



# Improving Catch Estimation Methods in Sparsely Sampled, Mixed Stock Fisheries.

Nicholas Grunloh

In Cooperation With:  
E.J. Dick, Don Pearson, John Field, Marc Mangel

UCSC :: CSTAR :: SWFSC :: NMFS

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## Diagnostic Tutorial

**Request:** As a diagnostic template, for each sampled stratum compare the posterior predictive distributions at the 68th, 95th, and 99th percentiles with the current observed species proportions (create fully stratified versions of tables 2 and 3 in the Grunloh et al. methods documentation). With each row, include sample sizes and associated landing weights with a graphical display to highlight problems and outliers (circle size proportional to landing weights).

**Rationale:** The Team provided broad-scale summary metrics (e.g., MSE and DIC) for evaluating the goodness-of-fit of the different model forms and structures. Fine-scale diagnostics are needed to help identify aspects of the data that are not adequately addressed by the different models. The diagnostic template will provide a mechanism for fine-scale exploration of goodness-of-fit.

**Response:** The following slides show the requested diagnostic plot and demonstrate how to maneuver as well as interpret them.



## Beta-Binomial Model

$$y_{ijklm\eta} \sim \text{Beta-Binomial}\left(\mu_{jklm\eta}, \sigma_{jklm\eta}^2\right)$$

$$\mu_{jklm\eta} = n \text{ logit}^{-1}(\theta_{jklm\eta})$$

$$\sigma_{jklm\eta}^2 = \mu_{jklm\eta} \left(1 - \frac{\mu_{jklm\eta}}{n}\right) \left(1 + (n-1) \rho\right)$$

$$\theta_{jklm\eta} = \beta_0 + \beta_j^{(s)} + \beta_k^{(p)} + \beta_l^{(g)} + \beta_{mn}^{(t)}$$

$y_{ijklm\eta}$ :  $i^{\text{th}}$  sample of the  $j^{\text{th}}$  species' integer weight, in the  $k^{\text{th}}$  port, caught with the  $l^{\text{th}}$  gear, in the  $\eta^{\text{th}}$  quarter, of year  $m$ , for a particular market category.

$j \in \{1, \dots, J\}$  Species

$k \in \{1, \dots, K\}$  Ports

$l \in \{1, \dots, L\}$  Gears

$m \in \{1, \dots, M\}$  Years

$\eta \in \{1, \dots, H\}$  Quarters



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## Diagnostic Tutorial

	M4
DIC	38721
WAIC	38725

← click

Text underlined in green links to the appropriate diagnostics for all species and stratum.

(M4)

$$\beta_{m\eta}^{(t)} = \beta_{m\eta}^{(y:q)}$$

$$\beta_{m\eta}^{(y:q)} \sim N(0, v)$$

- species-port-gear-year-qtr,  
species-gear-year,  
species-year
- disaggregated\*.csv,  
gearYearSpp\*.csv,  
yearSpp\*.csv
- marginal plots by species



## Diagnostic Tutorial

## MAD Diagnostic

Let  $\ell_i$  be the landings in stratum  $i$ ,  $\mathcal{O}_{ij}$  be the observed predictive accuracy of species  $j$  in stratum  $i$ , and  $\mathfrak{N}$  be the nominal level of prediction for a particular model run. The Mean Absolute Deviation (MAD) for species  $j$  in stratum  $i$  is

$$\text{MAD}_{ij} = \frac{\ell_i}{\sum_i \ell_i} |\mathcal{O}_{ij} - \mathfrak{N}|.$$

- Low MAD scores occur when  $\ell_i$  is low -or-  $|\mathcal{O}_{ij} - \mathfrak{N}|$  is small.
- High MAD scores occur when  $\ell_i$  is large and  $|\mathcal{O}_{ij} - \mathfrak{N}|$  is large.
- Thus high MAD scores represent important mistakes, and low MAD scores represent either unimportant mistakes, or important correctness :)

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## Diagnostic Tutorial

# Stratum Plots

We show predictive accuracy at three levels of stratification:

- species-port-gear-year-qtr is fully disaggregated predictions.
- species-gear-year marginalizes over port and quarter; showing marginalized predictions by species, gear, and year.
- species-year marginalizes over port, quarter, and gear; showing marginalized predictions by species and year.

In each run's directory (here is M4's) disaggregated\*.csv, gearYearSpp\*.csv, yearSpp\*.csv are csv versions of these images.

## Introduction

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## Time Model

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## Prior Model

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## Interaction Model

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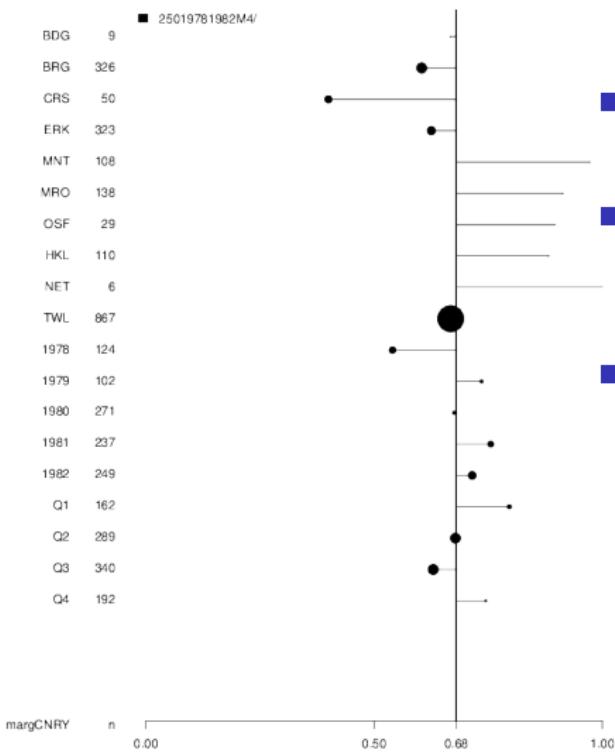
## Time Block

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## Proofs

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## Diagnostic Tutorial



- Marginal Plots condition on a single species (CNRY here).
- For a particular species, each row conditions on a single stratum and marginalizes over all other strata.
- Use:
  - Sort species by MAD score.
  - Given a particular species, explore margins via marginal plots.
  - Explore within the margins via the previously described stratum plots.

**Request:** Provide a summary table of species sample sizes in each market category by time block.

**Rationale:** The requested information will assist in understanding where there are gaps in the available data that the model is filling in by means of its pooling structure.

**Response:** The following slides show tables of total sample sizes and the frequency of occurrence by species within each sample (across all years, gears, ports and quarters within a time period) for the three rockfish market categories that we focus on in the presentation, as well as elasmobranchs and flatfish. Supplementary excel files include data summaries and pivot tables that can be used to review the same information for all other market categories, as well as these and other market categories at higher levels of stratification (year, port complex, gear, quarter) to address specific questions or concerns.

## Introduction

## Time Model

## Prior Model

## Interaction Model

### Time Block

## Proofs

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A 5x5 grid of 25 small circles, arranged in five rows and five columns.

A 5x5 grid of 25 small circles, arranged in five rows and five columns.

A 5x5 grid of 25 small circles, arranged in five rows and five columns.

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This table shows the total number of samples for Market Category 250 (Unspecified rockfish) in five major time periods. The sparseness of some species in the sample data (e.g., bronzespotted rockfish in the 1978-1982 period, when just one was encountered) directly relates to the challenges and poor diagnostics in the fits for such rare species.

#### Market Category 250: Unspecified Rockfish



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These tables show the total number of samples for Market Category 253 (Boccaccio) and 269 (Widow rockfish), with the frequency of occurrence of all other rockfish species in each sample, in five major time periods.

Market Category	253: Baccoccia						
	1978-82	1983-90	1991-99	2000-09	2010-17		
Total Samples	224	44	718	171	310		
ARRA	4	5	2				
BANK	39	19	53	2	1		
BCAC	207	37	709	170	310		
BLGL	9	9	10				
BLUR	6		2				
BRNZ			2				
BRWN	1		2				
CLPR	187	34	113	8	14		
CNRY	21	4	1				1
CWCD	6	1	15				
DBRK	4	6	8				
EGLS	2						2
FLAG	1	1					
GBLC	3						
GSPT	16	1	9	1			
GSRK	17	3	7				1
KUPG	1						
LCOD	17	1	2				
LSPN							1
MISC	2						
MKRF							1
OLVE	5		4				
QWVS			1				
PDBA	1						1
PNKR	1	2					
POP				1			
PTRL				1			
RDBO	2	5	2				
REX							1
REX	1						
RSTN				3			
SABL	3						
SBLY	9		2		1		
SHRP		1	2				
SLGR			7	1			
SNOS	27	12	18				
SPKL	5	1	6				
SSPN	6	2	1				
STAR							1
STRK	12	2	3				3
TIGR	1						
URCK							1
VRML	4		2				
WDOW	51	5	23				1
YTRK	19	1	19				

Market Category 269: Widow rockfish		1978-82	1983-90	1991-99	2000-09	2010-17
Total Samples		132	497	514	150	198
ARRA				1		
BANK			5	29	3	
BCAC		6	13	5	2	1
BLCK		1	1			
BLGL			2	7	2	
BLUR				2		
BRNZ				1		
CLPR		4	19	18	1	
CMLM			1			
CNRY		2	3			
CWCD				1		
DBRK		1	3	6		
EGLS						1
GSPT			1	2		
GSRK		1	2			
LCOO				2		
MISC				1		
OLVE				1		
POP						1
RDDB		1	1			
REX					1	
SBLY			1	2		
SHRP			3	1		
SLGR			1			
SNOS			1		1	
SPKL		2	3	30	1	3
SQRS				2		
STRK			3	4		
VRML			1			
WDOW		130	494	489	148	195

## Introduction

## Time Model

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## Time Block

## Proofs

A 4x6 grid of 24 small circles, arranged in four rows and six columns.

A 4x7 grid of 28 small circles, arranged in four rows and seven columns.

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A 4x6 grid of 24 small circles, arranged in four rows and six columns.

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Moving beyond rockfish into flatfish and elasmobranch (primarily skates) market categories, these tables shows the total number of samples and frequency of occurrence by species for the largest flatfish (table on left) and elasmobranch (table on right) market categories. Flatfish species composition data have only been collected since 2002, and elasmobranchs since 2009, so all years are combined here (and information at higher stratification levels, including more sparsely sampled market categories, are available in the excel file).

## Introduction

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A 5x5 grid of 25 small circles, arranged in five rows and five columns.

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A 5x5 grid of 25 small circles, arranged in five rows and five columns.

	201		206		209		211		
	Unspecifi- ed sole	200 arrowto- th flounder	205 sand sole	English sole	207 rex sole	petrale sole	Dover sole	Sanddabs	225 231 starry flounder
Total samples	85	253	154	444	511	1170	1159	346	199
ARTH		252		2	4		2	3	
BIMOL		4					1	1	1
BSKT									
BSOL			3						
CHB			2						2
CSOL	3			16	1	2		4	1
CTR8			2			1			
DOVR	7	7		16	77	22	1158		3
DSOL	22						26		
DTRB	4								
EGLS	40	1		443	14	65	4	30	2
FNTS	27								
FSOL					1				
GRDR							1		
GSRK							1		
HTRB	13		1	1					1
LSKT				1					
LSPN			1			1	11		
MISC							2	2	
PDBA	23			16	4	25	2	344	
PTRL	19	7	8	60	8	1169	11	27	2
PWHT							1		
RATF							1		
REX	2			22	397	20	57	9	
REX	2			7	114	4	93	10	
RSOL	2		3	8		3		3	
SABL						1	1		
SBLY							1		1
SHRK								1	
SLNS	5				2	6	2	2	8
SINOS						1	1		
SPSK		1							
SQRS							1		
SSOL			151				3	1	2
SSPN									
STRB	2								
STRY				13					199
UDAB									2
UFLT	1					2		2	1
USKT							1	1	
UTRB				1					1

	147		175		177
Longnose skate	152	spiny dogfish	unspecifi ed skate	176 big skate	Californi a skate
Total samples	374	12	32	70	3
BSKT	19		5	70	
CSKT	3		4		2
CSRK					
DSRK		12			
LSKT	372		21		5
PTRL	1				
RATF					
RTSK	5		5		1
SPSK	9		3		
SSKT			1		
SSPN	1				
URAY					
USKT	3		4		



**Request:** Redo the modeling of the early time block without southern CA ports. Explore spatially and temporally (i.e., alternative time blocks).

**Rationale:** The available dataset does not have any sample data in the early time block from the southern CA ports. It was unclear how this lack of data influenced the model results. The requested analysis will clarify the situation.

**Response:** All of the model runs and plots from this point forward only model ports north of point conception.

## Introduction

## Time Model

## Prior Model

## Interaction Model

## Time Block

Proofs

A 4x5 grid of 20 small circles, arranged in four rows and five columns.

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A 5x5 grid of 25 small circles, arranged in five rows and five columns.

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**Request:** The diagnostic template should be developed for each of the sensitivity runs (vary across a range of plausible time models and priors and limit to the top 2-3 market categories).

**Rationale:** Application of the diagnostics across a wide range of models will form a test of how well the diagnostics illustrate whether the models capture important structural features that are thought to be embedded in the data.

**Response:** The following slides show the requested diagnostic plots as applied to models across a range of time models and prior choices.

# Time Models

(M1)

$$\beta_{mn}^{(t)} = \beta_m^{(y)} + \beta_n^{(q)}$$

$$\beta_m^{(y)} \sim N(0, 32^2)$$

$$\beta_{\eta}^{(q)} \sim N(0, 32^2)$$

(M2)

$$\beta_{m\eta}^{(t)} = \beta_m^{(y)} + \beta_\eta^{(q)}$$

$$\beta_m^{(y)} \sim N(0, v^{(y)})$$

$$\beta_{\eta}^{(q)} \sim N(0, v^{(q)})$$

(M3)

$$\beta_{m\eta}^{(t)} = \beta_m^{(y)} + \beta_\eta^{(q)} + \beta_{m\eta}^{(y:q)}$$

$$\beta_m^{(y)} \sim N(0, v^{(y)})$$

$$\beta_{\eta}^{(q)} \sim N(0, v^{(q)})$$

$$\beta_{m\eta}^{(y:q)} \sim N(0, v)$$

(M4)

$$\beta_{m\eta}^{(t)} = \beta_{m\eta}^{(y:q)}$$

$$\beta_{m\eta}^{(y:q)} \sim N(0, v)$$

(M5)

$$\beta_{m\eta}^{(t)} = \beta_{m\eta}^{(y:q)}$$

$$\beta_{m\eta}^{(y:q)} \sim N(0, v_\eta)$$

(M6)

$$\beta_{m\eta}^{(t)} = \beta_{m\eta}^{(y:q)}$$

$$\beta_{m\eta}^{(y:q)} \sim N(0, v_m)$$

## Introduction

## Time Model

## Prior Model

## Interaction Model

## Time Block

Proofs

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MCAT 250

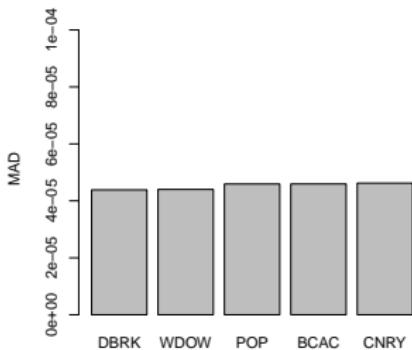
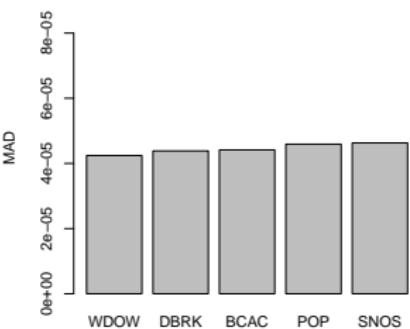
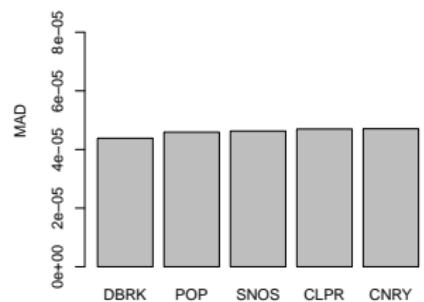
	M1	M2	M3	M4	M5	M6
$\Delta$ DIC	6448.98	0.33	0	4.45	9.3	7.42
$\Delta$ WAIC	6421.5	0.37	0	4.52	8.25	6.55

MCAT 250

M2

M3

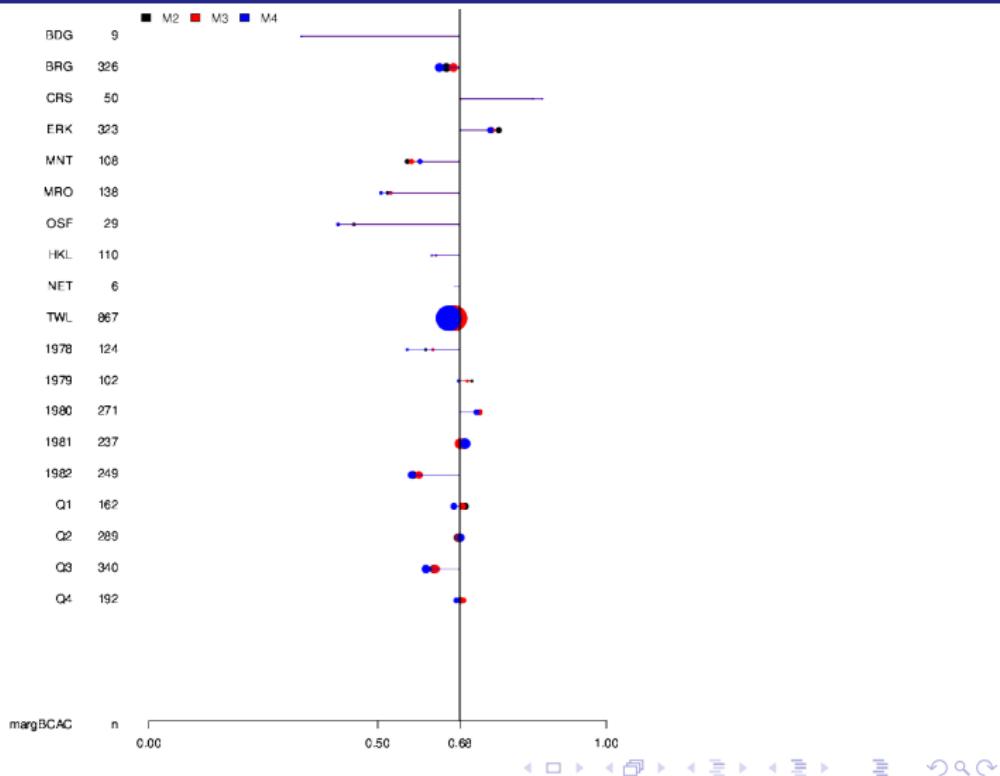
M4



## Combined

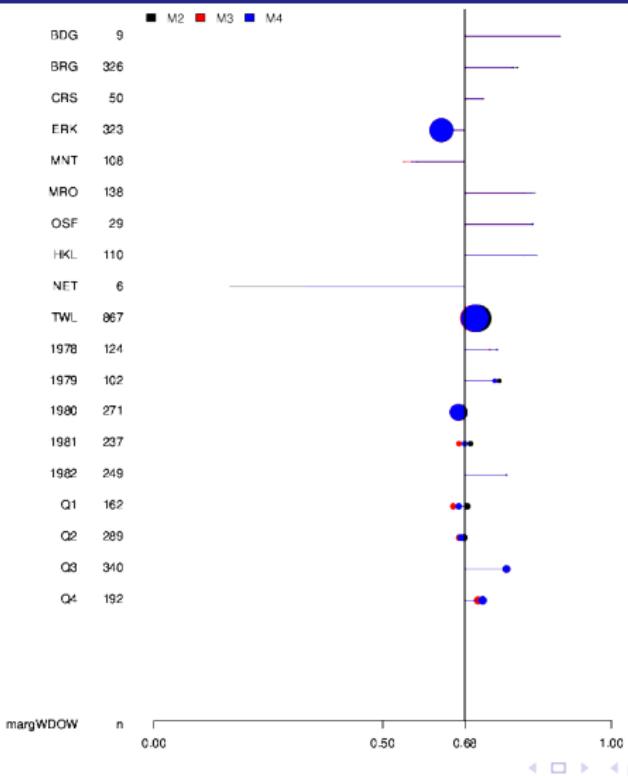


MCAT 250





MCAT 250



Nicholas Grunloh In Cooperation With: E.J. Dick, Don Pearson, John Field, Marc Mangel

Improving Catch Estimation Methods in Sparsely Sampled, Mixed Stock Fisheries.

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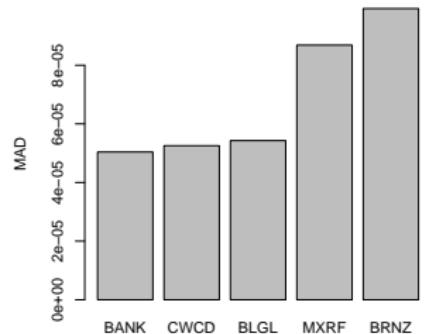
MCAT 250

M2

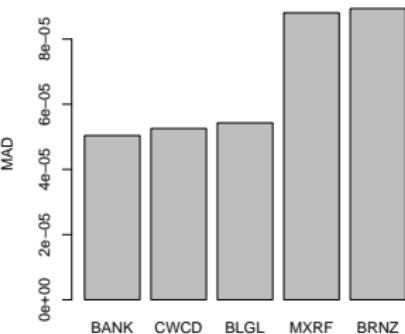
M3

M4

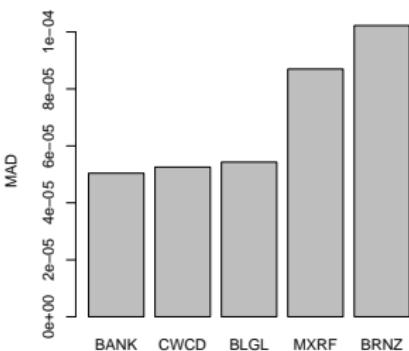
### MAD Ordered by Species



### MAD Ordered by Species



### MAD Ordered by Species



# Combined

## Introduction

## Time Model

## Prior Model

## Interaction Model

## Time Block

Proofs

A 4x4 grid of 16 small circles. The bottom-left circle is shaded dark grey, while the others are white.

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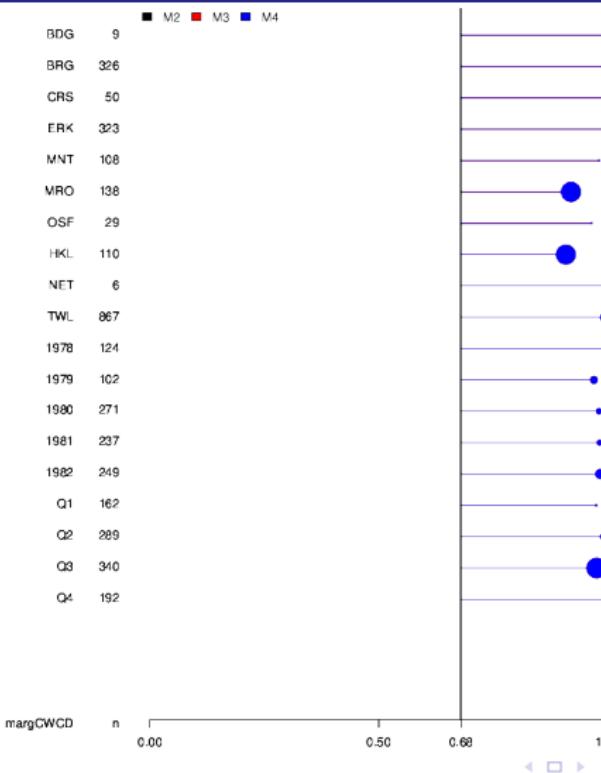
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## Introduction

## Time Model

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### Time Block

Proofs

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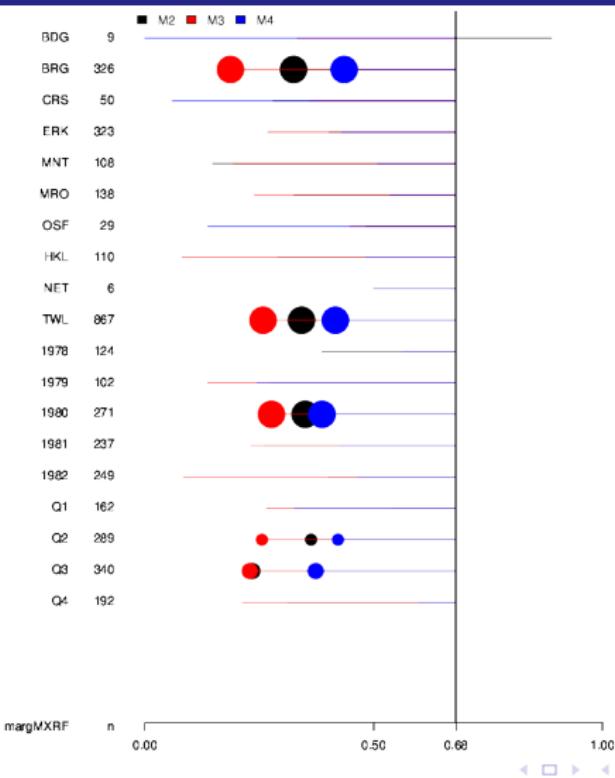
A 4x7 grid of 28 small circles, arranged in four rows and seven columns.

A 4x7 grid of 28 small circles, arranged in four rows and seven columns.

A 4x3 grid of 12 small circles, arranged in four rows and three columns.

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MCAT 250



## Introduction

## Time Model

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## Interaction Model

### Time Block

Proofs

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MCAT 253

	M1	M2	M3	M4	M5	M6
$\Delta$ DIC	1409.81	0.09	0.1	0.07	0.05	0
$\Delta$ WAIC	1391.66	0.16	0.18	0	0.13	0.08

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A 4x6 grid of 24 small circles, arranged in four rows and six columns.

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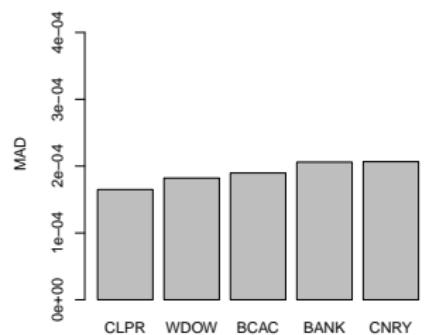
MCAT 253

M4

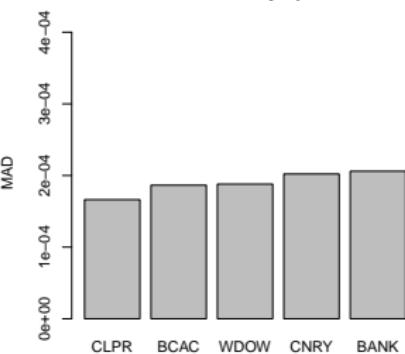
M5

M6

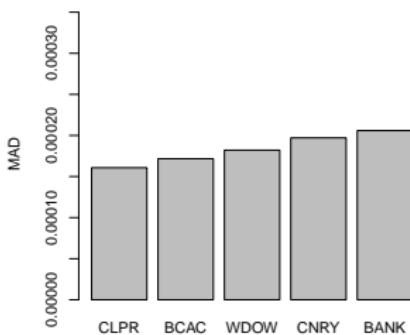
### MAD Ordered by Species



### MAD Ordered by Species



### MAD Ordered by Species



# Combined

## Introduction

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## Time Block

## Proofs

A 4x5 grid of 20 small circles, arranged in four rows and five columns.

