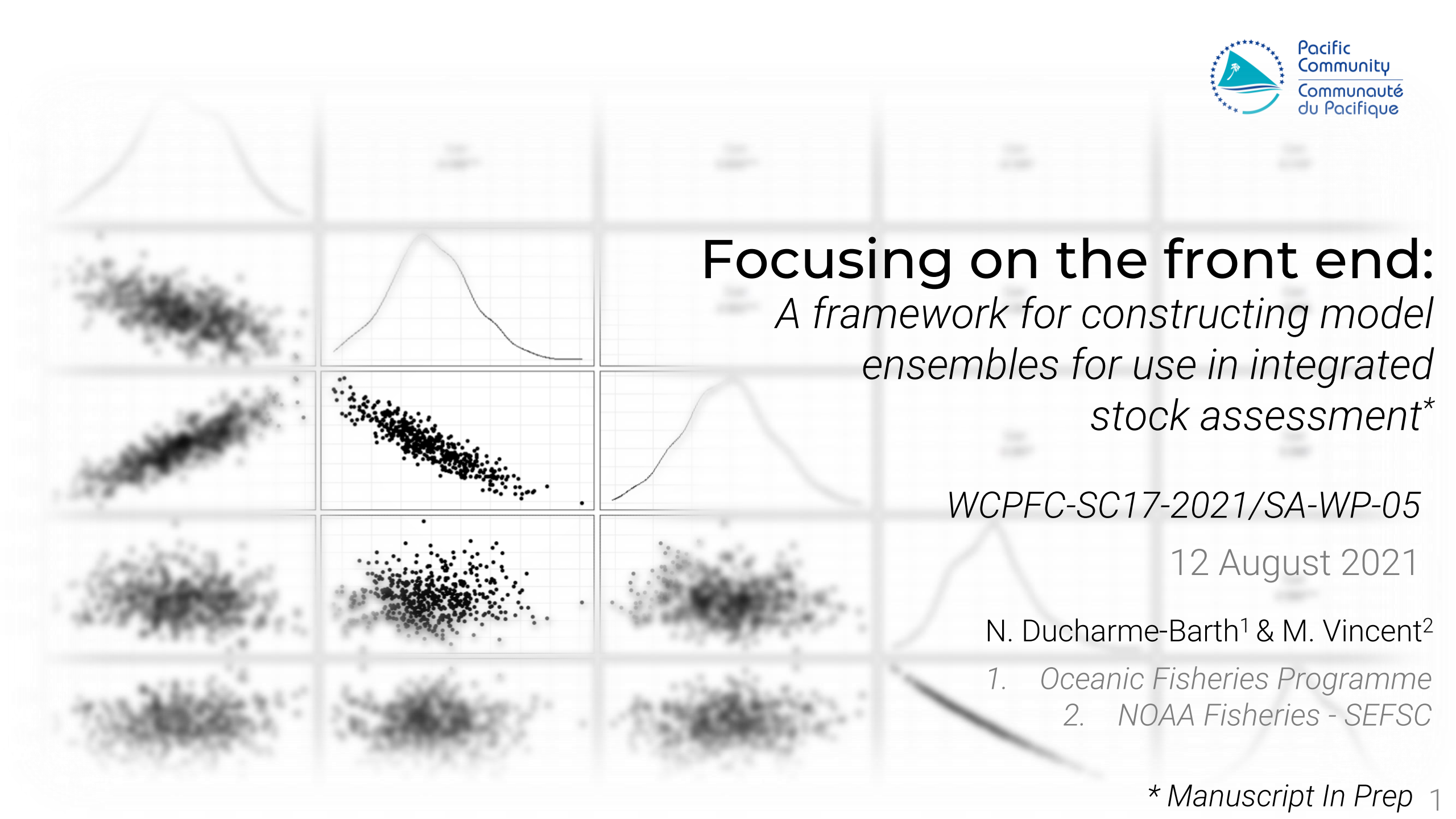

Focusing on the front end:

*A framework for constructing model ensembles for use in integrated stock assessment**

WCPFC-SC17-2021/SA-WP-05

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2. *NOAA Fisheries - SEFSC*

** Manuscript In Prep*

Background

- WCPO stock assessments have typically characterized uncertainty in estimated management quantities as the 'structural uncertainty' from a grid of models.
- 'Structural uncertainty grid' constructed as full-factorial combination of different levels of key 'axes' of uncertainty for fixed assumptions in model.

Natural Mortality (M)
0.2 (low)
0.3 (medium)
0.4 (high)

×

Growth (L2)
140 (low)
160 (medium)
180 (high)

»»

Model 1: M=0.2,L2=140	Model 2: M=0.2,L2=160	Model 3: M=0.2,L2=180
Model 4: M=0.3,L2=140	Model 5: M=0.3,L2=160	Model 6: M=0.3,L2=180
Model 7: M=0.4,L2=140	Model 8: M=0.4,L2=160	Model 9: M=0.4,L2=180

Weaknesses

- Inefficient: factorial combination quickly produces intractable # of models
- Unrealistic combinations: High M and High L2 ???
- Ad-hoc, subjective weighting of models

