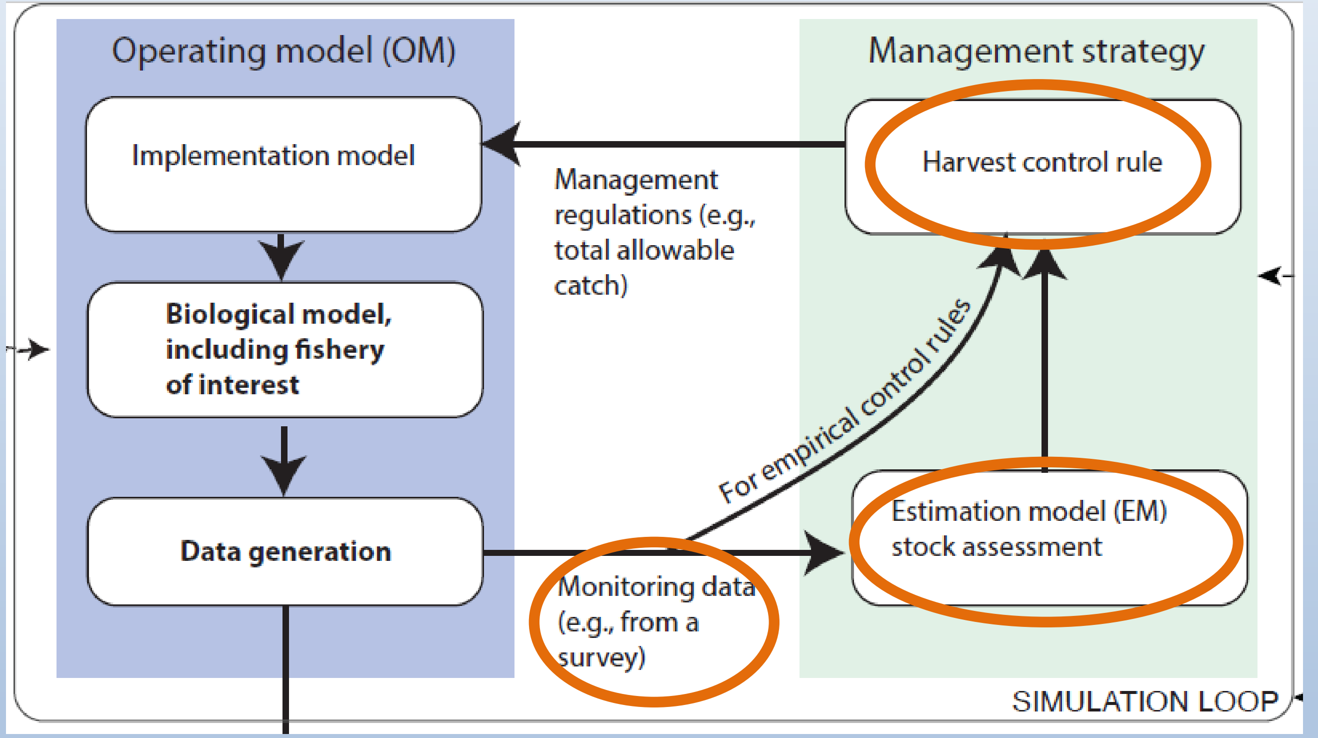


Siple *et al.* (2021) F&F 22:1167-1186

Management Strategy Evaluation

- What is a Management Procedure (MP)?
- Pre-defined and pre-agreed:
- Data collection schemes
- Analyses applied to those data
- Decision rules





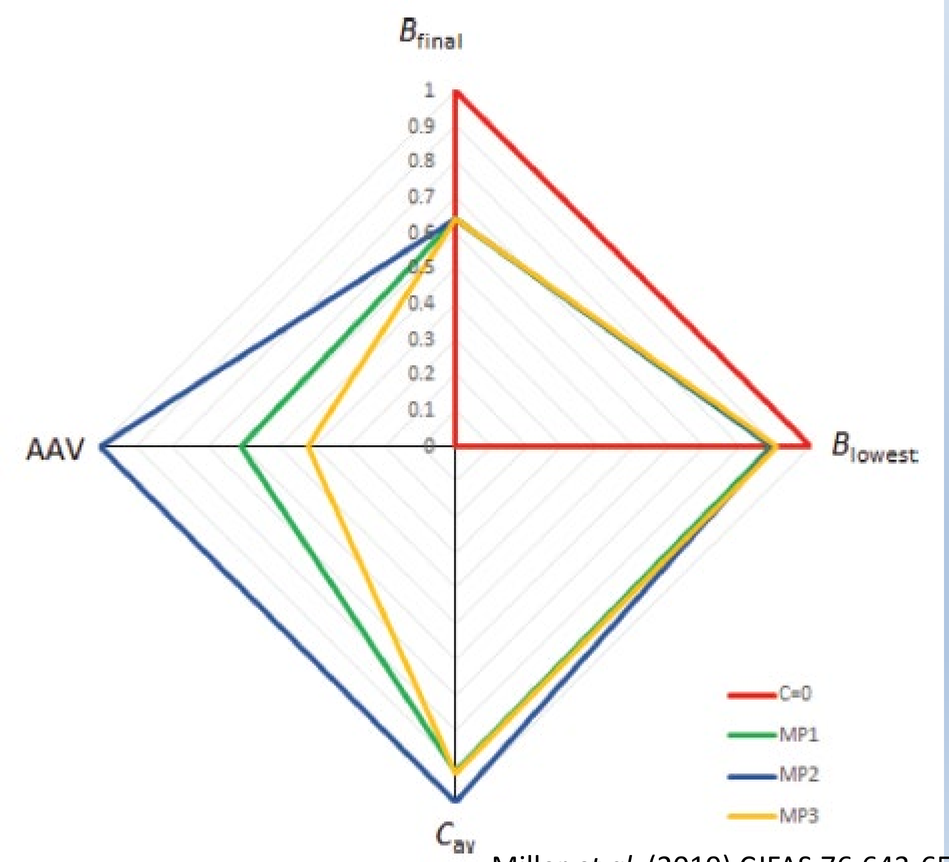
Siple *et al*. (2021) F&F 22:1167-1186

Management Strategy Evaluation

- Key advantage of MSE:
- Allow managers to select an MP which has been simulation tested to satisfy pre-determined objectives

- transparently informed about trade-offs between competing objectives
- while taking into account uncertainties

How much uncertainty can one realistically incorporate?



Miller *et al*. (2019) CJFAS 76:643-656

Management Strategy Evaluation

- Does the (greater) uncertainty associated with SPF exclude them from MSE?
- Does the high variability associated with SPF recruitment and biomass exclude them from MPs?
- Some have argued that MPs with their pre-agreed HCRs would never work
- Do they require dynamic "rules" and within-season negotiations?

No!

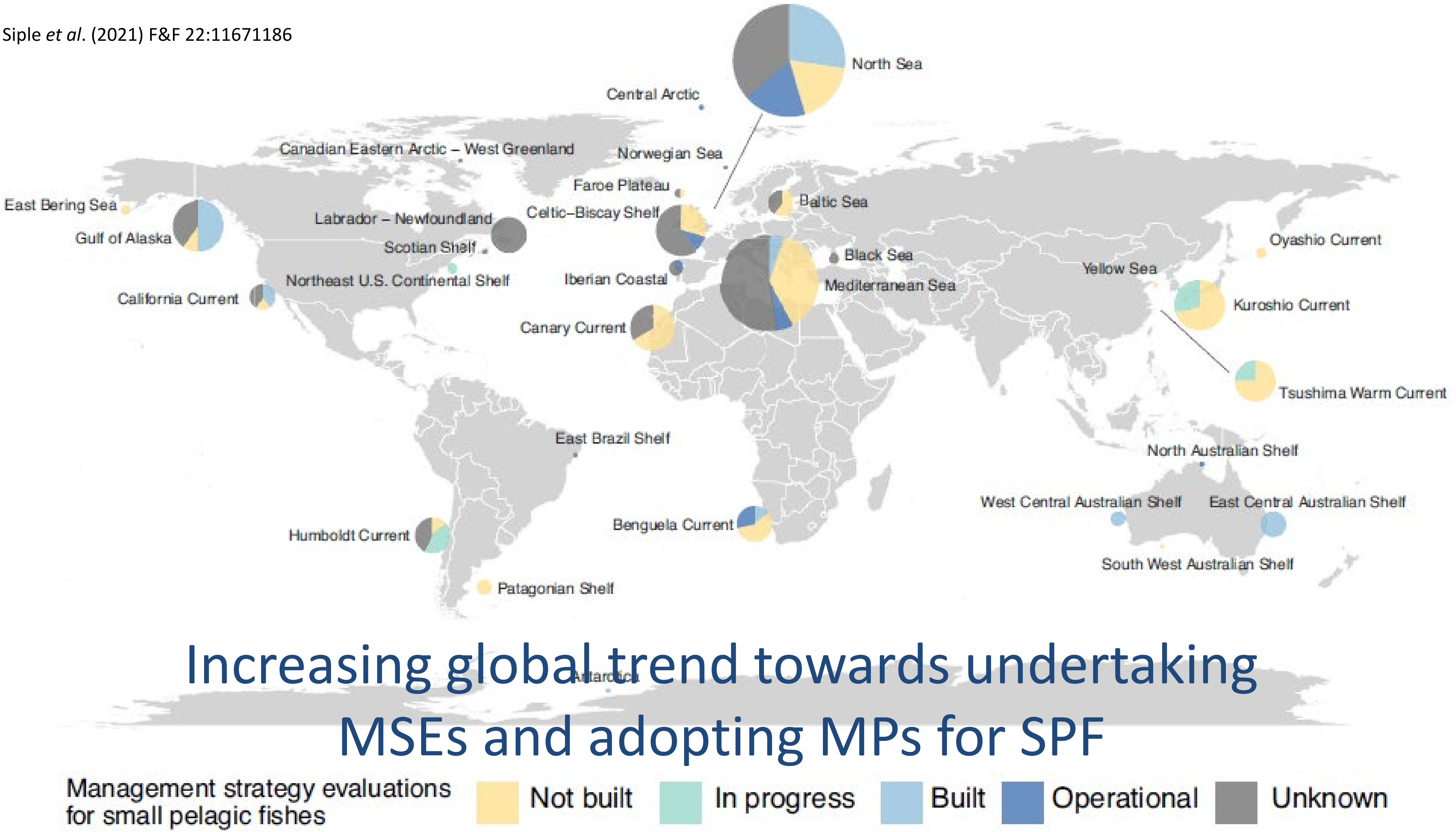
- MSE has been shown to be an effective means of managing SPF