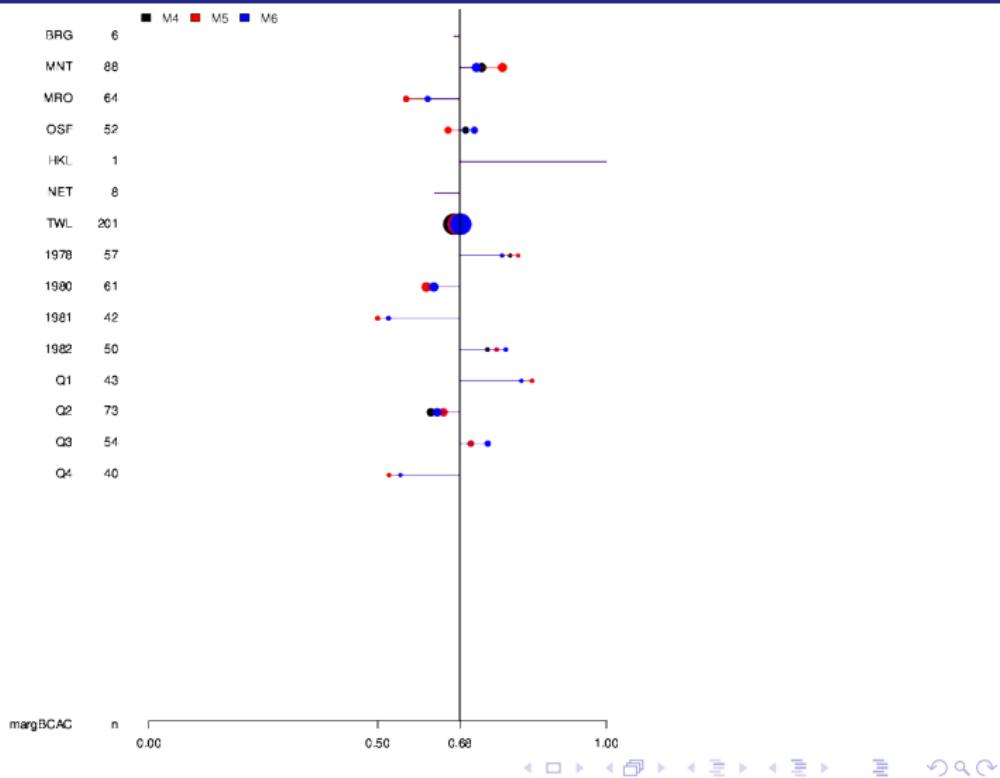
A 4x7 grid of 28 small circles, arranged in four rows and seven columns.

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A 4x6 grid of 24 small circles, arranged in four rows and six columns.

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MCAT 253



Introduction

## Time Model

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## Time Block

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A 4x5 grid of 20 small circles, arranged in four rows and five columns.

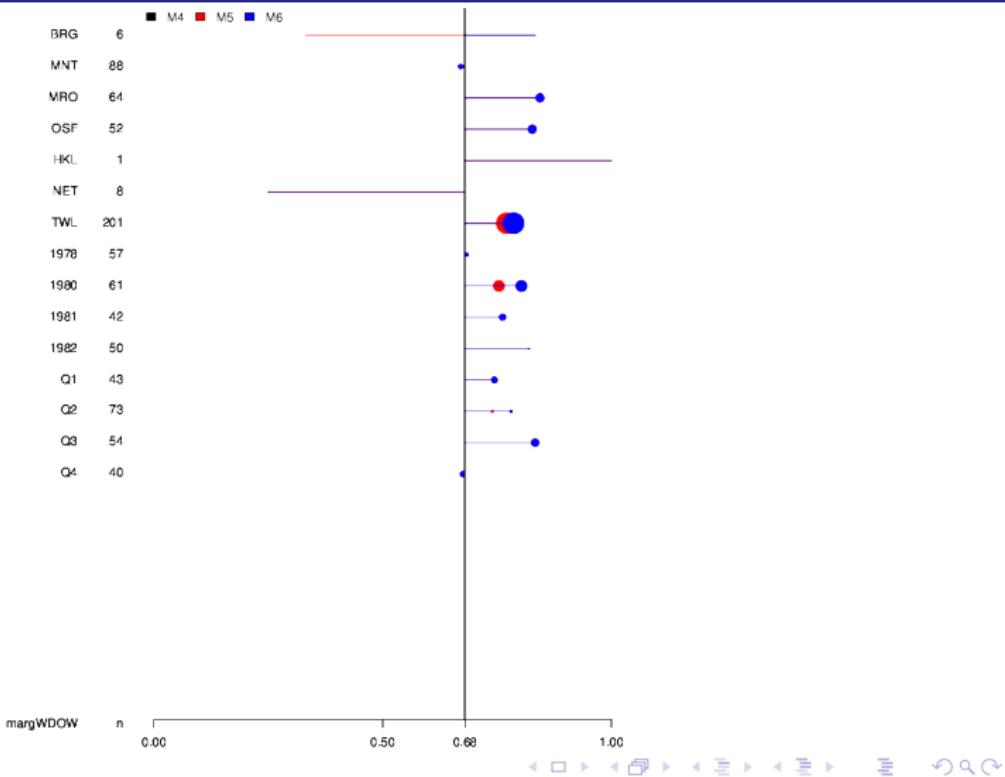
A 4x8 grid of 32 small circles, arranged in four rows and eight columns.

A 4x7 grid of 28 small circles, arranged in four rows and seven columns.

A 4x3 grid of 12 small circles, arranged in four rows and three columns.

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MCAT 253



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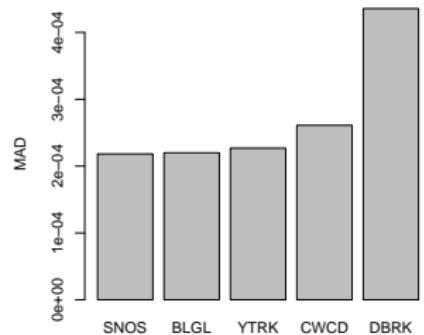
MCAT 253

M4

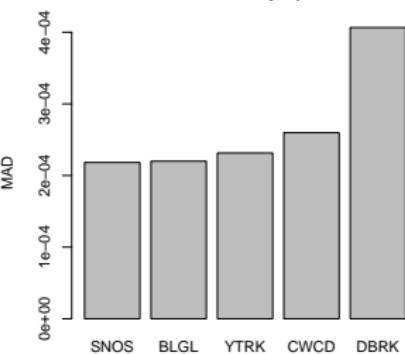
M5

M6

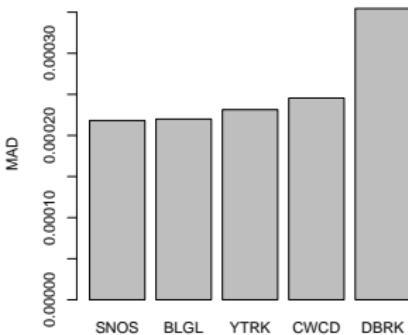
### MAD Ordered by Species



### MAD Ordered by Species



### MAD Ordered by Species



## Combined

## Introduction

## Time Model

## Prior Model

## Interaction Model

## Time Block

## Proofs

A 4x3 grid of 12 small circles, arranged in four rows and three columns.

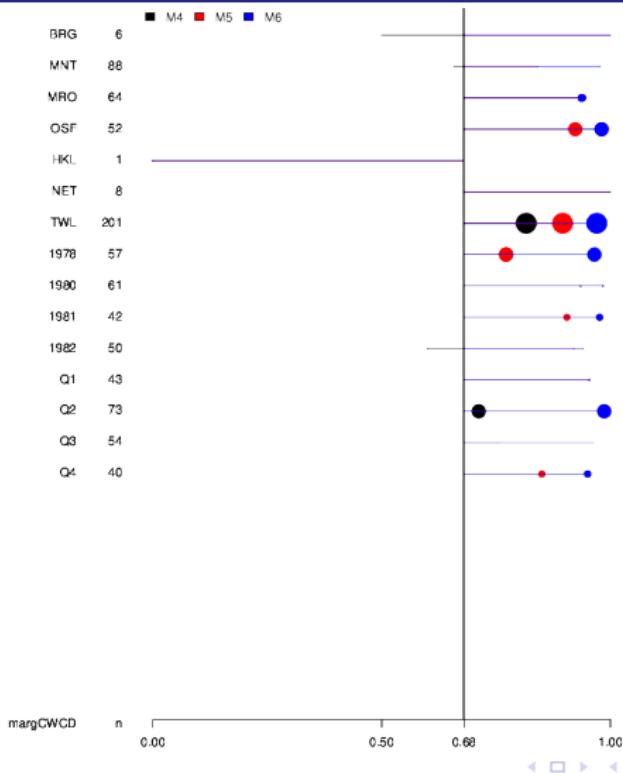
A 4x7 grid of 28 small circles, arranged in four rows and seven columns.

A 4x7 grid of 28 small circles, arranged in four rows and seven columns.

○

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MCAT 253



Introduction

## Time Model

Prior Model

## Interaction Model

## Time Block

Proofs

A 4x5 grid of 20 small circles, arranged in four rows and five columns.

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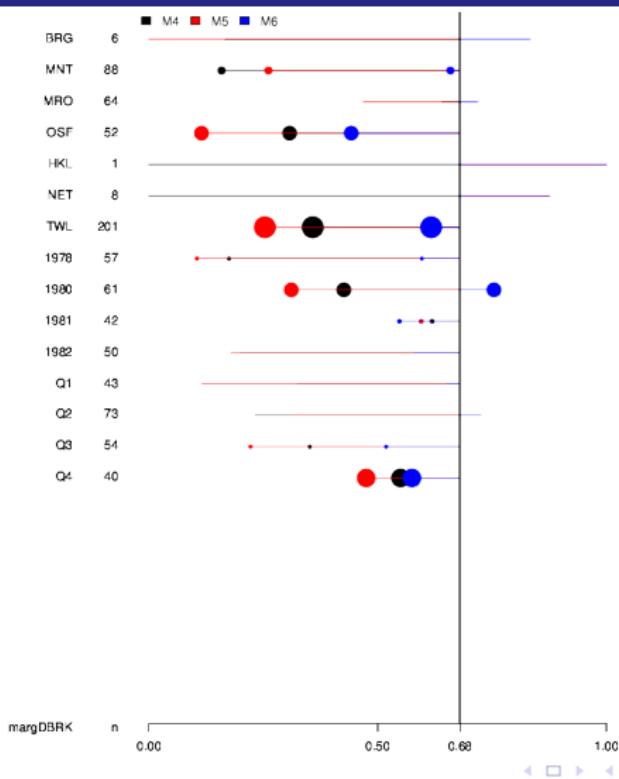
A 4x7 grid of 28 small circles, arranged in four rows and seven columns.

A 4x6 grid of 24 small circles, arranged in four rows and six columns.

A 4x6 grid of 24 small circles, arranged in four rows and six columns.

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MCAT 253



## Introduction

## Time Model

### Prior Model

## Interaction Model

### Time Block

Proofs

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MCAT 269

	M1	M2	M3	M4	M5	M6
$\Delta$ DIC	572.51	176.63	599.41	0.57	0	193.35
$\Delta$ WAIC	427.48	69.37	454.41	0.23	0	78.07

A 4x4 grid of 16 small circles, arranged in four rows and four columns.

A 4x7 grid of 28 small circles, arranged in four rows and seven columns.

A 4x7 grid of 28 small circles, arranged in four rows and seven columns.

A 4x6 grid of 24 small circles, arranged in four rows and six columns.

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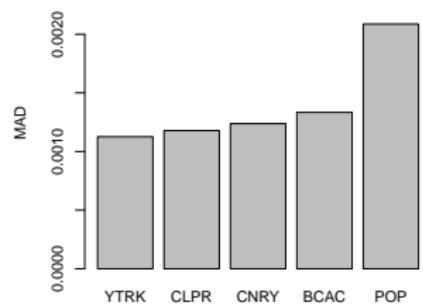
MCAT 269

M4

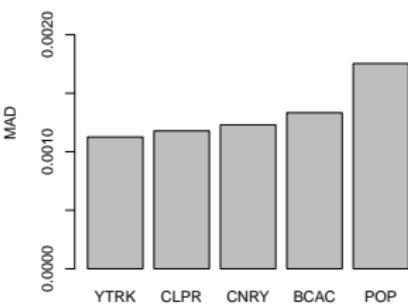
M5

M6

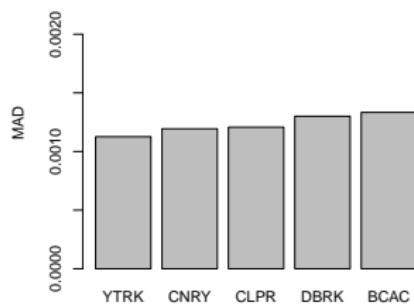
#### MAD Ordered by Species



### MAD Ordered by Species



### MAD Ordered by Species



# Combined

## Introduction

## Time Model

## Prior Model

## Interaction Model

## Time Block

Proofs

A 4x6 grid of 24 small circles, arranged in four rows and six columns.

A 4x5 grid of circles. The last circle in the bottom row is shaded black.

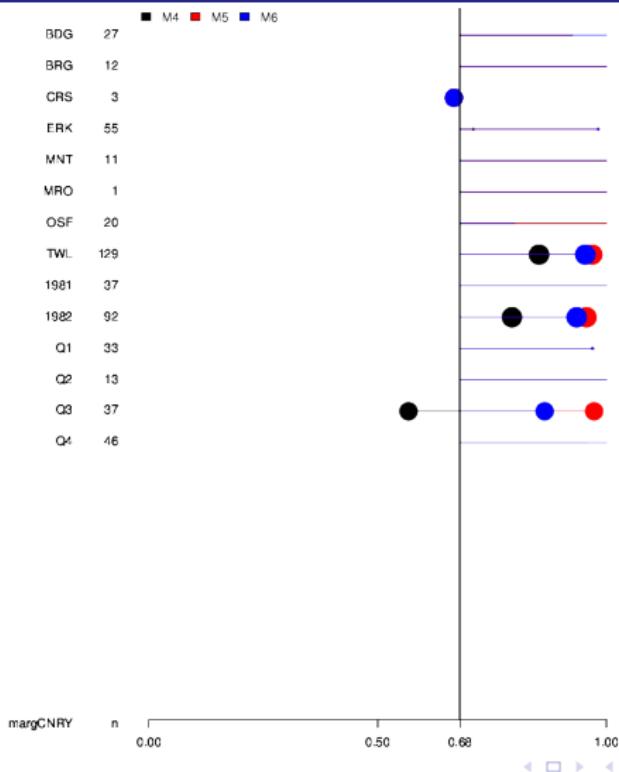
A 4x7 grid of 28 small circles, arranged in four rows and seven columns.

A 4x7 grid of 28 small circles, arranged in four rows and seven columns.

A 4x6 grid of 24 small circles, arranged in four rows and six columns.

○

MCAT 269



Introduction

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Time Model

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Prior Model

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Interaction Model

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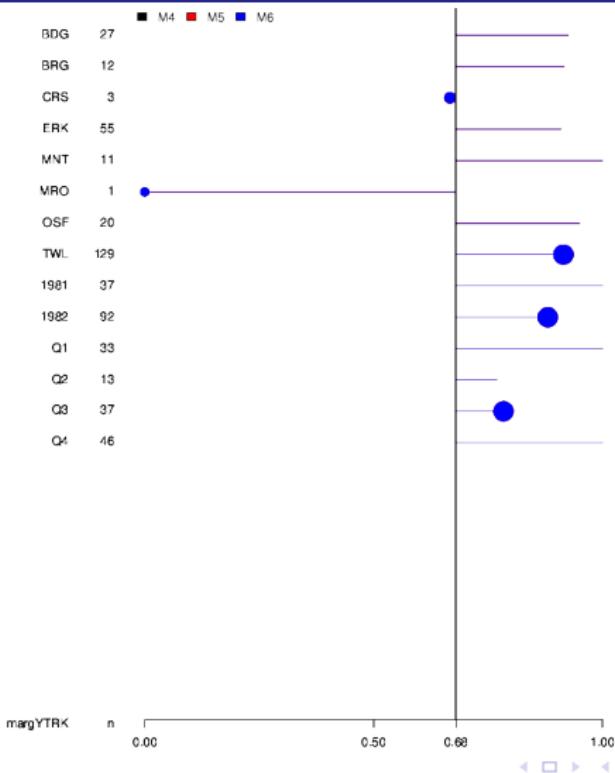
Time Block

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Proofs

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MCAT 269

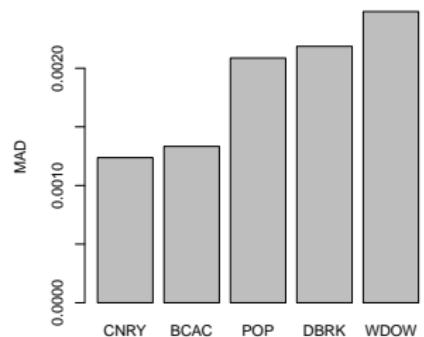


M4

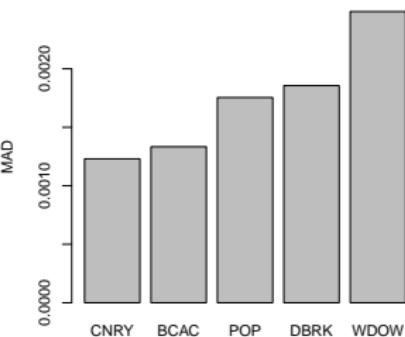
M5

M6

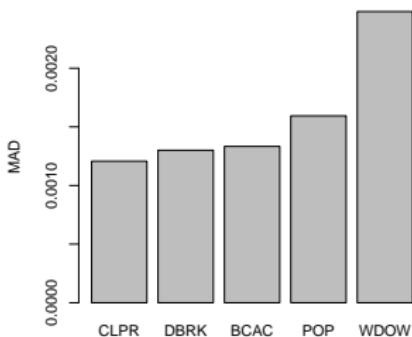
### MAD Ordered by Species



### MAD Ordered by Species



### MAD Ordered by Species



## Combined

Introduction

## Time Model

## Prior Model

## Interaction Model

## Time Block

Proofs

A 4x5 grid of 20 small circles, arranged in four rows and five columns.

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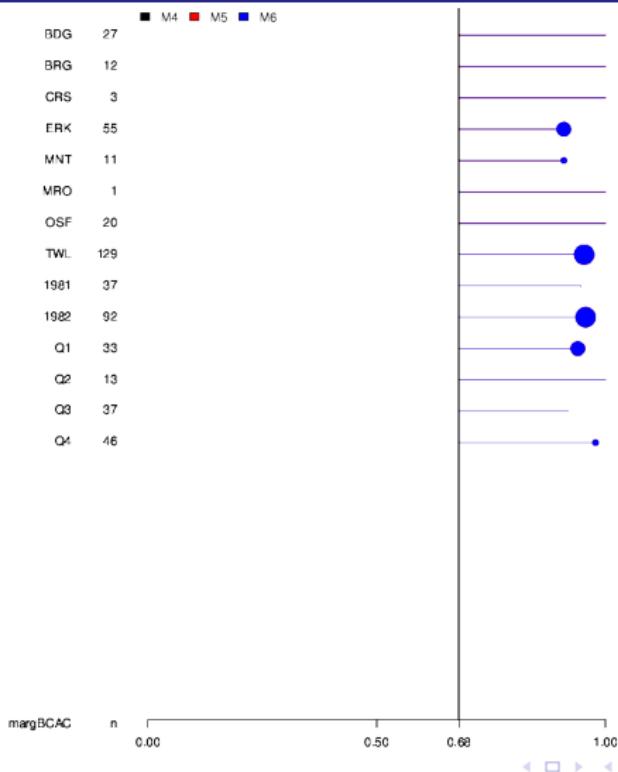
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MCAT 269



Introduction

## Time Model

Prior Model

## Interaction Model

## Time Block

Proofs

A 4x4 grid of 16 small circles. The bottom-left circle is shaded dark grey, while the others are white.

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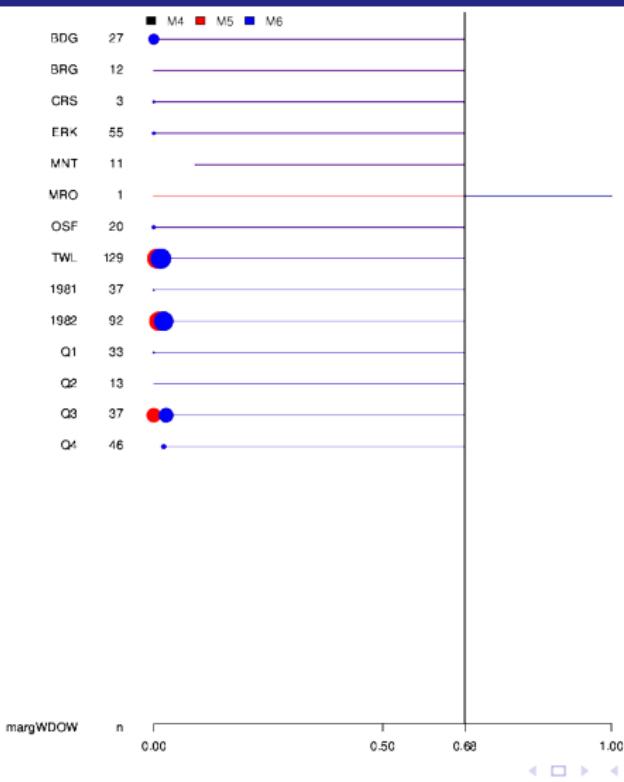
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MCAT 269



## Landings Sensitivity

**Request:** Compare alternative ComX outputs and the current time series of estimated catches.

**Rationale:** It would be informative to see the landings estimates corresponding to the additional models developed in response to the above requests. The landings estimates can be generated for a small set of illustrative species and do not need to be comprehensive.

**Response:** The following slides show expanded landings (by year and by year:gear) from the early time period, summing across market categories 250, 253, and 269 associated with time model, prior, interaction model, and time block sensitivity runs.

Introduction

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Time Model

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Prior Model

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Interaction Model

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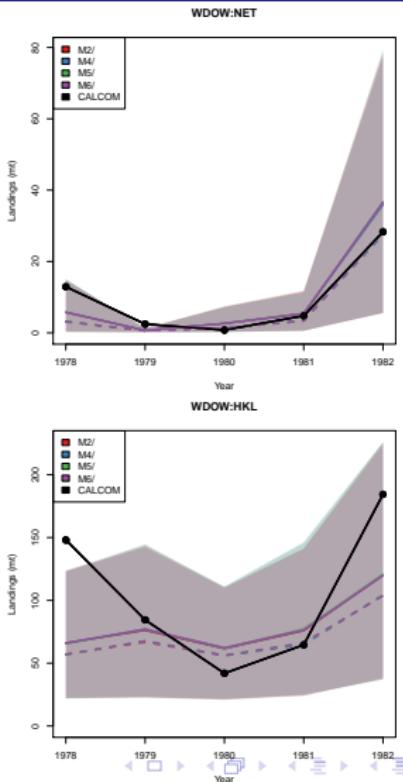
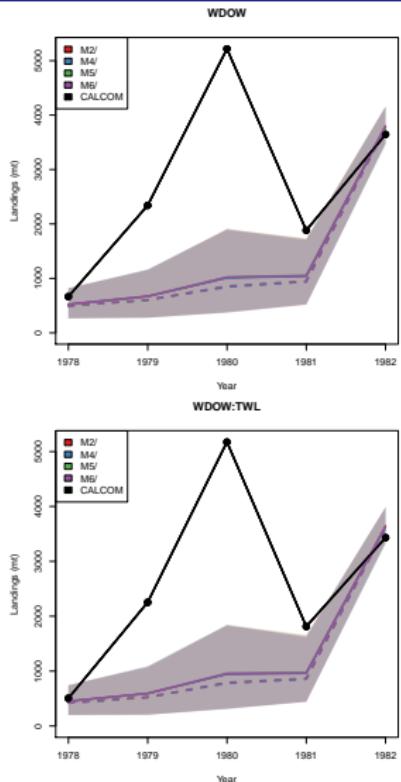
Time Block

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## Landings Sensitivity



Nicholas Grunloh In Cooperation With: E.J. Dick, Don Pearson, John Field, Marc Mangel

Improving Catch Estimation Methods in Sparsely Sampled, Mixed Stock Fisheries.



Introduction

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Time Model

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Prior Model

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Interaction Model

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Time Block

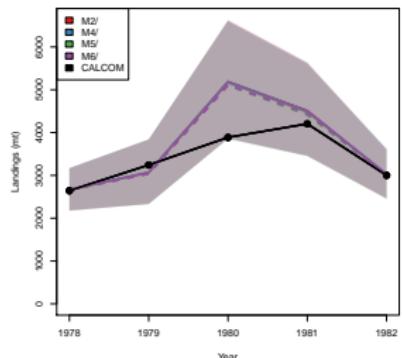
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Proofs

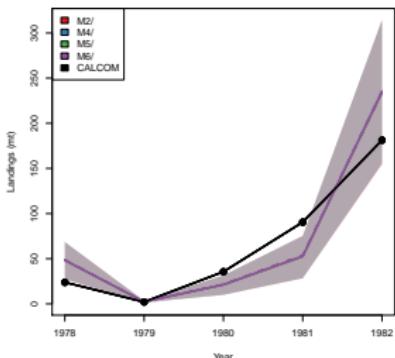
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## Landings Sensitivity

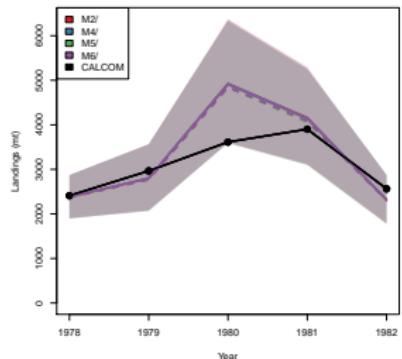
BCAC



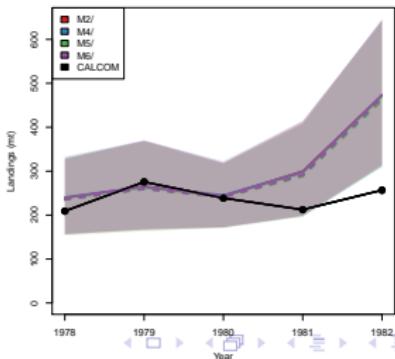
BCAC:NET



BCAC:TWL



BCAC:HKL



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Improving Catch Estimation Methods in Sparsely Sampled, Mixed Stock Fisheries.