Biological parameter uncertainty

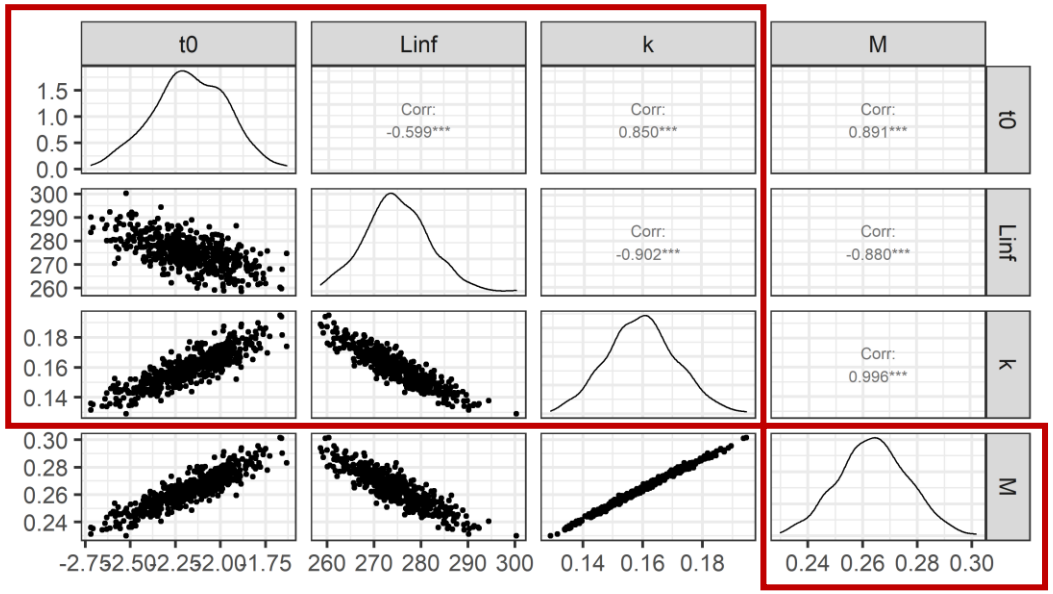
- Preserve parameter correlation from external analyses
- Life history theory can inform plausible parameter combinations
- Biological parameters come from continuous distribution.

Solution

- *Preserve parameter correlation from external analyses* → Create a Multivariate prior (FishLife/Bayesian analysis)
- *Life history theory can inform plausible parameter combinations* → Extend to other parameters
- *Biological parameters come from continuous distribution* → Implicit parameter weighting

→ Fully-Bayesian Integrated Assessment

✗ Model 1: M=0.2,L2=140	? Model 2: M=0.2,L2=160	✓ Model 3: M=0.2,L2=180
? Model 4: M=0.3,L2=140	✓ Model 5: M=0.3,L2=160	? Model 6: M=0.3,L2=180
✓ Model 7: M=0.4,L2=140	? Model 8: M=0.4,L2=160	✗ Model 9: M=0.4,L2=180

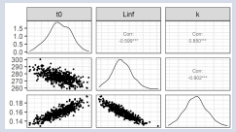


e.g. $M = 4.118 \times k^{0.73} Linf^{-0.33}$; *Then et al. 2015*

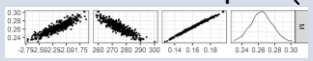
Model ensemble framework

Joint Prior

Develop multivariate prior for key biological parameters (e.g. growth & maturity)



Extend uncertainty and correlation structure to other key biological inputs using Life-History relationships (e.g. M)



Combine with priors for other biological structural uncertainties (e.g. movement & steepness)

As an interim step, we propose the following framework for constructing a model ensemble to capture parameter uncertainty.

This approach propagates parameter uncertainty and correlation through the stock assessment while providing an implicit model weighting based on data and previous analyses.

Sample	k	…	Steepness
1	0.147	…	0.736
…	…	…	…
n	0.183	…	0.891

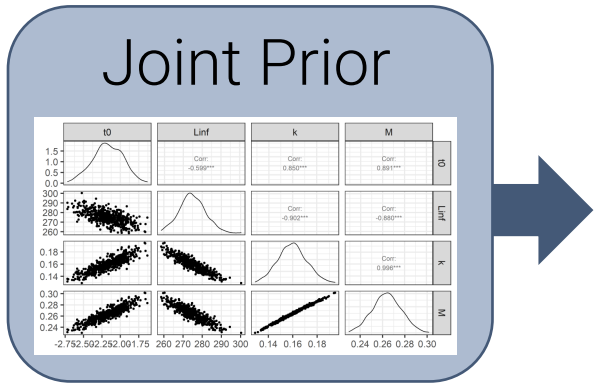
Take *n* random draws from joint prior

Ensemble

- Model 1
- Model …
- Model *n*

Extending the framework

Combine with factorial approach to extend model ensemble framework to incorporate structural uncertainty not captured in the joint prior (e.g. spatial structure)