ICES Journal of Marine Science (2011), 68(10), 2075–2085. doi:10.1093/icesjms/fsr165

Is the management procedure approach equipped to handle short-lived pelagic species with their boom and bust dynamics? The case of the South African fishery for sardine and anchovy

Carryn L. de Moor[1]*, Douglas S. Butterworth[1], and José A. A. De Oliveira[2]

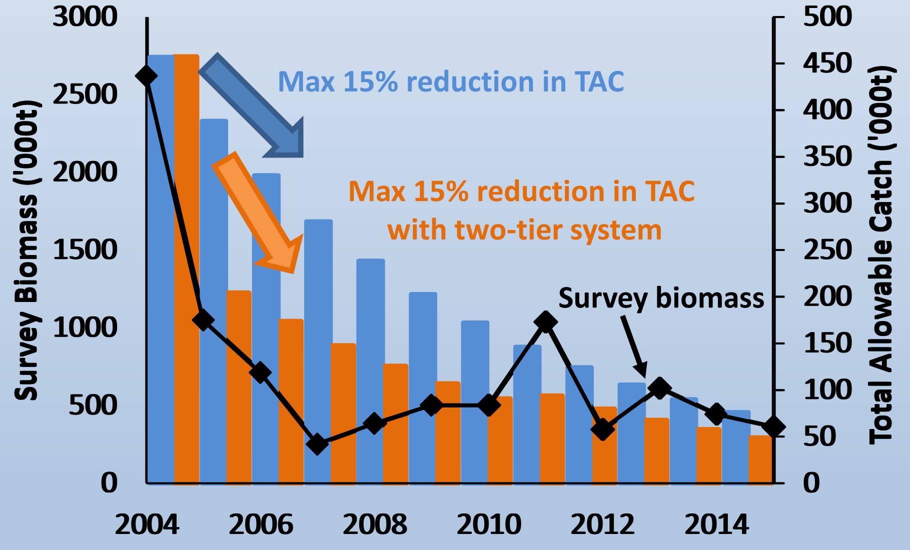
Siple *et al*. (2021) F&F 22:11671186

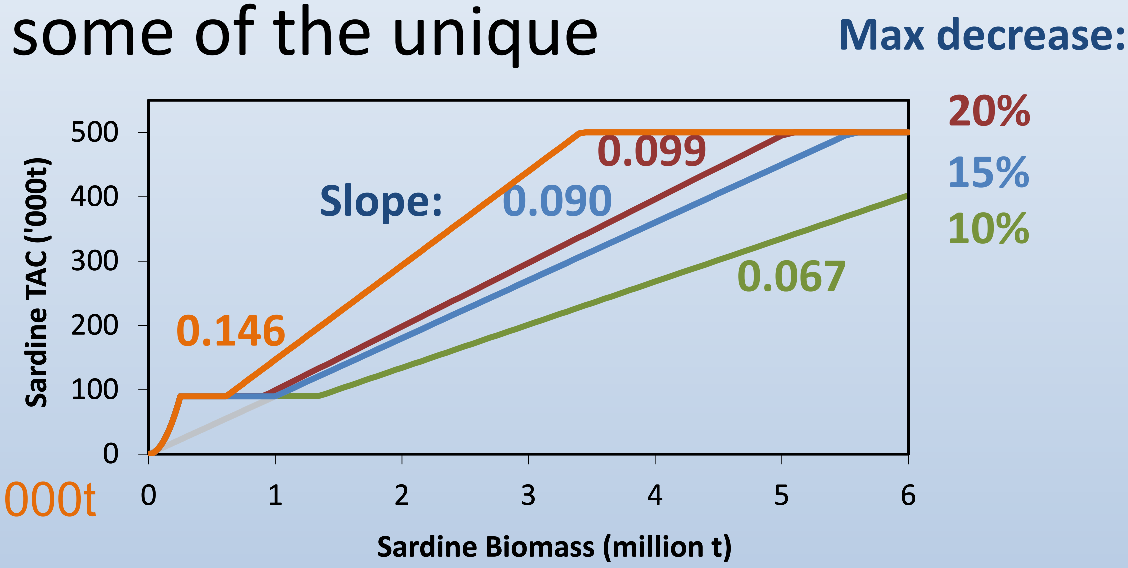


Increasing global trend towards undertaking MSEs and adopting MPs for SPF

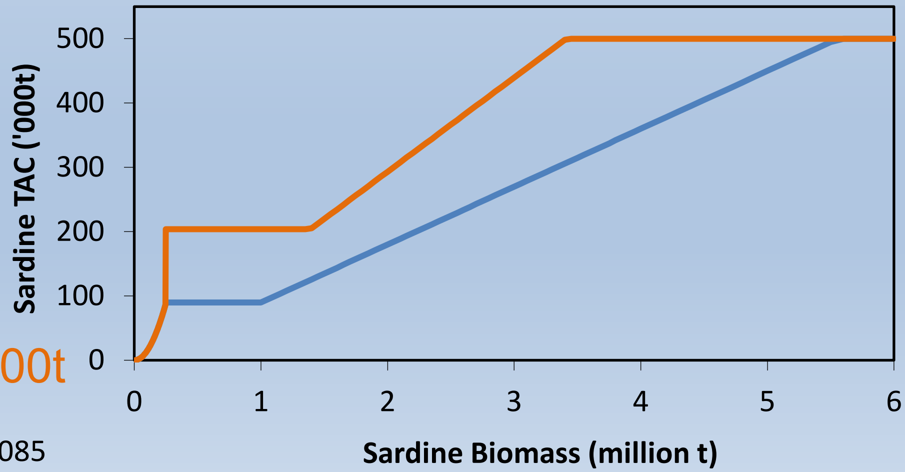
Management Strategy Evaluation

- Don’t restrict yourself to ‘standard’ MPs (e.g. constant F)
- HCRs can be designed to accommodate some of the unique characteristics of SPF





If $TAC_{y-1} \leq 240\ 000$t

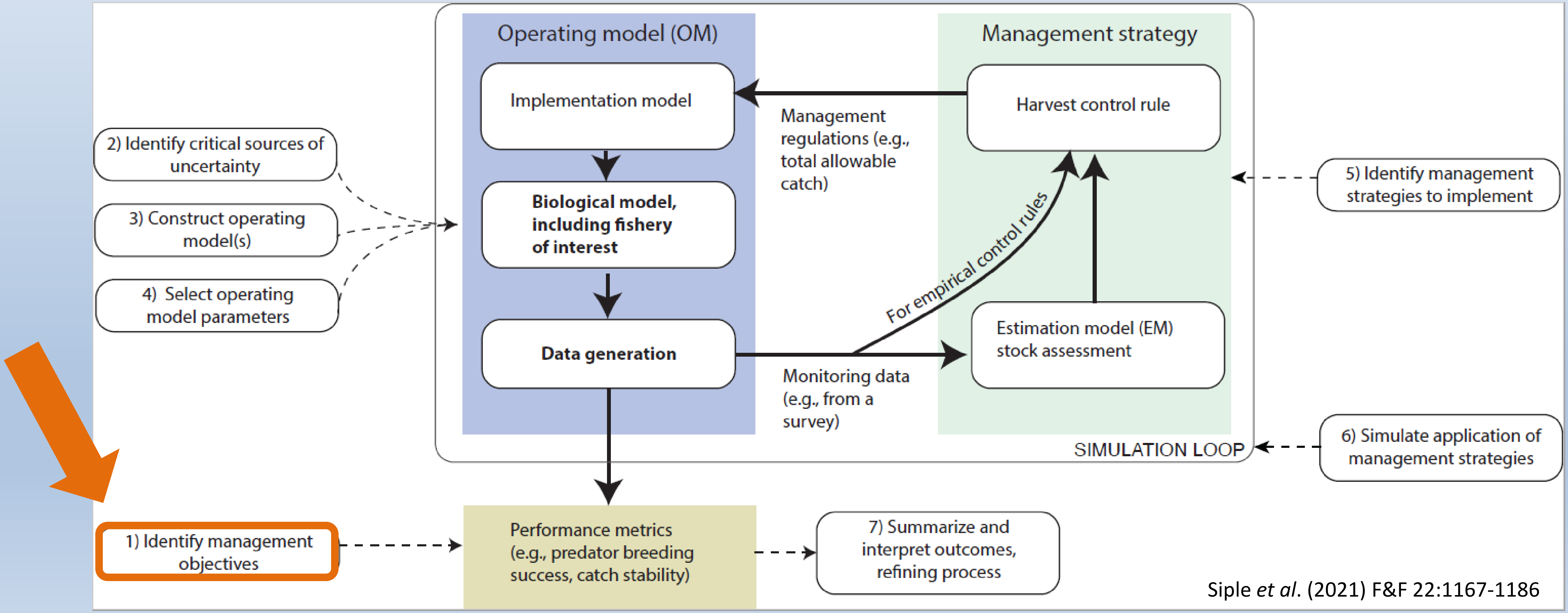


If $TAC_{y-1} > 240\ 000$t

de Moor et al. (2011) IJMS 68:2075-2085

Explicitly Taking an EAF in MSE for SPF

- The starting point for MSE is the objectives
- Objectives should explicitly include consideration of the role the targeted resource (SPF) plays within the ecosystem