## Introduction

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## Time Model

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## Prior Model

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## Interaction Model

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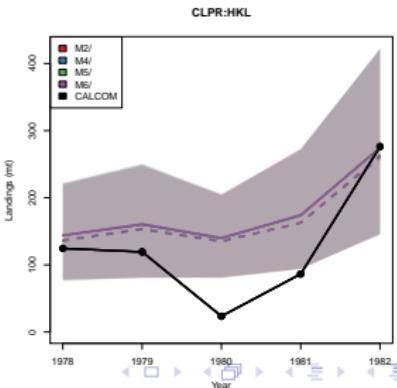
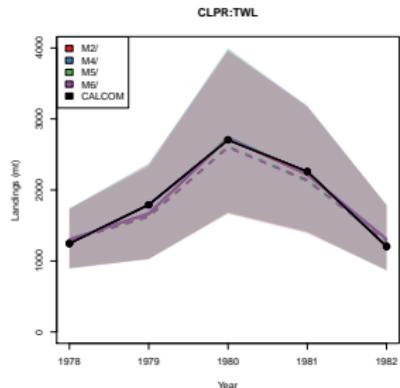
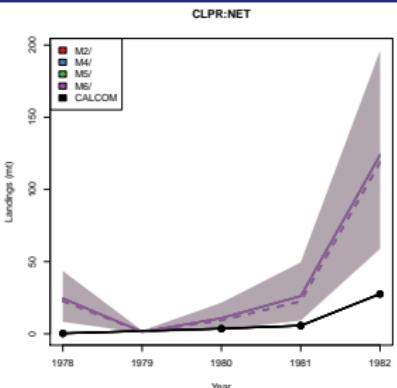
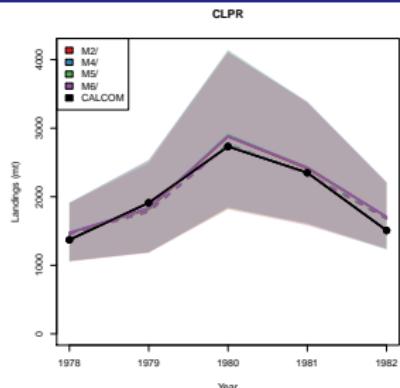
## Time Block

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## Proofs

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## Landings Sensitivity



Introduction

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Time Model

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Prior Model

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Interaction Model

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Time Block

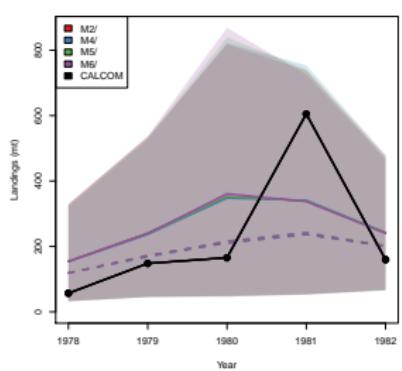
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Proofs

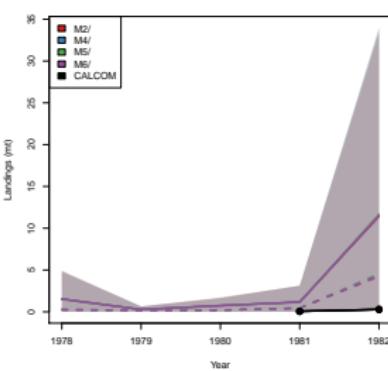
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## Landings Sensitivity

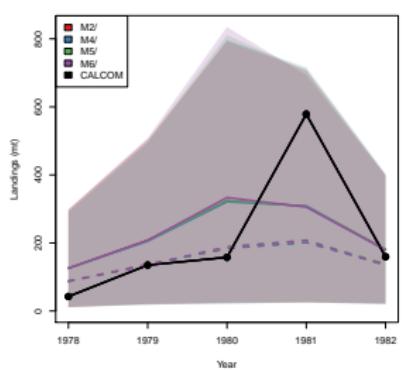
DBRK



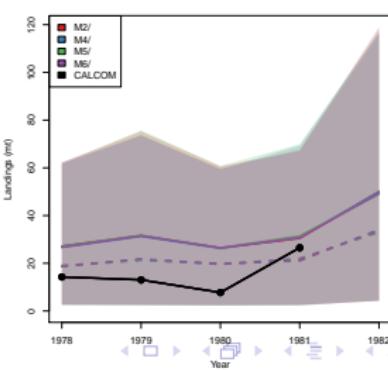
DBRK-NET



DBRK:TWL



DBRK:HKL



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Improving Catch Estimation Methods in Sparsely Sampled, Mixed Stock Fisheries.



Introduction

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Time Model

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Prior Model

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Interaction Model

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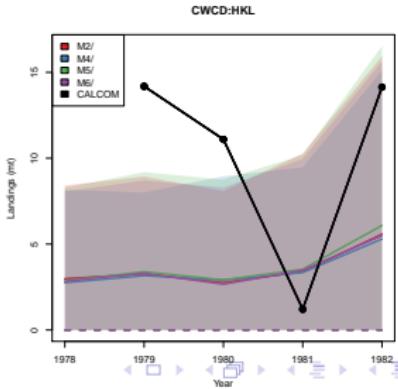
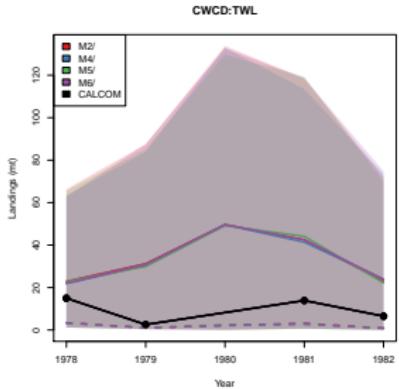
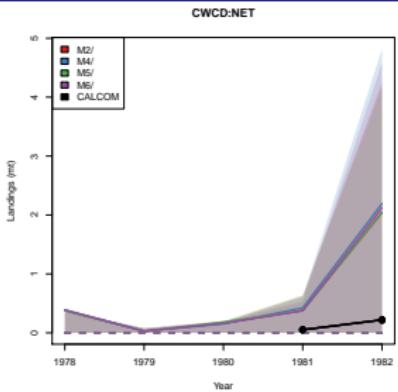
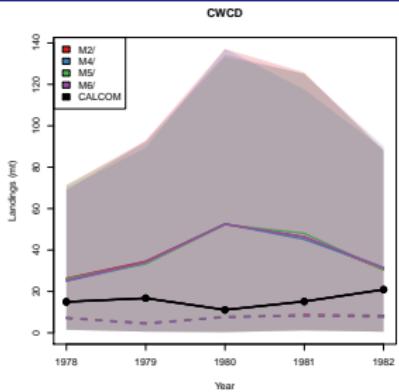
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Proofs

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## Landings Sensitivity



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Improving Catch Estimation Methods in Sparsely Sampled, Mixed Stock Fisheries.



Introduction

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Time Model

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Interaction Model

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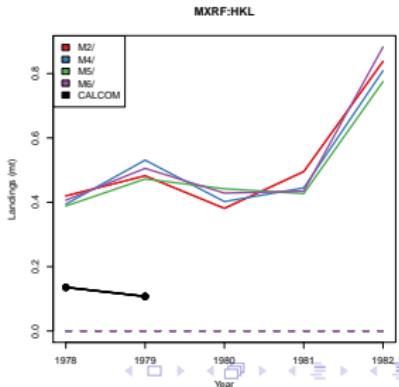
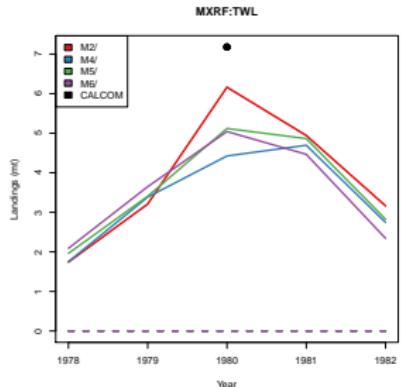
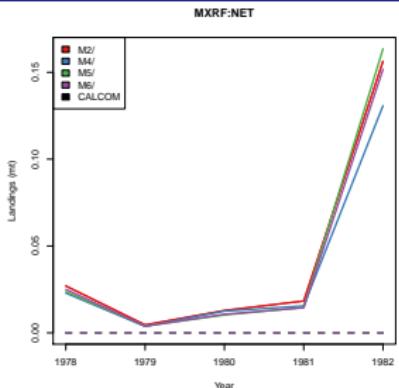
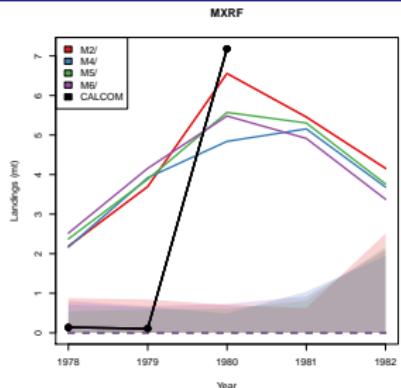
Time Block

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Proofs

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## Landings Sensitivity



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Improving Catch Estimation Methods in Sparsely Sampled, Mixed Stock Fisheries.



## Landings Sensitivity

## Time Model Summary

- The time model appears to be slightly dependent on market category, although several models perform similarly.
  - M4 generally performs well in a data-poor environment
  - Differences are small in a data-rich environment.

MCAT 250 Combined Plots

## MCAT 253 Combined Plots

## MCAT 269 Combined Plots

## All Species Landings

## Priors

$$\beta_0 \propto 1$$

$$\beta_i^{(s)} \sim N(0, 32^2)$$

$$\beta_k^{(p)} \sim N(0, 32^2)$$

$$\beta_I^{(g)} \sim N(0, 32^2)$$

$$\text{logit}(\rho) \sim N(0, 2^2)$$

IG :  $v \sim \text{Inv-Gamma}(1, 2 \times 10^3)$   $\forall v$

$$HC1 : \sqrt{v} \sim \text{Half-Cauchy}(10^1) \quad \forall v$$

$$\text{HC3 : } \sqrt{v} \sim \text{Half-Cauchy}(10^3) \quad \forall v$$

$$U4 : \sqrt{v} \sim \text{Uniform}(0, 10^4) \quad \forall v$$

## Introduction

## Time Model

## Prior Model

## Interaction Model

### Time Block

Proofs

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MCAT 250

	M4IG	M4HC1	M4HC3	M4U4
$\Delta$ DIC	3.87	0.02	0.1	0
$\Delta$ WAIC	3.78	0.03	0.11	0

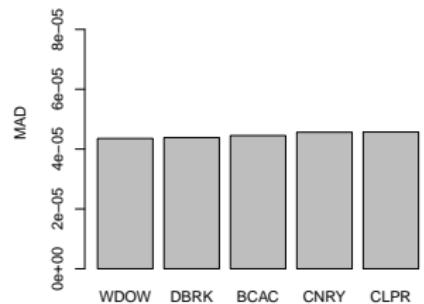
MCAT 250

M4HC1

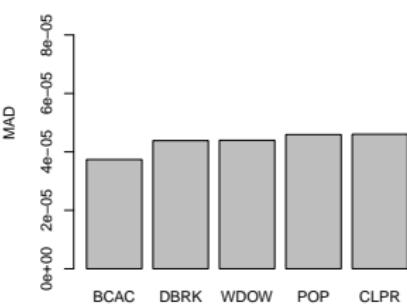
M4HC3

M4U4

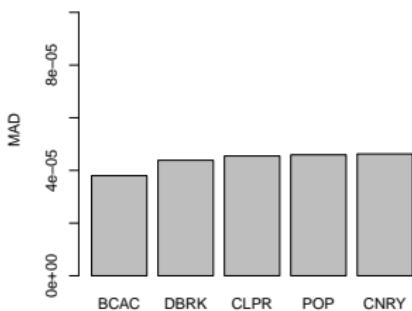
### MAD Ordered by Species



### MAD Ordered by Species



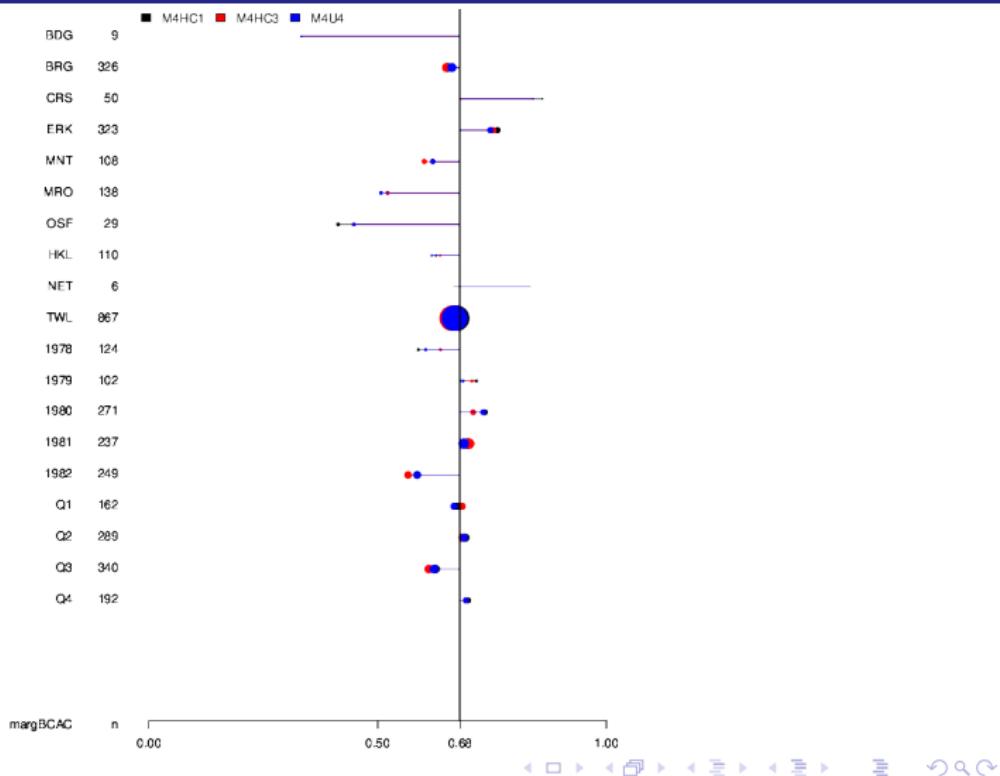
### MAD Ordered by Species



## Combined



MCAT 250

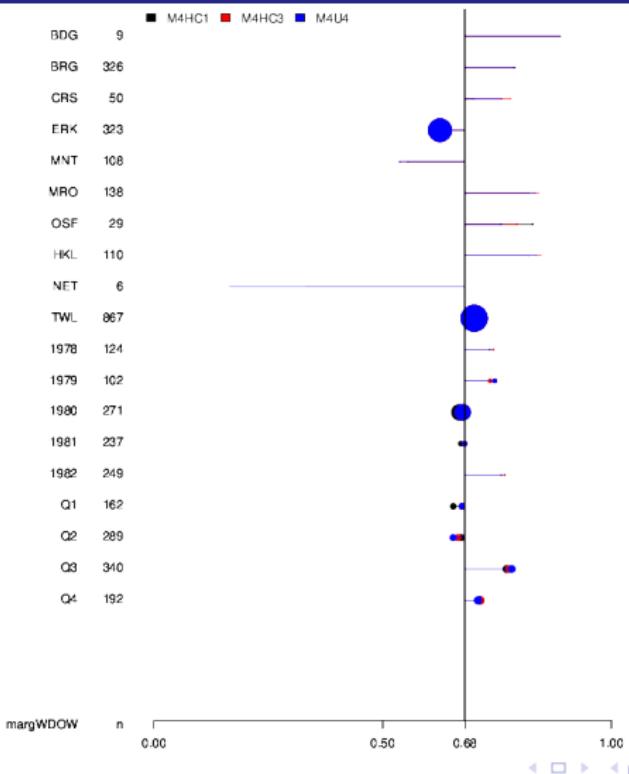


Nicholas Grunloh In Cooperation With: E.J. Dick, Don Pearson, John Field, Marc Mangel

Improving Catch Estimation Methods in Sparsely Sampled, Mixed Stock Fisheries.



## MCAT 250



Introduction

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Time Model

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Prior Model

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Interaction Model

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Time Block

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Proofs

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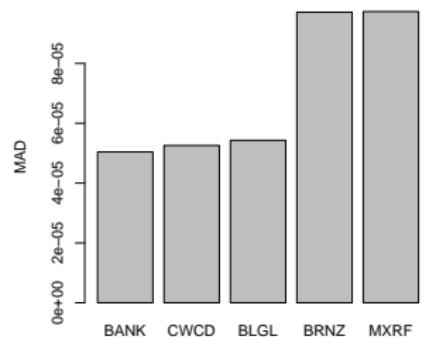
MCAT 250

M4HC1

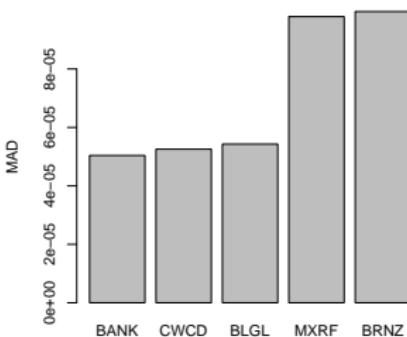
M4HC3

M4U4

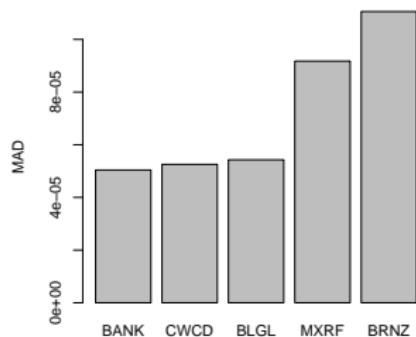
MAD Ordered by Species



MAD Ordered by Species



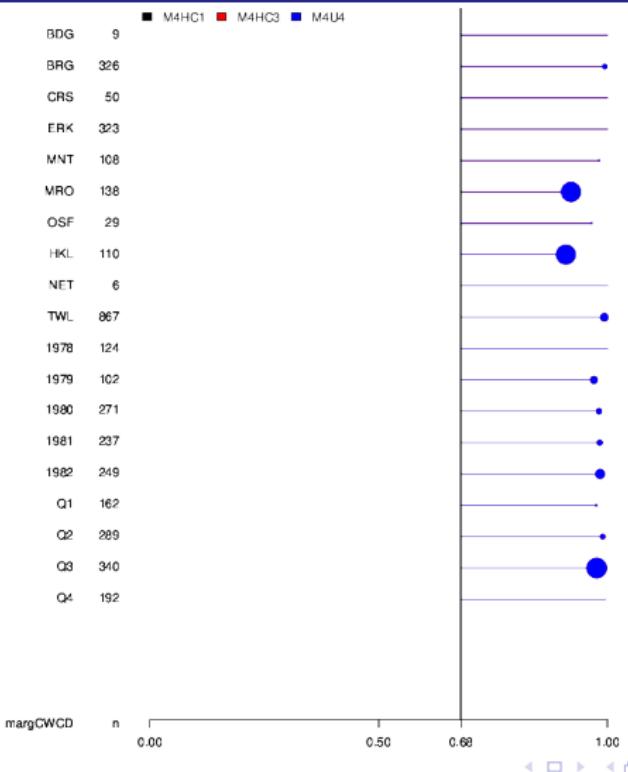
MAD Ordered by Species

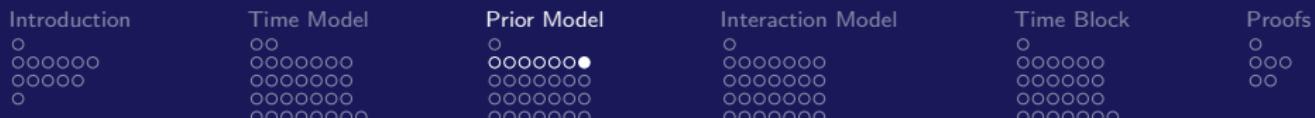


Combined

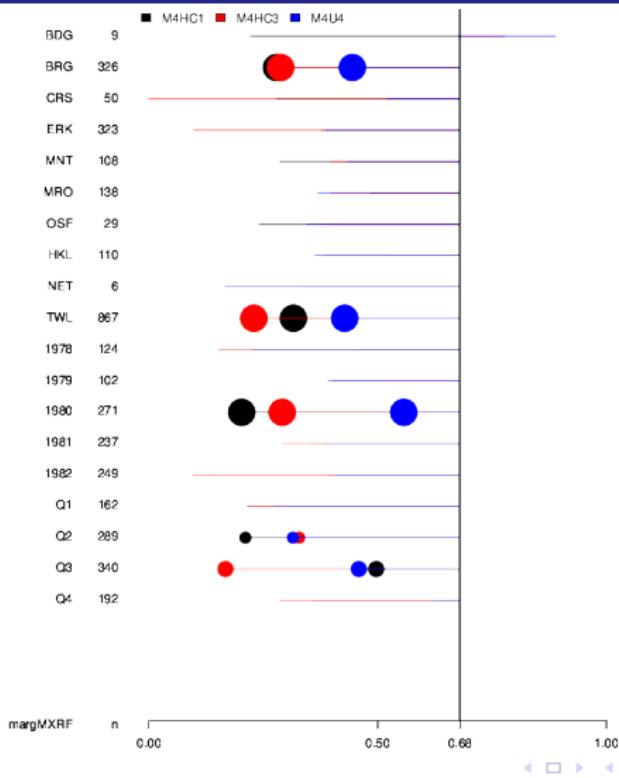


## MCAT 250





MCAT 250



Nicholas Grunloh In Cooperation With: E.J. Dick, Don Pearson, John Field, Marc Mangel

Improving Catch Estimation Methods in Sparsely Sampled, Mixed Stock Fisheries.

## Introduction

## Time Model

## Prior Model

## Interaction Model

### Time Block

Proofs

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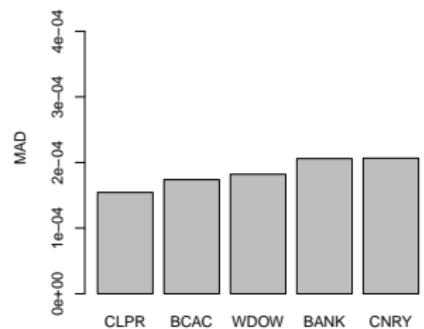
MCAT 253

	M4IG	M4HC1	M4HC3	M4U4
$\Delta$ DIC	0.88	0.8	0.8	0
$\Delta$ WAIC	0.76	0.83	0.83	0

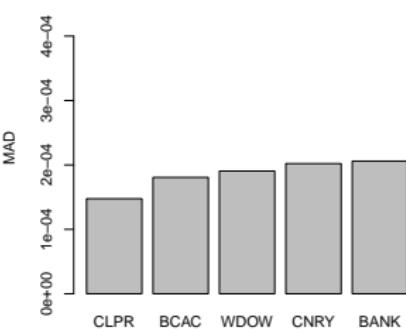
MCAT 253



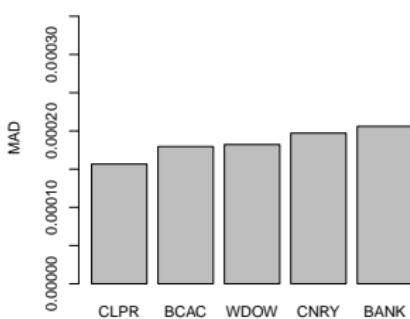
### MAD Ordered by Species



### MAD Ordered by Species



### MAD Ordered by Species



## Combined

Introduction

## Time Model

## Prior Model

## Interaction Model

### Time Block

Proofs

A 4x5 grid of 20 small circles, arranged in four rows and five columns.

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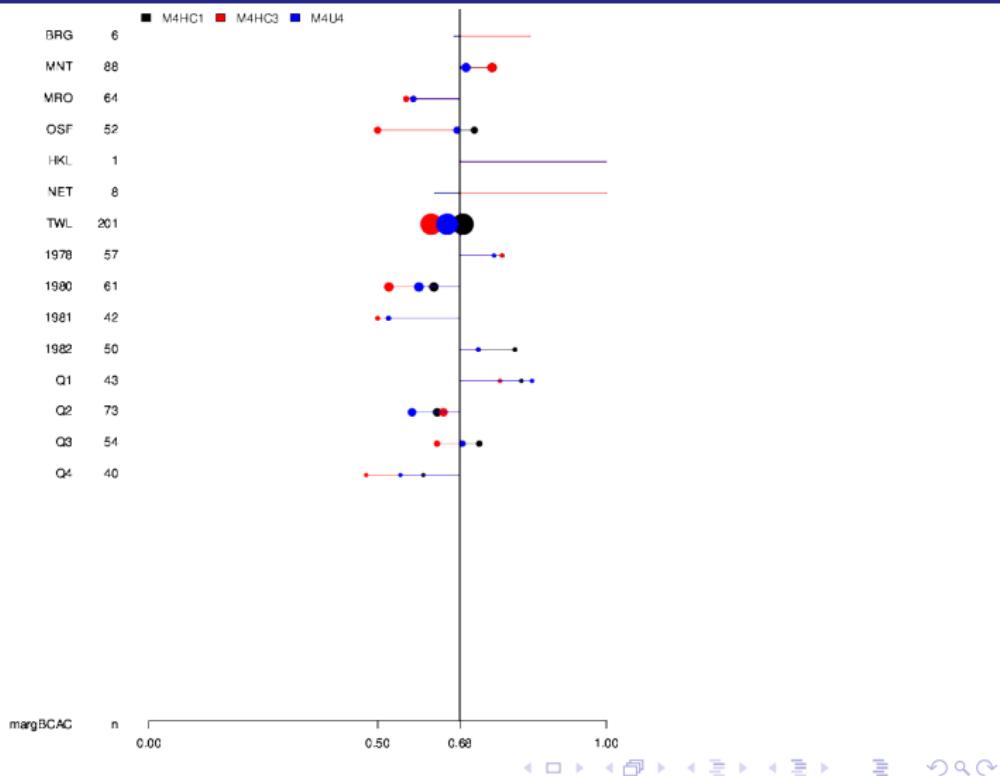
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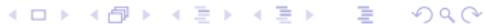
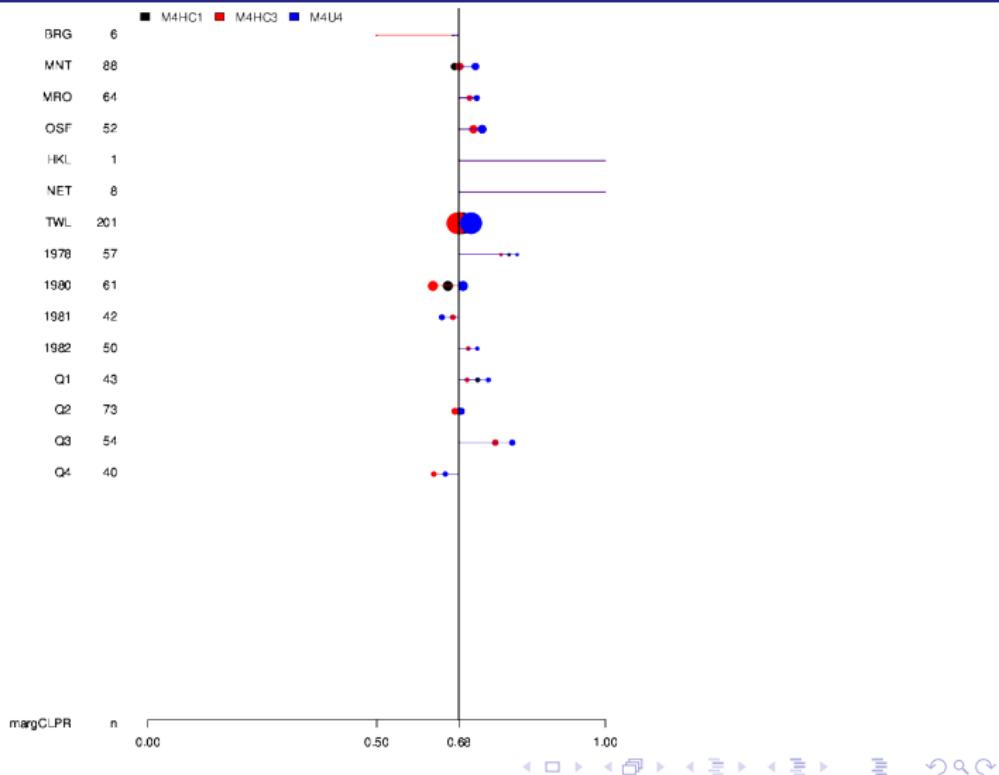
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MCAT 253





MCAT 253



Nicholas Grunloh In Cooperation With: E.J. Dick, Don Pearson, John Field, Marc Mangel

Improving Catch Estimation Methods in Sparsely Sampled, Mixed Stock Fisheries.