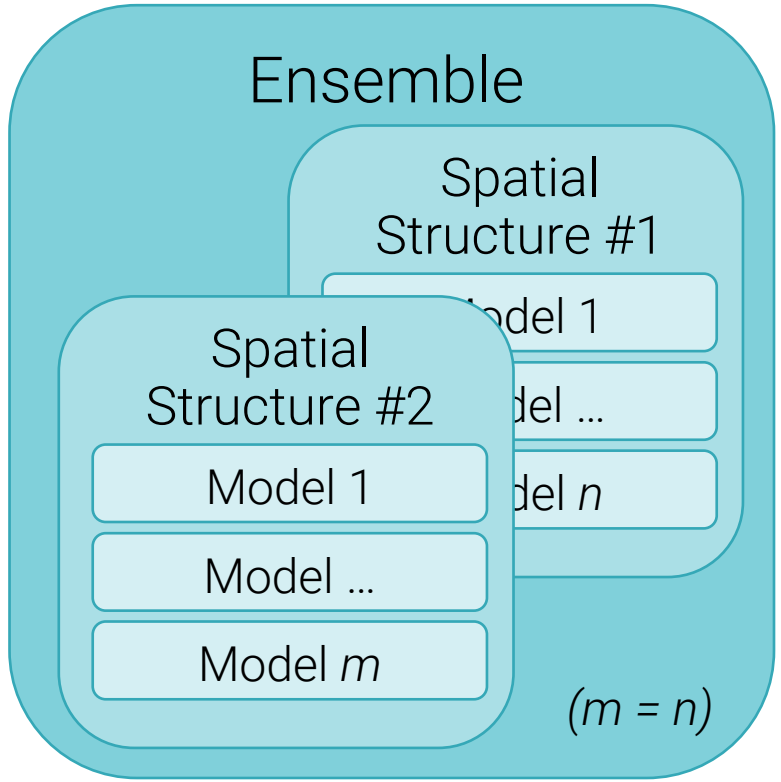


Spatial Structure #1

Sample	k	…	Steepness
1	0.147	…	0.736
…	…	…	…
n	0.183	…	0.891

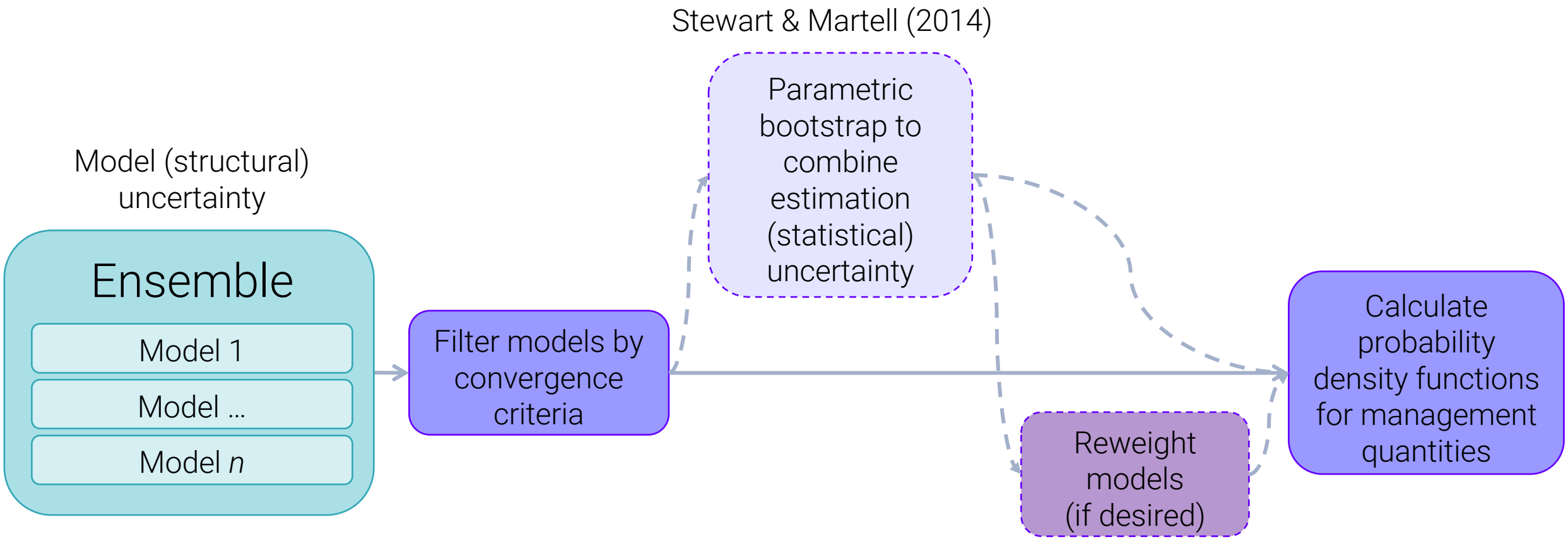
Spatial Structure #2

Sample	k	…	Steepness
1	0.151	…	0.827
…	…	…	…
m	0.196	…	0.758



Model weighting approaches (e.g. *Maunder et al. 2020-SAC-11 INF-F* or *Kell et al. 2021*) can be used to re-weight different models in the ensemble if desired