Siple *et al*. (2021) F&F 22:1167-1186

Explicitly Taking an EAF in MSE for SPF

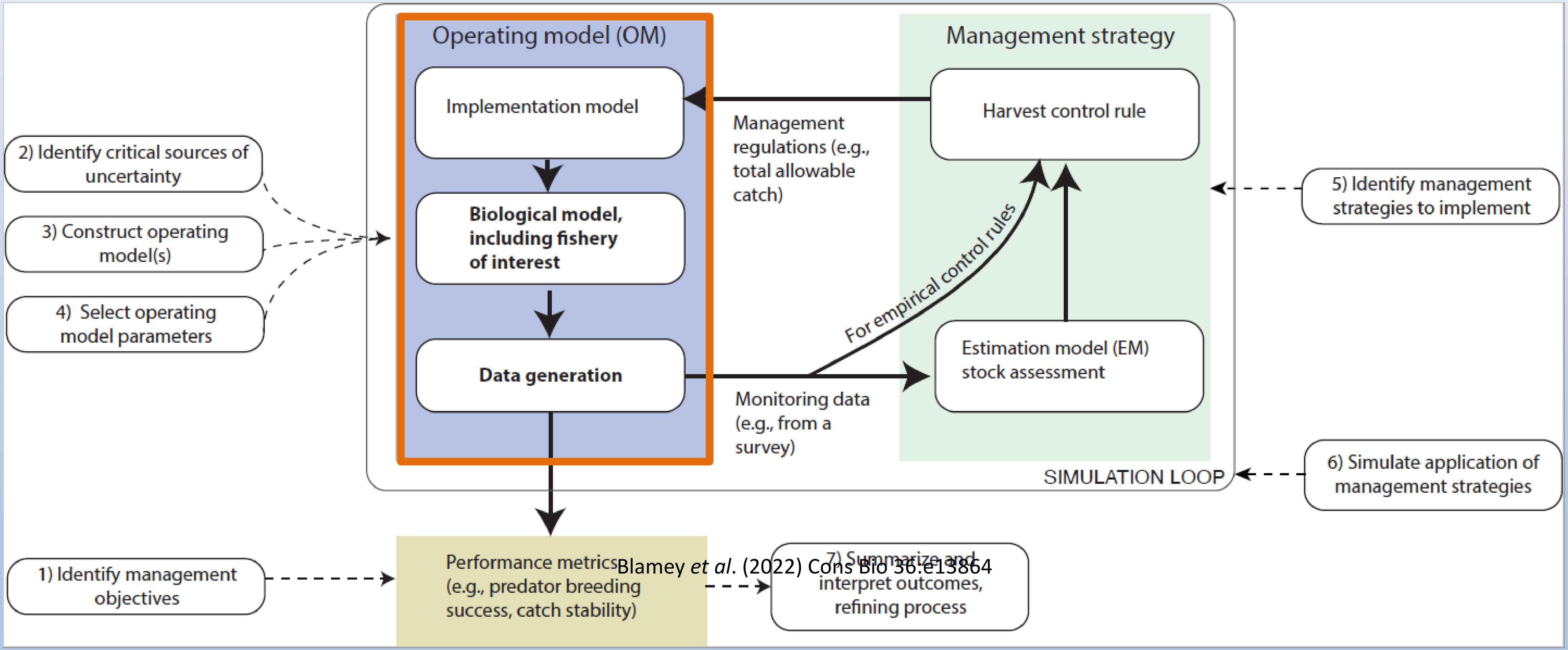
- The starting point for MSE is the objectives
- Objectives should explicitly include consideration of the role the targeted resource (SPF) plays within the ecosystem
- Conceptual objective (e.g. maintain a sustainable fishery)
    - High-level policy goals
- Tactical objective (e.g. ensure SSB remains above SSB_{lim})
    - Operational
- Performance statistic (e.g. $p(SSB<SSB_{lim})\leq 0.05$)

Explicitly Taking an EAF in MSE for SPF

- Six primary ways in which EAF can be explicitly considered in MSE
- OM level of detail driven by: - Available data
  - Objectives

Explicitly Taking an EAF in MSE for SPF

1) Use an ecosystem model as (one of) the OMs



Blamey *et al*. (2022) Cons Bio 36:e13864

Explicitly Taking an EAF in MSE for SPF

1) Use an ecosystem model as (one of) the OMs

- Most demanding w.r.t. data and computational requirements
- Models of Intermediate Complexity for Ecosystem assessments (MICE)

- Include limited, key components of the ecosystem
- Conditioned to available data for all of the components
- In principle, useful for **tactical** management advice
- Realistic computing time (compared to other ecosystem models)


FISH and FISHERIES

FISH and FISHERIES, 2014, 15, 1–22

Multispecies fisheries management and conservation: tactical applications using models of intermediate complexity

Éva E Plagányi[1], André E Punt[2,3], Richard Hillary[2], Elisabetta B Morello[1], Olivier Thébaud[1], Trevor Hutton[1], Richard D Pillans[1], James T Thorson[1,3], Elizabeth A Fulton[2], Anthony D M Smith[2], Franz Smith[4], Peter Bayliss[1], Michael Haywood[1], Vincent Lyne[2] & Peter C Rothlisberg[1]

Blamey *et al.* (2022) Cons Bio 36:e13864

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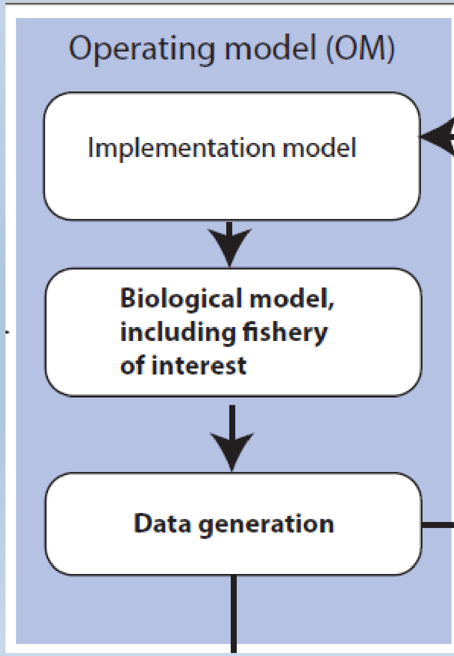
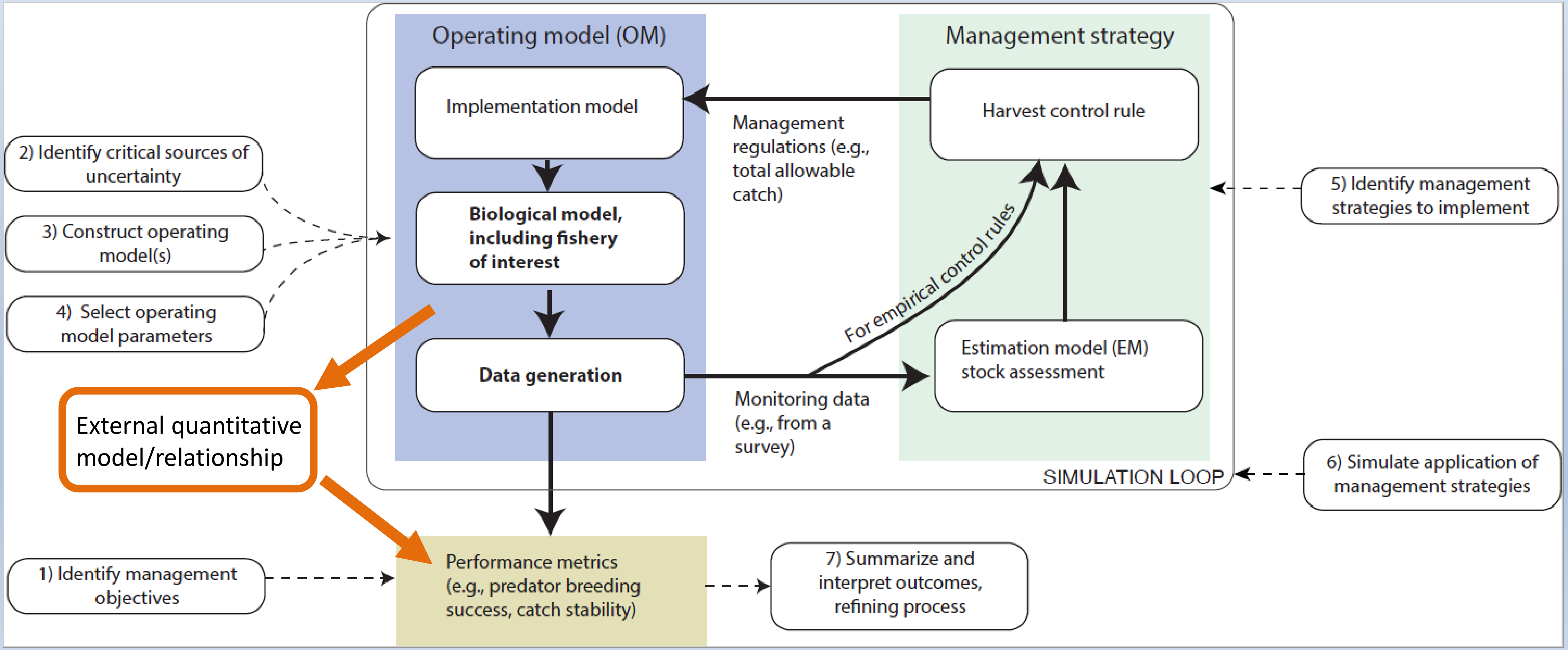