Introduction

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Time Model

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Prior Model

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Interaction Model

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Time Block

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Proofs

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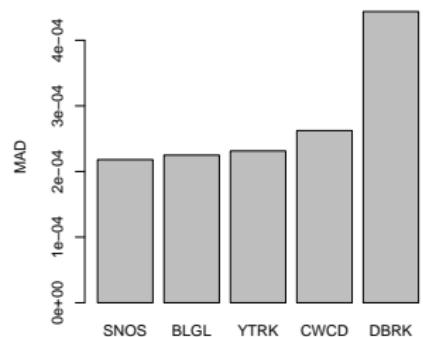
MCAT 253

M4HC1

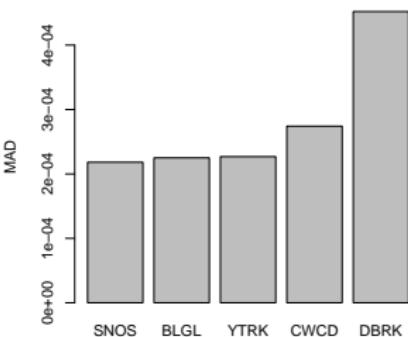
M4HC3

M4U4

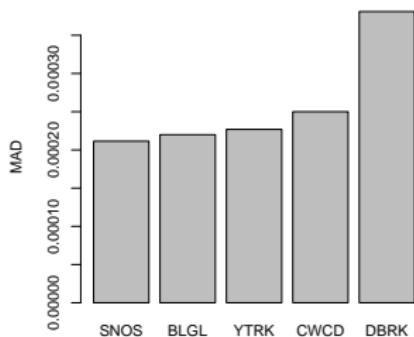
MAD Ordered by Species



MAD Ordered by Species



MAD Ordered by Species



Combined

Introduction

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Time Model

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Prior Model

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Interaction Model

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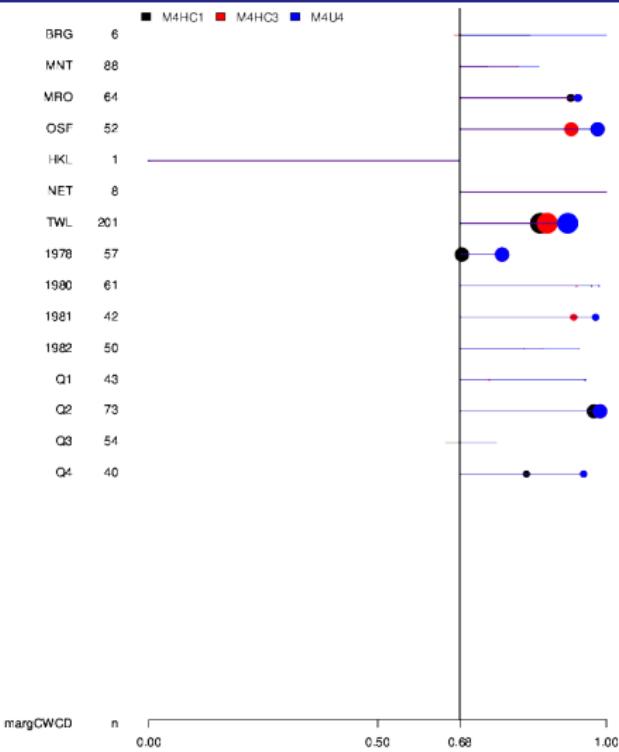
Time Block

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Proofs

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MCAT 253



## Introduction

## Time Model

## Prior Model

## Interaction Model

## Time Block

Proofs

A 4x4 grid of 16 small circles, arranged in four rows and four columns.

A 5x5 grid of 25 small circles, arranged in five rows and five columns.

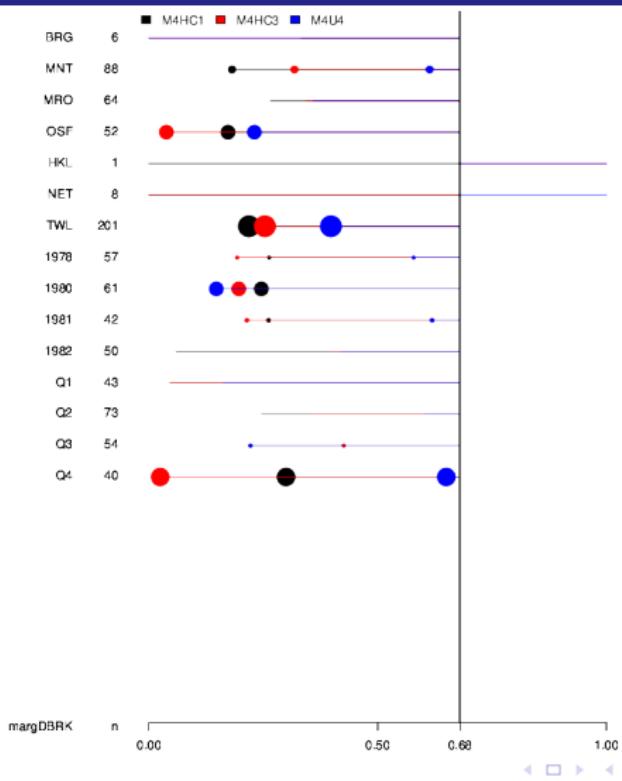
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A 5x5 grid of 25 small circles, arranged in five rows and five columns.

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MCAT 253



## Introduction

## Time Model

## Prior Model

## Interaction Model

## Time Block

Proofs

A 4x5 grid of 20 small circles, arranged in four rows and five columns.

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MCAT 269

	M4IG	M4HC1	M4HC3	M4U4
$\Delta$ DIC	0.18	176.33	0.2	0
$\Delta$ WAIC	0.08	69.19	0.08	0

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A 4x6 grid of 24 small circles, arranged in four rows and six columns.

A 4x6 grid of 24 small circles, arranged in four rows and six columns.

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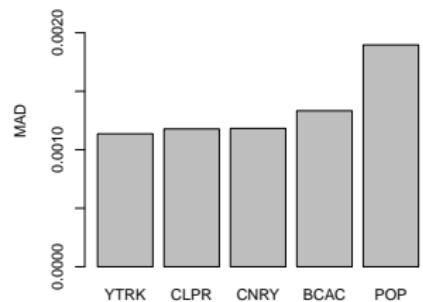
MCAT 269

M4HC1

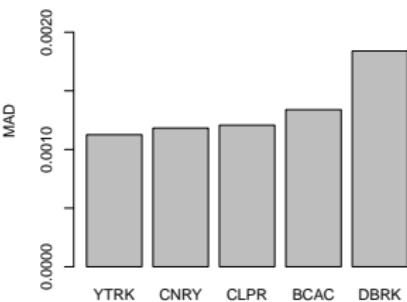
M4HC3

M4U4

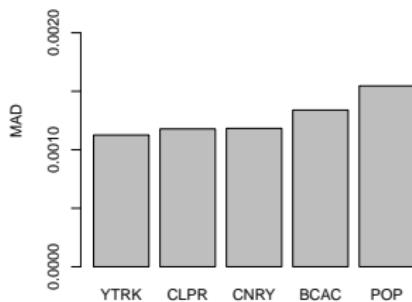
### MAD Ordered by Species



### MAD Ordered by Species



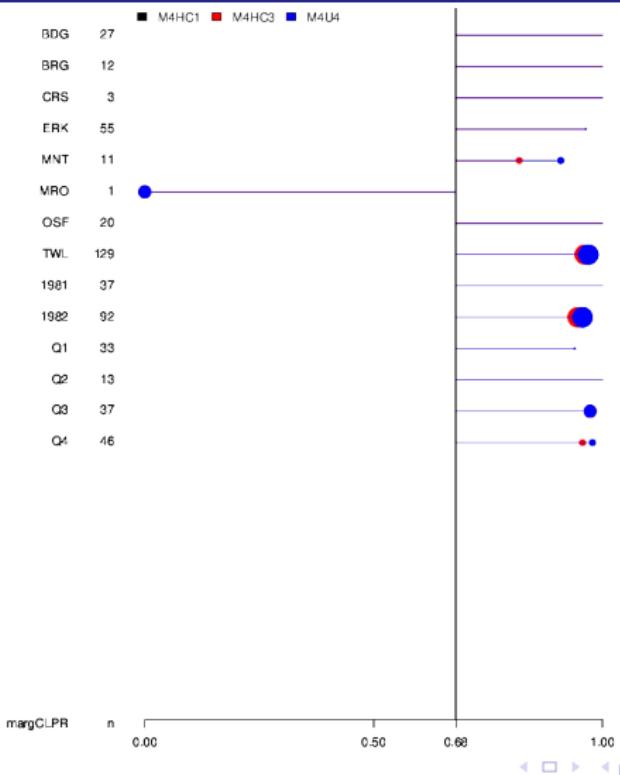
### MAD Ordered by Species



## Combined



MCAT 269



Introduction

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Time Model

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Prior Model

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Interaction Model

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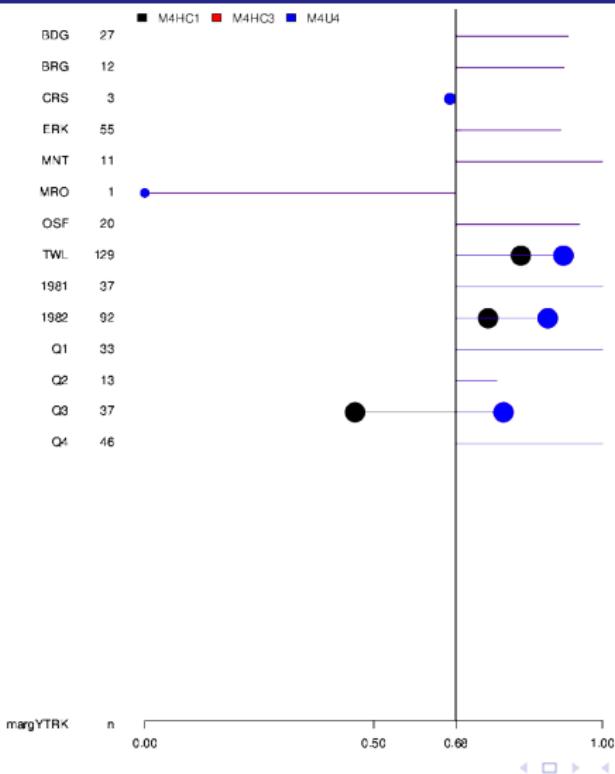
Time Block

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Proofs

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## MCAT 269

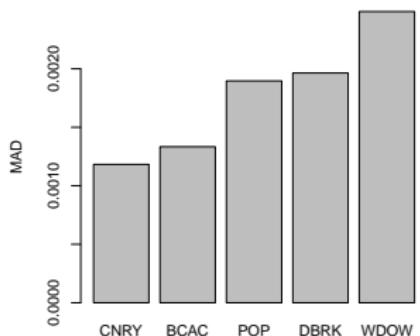


M4HC1

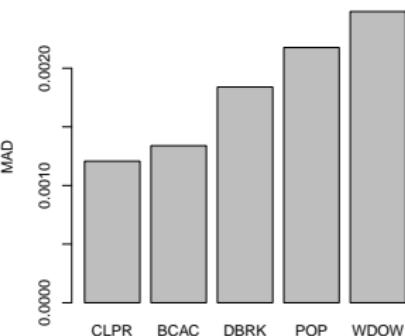
M4HC3

M4U4

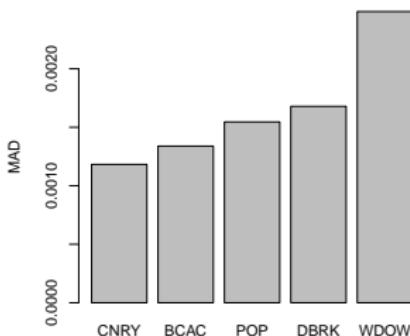
### MAD Ordered by Species



### MAD Ordered by Species



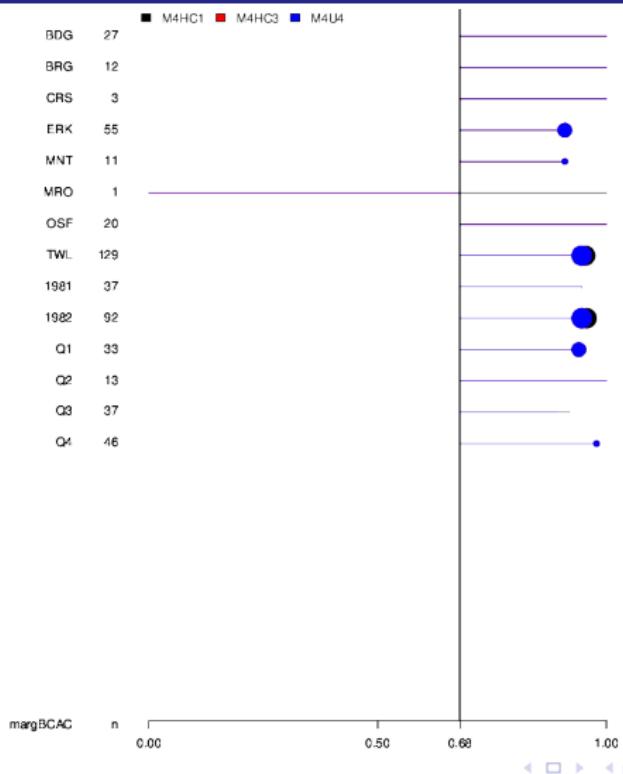
### MAD Ordered by Species



# Combined



MCAT 269



## Introduction

## Time Model

## Prior Model

## Interaction Model

## Time Block

Proofs

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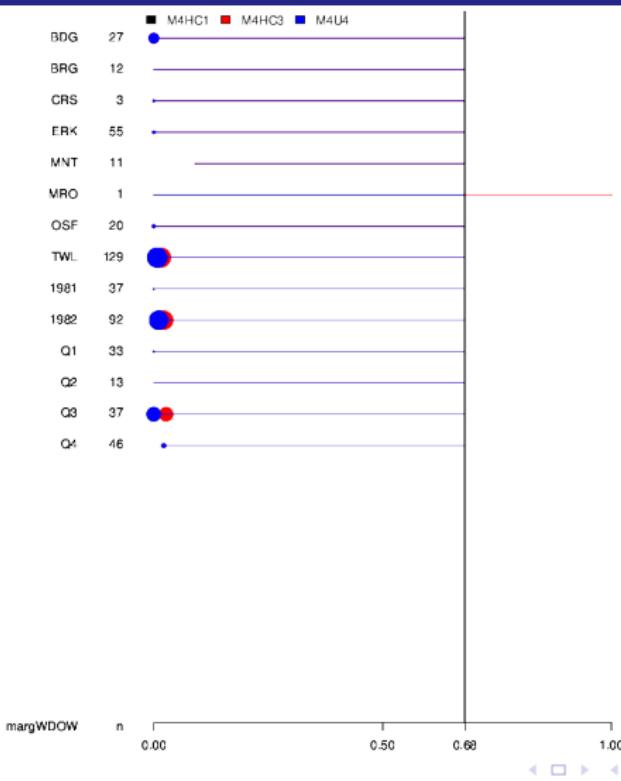
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MCAT 269



## Introduction

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## Time Model

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## Prior Model

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## Interaction Model

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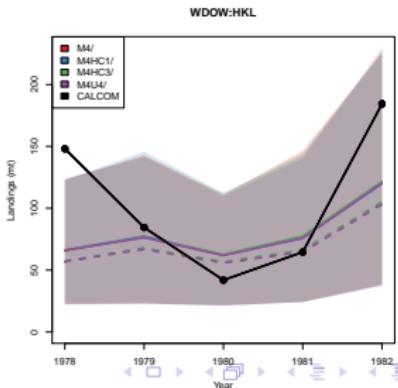
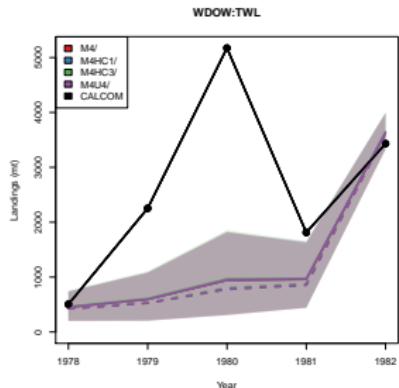
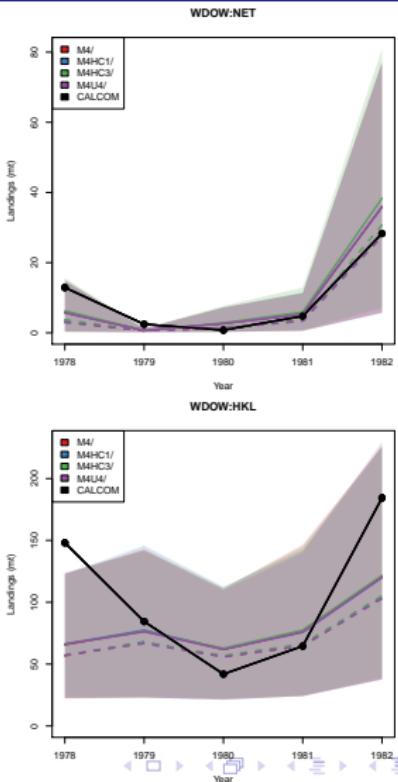
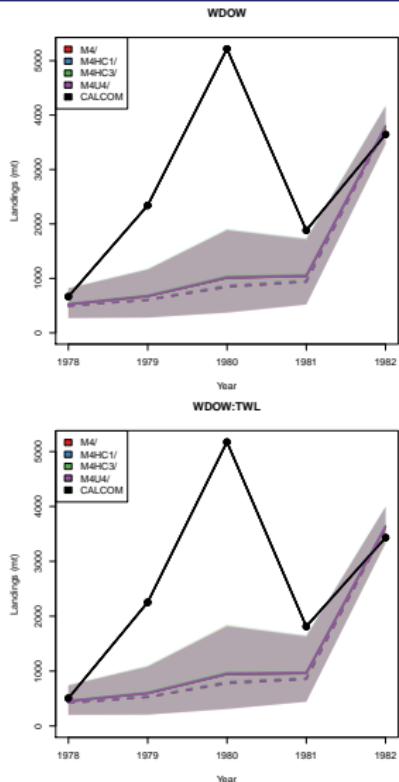
## Time Block

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## Proofs

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## Landings Sensitivity



Nicholas Grunloh In Cooperation With: E.J. Dick, Don Pearson, John Field, Marc Mangel

Improving Catch Estimation Methods in Sparsely Sampled, Mixed Stock Fisheries.



Introduction

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Time Model

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Prior Model

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Interaction Model

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Time Block

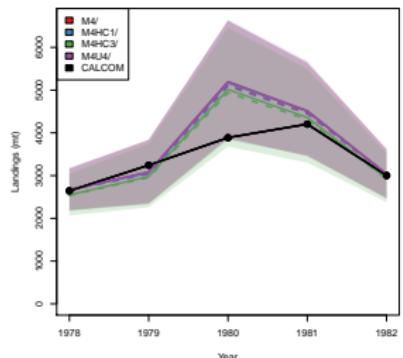
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Proofs

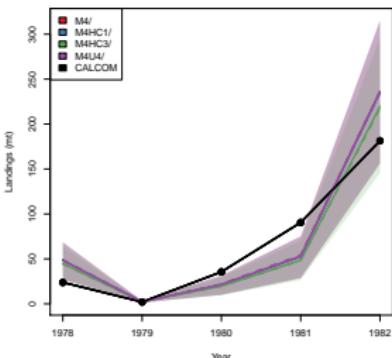
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## Landings Sensitivity

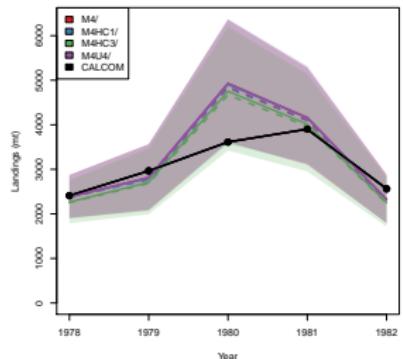
BCAC



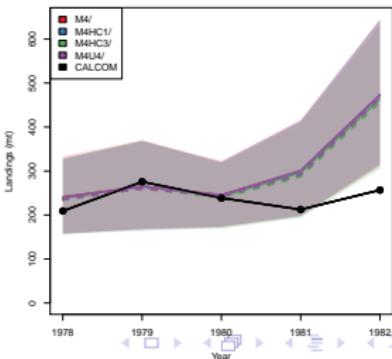
BCAC:NET



BCAC:TWL



BCAC:HKL



Nicholas Grunloh In Cooperation With: E.J. Dick, Don Pearson, John Field, Marc Mangel

Improving Catch Estimation Methods in Sparsely Sampled, Mixed Stock Fisheries.



## Introduction

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## Time Model

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## Prior Model

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## Interaction Model

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## Time Block

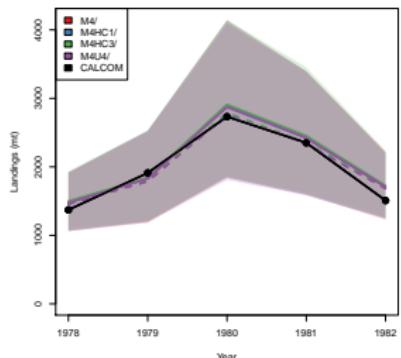
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## Proofs

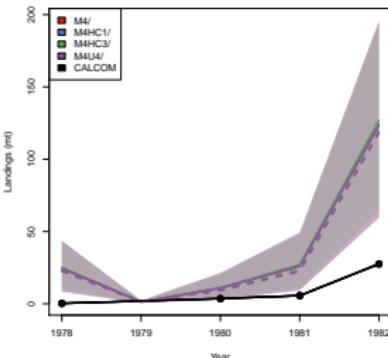
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## Landings Sensitivity

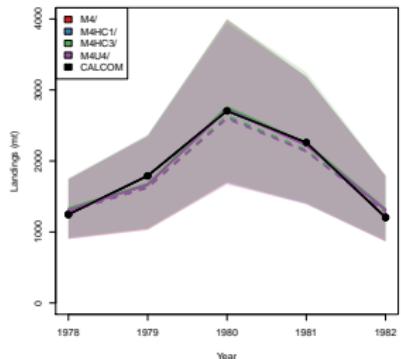
CLPR



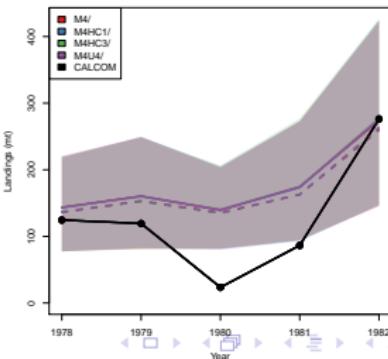
CLPR:NET



CLPR:TWL



CLPR:HKL



Nicholas Grunloh In Cooperation With: E.J. Dick, Don Pearson, John Field, Marc Mangel

Improving Catch Estimation Methods in Sparsely Sampled, Mixed Stock Fisheries.



## Introduction

## Time Model

## Prior Model

## Interaction Model

### Time Block

Proofs

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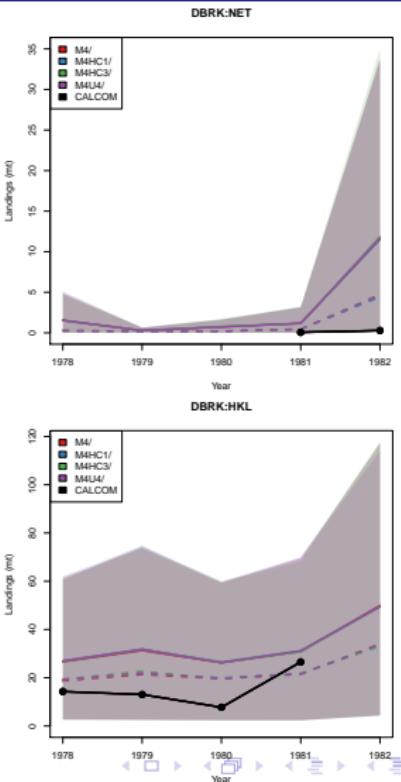
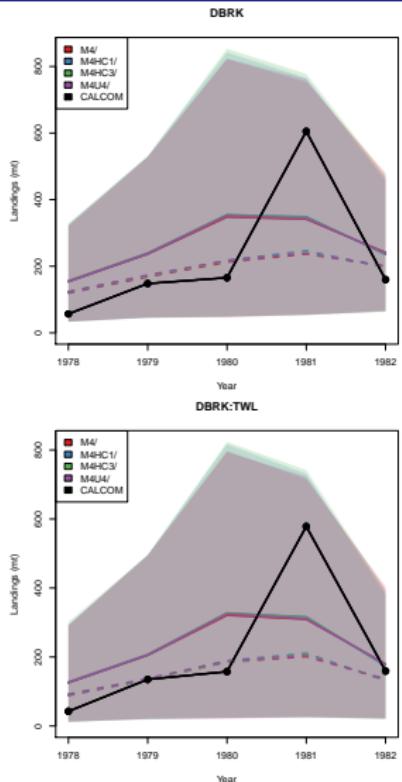
A 5x5 grid of 25 small circles, arranged in five rows and five columns.

A 5x5 grid of 25 small circles, arranged in five rows and five columns.