Presenting results

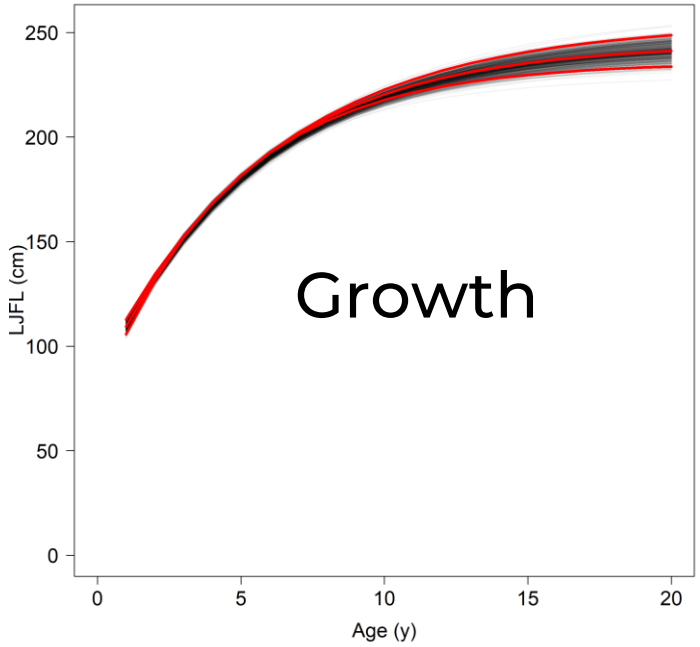


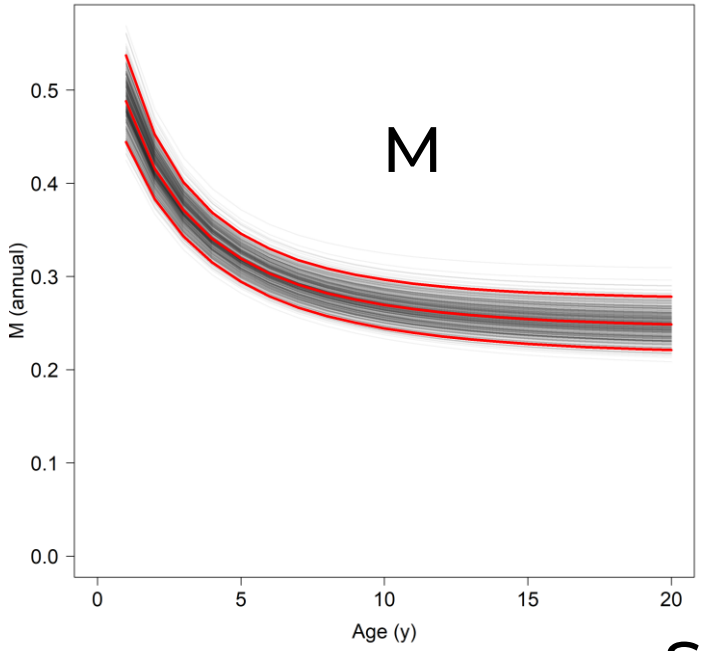
Proof of Concept: *2017 SWPO swordfish*

- Joint prior for Growth, Maturity, and Length-Weight parameters constructed by combining posteriors from Bayesian analysis (STAN)
- Prior for adult M created by applying $M = 4.118 \times k^{0.73} Linf^{-0.33}$ *(Then et al. 2015)*, and M-at-age created by applying Lorenzen M-at-age formulation to M prior (*Methot and Wetzel 2013).*
- Assumed Uniform(0.65,0.95) prior for steepness

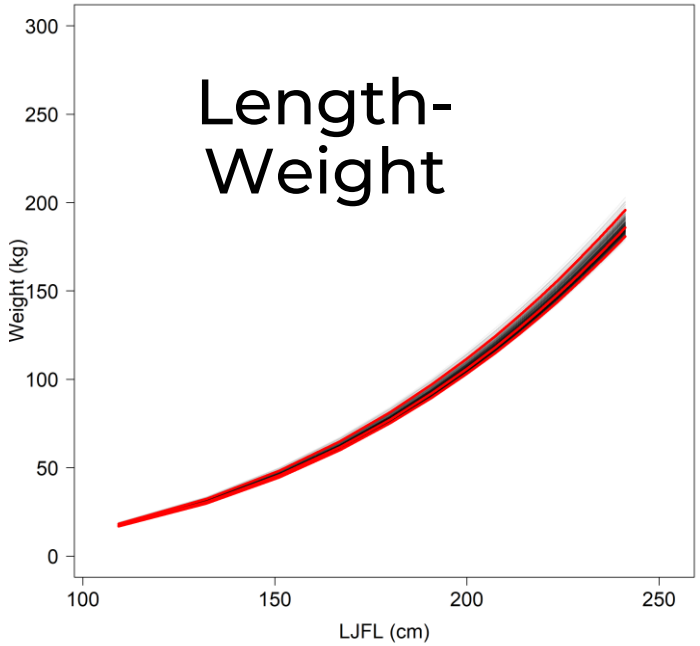
Uncertainty grid experiment

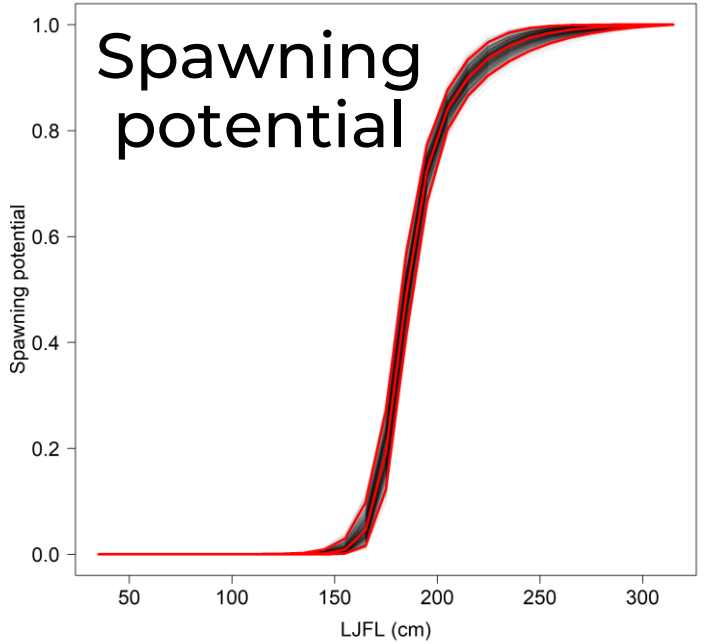
- Conventional grid
  - 5 axes (243 models) based off of 2.5%, 50%, 97.5% percentiles from joint prior
    - Growth (3), M (3), Length-Weight (3), Spawning potential (3), Steepness (3)
- 'Ensemble' grid (500 models)
  - Test if management quantities change with different size ensembles
  - Use GLM to identify which fixed parameters have greatest influence on management quantities