Siple *et al.* (2021) F&F 22:1167-1186

Explicitly Taking an EAF in MSE for SPF

2) One-way coupling of the OM with another model/relationship to provide EAF performance statistics

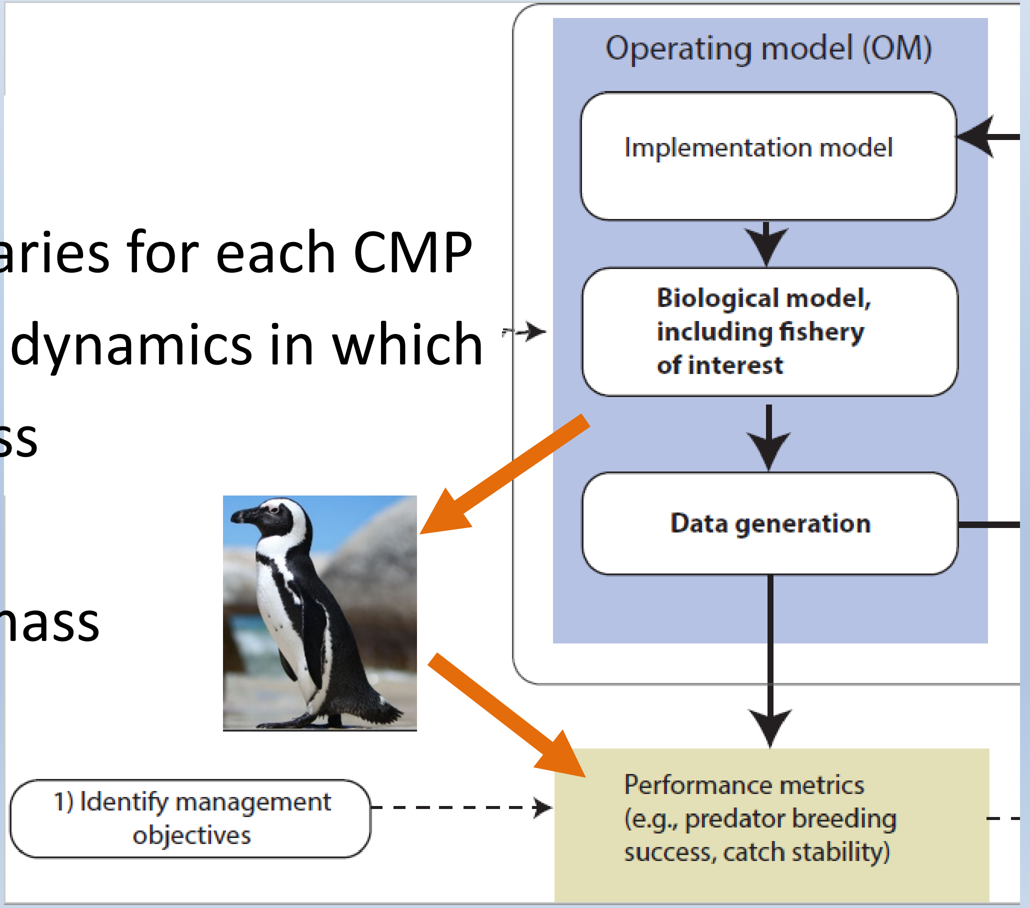
- Output from OM is input to additional model/relationship



Explicitly Taking an EAF in MSE for SPF

2) One-way coupling of the OM with another model/relationship to provide EAF performance statistics

- Output from OM is input to additional model/relationship
- For example
- OM based on SPF target species (sardine)
- Output is projected future sardine biomass; this varies for each CMP
- Input future sardine biomass to model of penguin dynamics in which penguin survival is dependent on sardine biomass
- Calculate rate of increase (or decrease) in penguin numbers based on projected future sardine biomass



Explicitly Taking an EAF in MSE for SPF

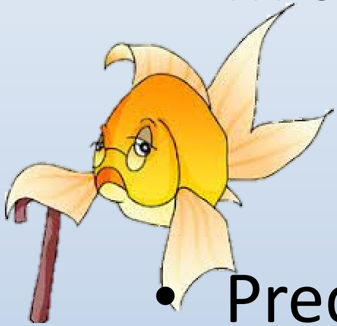
2) One-way coupling of the OM with another model/relationship to provide EAF performance statistics

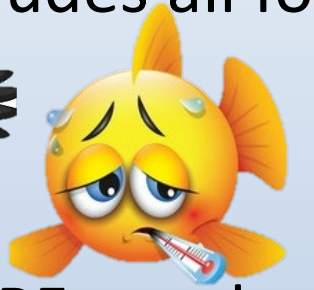
- Computationally more efficient than using an ecosystem model as OM
- (Only) key components of ecosystem need to be considered
- OM and other model/relationship can be developed independently
- One-way only (e.g. SPF impact on predator not vice versa)

Explicitly Taking an EAF in MSE for SPF

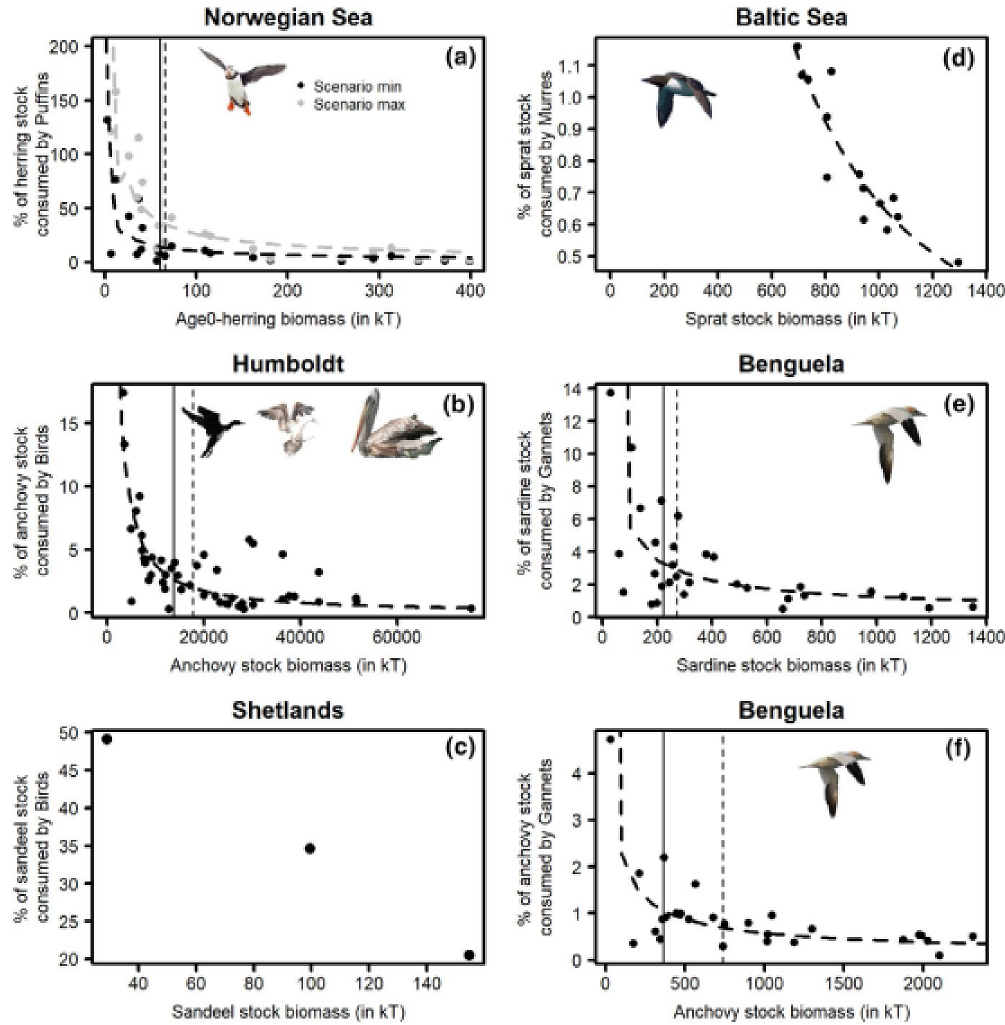
3) Density-dependent natural mortality (M)

- M typically includes all forms of non-fishery-related deaths





- Predation on SPF may be relatively greater when the forage fish biomass is low
- Use density-dependent M as a proxy for non-negligible changes in predation pressure
- One-way only (e.g. predator impact on SPF not vice versa)



Saraux *et al*. (2021) F&F 22:262-279

Explicitly Taking an EAF in MSE for SPF

4) Performance statistics based on ecosystem thresholds

- For example:

- Proportion of years for which SPF biomass (or combined prey biomass) is predicted to fall below a threshold level for a given CMP
- The extent to which SPF biomass falls below a threshold level for a given CMP

- Threshold should be selected from external data / quantitative relationships
- OMP-14 and OMP-18
  - p(B_w^{obs}<336 000t)
  - Avg # consec years B_w^{obs}<336 000t

336 000t

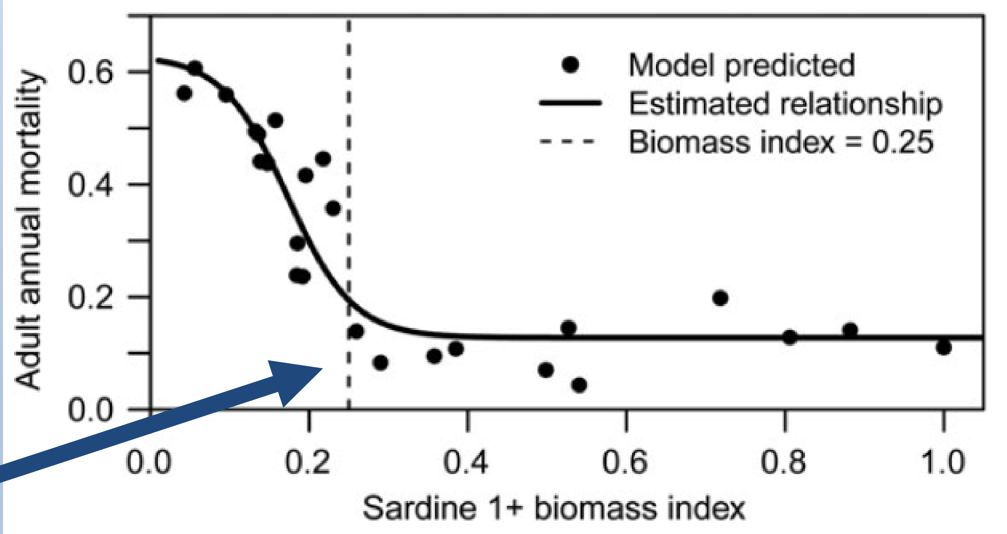


Figure 4. The estimated relationship (posterior mode) between the sardine 1+ biomass index (scaled to the maximum November survey estimate of 1 343 000 t in 2003) and penguin adult mortality. The vertical dashed line is at 25% of the maximum observed biomass.