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## Landings Sensitivity



**Nicholas Grunloh In Cooperation With: E.J. Dick, Don Pearson, John Field, Marc Mangel**

## **Improving Catch Estimation Methods in Sparsely Sampled, Mixed Stock Fisheries.**

## Introduction

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## Time Model

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## Prior Model

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## Interaction Model

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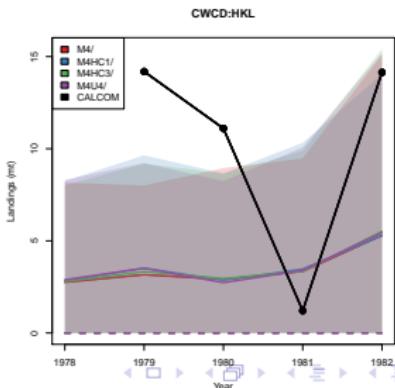
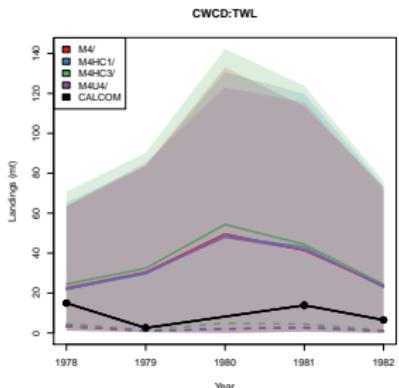
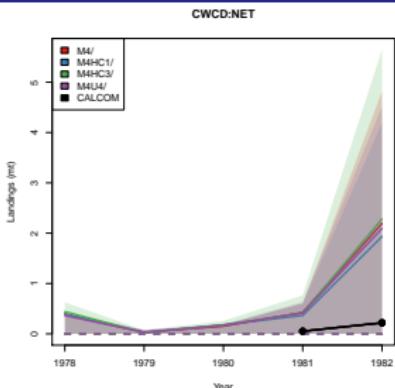
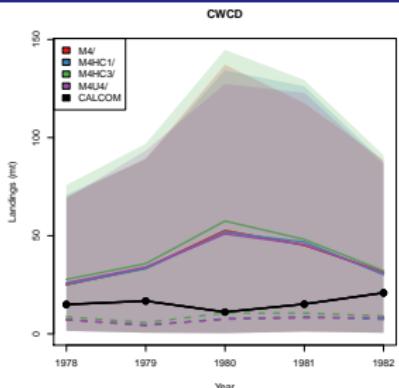
## Time Block

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## Proofs

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## Landings Sensitivity



Nicholas Grunloh In Cooperation With: E.J. Dick, Don Pearson, John Field, Marc Mangel

Improving Catch Estimation Methods in Sparsely Sampled, Mixed Stock Fisheries.



Introduction

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Time Model

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Prior Model

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Interaction Model

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Time Block

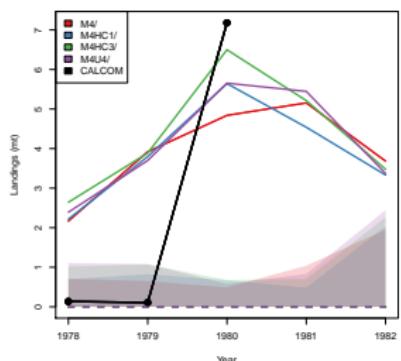
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Proofs

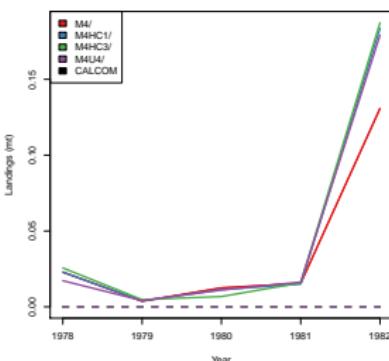
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## Landings Sensitivity

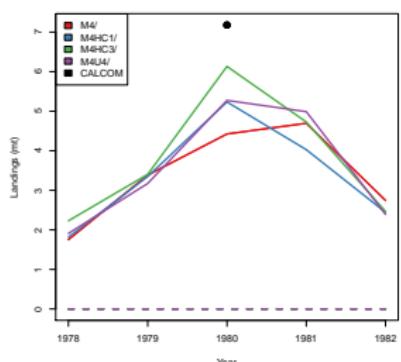
MXRF



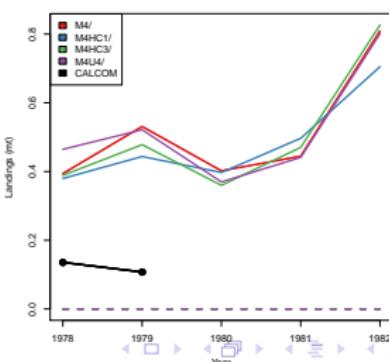
MXRF.NET



MXRF:TWL



MXRF:HKL



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Improving Catch Estimation Methods in Sparsely Sampled, Mixed Stock Fisheries.



## Landings Sensitivity

## Prior Summary

- In a data-rich setting, the prior has little influence on performance.
  - In a data-poor setting, the U4 prior often performs well.
  - Despite better performance, the U4 prior is less stable in a data-poor setting.

MCAT 250 Combined Plots

## MCAT 253 Combined Plots

## MCAT 269 Combined Plots

## All Species Landings



**Request:** Explore various two-way interactions (beyond the current explorations; e.g., Species : Port and Species : Gear).

**Rationale:** The Team did not have time to search across the multitude of possible interaction terms that they could have included in the model. From various anecdotal comments made during the review it seemed likely that the model would benefit from the inclusion of other interaction terms. Explorations with the diagnostic template may suggest potentially beneficial terms.

**Response:** The following slides show the diagnostic plots as applied to models exploring the inclusion of species:port and species:gear interaction terms.

## Introduction

## Time Model

### Prior Model

## Interaction Model

### Time Block

Proofs

1

A 4x4 grid of 16 small circles, arranged in four rows and four columns.

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MCAT 250

	M4	M4SG	M4SP
$\Delta$ DIC	58229.78	21403.07	0
$\Delta$ WAIC	24203.2	10186.57	0

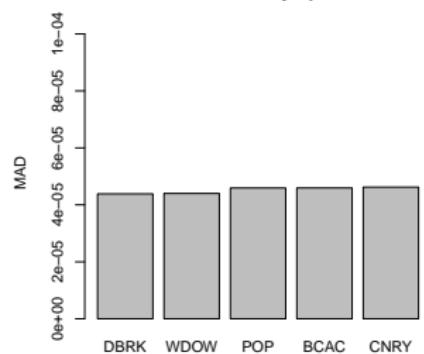
MCAT 250

M4

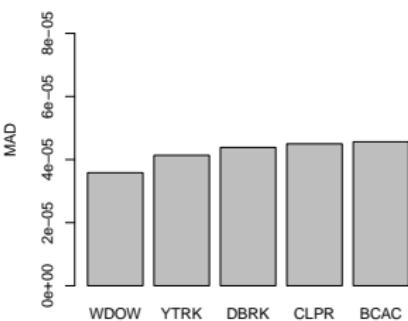
M4SG

M4SP

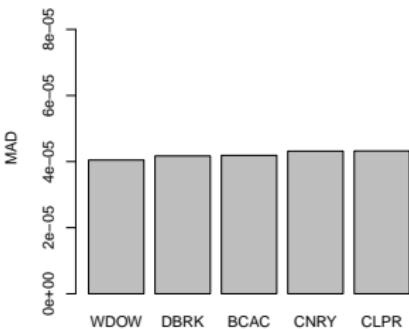
### MAD Ordered by Species



### MAD Ordered by Species



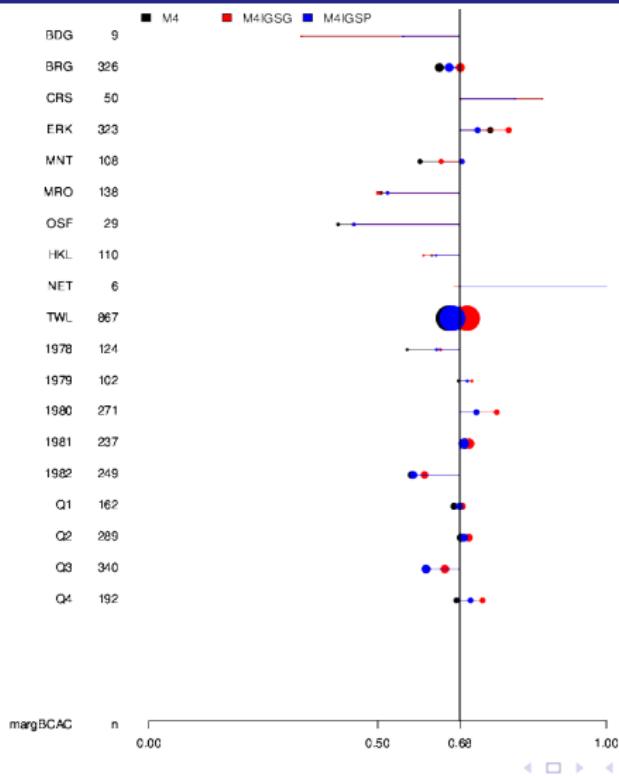
### MAD Ordered by Species



## Combined



MCAT 250

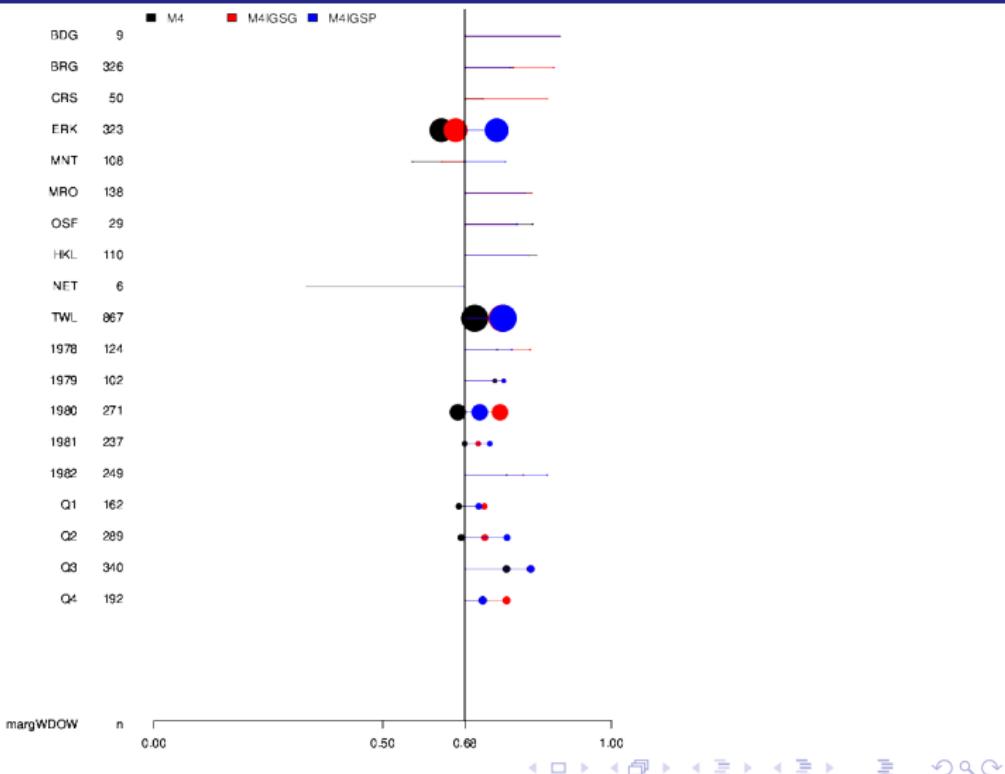


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Improving Catch Estimation Methods in Sparsely Sampled, Mixed Stock Fisheries.



MCAT 250

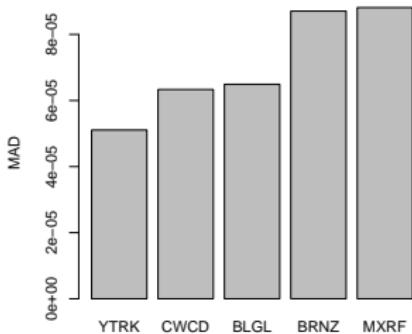
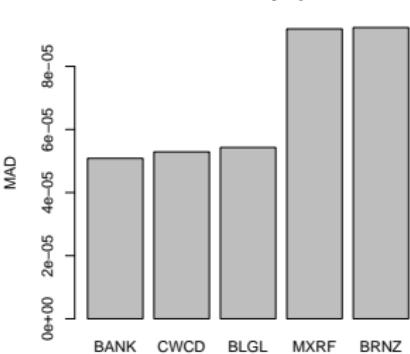
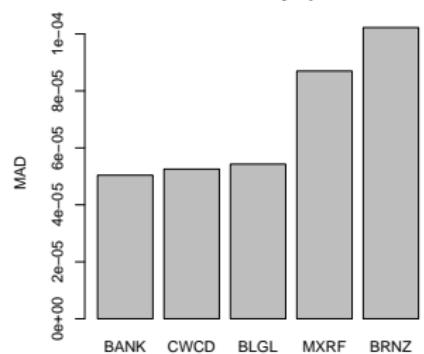


MCAT 250

M4

M4SG

M4SP



# Combined

Introduction

## Time Model

## Prior Model

## Interaction Model

### Time Block

## Proofs

A 4x5 grid of 20 small circles, arranged in four rows and five columns.

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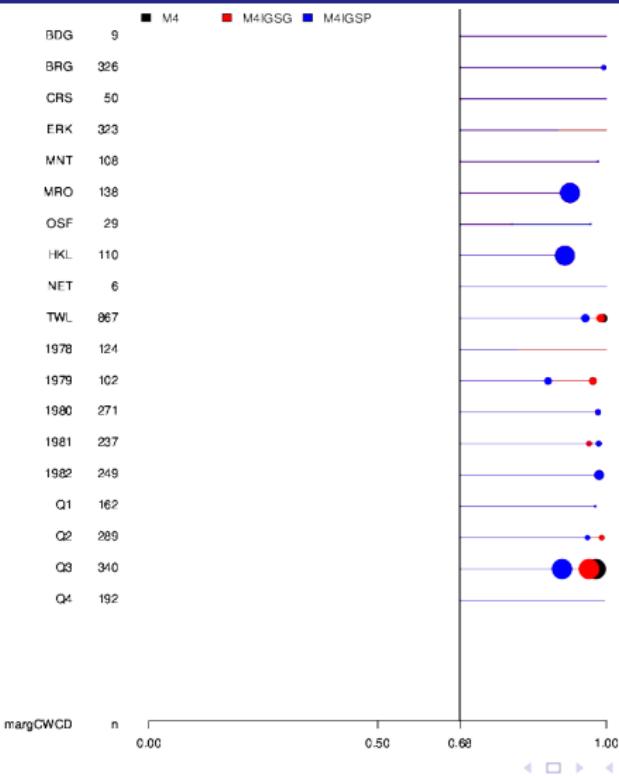
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MCAT 250



Introduction

## Time Model

## Prior Model

## Interaction Model

## Time Block

## Proofs

A 4x5 grid of 20 small circles, arranged in four rows and five columns.

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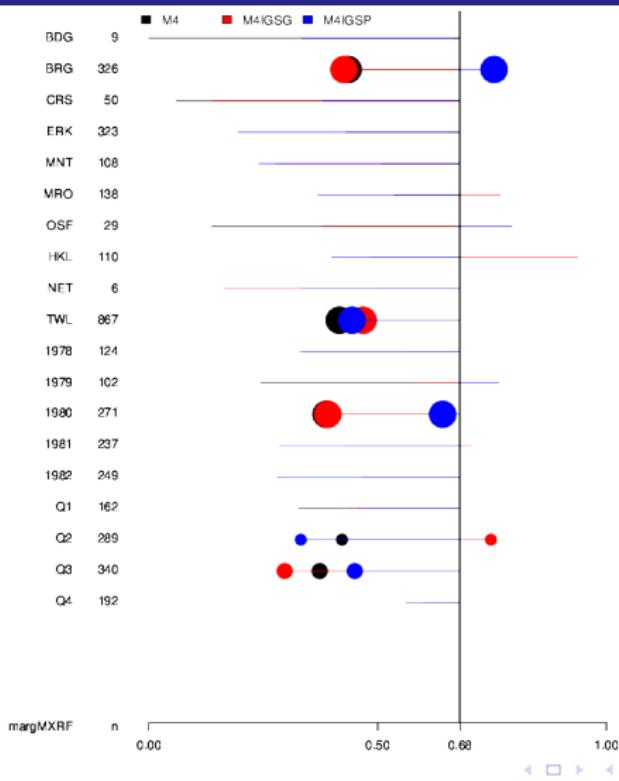
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MCAT 250



## Introduction

## Time Model

### Prior Model

## Interaction Model

### Time Block

Proofs

1

A 4x4 grid of 16 small circles, arranged in four rows and four columns.

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MCAT 253

	M4	M4SG	M4SP
$\Delta$ DIC	403.42	308.65	0
$\Delta$ WAIC	872.35	778.17	0

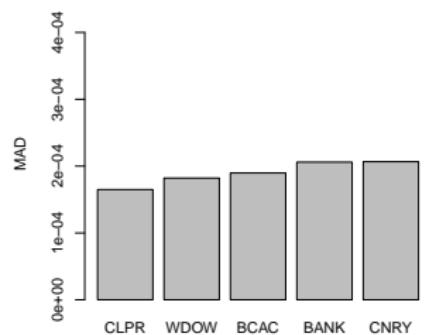
MCAT 253

M4

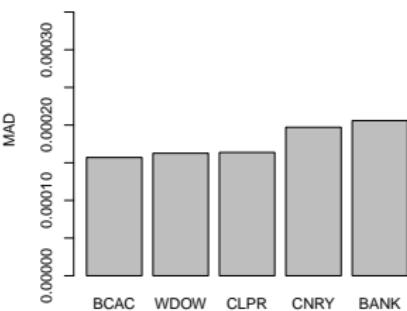
M4SG

M4SP

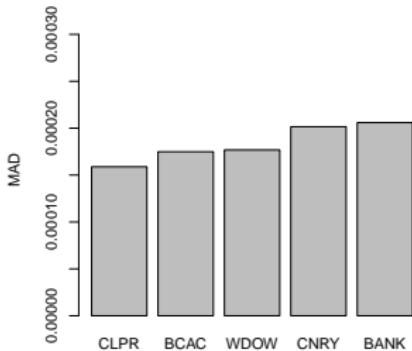
### MAD Ordered by Species



### MAD Ordered by Species



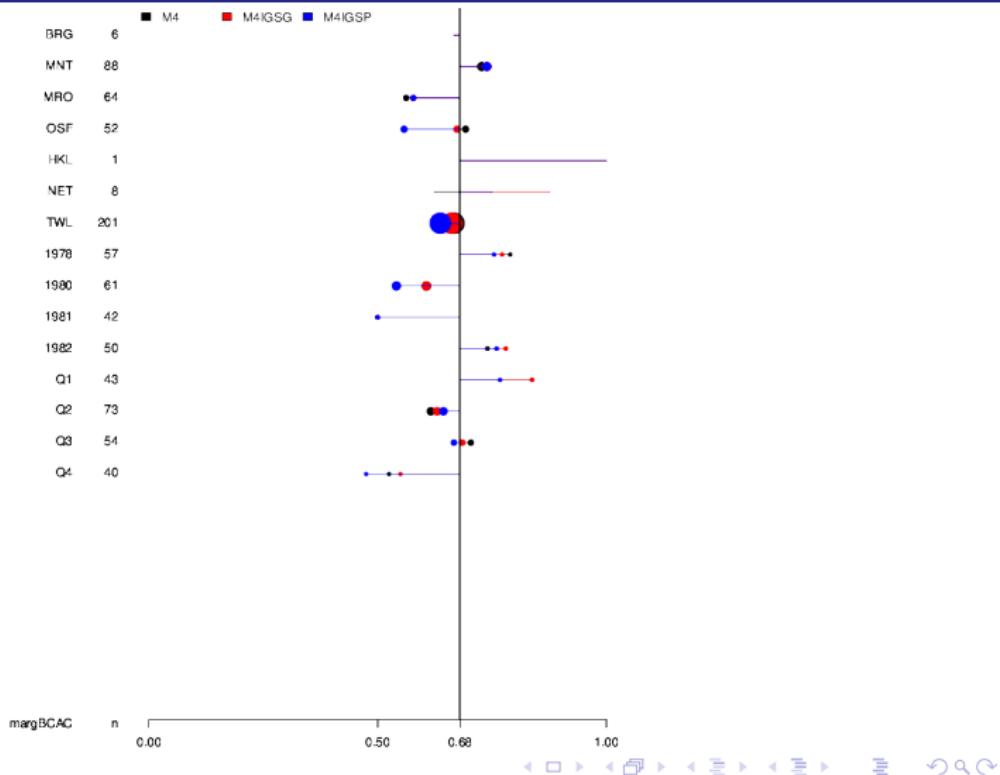
### MAD Ordered by Species



# Combined

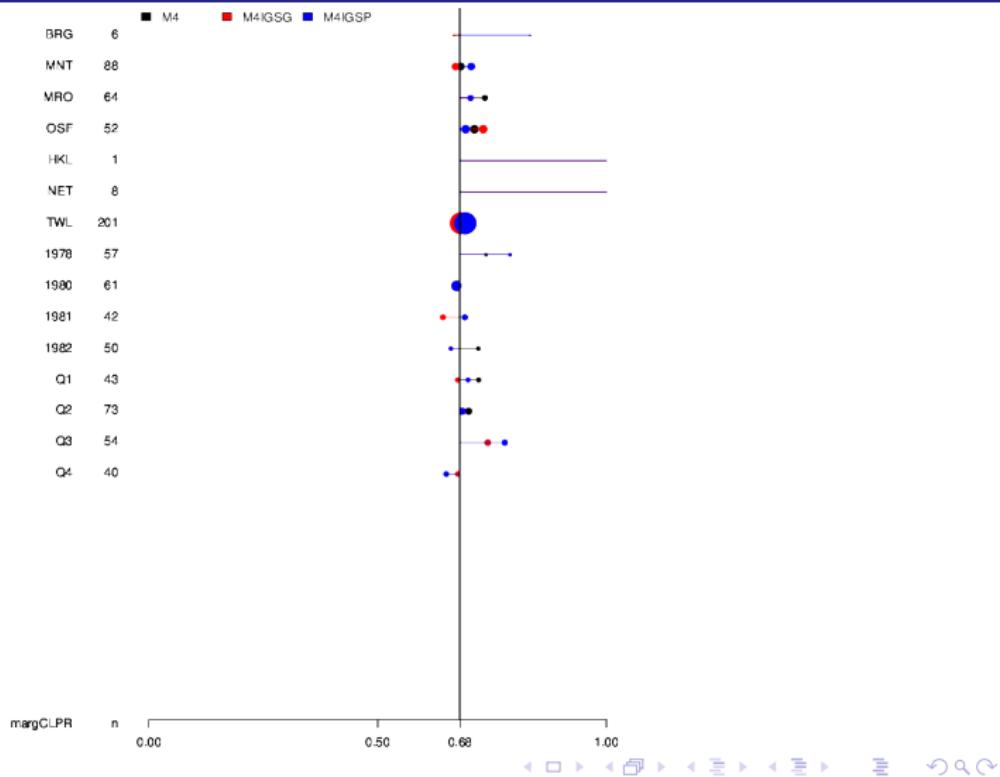


MCAT 253





MCAT 253



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A 4x6 grid of 24 small circles, arranged in four rows and six columns.

A 4x7 grid of 28 small circles, arranged in four rows and seven columns.

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A 4x4 grid of 16 small circles, arranged in four rows and four columns.

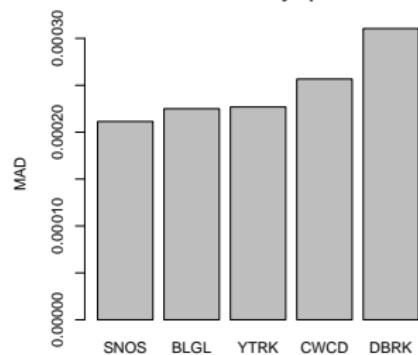
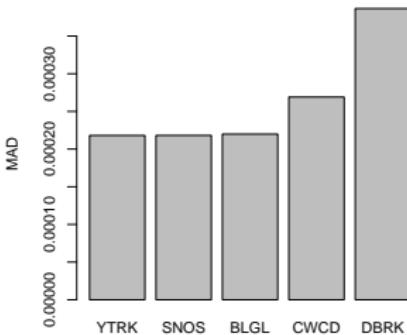
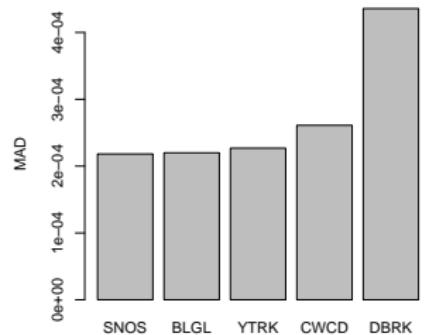
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MCAT 253

M4

M4SG

M4SP



## Combined

Introduction

## Time Model

## Prior Model

## Interaction Model

## Time Block

Proofs

A 4x5 grid of 20 small circles, arranged in four rows and five columns.

A 5x5 grid of 25 small circles, arranged in five rows and five columns.

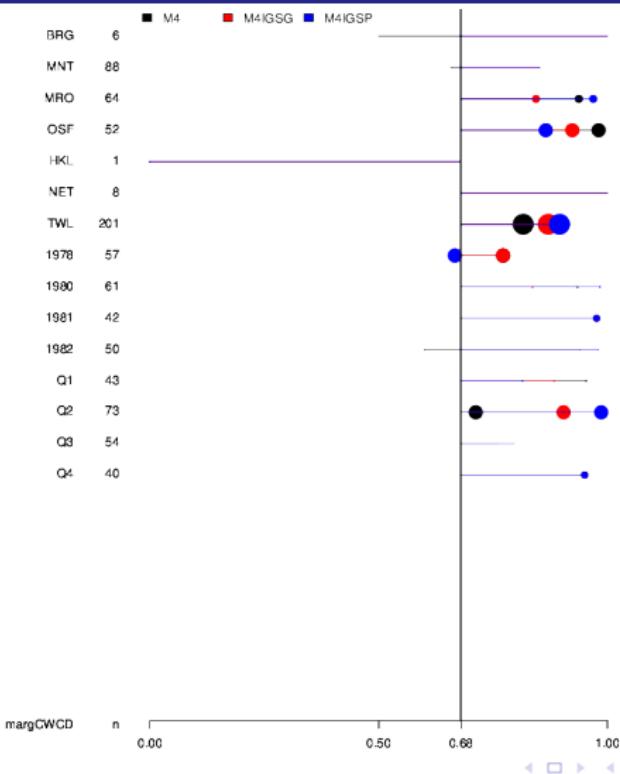
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MCAT 253



Introduction

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Time Model

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Prior Model

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Interaction Model

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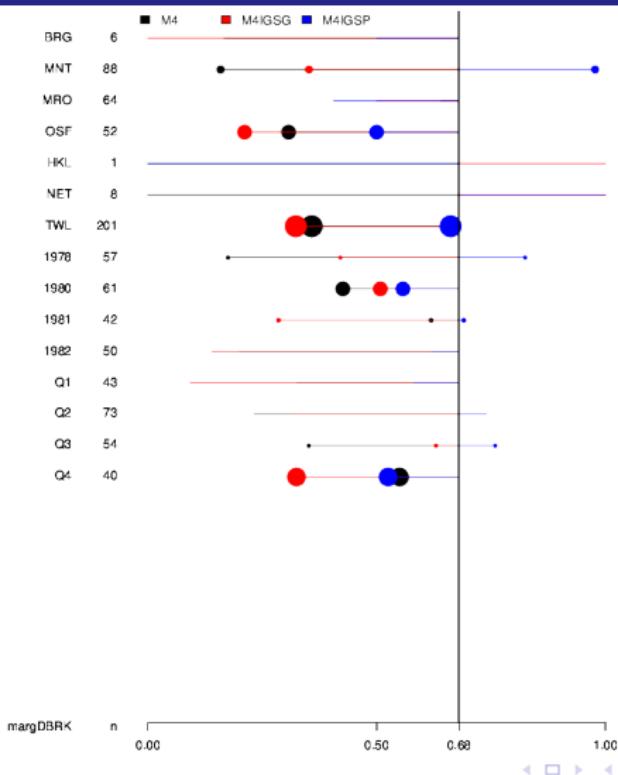
Time Block

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MCAT 253



## Introduction

## Time Model

### Prior Model

## Interaction Model

### Time Block

Proofs

A 4x5 grid of 20 small circles, arranged in four rows and five columns.