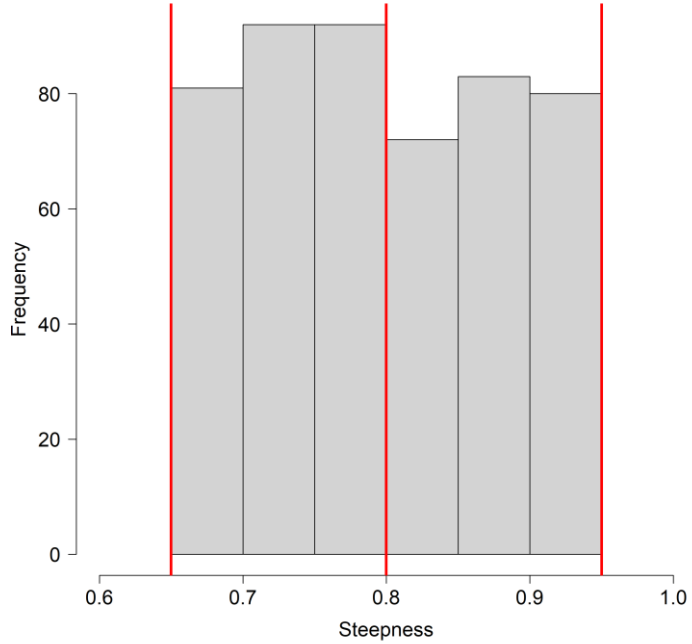


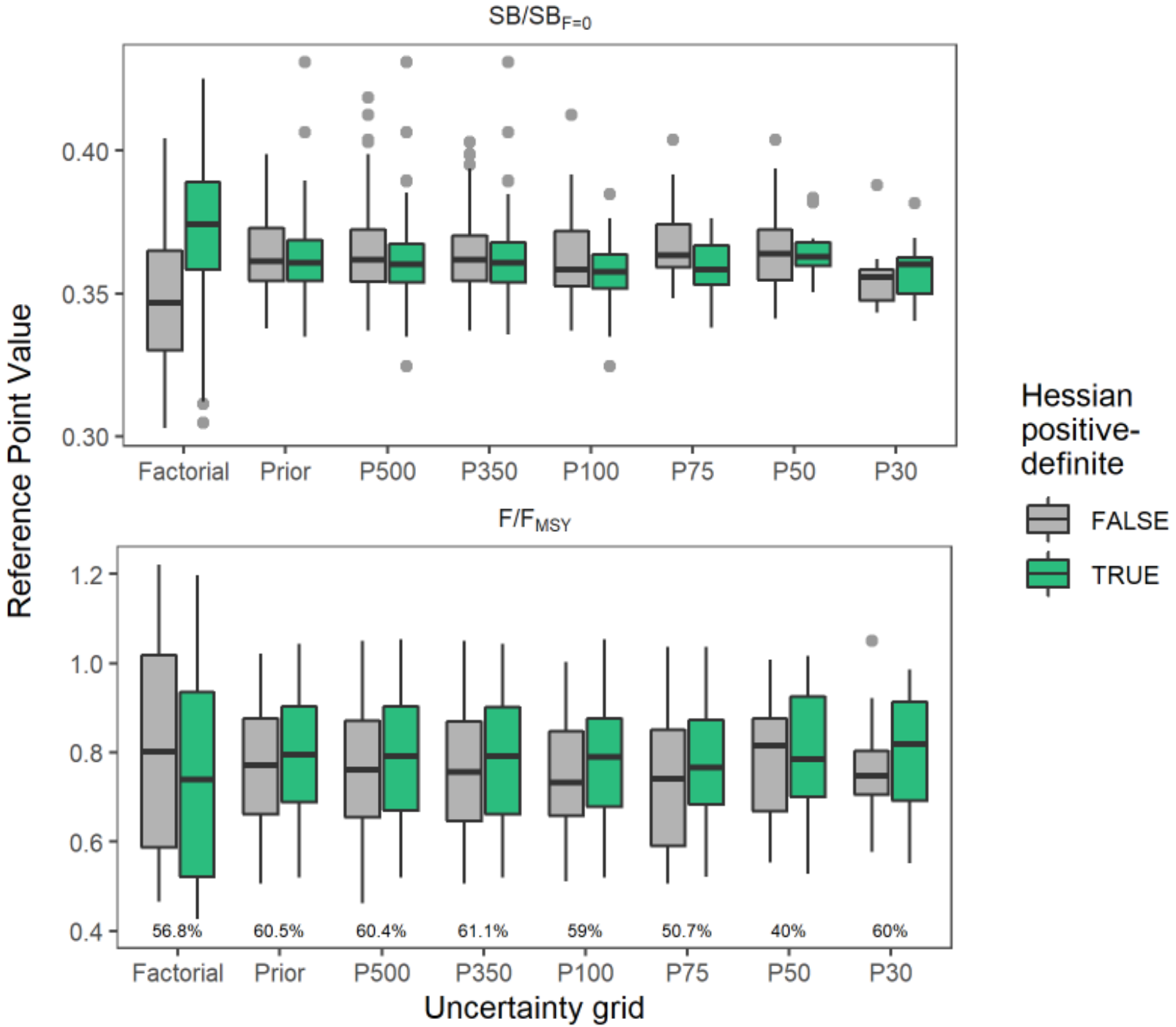
Pacific Community
Communauté du Pacifique