Robinson *et al*. (2015) IJMS 72:1822-1833

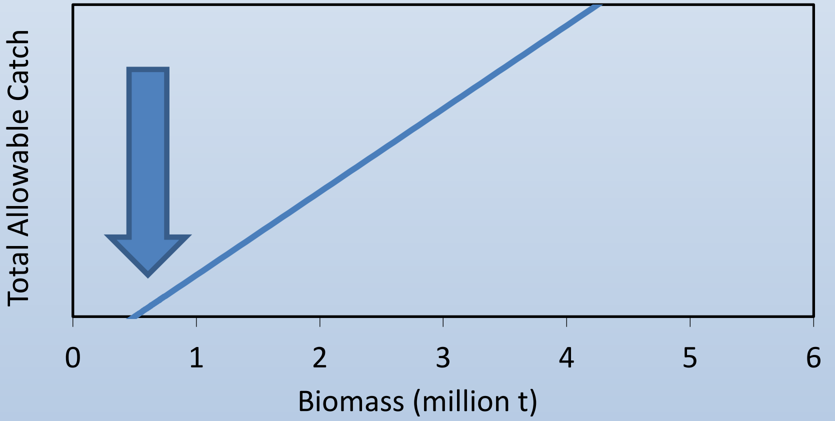
Explicitly Taking an EAF in MSE for SPF

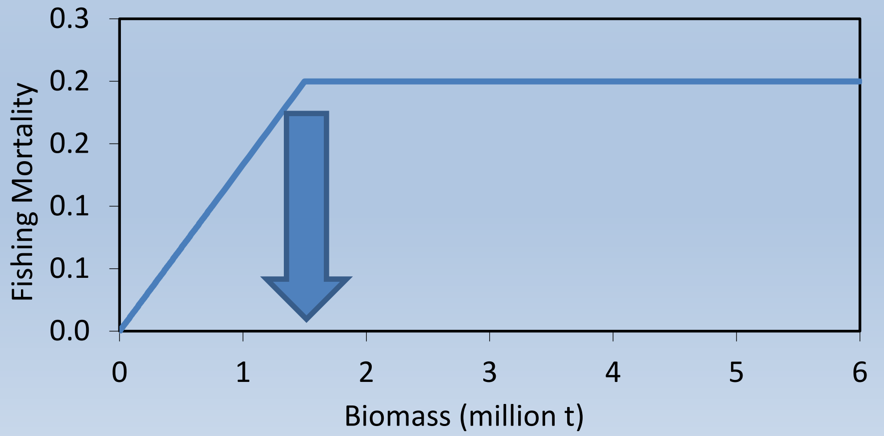
5) Informing control parameters of the HCR

- For example:

- Using external data/relationships to pre-select HCR threshold

- Control parameters ideally selected by "tuning" the MP to ensure performance statistics meet objectives and/or trade-off between objectives
- An MPs performance in relation to e.g. an EAF threshold can be highly dependent on the OMs used and their relative weighting
- Not recommended; rather use (4)





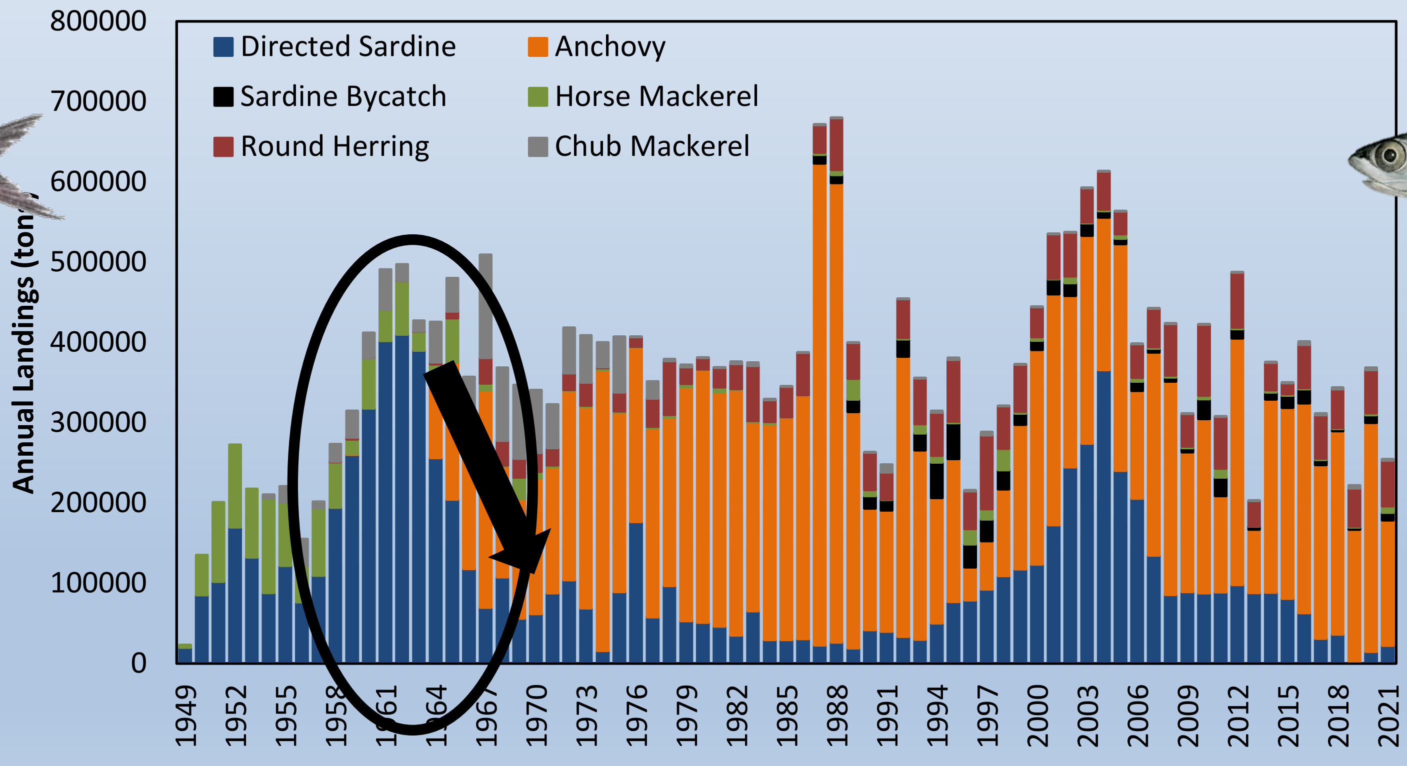
Explicitly Taking an EAF in MSE for SPF

6) Adjusting reference points (RPs)

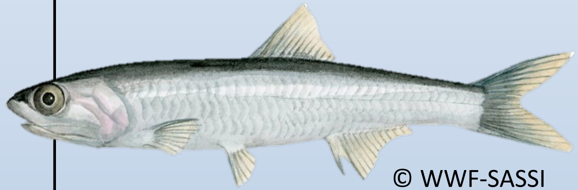
- Performance statistics often based on Target and/or limit RPs
- For example: $p(SSB<SSB_{lim})$ or $p(B>B_{MSY})$
- Marine Stewardship Council : Target RP of 75%B_0 for SPF