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MCAT 269

	M4	M4SG	M4SP
$\Delta$ DIC	0	0.31	182.15
$\Delta$ WAIC	0	0.13	68.48

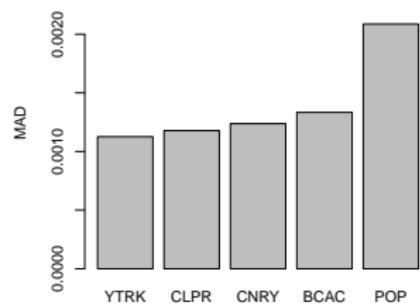
MCAT 269

M4

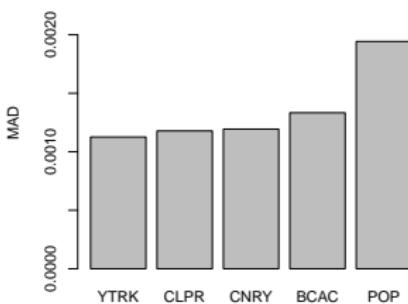
M4SG

M4SP

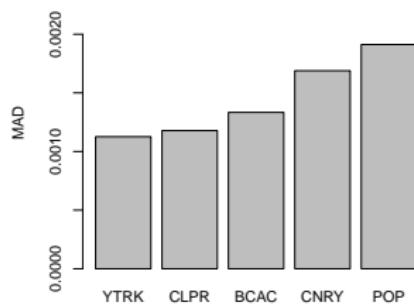
### MAD Ordered by Species



### MAD Ordered by Species



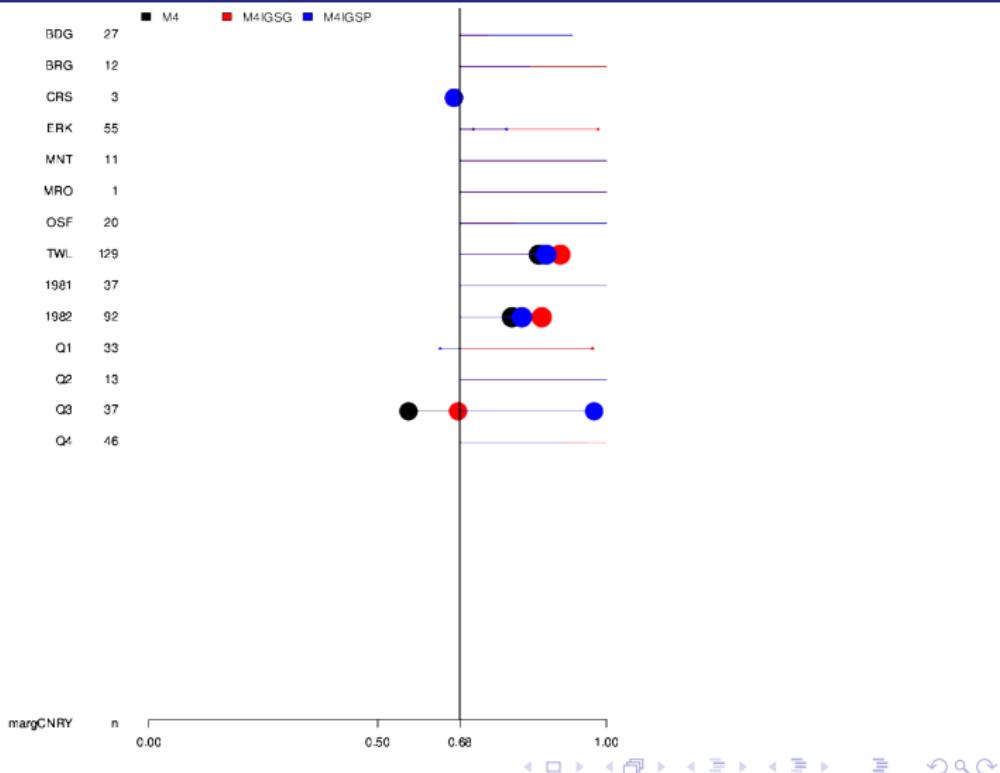
### MAD Ordered by Species



## Combined

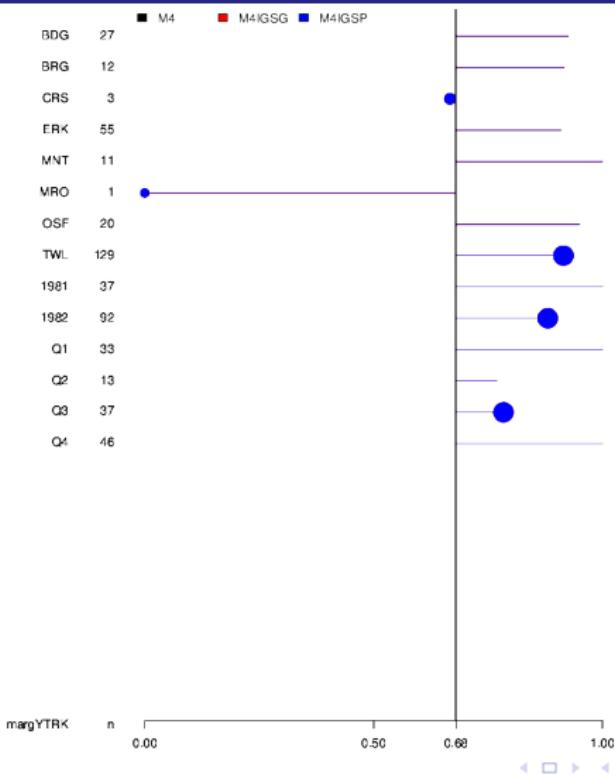


MCAT 269





MCAT 269



10

A 4x4 grid of 16 small circles, arranged in four rows and four columns.

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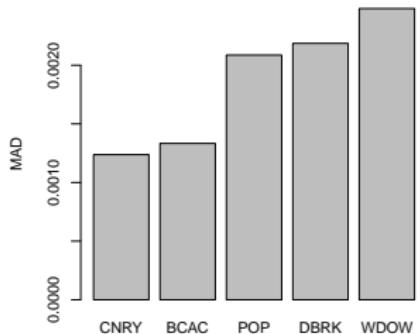
MCAT 269

M4

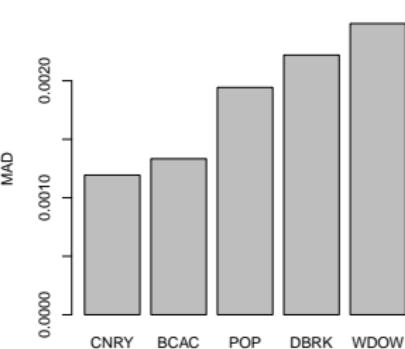
M4SG

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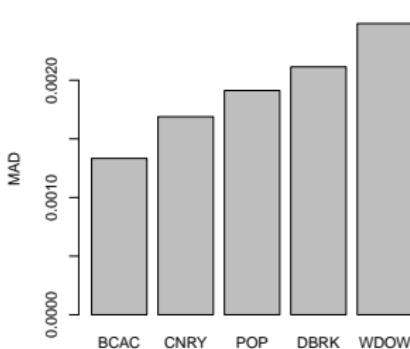
### MAD Ordered by Species



### MAD Ordered by Species



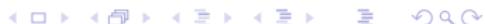
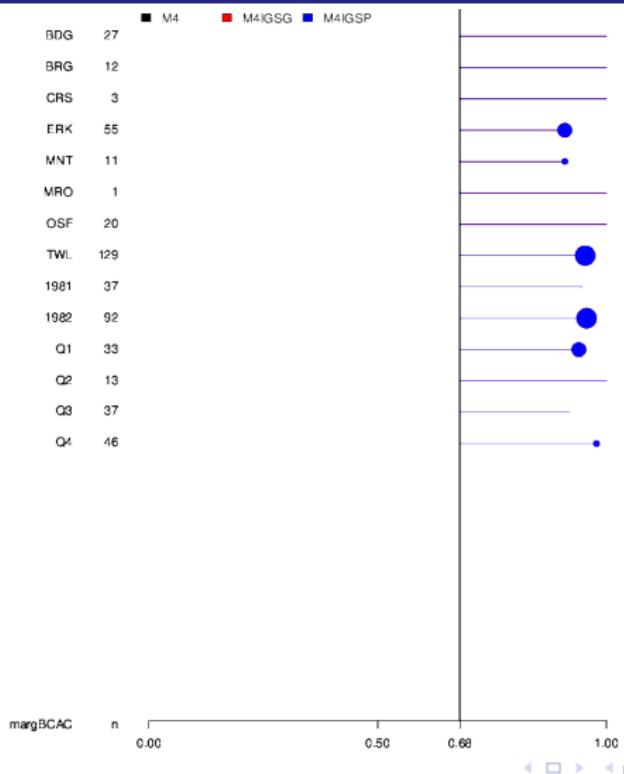
### MAD Ordered by Species



## Combined



MCAT 269

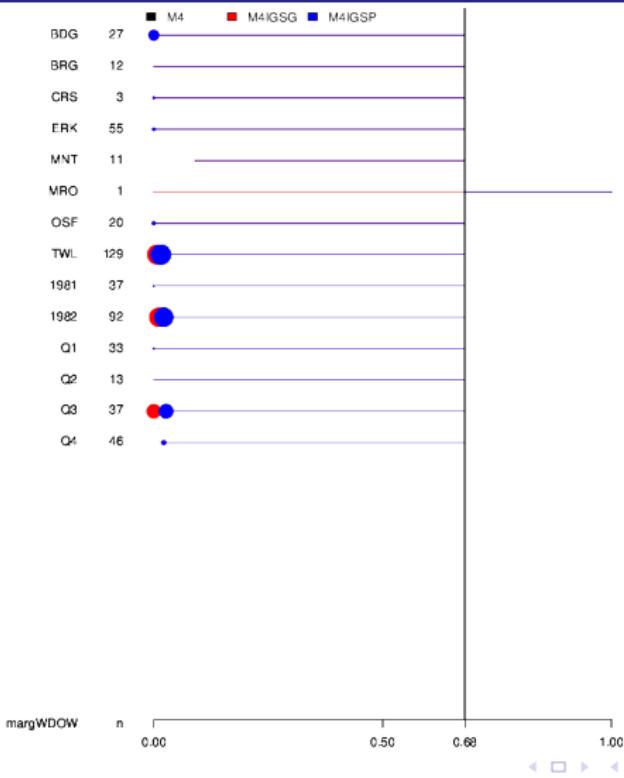


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Improving Catch Estimation Methods in Sparsely Sampled, Mixed Stock Fisheries.



MCAT 269



Nicholas Grunloh In Cooperation With: E.J. Dick, Don Pearson, John Field, Marc Mangel

Improving Catch Estimation Methods in Sparsely Sampled, Mixed Stock Fisheries.

Introduction

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Time Model

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Prior Model

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Interaction Model

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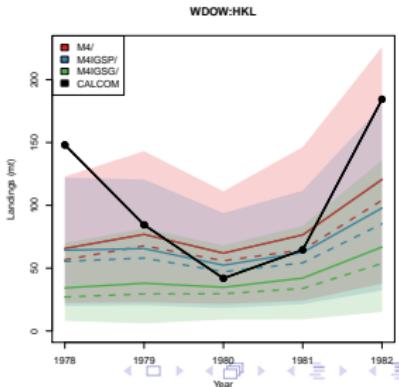
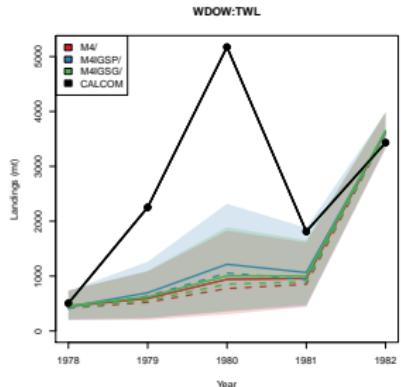
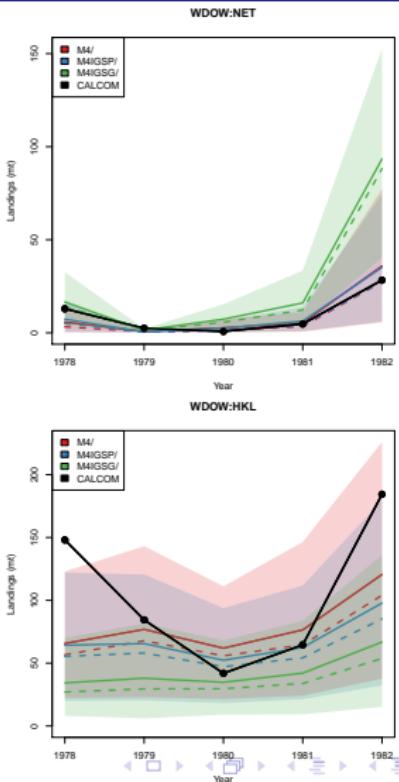
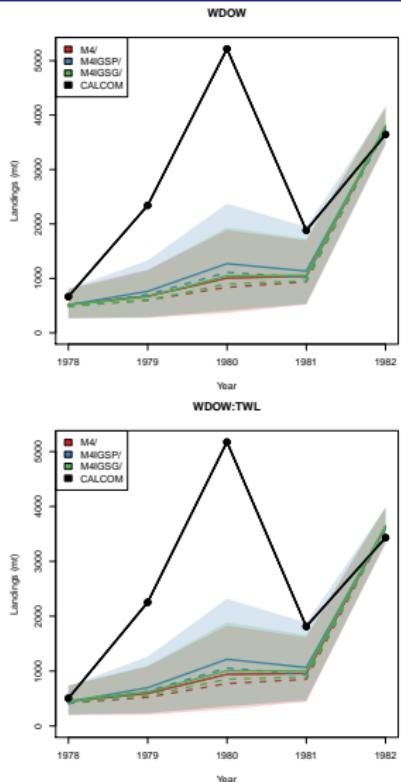
Time Block

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Proofs

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## Landings Sensitivity



Nicholas Grunloh In Cooperation With: E.J. Dick, Don Pearson, John Field, Marc Mangel

Improving Catch Estimation Methods in Sparsely Sampled, Mixed Stock Fisheries.



## Introduction

## Time Model

### Prior Model

## Interaction Model

### Time Block

Proofs

A 4x3 grid of 12 small circles, arranged in four rows and three columns.

A 4x6 grid of 24 small circles, arranged in four rows and six columns.

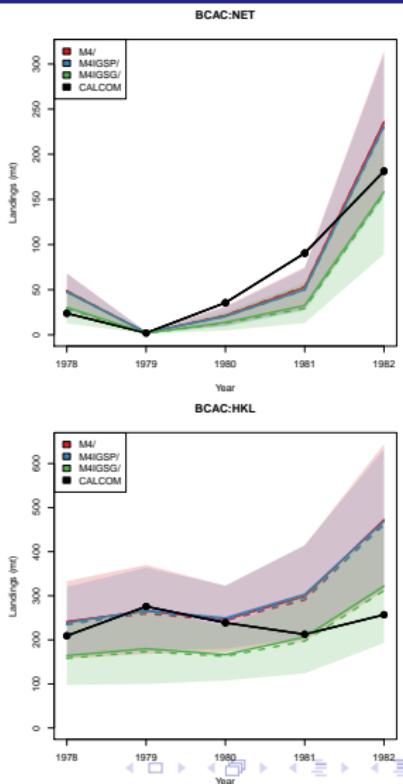
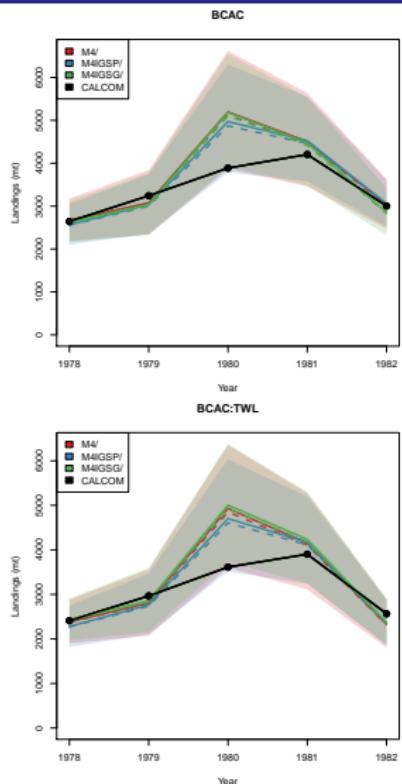
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A 4x6 grid of 24 small circles, arranged in four rows and six columns.

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Landings Sensitivity



Nicholas Grunloh In Cooperation With: E.J. Dick, Don Pearson, John Field, Marc Mangel

## Improving Catch Estimation Methods in Sparsely Sampled, Mixed Stock Fisheries.

## Introduction

## Time Model

## Prior Model

## Interaction Model

### Time Block

Proofs

A 4x5 grid of 20 small circles, arranged in four rows and five columns.

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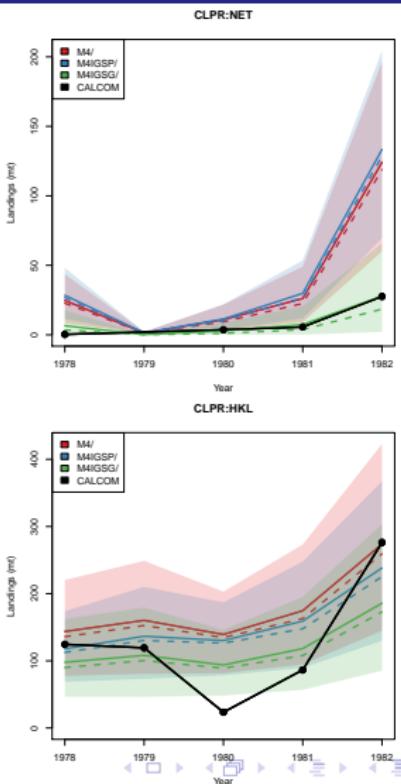
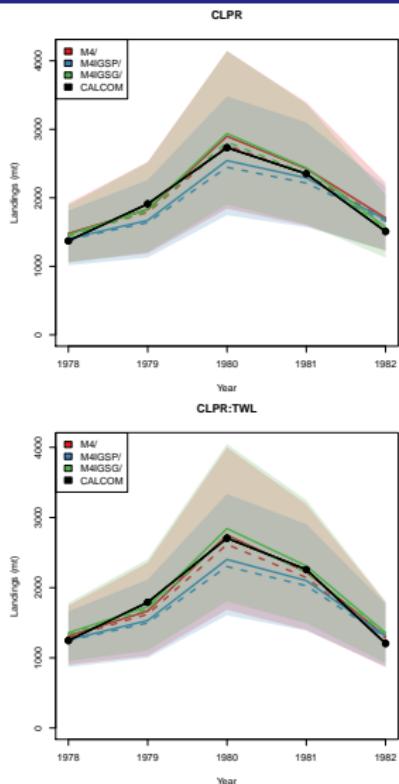
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Landings Sensitivity



**Nicholas Grunloh In Cooperation With: E.J. Dick, Don Pearson, John Field, Marc Mangel**

## **Improving Catch Estimation Methods in Sparsely Sampled, Mixed Stock Fisheries.**

Introduction

## Time Model

### Prior Model

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### Time Block

Proofs

A 4x5 grid of 20 small circles, arranged in four rows and five columns.

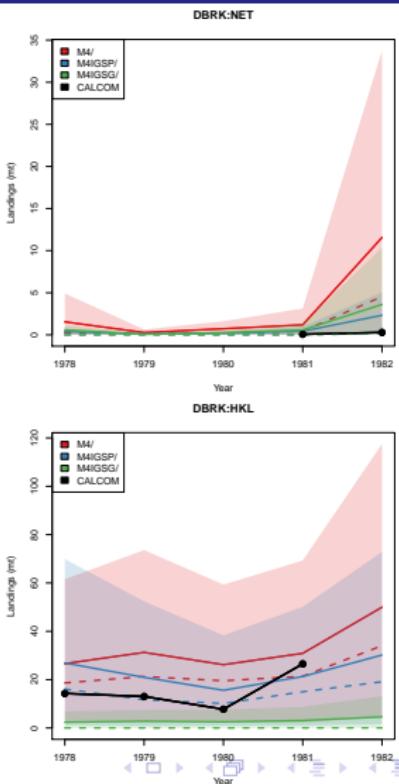
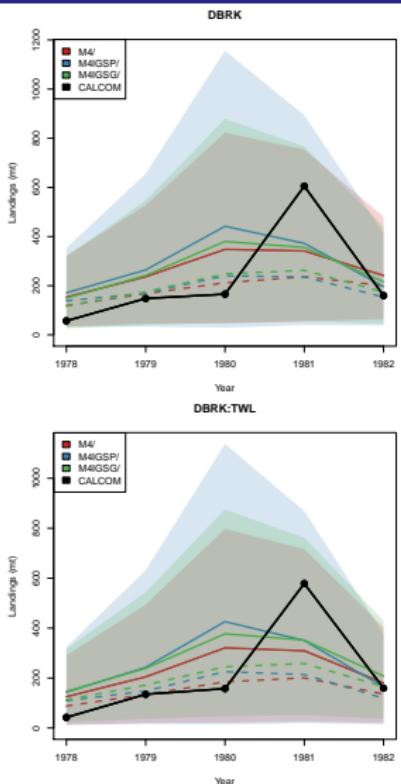
A 4x6 grid of 24 small circles, arranged in four rows and six columns.

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Landings Sensitivity



**Nicholas Grunloh In Cooperation With: E.J. Dick, Don Pearson, John Field, Marc Mangel**

## **Improving Catch Estimation Methods in Sparsely Sampled, Mixed Stock Fisheries.**

## Introduction

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## Time Model

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## Prior Model

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## Interaction Model

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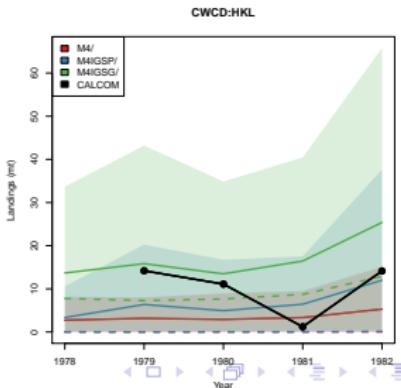
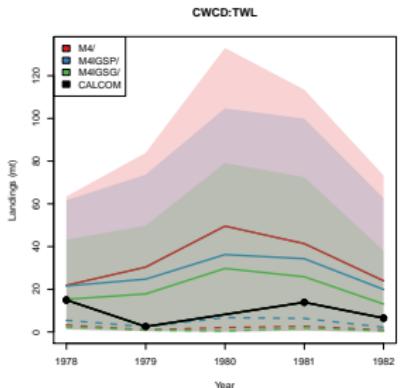
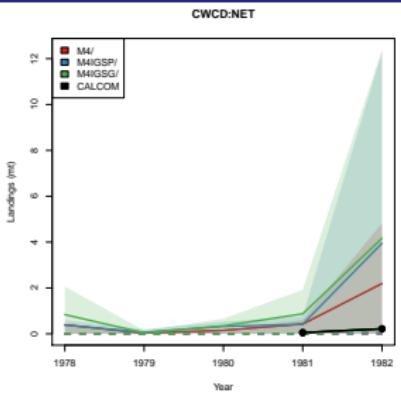
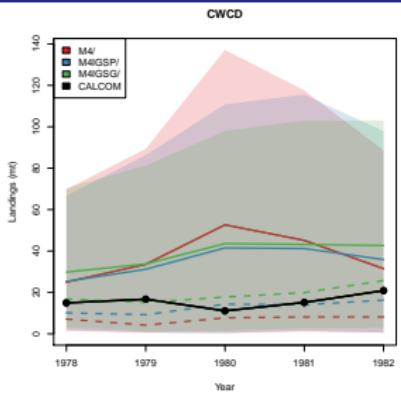
## Time Block

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## Proofs

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## Landings Sensitivity



Nicholas Grunloh In Cooperation With: E.J. Dick, Don Pearson, John Field, Marc Mangel

Improving Catch Estimation Methods in Sparsely Sampled, Mixed Stock Fisheries.



Introduction

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Time Model

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Prior Model

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Interaction Model

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Time Block

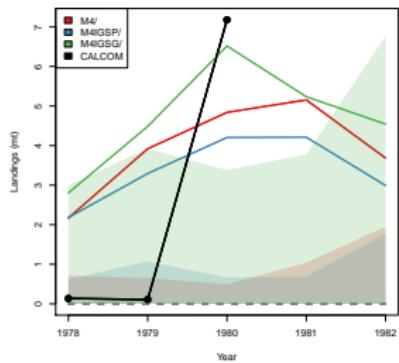
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Proofs

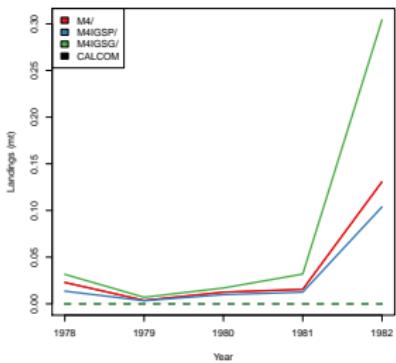
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## Landings Sensitivity

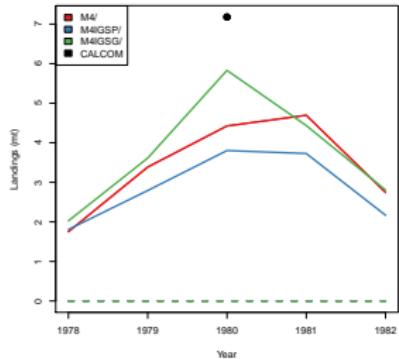
MXRF



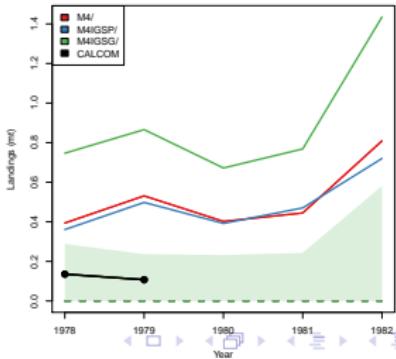
MXRF.NET



MXRF:TWL



MXRF:HKL



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## Landings Sensitivity

## Interaction Summary

- Both Species:Gear and Species:Port interactions may be appropriate.
  - Interactions appear to be market category dependent.
  - Possibly include both with shrinkage priors to allow each to fit on a MCAT-to-MCAT basis.

MCAT 250 Combined Plots

## MCAT 253 Combined Plots

## MCAT 269 Combined Plots

## All Species Landings

**Request:** Explore an alternative time block: an extension of 1983 and 1984 to the first time block.

**Rationale:** The panel expressed concerns about how the model would perform when applied to shorter time periods, as will occur when the model is used with data more recent than 1990. Results from the above recommendation could be compared to the results from the current two time blocks (1978-1982; 1983-1990) to explore how fits to data from the late period degrade when the model for the late period is based on fewer years of data. Also, comparisons of the two forms of blocking serve as a sensitivity evaluation of the selection of the block boundary, which was chosen on a fairly arbitrary basis.