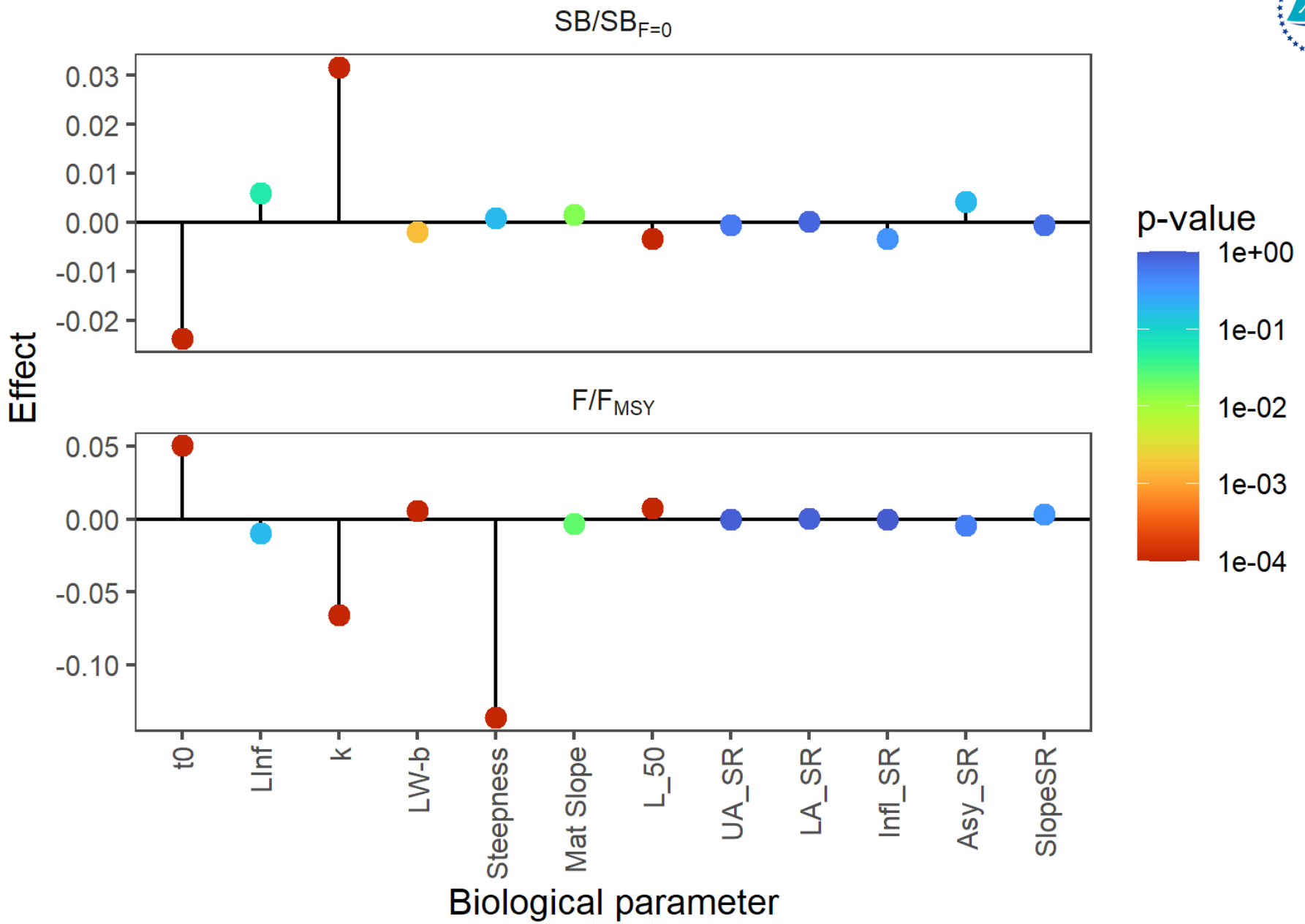




Steepness




SB/SB$_{F=0}$
0.40
0.35
0.30
Reference Point Value
Factorial
Prior
P500
P350
P100
P75
P50
P30
F/F$_{MSY}$
1.2
1.0
0.8
0.6
0.4
56.8%
60.5%
60.4%
61.1%
59%
50.7%
40%
60%
Uncertainty grid
Hessian positive-definite
FALSE
TRUE


SB/SB$_{F=0}$
0.03
0.02
0.01
0.00
-0.01
-0.02
F/F$_{MSY}$
0.05
0.00
-0.05
-0.10
Effect
t0
LInf
k
LW-b
Steepness
Mat Slope
L_50
UA_SR
LA_SR
Infl_SR
Asy_SR
SlopeSR
Biological parameter
p-value
1e+00
1e-01
1e-02
1e-03
1e-04

Presenting results

Parametric bootstrap to combine model statistical uncertainty

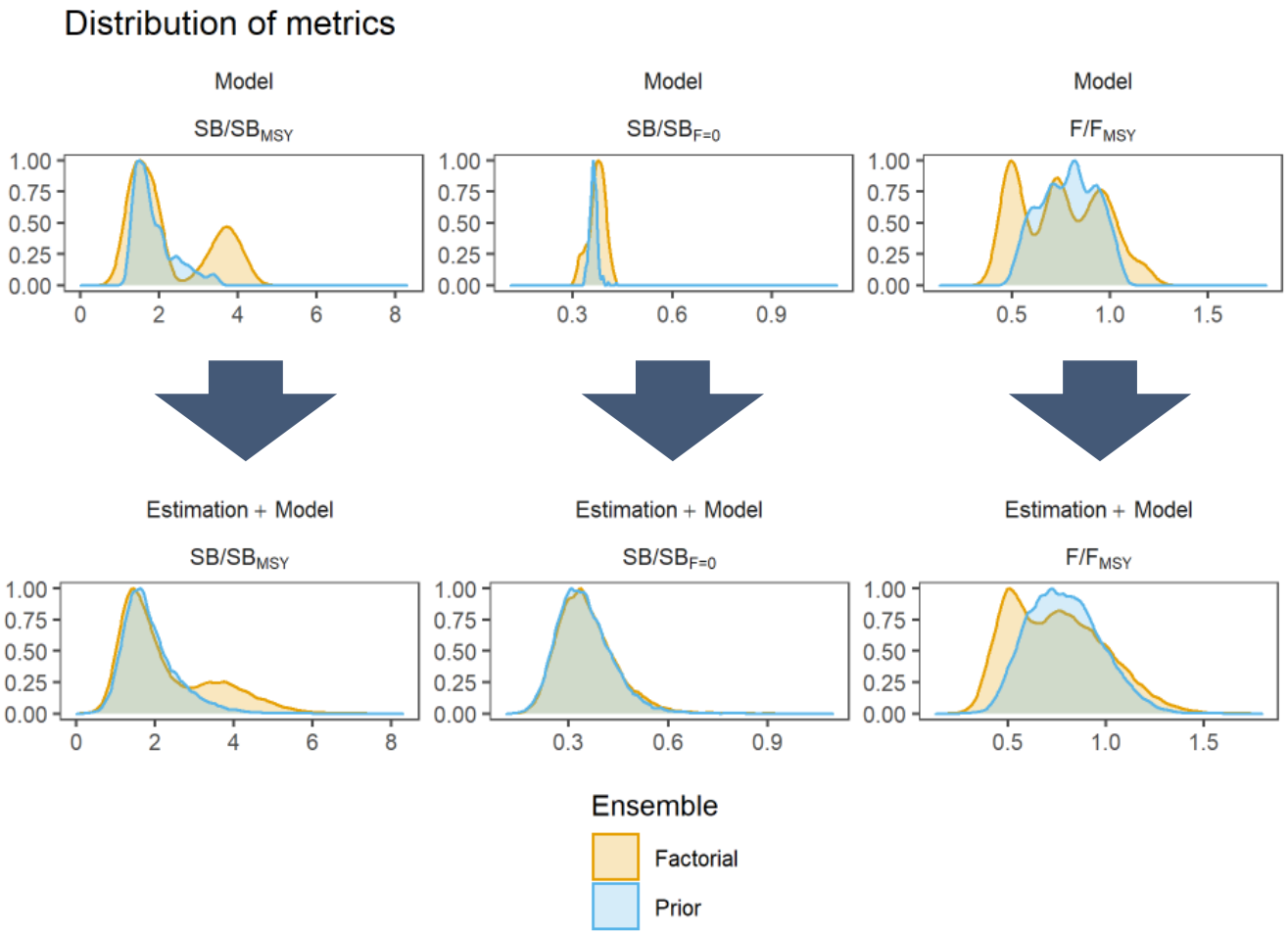
1) For each model in the ensemble conduct a parametric bootstrap (*j* samples) using the estimated mean and statistical variance for each metric of management interest.