RSA Purse-seine Fishery

Sardinops sagax



Engraulis encrasicolus



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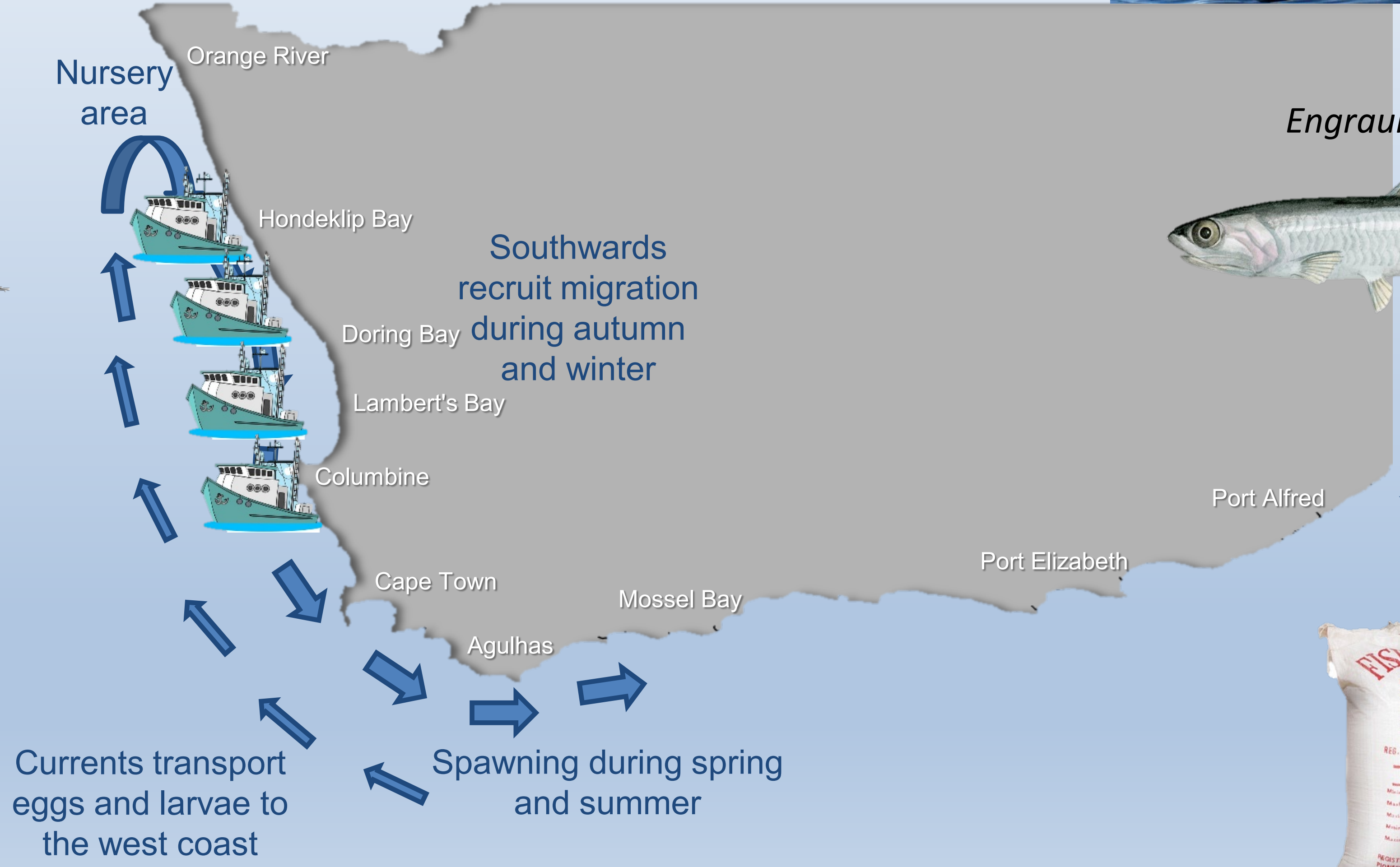
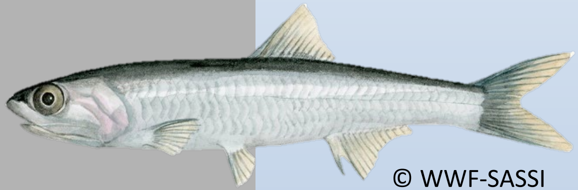
RSA Purse-seine Fishery