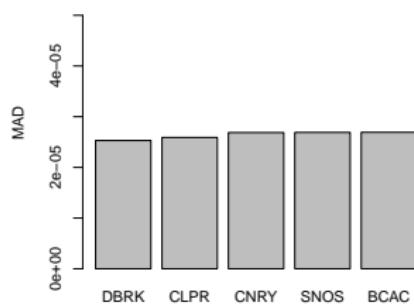
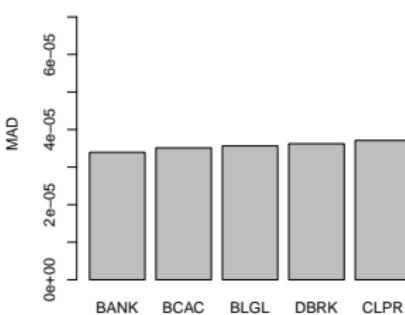
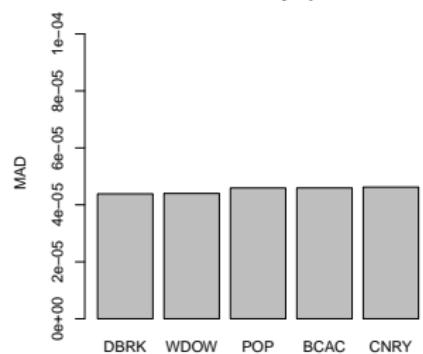
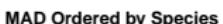
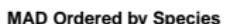
**Response:** The following slides show the diagnostic plots as applied to model M4 when fit to data from 78-82 as well as data from 78-83, 78-84, and 78-85.

MCAT 250

78-82

78-83

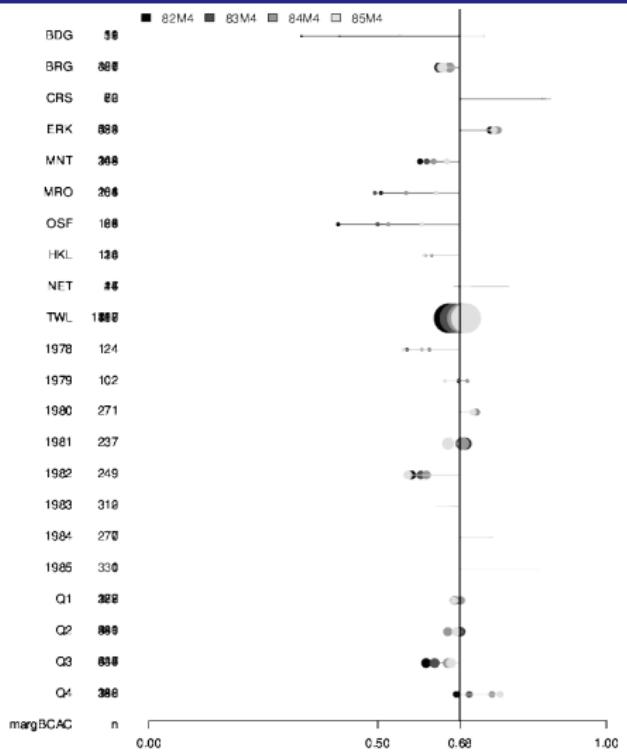
78-84



## Combined



MCAT 250

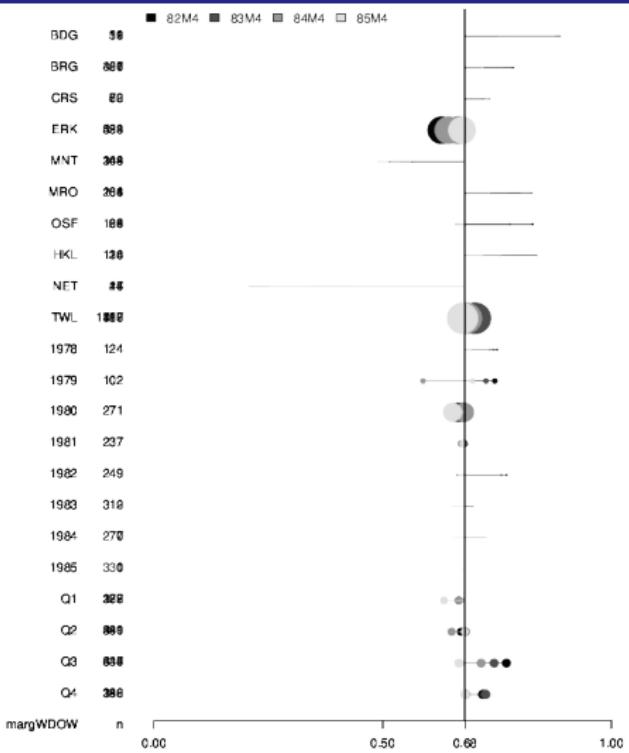


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Improving Catch Estimation Methods in Sparsely Sampled, Mixed Stock Fisheries.



## MCAT 250



Nicholas Grunloh In Cooperation With: E.J. Dick, Don Pearson, John Field, Marc Mangel

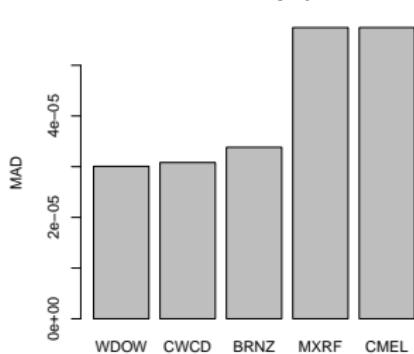
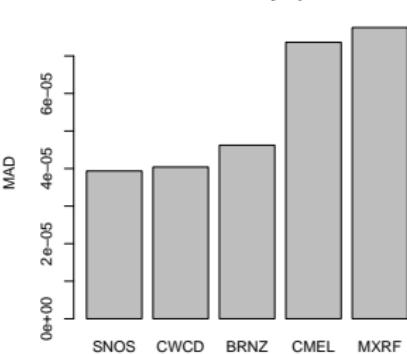
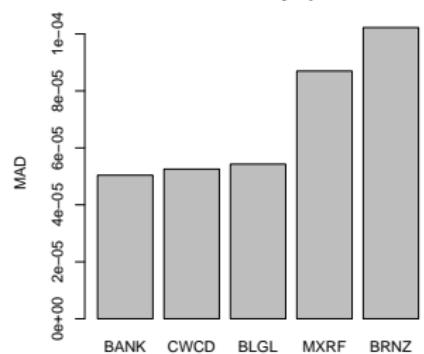
Improving Catch Estimation Methods in Sparsely Sampled, Mixed Stock Fisheries.

MCAT 250

78-82

78-83

78-84



## Combined

## Introduction

## Time Model

### Prior Model

## Interaction Model

### Time Block

## Proofs

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A 4x7 grid of 28 small circles, arranged in four rows and seven columns.

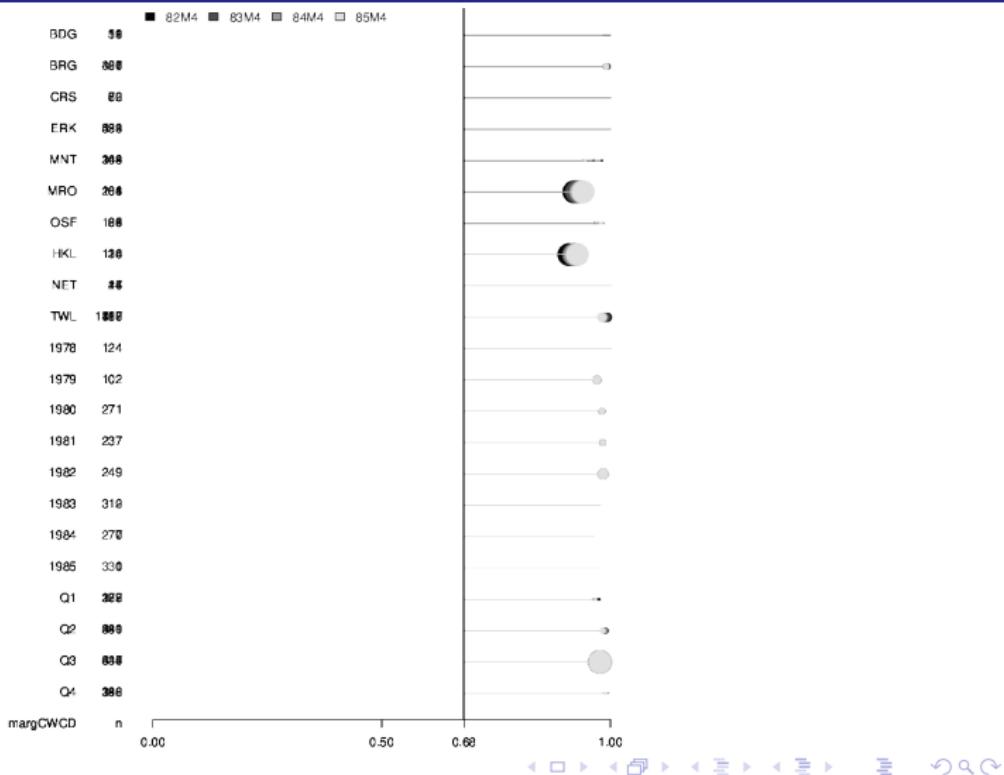
A 4x7 grid of 28 small circles, arranged in four rows and seven columns.

A 4x7 grid of 28 small circles, arranged in four rows and seven columns.

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55

MCAT 250



## Introduction

## Time Model

### Prior Model

## Interaction Model

## Time Block

Proofs

10

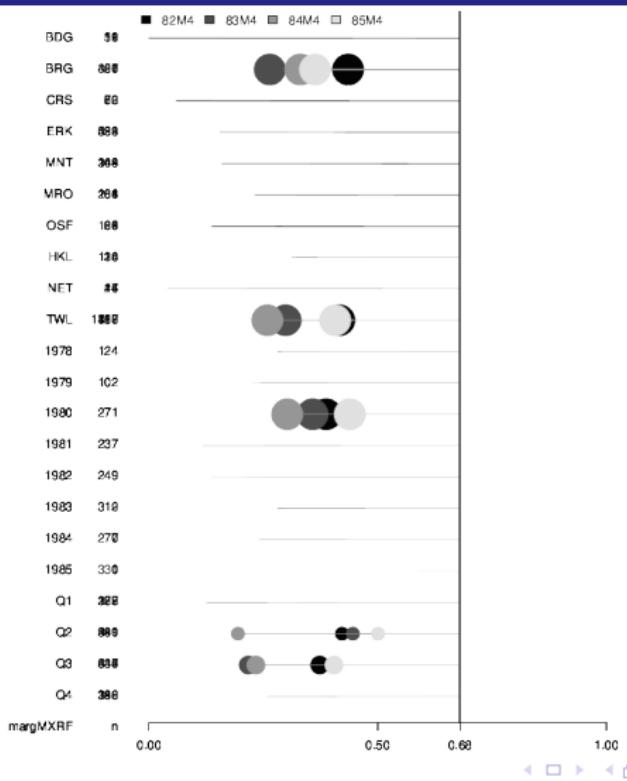
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MCAT 250



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A 4x6 grid of 24 small circles, arranged in four rows and six columns.

A 4x7 grid of 28 small circles, arranged in four rows and seven columns.

A 4x7 grid of 28 small circles, arranged in four rows and seven columns.

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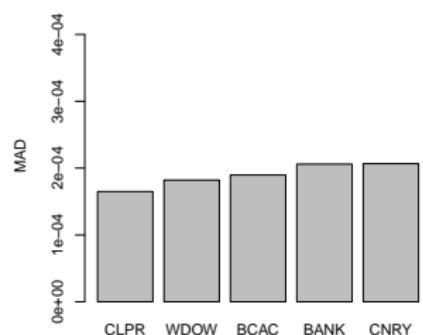
MCAT 253

78-82

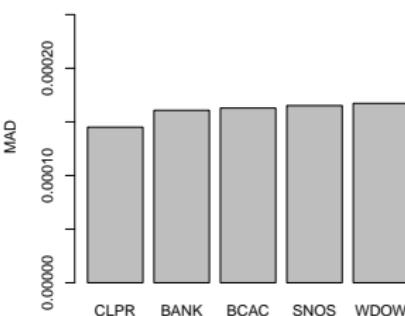
78-83

78-84

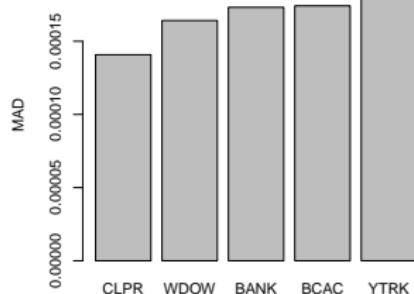
#### MAD Ordered by Species



### MAD Ordered by Species



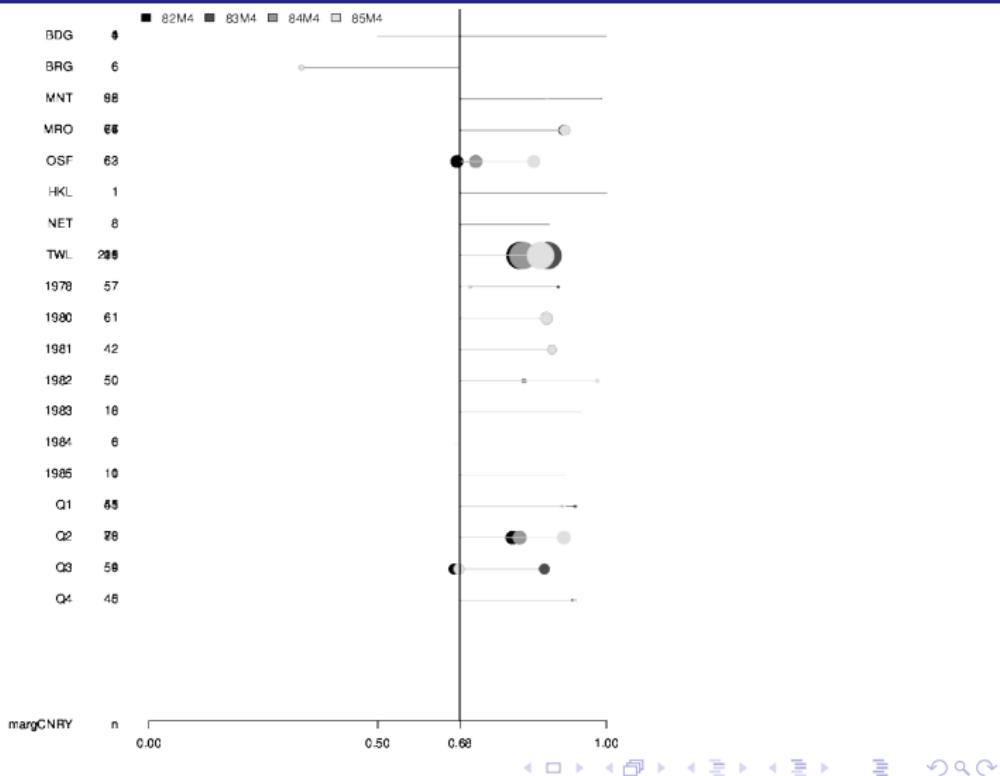
#### MAD Ordered by Species



## Combined



MCAT 253

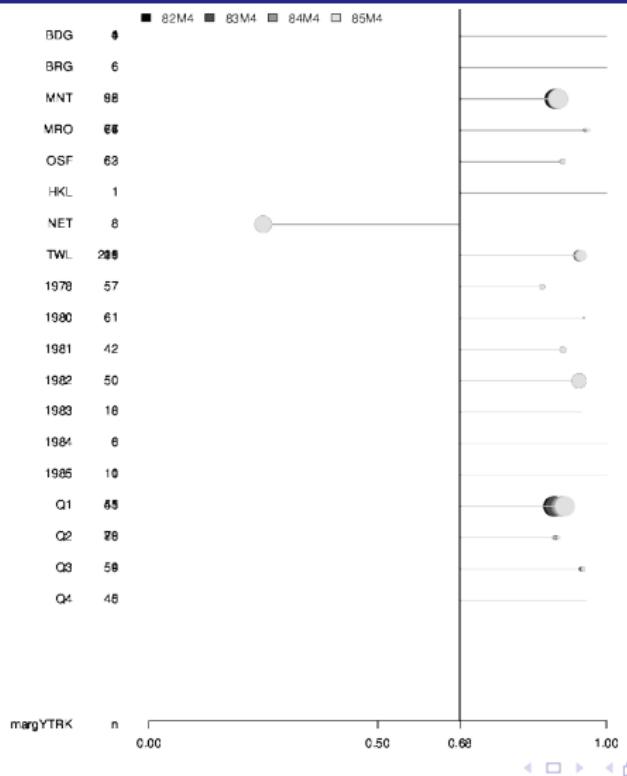


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Improving Catch Estimation Methods in Sparsely Sampled, Mixed Stock Fisheries.



MCAT 253



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A 4x6 grid of 24 small circles, arranged in four rows and six columns.

A 4x7 grid of 28 small circles, arranged in four rows and seven columns.

A 4x6 grid of 24 small circles, arranged in four rows and six columns.

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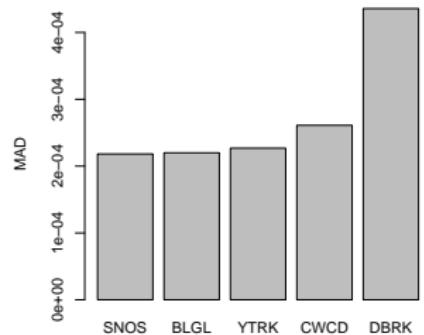
MCAT 253

78-82

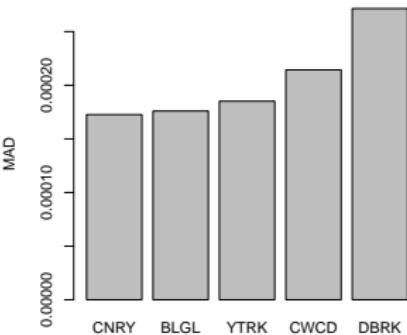
78-83

78-84

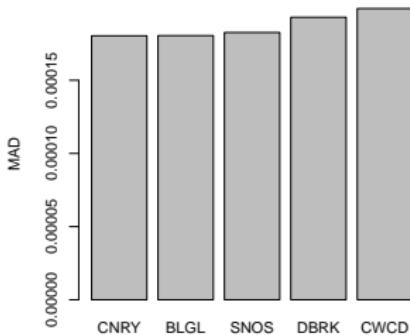
### MAD Ordered by Species



### MAD Ordered by Species



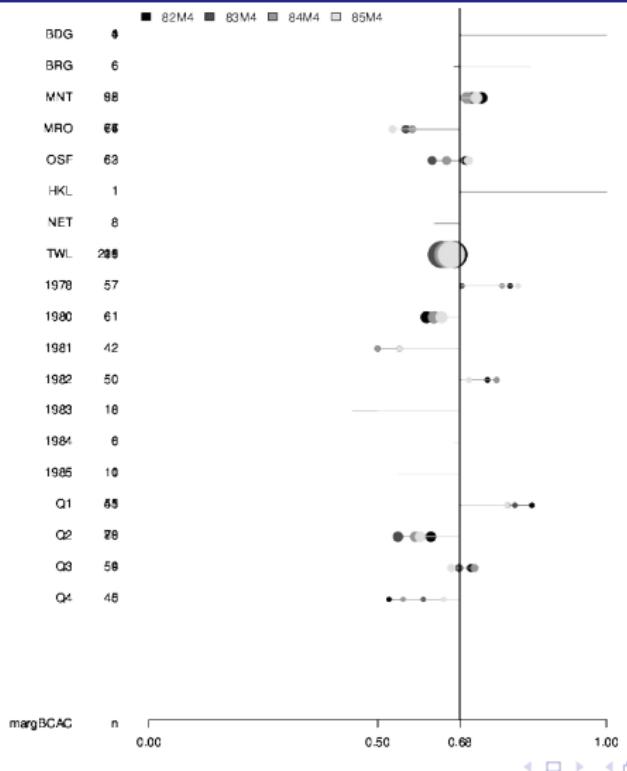
### MAD Ordered by Species



# Combined



MCAT 253



Nicholas Grunloh In Cooperation With: E.J. Dick, Don Pearson, John Field, Marc Mangel

Improving Catch Estimation Methods in Sparsely Sampled, Mixed Stock Fisheries.

Introduction

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Time Model

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Prior Model

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Interaction Model

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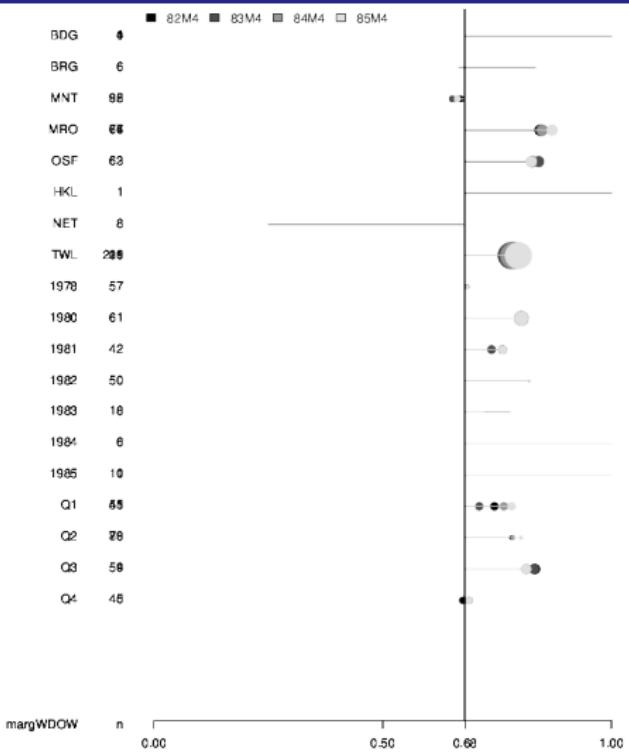
Time Block

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Proofs

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## MCAT 253

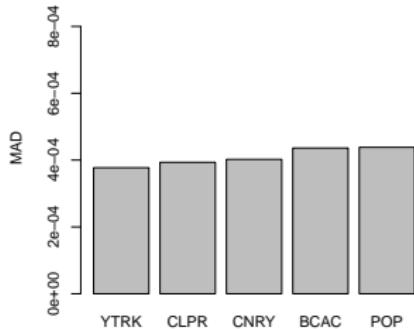
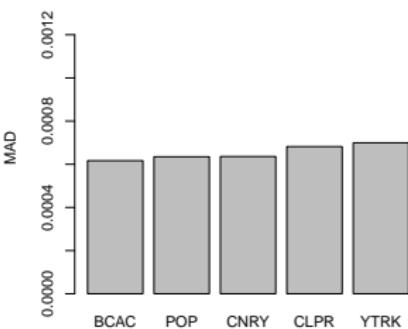
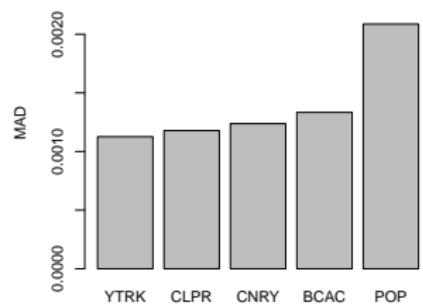


MCAT 269

78-82

78-83

78-84



## Combined

## Introduction

## Time Model

## Prior Model

## Interaction Model

## Time Block

## Proofs

A 4x5 grid of 20 small circles, arranged in four rows and five columns.

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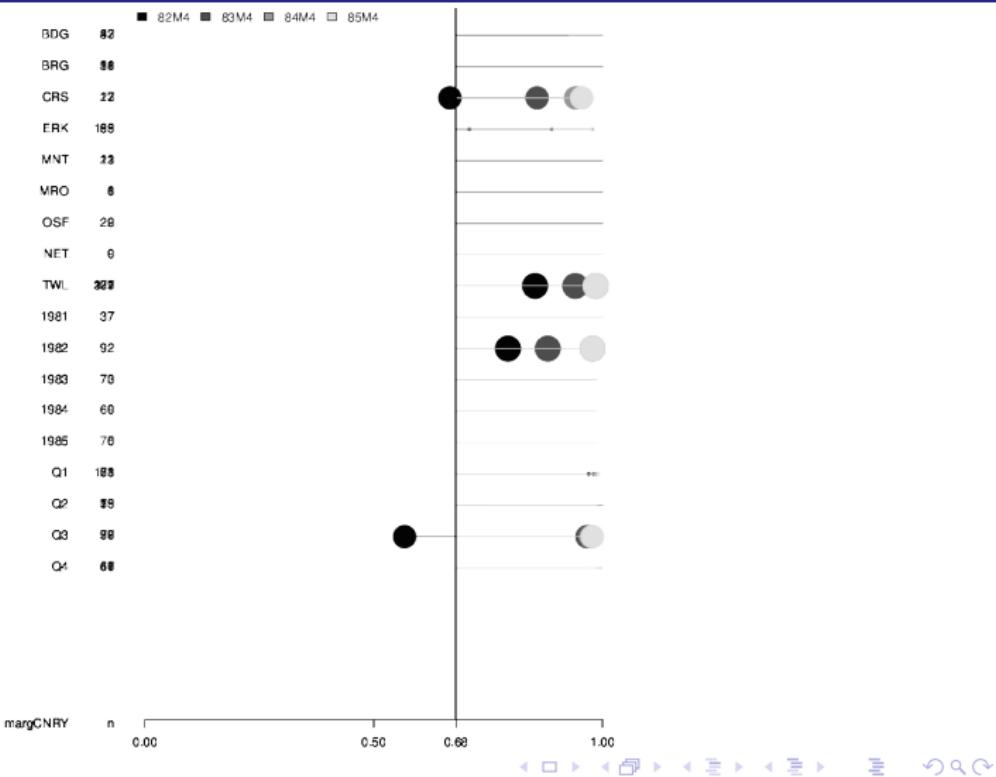
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MCAT 269



Introduction

## Time Model

Prior Model

## Interaction Model

## Time Block

## Proofs

A 4x5 grid of 20 small circles, arranged in four rows and five columns.

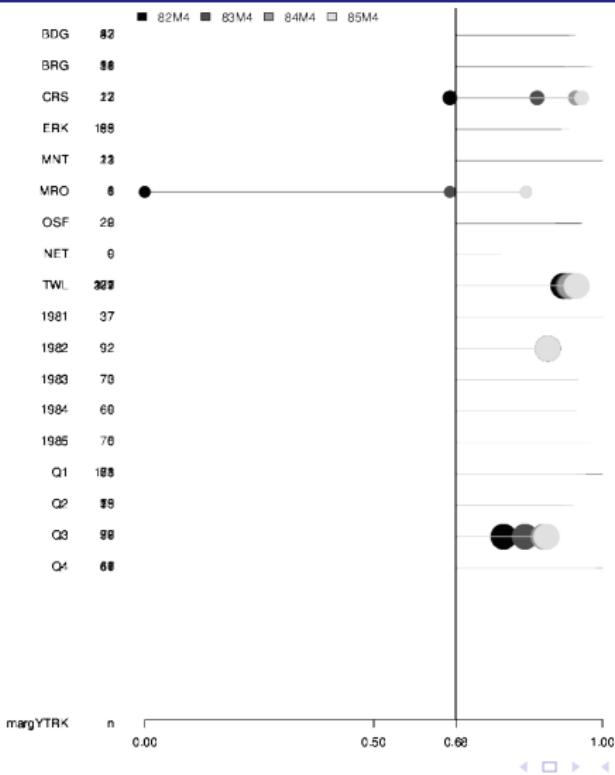
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A 5x5 grid of 25 small circles, arranged in five rows and five columns.