Metric	Mean	SE
SB/SB_{MSY}	1.56	0.3
...	...	...
$SB/SB_{F=0}$	0.35	0.2

Metric	1	*j*
SB/SB_{MSY}	0.89	1.73
...	...	...
$SB/SB_{F=0}$	0.23	0.41

$\times n$ models

2) Combine bootstrap samples across all n models in the ensemble to get holistic description of the uncertainty: Model & Estimation



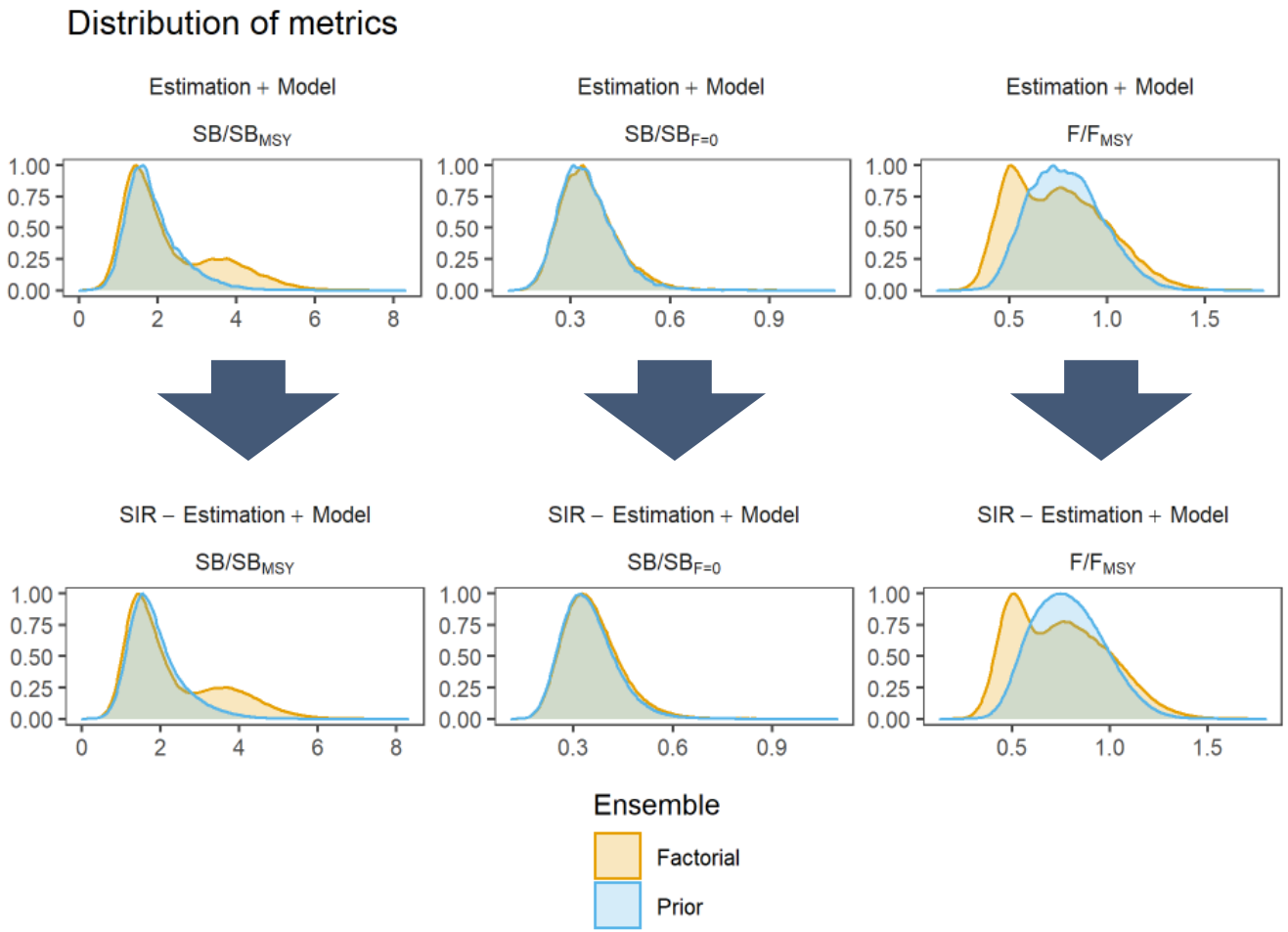
Presenting results

Reweight models (if desired)

Although the joint prior approach imposes an implicit weighting based on the shape of the multivariate prior distribution, it may be desirable to re-weight the models in the ensemble *post-hoc* based on a pre-determined weighting scheme.