Sardinops sagax

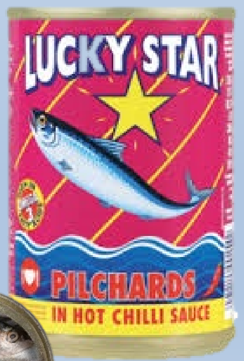


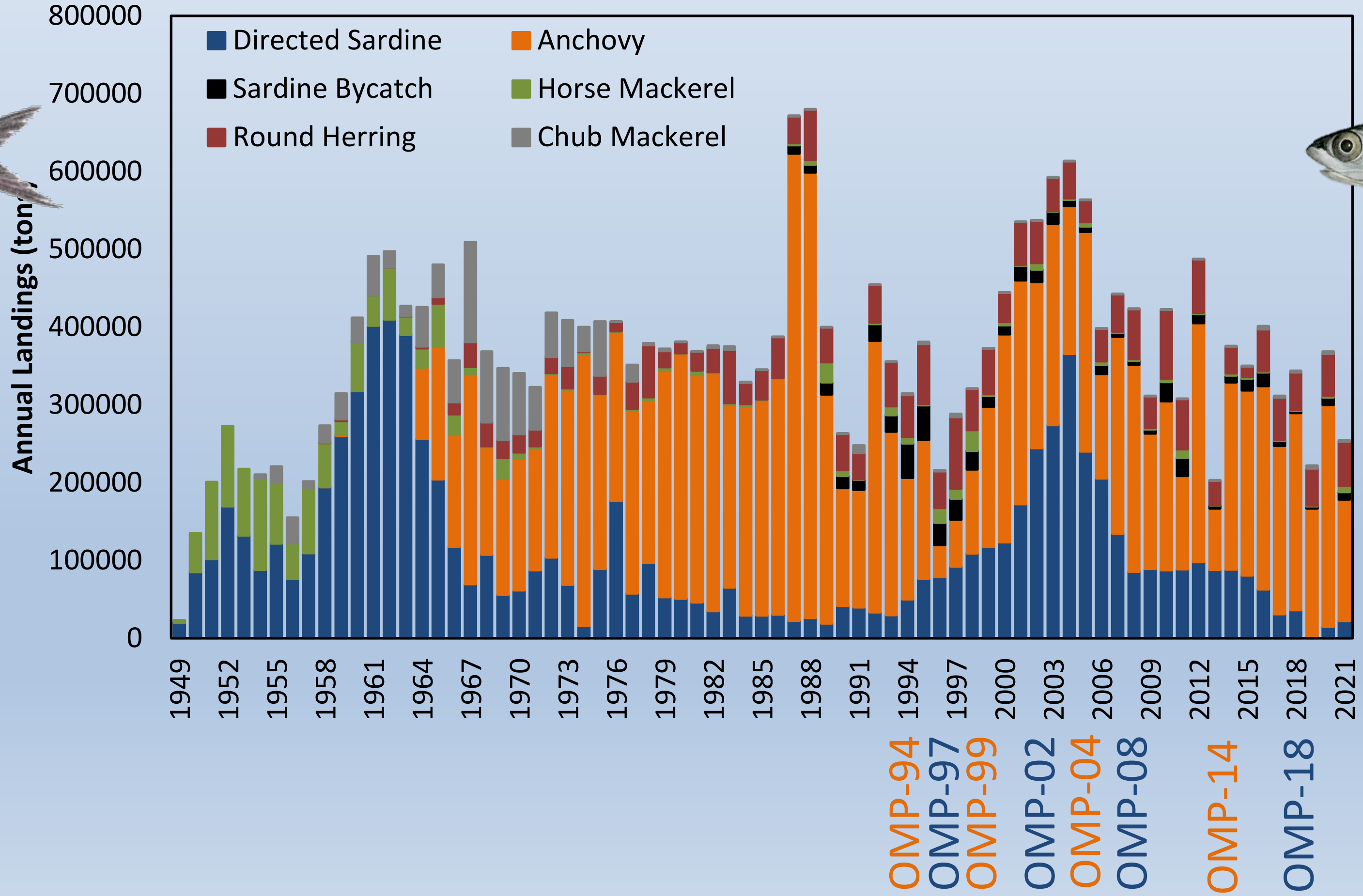
Engraulis encrasicolus



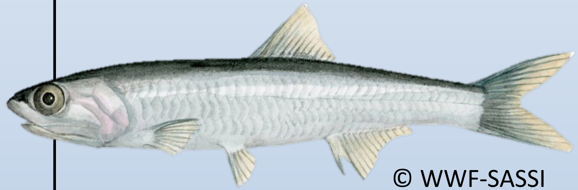
RSA Purse-seine Fishery

Sardinops sagax



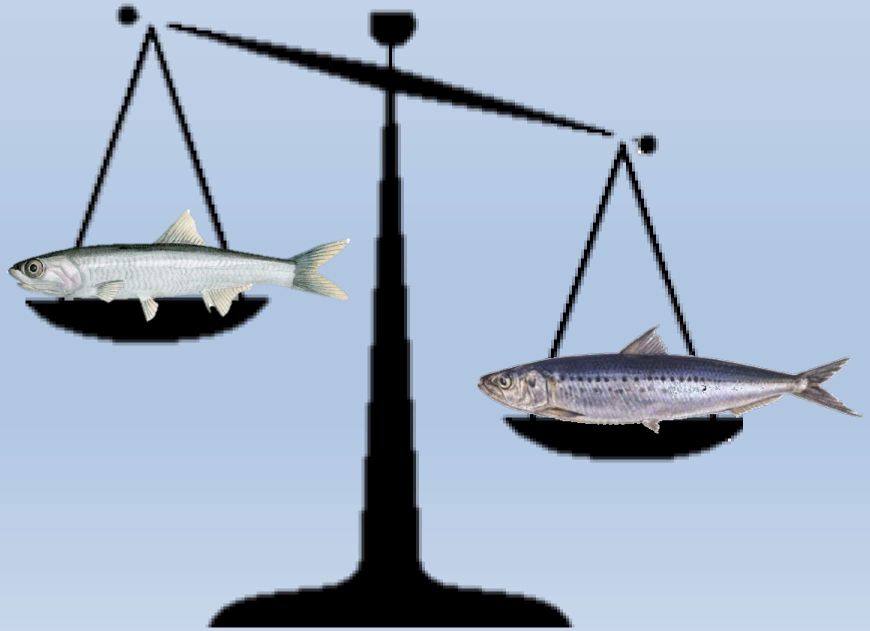


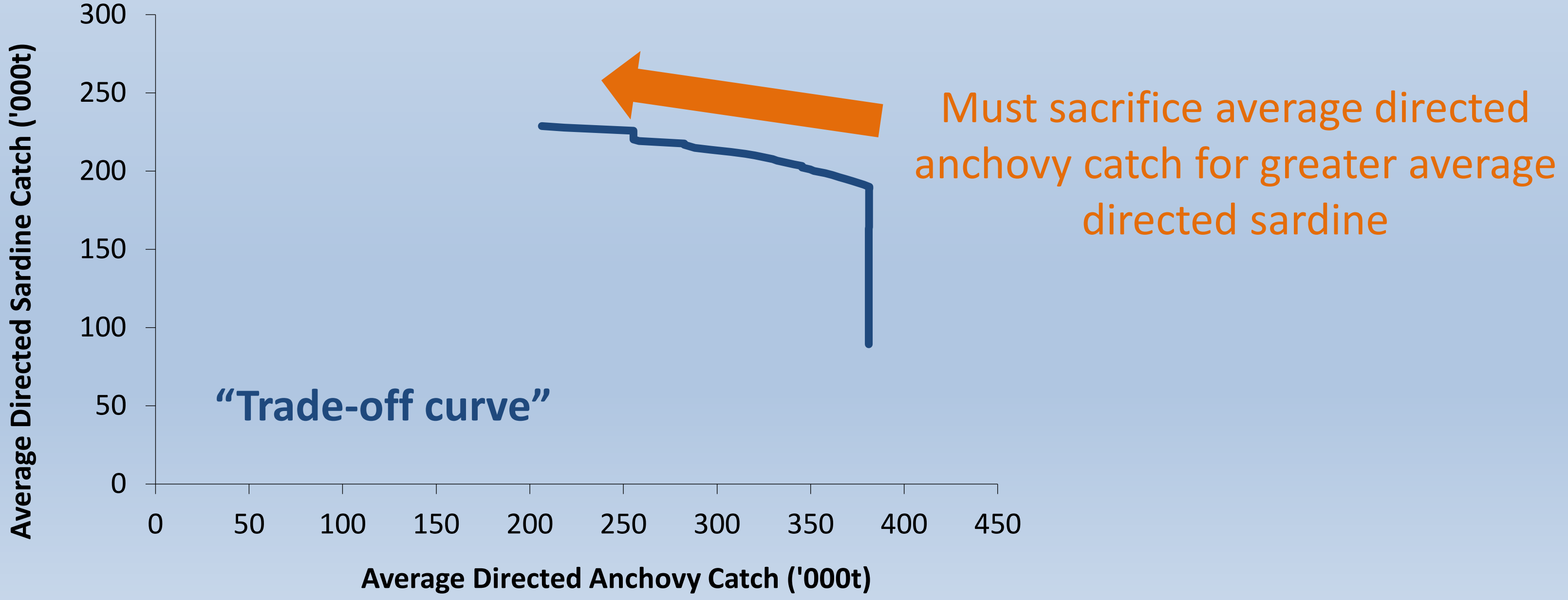
Engraulis encrasicolus



Explicitly Taking an EAF in RSA?

- Jointly modelling and managing sardine and anchovy
- Explicitly considering the impact of juvenile sardine bycatch with the anchovy directed fishery
- First step to taking ecosystem aspects into account?
- Primarily driven by technological interactions rather than biological ones
- Implicit objective being to best maximise catch for both species





Explicitly Taking an EAF in RSA

Explicitly defined objectives

- MPs regularly reviewed and updated to accommodate new research:
- e.g. stock structure, stock-recruitment

OMP-94 (OMP-97) OMP-99 OMP-02 OMP-04 OMP-08 OMP-14 OMP-18

- OMP-14 - First time impact of fishery on ecosystem explicitly considered

Small Pelagic Scientific Working Group

Objectives

and

Performance Statistics

- No *a priori* limit to # of objectives we considered

Explicitly Taking an EAF in RSA

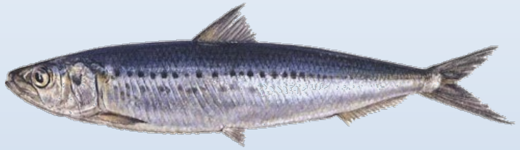
- Humans are apparently only able to mentally make comparisons consistently over no more than about 7 statistics

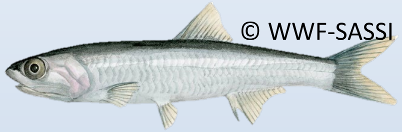
- Why not rather maximise a utility function?
- Multi-Criteria Decision Making (MCDM) considered in 1990s
- Developing a defensible utility function of all the performance stats for the stakeholders was impractical in a fisheries management setting

Explicitly Taking an EAF in RSA

- Separated objectives into 3 categories

Target resource





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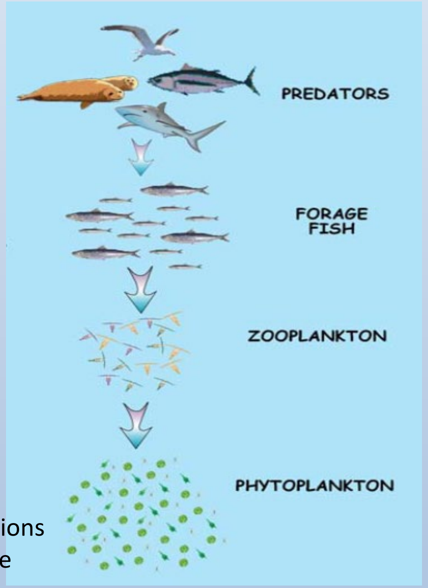
Socio-economics



Ecosystem

Cury *et al*. (2005) Processes and patterns of interactions in marine fish populations: an ecosystem perspective

- The role these fish play in the ecosystem and the impact of the fishery on that role would be explicitly considered in the MSE

Explicitly Taking an EAF in RSA

- Separated objectives into 3 categories

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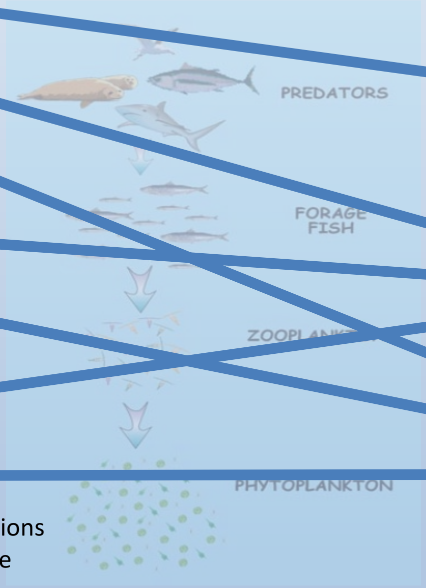


Target resource

Socio-economics

Ecosystem

Cury *et al*. (2005) Processes and patterns of interactions in marine fish populations: an ecosystem perspective

Prioritised performance statistics:

"Non-negotiable"

"Core decision"

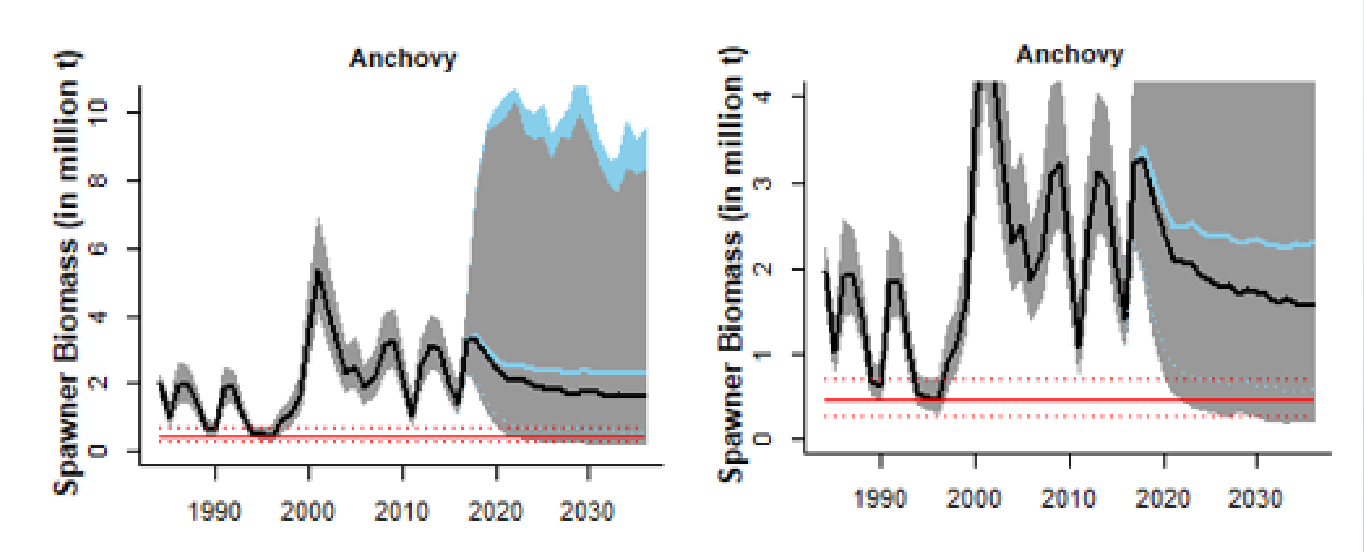
"Trade-off"

- The role these fish play in the ecosystem and the impact of the fishery on that role would be explicitly considered in the MSE

Explicitly Taking an EAF in RSA

Non-negotiable performance statistics

- One for each target resource
- Risk
- $p(SSB_y < SSB_{lim}) <$ pre-agreed %



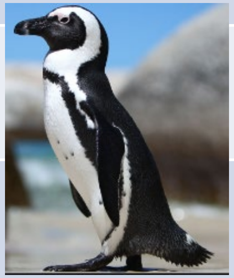
- While this focuses on the target resource only, it has fundamental implications for industry and ecosystem

- All CMPs were tuned to ‘just’ achieve pre-agreed risk %
- If this could not be achieved, CMP was not considered further