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MCAT 269

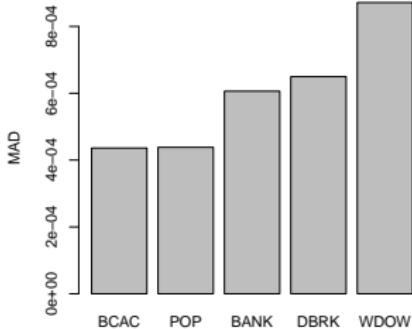
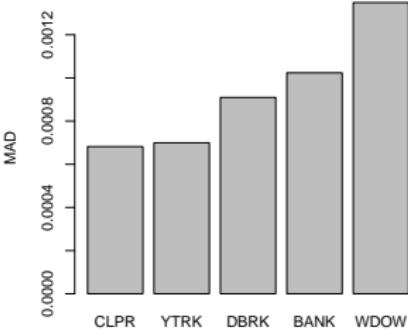
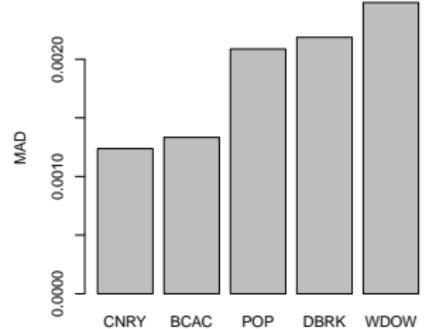


MCAT 269

78-82

78-83

78-84



## Combined

## Introduction

## Time Model

### Prior Model

## Interaction Model

### Time Block

Proofs

A 4x4 grid of 16 small circles. The bottom-left circle is shaded dark grey, while the others are white.

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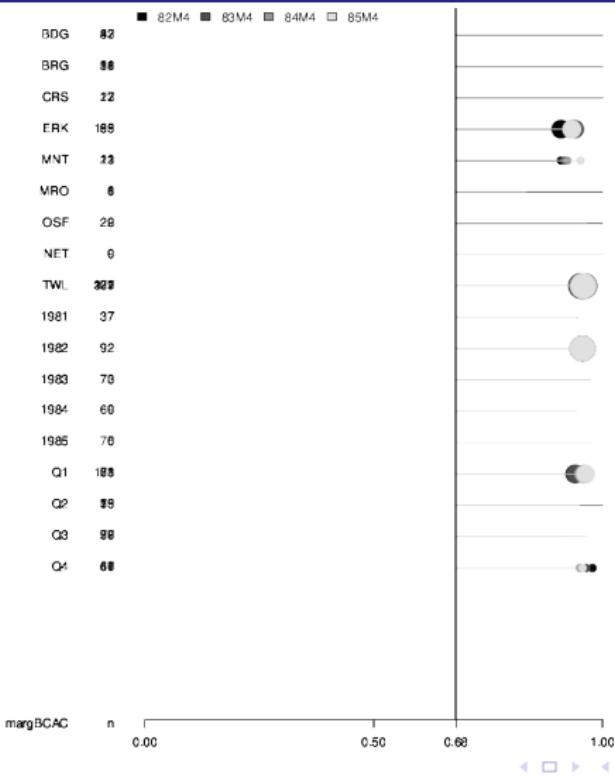
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MCAT 269



Introduction

## Time Model

## Prior Model

## Interaction Model

### Time Block

Proofs

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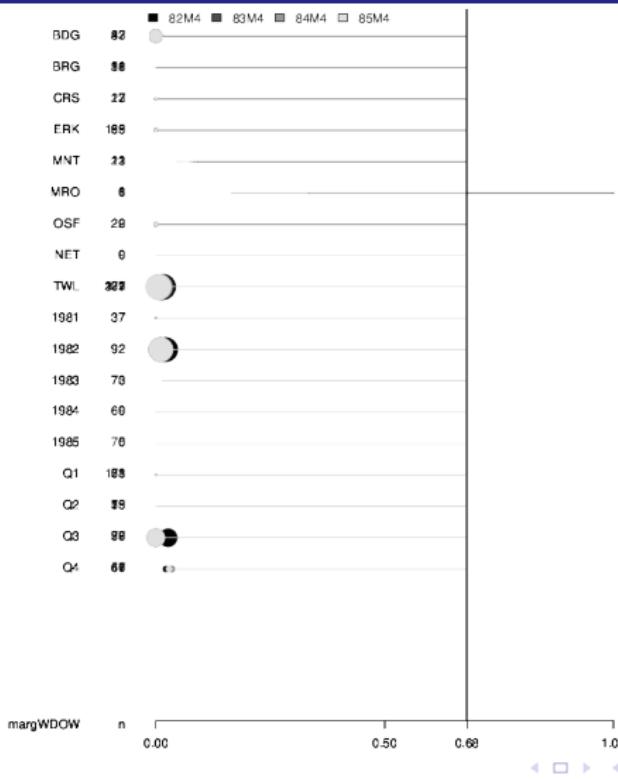
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MCAT 269



## Introduction

## Time Model

## Prior Model

## Interaction Model

## Time Block

## Proofs

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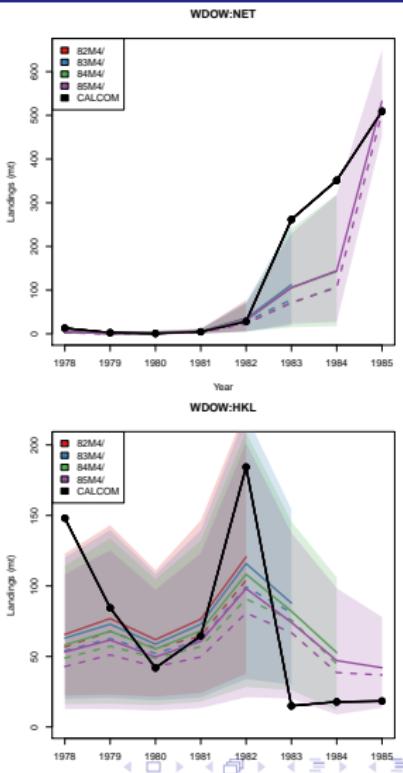
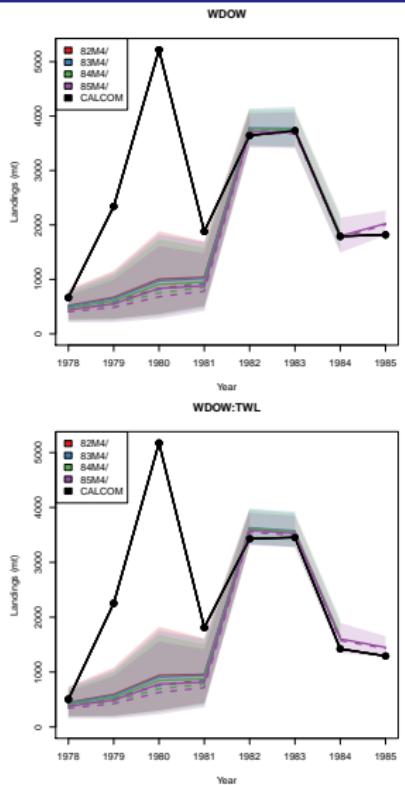
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Landings Sensitivity



## Introduction

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## Time Model

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## Prior Model

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## Interaction Model

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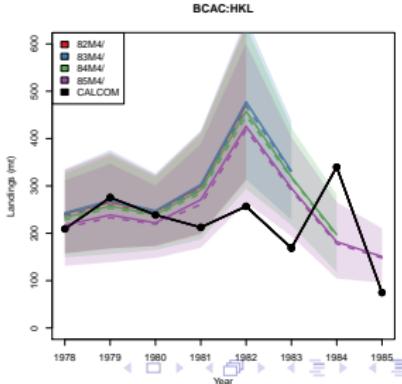
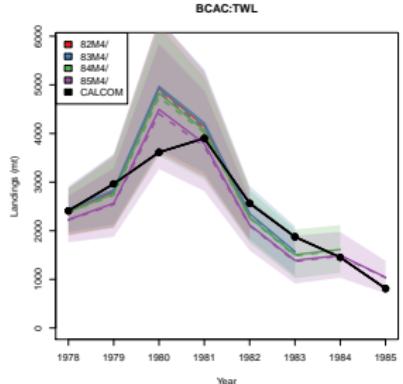
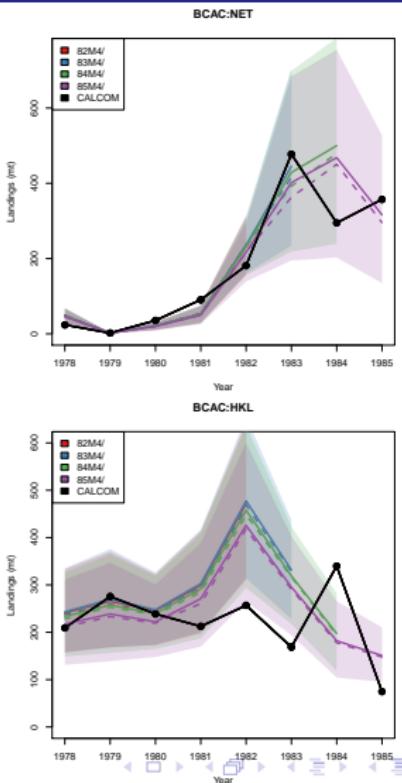
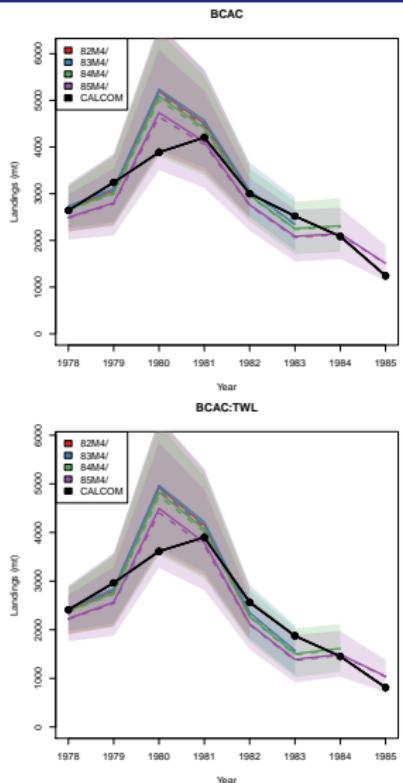
## Time Block

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## Proofs

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## Landings Sensitivity



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Improving Catch Estimation Methods in Sparsely Sampled, Mixed Stock Fisheries.



## Introduction

## Time Model

### Prior Model

## Interaction Model

## Time Block

Proofs

○

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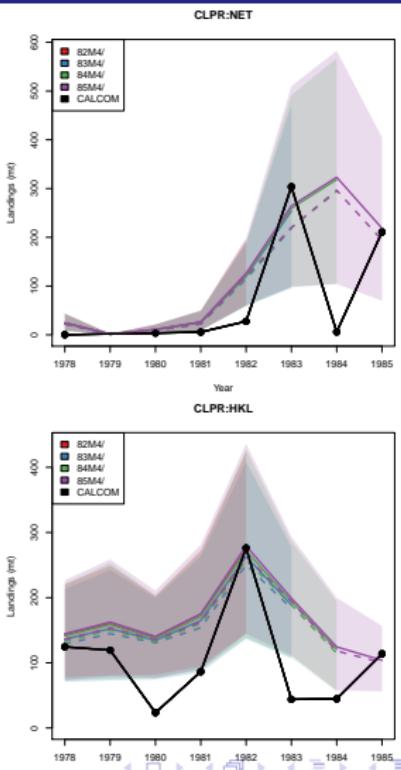
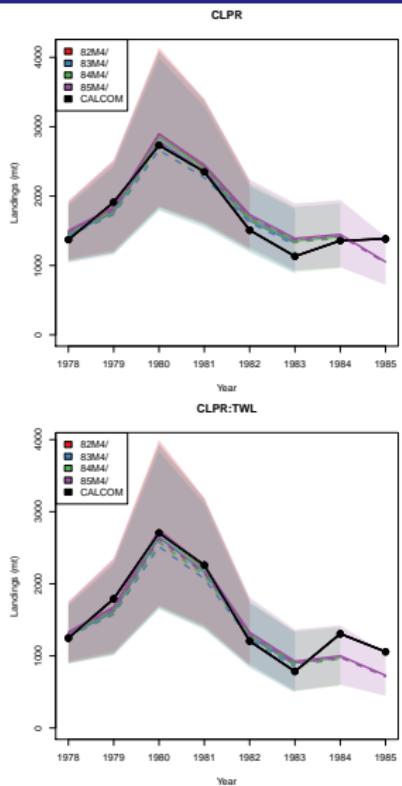
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Landings Sensitivity



Introduction

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Time Model

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Prior Model

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Interaction Model

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Time Block

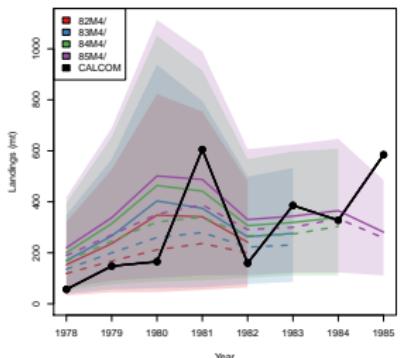
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Proofs

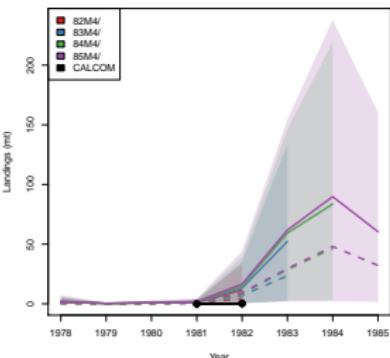
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## Landings Sensitivity

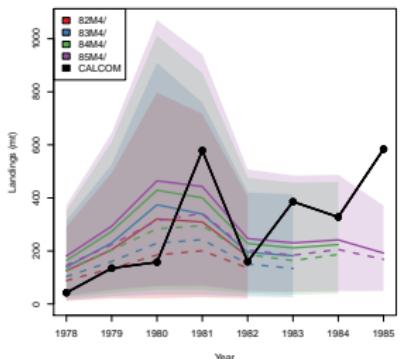
DBRK



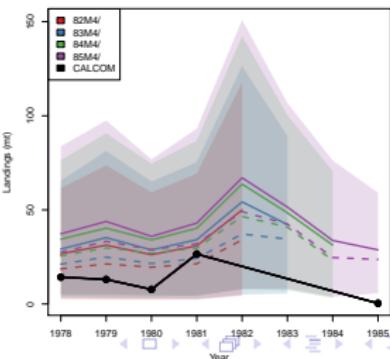
DBRK-NET



DBRK:TWL



DBRK:HKL



Nicholas Grunloh In Cooperation With: E.J. Dick, Don Pearson, John Field, Marc Mangel

Improving Catch Estimation Methods in Sparsely Sampled, Mixed Stock Fisheries.



Introduction

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Time Model

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Prior Model

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Interaction Model

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Time Block

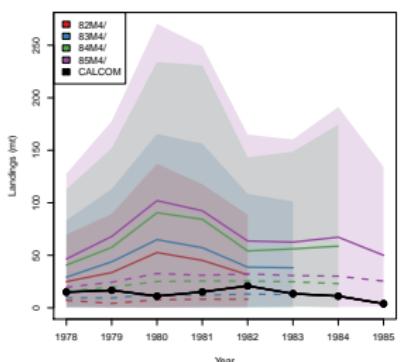
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Proofs

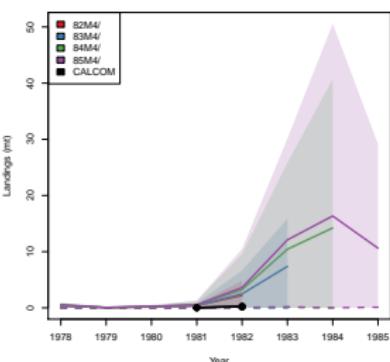
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## Landings Sensitivity

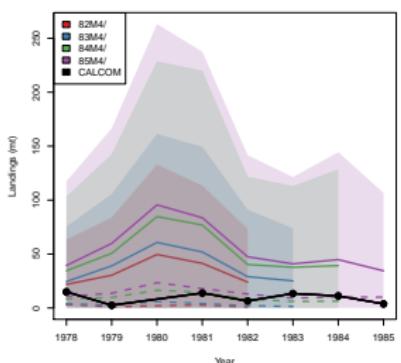
CWCD



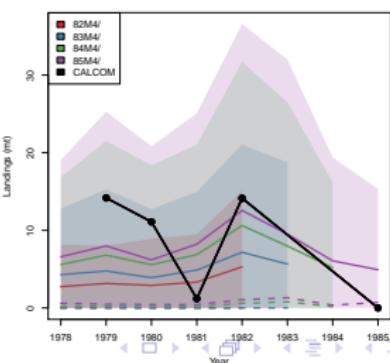
CWCD:NET



CWCD:TWL



CWCD:HKL



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## Introduction

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## Time Model

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## Prior Model

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## Interaction Model

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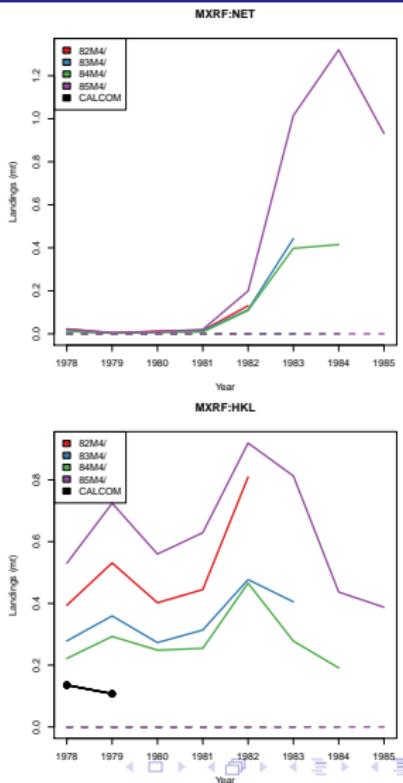
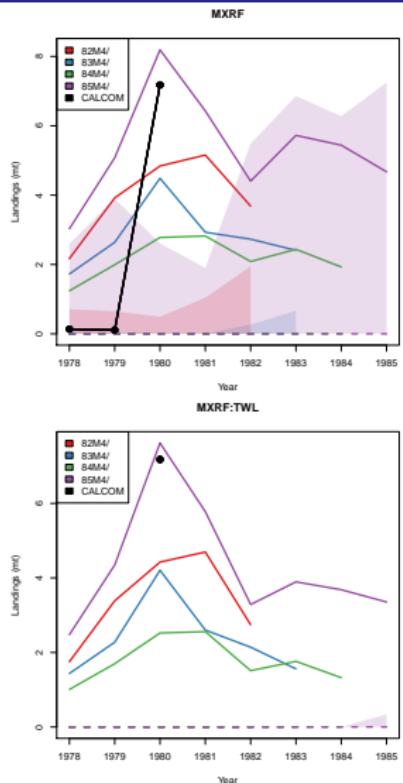
## Time Block

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## Proofs

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## Landings Sensitivity



Nicholas Grunloh In Cooperation With: E.J. Dick, Don Pearson, John Field, Marc Mangel

Improving Catch Estimation Methods in Sparsely Sampled, Mixed Stock Fisheries.



## Landings Sensitivity

## Time Blocking Summary

- The presented model is reasonably robust to time blocking decisions.
  - MCATs 250 and 253 show small shifts in performance.
  - MCAT 269 shifts performance to a greater extent.

## MCAT 250 Combined Plots

MCAT 253 Combined Plots

## MCAT 269 Combined Plots

## All Species Landings



## Proof: Species Comps Sum to One... as do Their Means.

If  $y_{jk}$  is the  $k^{\text{th}}$  draw,  $k \in \{1, \dots, K\}$ , of the posterior predictive weight of species  $j$  in a particular stratum. Then,

$$\pi_{jk} = \frac{y_{jk}}{\sum_j y_{jk}} \quad \mathbf{y}_k \neq \mathbf{0}. \quad (1)$$

The predictive mean for species  $j$  is,

$$\hat{\pi}_j = \frac{\sum_k^K \pi_{jk}}{K}. \quad (2)$$

Summing  $\hat{\pi}_j$  across species, it follows from (1) and (2) that,

$$\sum_j \hat{\pi}_j \stackrel{(2)}{=} \sum_j \frac{\sum_k^K \pi_{jk}}{K} = \frac{\sum_k^K \sum_j \pi_{jk}}{K} \stackrel{(1)}{=} \frac{\sum_k^K \sum_j \frac{y_{jk}}{\sum_j y_{jk}}}{K} = \frac{\sum_k^K 1}{K} = \frac{K}{K} = 1. \blacksquare$$



Species Comps are Negatively Correlated.

Consider a two species system.

$$\pi_1 = \frac{y_1}{y_1 + y_2} \quad \pi_2 = \frac{y_2}{y_1 + y_2} \quad \Rightarrow \quad \pi_1 + \pi_2 = 1$$

We seek to show  $\text{Corr}(\pi_1, \pi_2) < 0$ .

$$Corr(\pi_1, \pi_2) = \frac{Cov(\pi_1, \pi_2)}{\sigma_{\pi_1}\sigma_{\pi_2}} \quad \sigma_{\pi_1} \geq 0, \sigma_{\pi_2} \geq 0$$

$$\text{Corr}(\pi_1, \pi_2) \leq 0 \iff \text{Cov}(\pi_1, \pi_2) \leq 0$$

$$\begin{aligned} \text{Cov}(\pi_1, \pi_2) &= \mathbb{E}[(\pi_1 - \mathbb{E}[\pi_1])(\pi_2 - \mathbb{E}[\pi_2])] \\ &= \mathbb{E}[\pi_1 \pi_2] - \mathbb{E}[\pi_1] \mathbb{E}[\pi_2] \end{aligned}$$

$$\text{Cov}(\pi_1, \pi_2) \leq 0 \iff \mathbb{E}[\pi_1] \mathbb{E}[\pi_2] \geq \mathbb{E}[\pi_1 \pi_2]$$

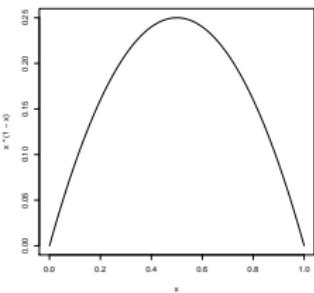
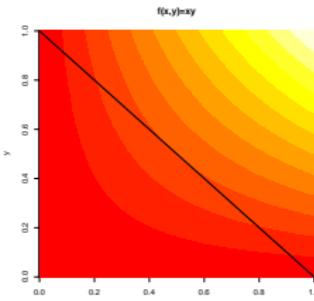
Now consider  $f(x, y) = xy$  such that  $x+y=1$ ,  $x \geq 0$ , and  $y \geq 0$ .

Jensen's Inequality for  $f$  is:

$$f(\mathbb{E}[x], \mathbb{E}[y]) \geq \mathbb{E}[f(x, y)] \quad (3)$$

Applying (3) to  $\pi$  gives  $\mathbb{E}[\pi_1] \mathbb{E}[\pi_2] \geq \mathbb{E}[\pi_1 \pi_2]$ , with equality only when  $\pi$  is a constant.

Thus  $\text{Cov}(\pi_1, \pi_2) < 0$  and  $\text{Corr}(\pi_1, \pi_2) < 0$ .



Introduction

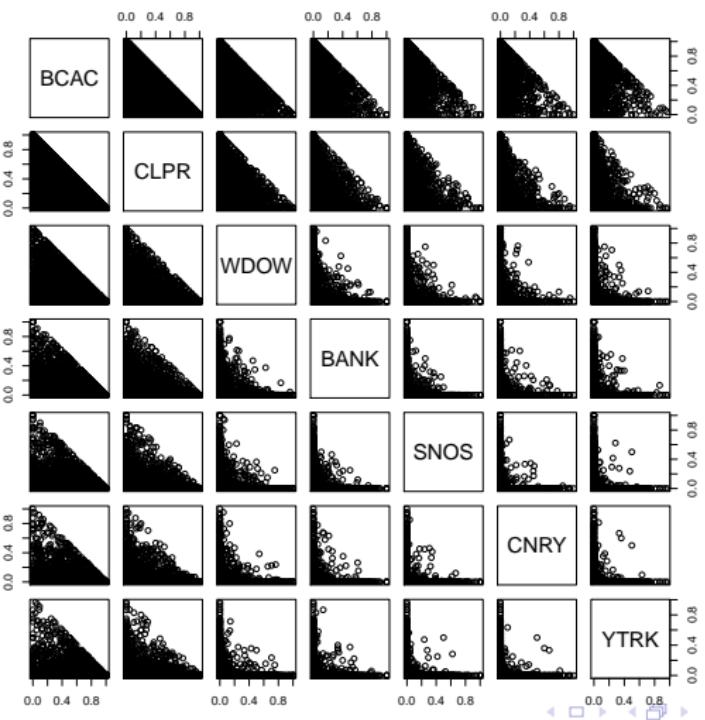
## Time Model

## Prior Model

## Interaction Model

## Time Block

Proofs



A 4x6 grid of 24 small circles, arranged in four rows and six columns.

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Proof: Species Comps are Negatively Correlated.

Here we seek to show for any two species  $l \neq m$ ,  $\text{Corr}(\pi_l, \pi_m) < 0$ .

Recall:

$$Corr(\pi_I, \pi_m) = \frac{Cov(\pi_I, \pi_m)}{\sigma_{\pi_I} \sigma_{\pi_m}} \quad \sigma_{\pi_I} \geq 0, \quad \sigma_{\pi_m} \geq 0$$

$$\text{Corr}(\pi_I, \pi_m) \leq 0 \iff \text{Cov}(\pi_I, \pi_m) \leq 0$$

$$\text{Cov}(\pi_I, \pi_m) = \mathbb{E}[(\pi_I - \mathbb{E}[\pi_I])(\pi_m - \mathbb{E}[\pi_m])] \\ = \mathbb{E}[\pi_I \pi_m] - \mathbb{E}[\pi_I] \mathbb{E}[\pi_m]$$

$$\text{Cov}(\pi_I, \pi_m) \leq 0 \iff \mathbb{E}[\pi_I]\mathbb{E}[\pi_m] \geq \mathbb{E}[\pi_I\pi_m]$$

Introduction

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Time Model

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Prior Model

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Interaction Model

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Time Block

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Proofs

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## Proof: Species Comps are Negatively Correlated Cont.

Consider the strictly concave function:

$$f(\mathbf{x}) = \prod_i x_i : \mathbf{x} \in \left\{ \mathbf{y} \mid \sum_i y_i = 1, y_i \geq 0 \right\}$$

Jensen's Inequality for  $f$  is,

$$f(\mathbb{E}[\mathbf{x}]) \geq \mathbb{E}[f(\mathbf{x})]. \quad (4)$$

From the previous proof:  $\sum_j \pi_j = 1$ ,  $\pi_j \geq 0$  and  $\sum_j \hat{\pi}_j = 1$ ,  $\hat{\pi}_j \geq 0$ .  
 Thus applying (4) to  $\pi$  gives

$$\mathbb{E}[\pi_I] \mathbb{E}[\pi_m] \geq \mathbb{E}[\pi_I \pi_m] \quad (5)$$

with equality only if  $\pi$  is a constant. Since  $\pi$  is never a constant,

$$\mathbb{E}[\pi_I] \mathbb{E}[\pi_m] > \mathbb{E}[\pi_I \pi_m] \implies \text{Cov}(\pi_I, \pi_m) < 0 \implies \text{Corr}(\pi_I, \pi_m) < 0. \blacksquare$$