Such weighting schemes could be based on:

- Expert opinion
- Likelihood (e.g. Sample Importance Resampling – SIR)
- Model diagnostics (e.g. hindcast performance)
- Any combination of the above

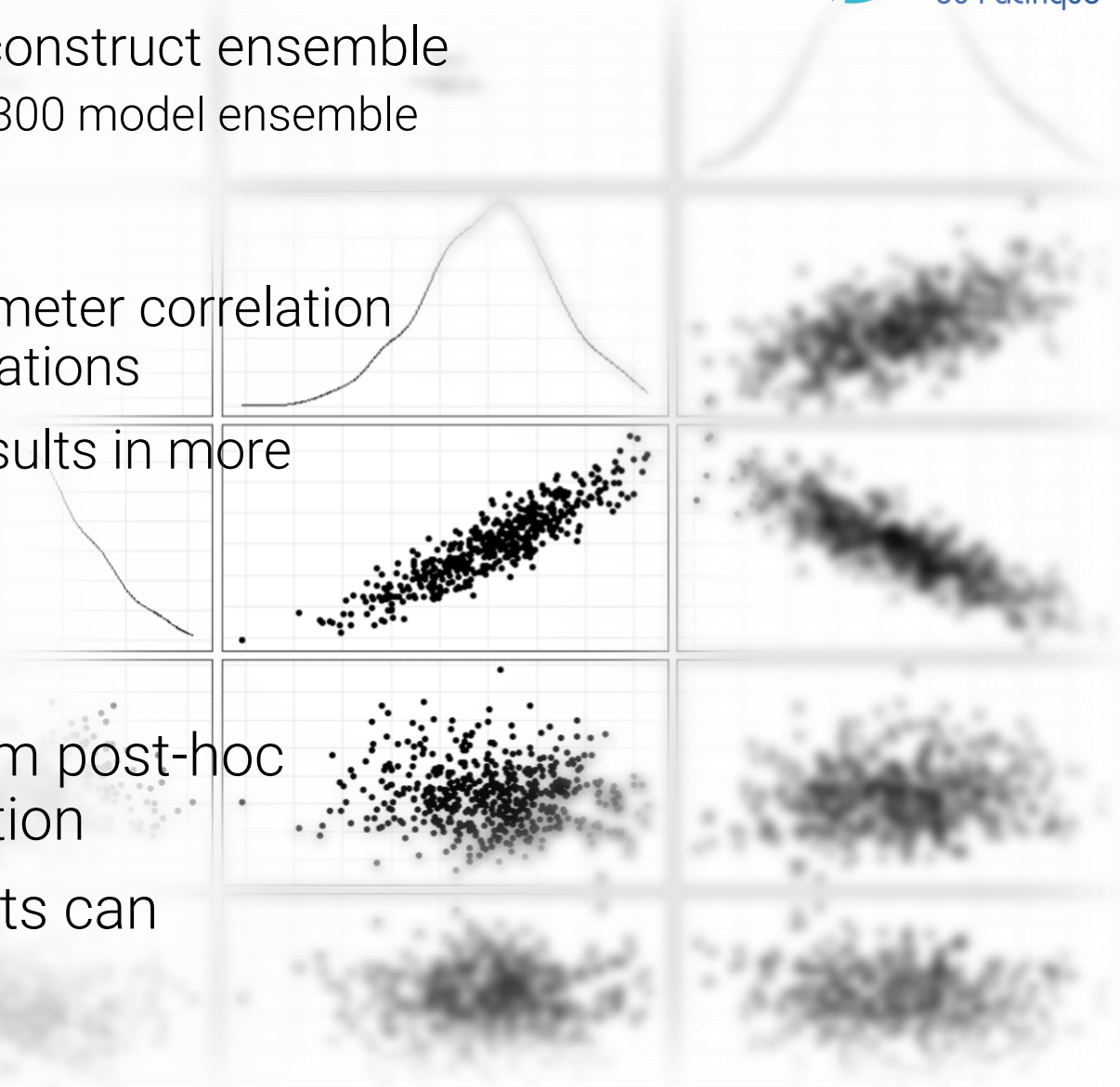


Summary

- Joint prior approach is more efficient way to construct ensemble
  - Management advice provided from 30 model or 300 model ensemble statistically similar
  - Marginally better convergence rate
- Reduction in model uncertainty by using parameter correlation and life-history to remove implausible combinations
- Combining model + estimation uncertainty results in more holistic portrayal of uncertainty

Implications

- ‘Focus on the front end’ shifts scrutiny from post-hoc model weighting to a-priori prior specification
- Meta-analytic approach of ensemble results can target areas for future research



Discussion

We invite the SC to:

- Recommend that the WCPFC considers adopting a standard approach for presenting uncertainty in management reference points and that the standard approach combines the statistical and structural uncertainty across an ensemble of models.
- Consider the merits of the framework outlined in this paper as a suitable approach for combining statistical and structural uncertainty across an ensemble of models for WCPFC assessments.
- Note the application of this framework in the 2021 southwest Pacific Ocean swordfish assessment.
- Support additional research into ensemble modeling and model weighting for the provision of management advice.
- Note that certain computationally intensive model weighting approaches (e.g. hindcasting) may not be tractable for models with long run times.