Explicitly Taking an EAF in RSA

Core-decision performance statistics

Concern	Objective	Performance Statistic
Target resource	Avoid the resource declining to an unacceptably low level	B_{min} / B_0
		B_{min} / B_{lim}
	Sound resource at the end of the projection period	B_{final} / B_0
		B_{final} / B_{lim}
		B_{final} / B_{start}
Socio-economics	Maximise average directed sardine and anchovy annual catch, subject to known trade-off between these fisheries	Average $C_{directed}$
	Minimise average inter-annual variation in directed sardine and anchovy catch	AAV $C_{directed}$
Ecosystem	Avoid an unacceptable fishery-induced impact on top predators [African penguins]	ROI of number of moulters of Robben Island penguins over first 5 and 10 years
		Number of moulters of Robben Island penguins 5 and 10 years into projection period : current



Explicitly Taking an EAF in RSA

Trade-off performance statistics

- Considered only together with semi-final CMP options
- Ecosystem objectives

- Ensure sardine biomass remains sufficient over time on both west and south coasts
- Ensure combined sardine+anchovy biomass remains sufficient to avoid potential catastrophic ecosystem implications

	Sardine			Anchovy		
		No Catch	OMP-18		No Catch	OMP-18
Risk statistics	β	-	0.124	α	-	1.16
	$Risk_S$	0.070	0.153	$Risk_A$	0.018	0.089
	p(TAC^S<20)	-	0.02			
Biomass statistics	$B^{sp,S}_{tot,2036}$	416 373	297 254	$B^{sp,A}_{2036}$	3384 2341	2669 1613
	$B^{sp,S}_{west,2036}$	178 147	127 98			
	$B^{sp,S}_{south,2036}$	238 209	170 145			
	$B^{sp,S}_{tot,2036}/B^{sp,S}_{tot,2015}$	4.4	3.0	$B^{sp,A}_{2036}/B^{sp,A}_{2015}$	1.6	1.1
	$B^{sp,S}_{west,2036}/B^{sp,S}_{west,2015}$	3.0	2.1			
	$B^{sp,S}_{south,2036}/B^{sp,S}_{south,2015}$	1.1	0.8			
	$effB^{sp,S}_{west,2036}/effB^{sp,S}_{west,2007}$	4.1	2.7	$B^{sp,A}_{2036}/B^{sp,A}_{1996}$	4.9	3.4
	$effB^{sp,S}_{west,2036}/K^{S}_{west}$	0.5	0.3	$B^{sp,A}_{2036}/K^{A}$	1.2	0.9
	$B^{sp,S}_{tot,min}$	180	121	$B^{sp,A}_{min}$	920	543
	$B^{sp,S}_{west,min}$	25	16			
	$B^{sp,S}_{south,min}$	90	57			
	$effB^{sp,S}_{west,min}/effB^{sp,S}_{west,2007}$	1.0	0.7	$B^{sp,A}_{min}/B^{sp,A}_{1996}$	2.0	1.2
	$effB^{sp,S}_{west,min}/K^{S}_{west}$	0.1	0.1	$B^{sp,A}_{min}/K^{A}$	0.5	0.3
Catch statistics	C^S_{tot}	2 0	87 68	C^A	11 0	311 350
	Med C^S_{tot}[8]	0	70	Med C^A	0	350
	C^S_{west}	1 0	61 54			
	C^S_{south}	0 0	26 19			
	C^S_{west}/C^S_{tot}	0	0.75			
	ByC^S_{tot}	0.3 0	19 11			
	ByC^S_{west}	0.3 0	19 11			
	ByC^S_{south}	0.0 0	0 0			
	MAV^S_{tot}[9]	-	0.44	MAV^A	-	0.00
	MAV^S_{west}	-	0.42			
	MAV^S_{south}	-	0.61			
Critical Biomass statistics	$p\left(B^{Sobs}_y < B^S_{crit}, B_y < B^S_{crit}/k^S_N\right)$	-	0.07	$p\left(B^{Aobs}_y < B^A_{crit}, B_y < B^A_{crit}/k^A_N\right)$	-	0.07
	$p\left(B^{Sobs}_y < B^S_{crit}, B_y \geq B^S_{crit}/k^S_N\right)$	-	0.15	$p\left(B^{Aobs}_y < B^A_{crit}, B_y \geq B^A_{crit}/k^A_N\right)$	-	0.01
	$p\left(B^{Sobs}_y \geq B^S_{crit}, B_y < B^S_{crit}/k^S_N\right)$	-	0.05	$p\left(B^{Aobs}_y \geq B^A_{crit}, B_y < B^A_{crit}/k^A_N\right)$	-	0.01
	$p\left(B^{Sobs}_y \geq B^S_{crit}, B_y \geq B^S_{crit}/k^S_N\right)$	-	0.73	$p\left(B^{Aobs}_y \geq B^A_{crit}, B_y \geq B^A_{crit}/k^A_N\right)$	-	0.91
	Avg # years $B^{Sobs}_y < B^S_{crit}$ consecutively	-	1.4 yrs	Avg # years $B^{Aobs}_y < B^A_{crit}$ consecutively		2.3 yrs
Ecosystem statistics	ROI (5yrs)	-0.095	-0.109	P(Bsar+Banch) < historical min	0.01	0.07
	ROI (10yrs)	-0.073	-0.078			
	ROI (15yrs)	-0.057	-0.060			
	# Moulters (2022:2017)	0.525	0.457			
	#Moulters (2027:2017)	0.273	0.217			
	# Moulters (2032:2017)	0.145	0.106			
	$p(B^{obs,S}_w < 336)$	0.51	0.60			
	$avg\ \#\ years\ B^{obs,S}_w < 336$	2.69	3.26			

Explicitly Taking an EAF in RSA

Why did this method work?

- It brought EAF front and centre in our MSE
- required ecosystem objectives to be defined and theoretically considered equally to those of the target resources and industry
- Prioritising the objectives enabled effective development of CMPs while recognising that different stakeholders wanted to focus on stats meaningful to them
- Forced consideration of what parts of the ecosystem could be reasonably quantitatively modelled to depend on SPF

- However, varying level of total catch had only a limited impact on penguins. Distribution of sardine biomass far more important
- In practice, ecosystem performance stats did not play an equal role

Explicitly Taking an EAF in RSA

- Note! Not all objectives can be included in an MSE
- Does purse seine fishing within a 20km radius of penguin breeding colonies negatively impact the bird population?
- Requires highly spatially-disaggregated OM
- Run a parallel process to MP

- Experiment of opening and closing islands to purse seine fishing
- Did not affect total catch limits, only affected alternating small areas where the catch could not be taken

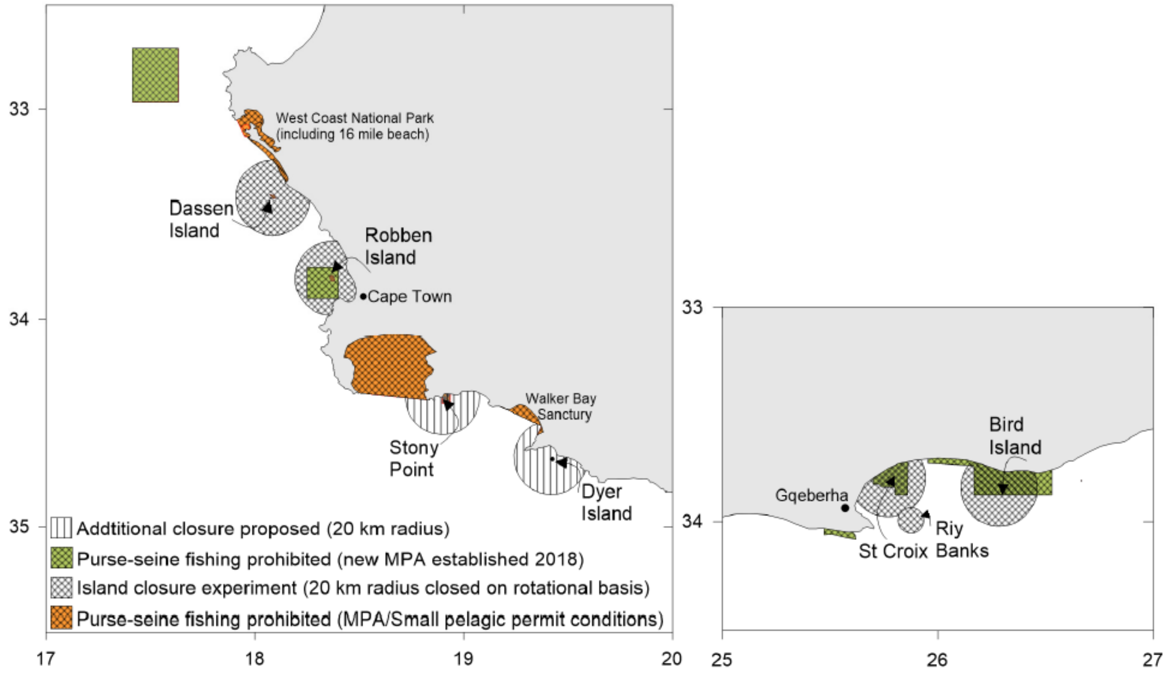


Figure 8. The location of the islands on the West Coast (left) and South Coast (right) around which purse-seine fishing is closed on an experimental basis. Circles indicate the extent of the 20 km closure.

DFFE (2021) A Synthesis of Current Scientific Information Relating to the Decline in the African Penguin Population, the Small Pelagic Fishery and Island Closures

Recommendations

- MSE for SPF had gained some good ground in recent years
- There is a collective desire to take an EAF in managing SPF
- and to do so quantitatively
- Outlined 5 (or 6) ways one can do this
- Biggest current restriction?
- Data limitation, delaying the estimation of credible quantitative thresholds, one-way relationships and MICE

Thank you for your attention!