Lower Missouri River Collaborative Pallid Sturgeon Population Model (CPSPM)

Fall Science Meeting
November 1, 2021

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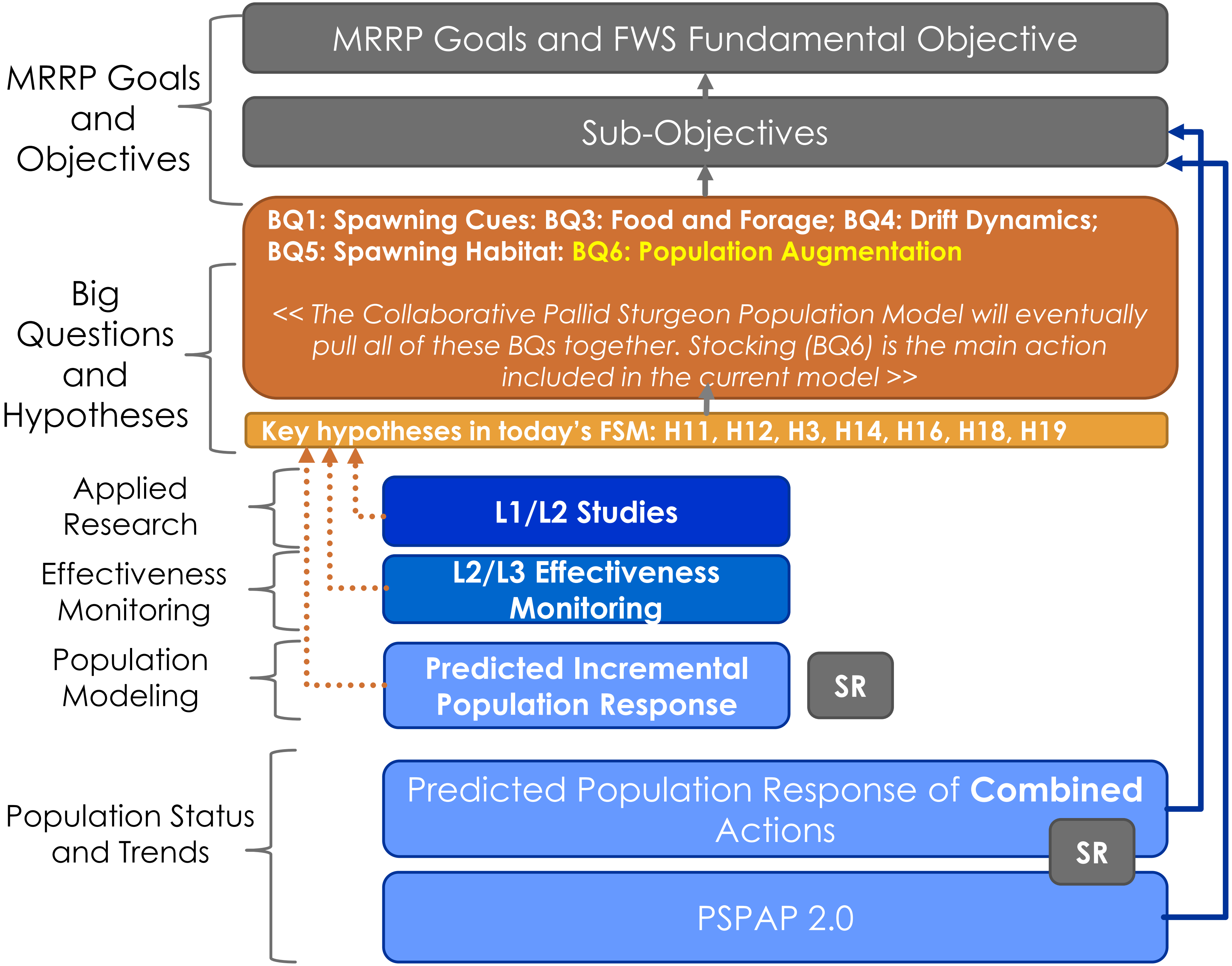


Progress Report / Management Application: Progress in modeling the pallid sturgeon population in the LMOR, and trajectories under different scenarios

→ *implications for the range of population trajectories with just stocking actions*
→ *critical life history stages*

Lower River CPSPM Structure

4 Options:

1. Deterministic Leslie Matrix Model
    - Like that used in the Upper River for the Fort Peck EIS

Deterministic CPSPM: Leslie Matrix Model

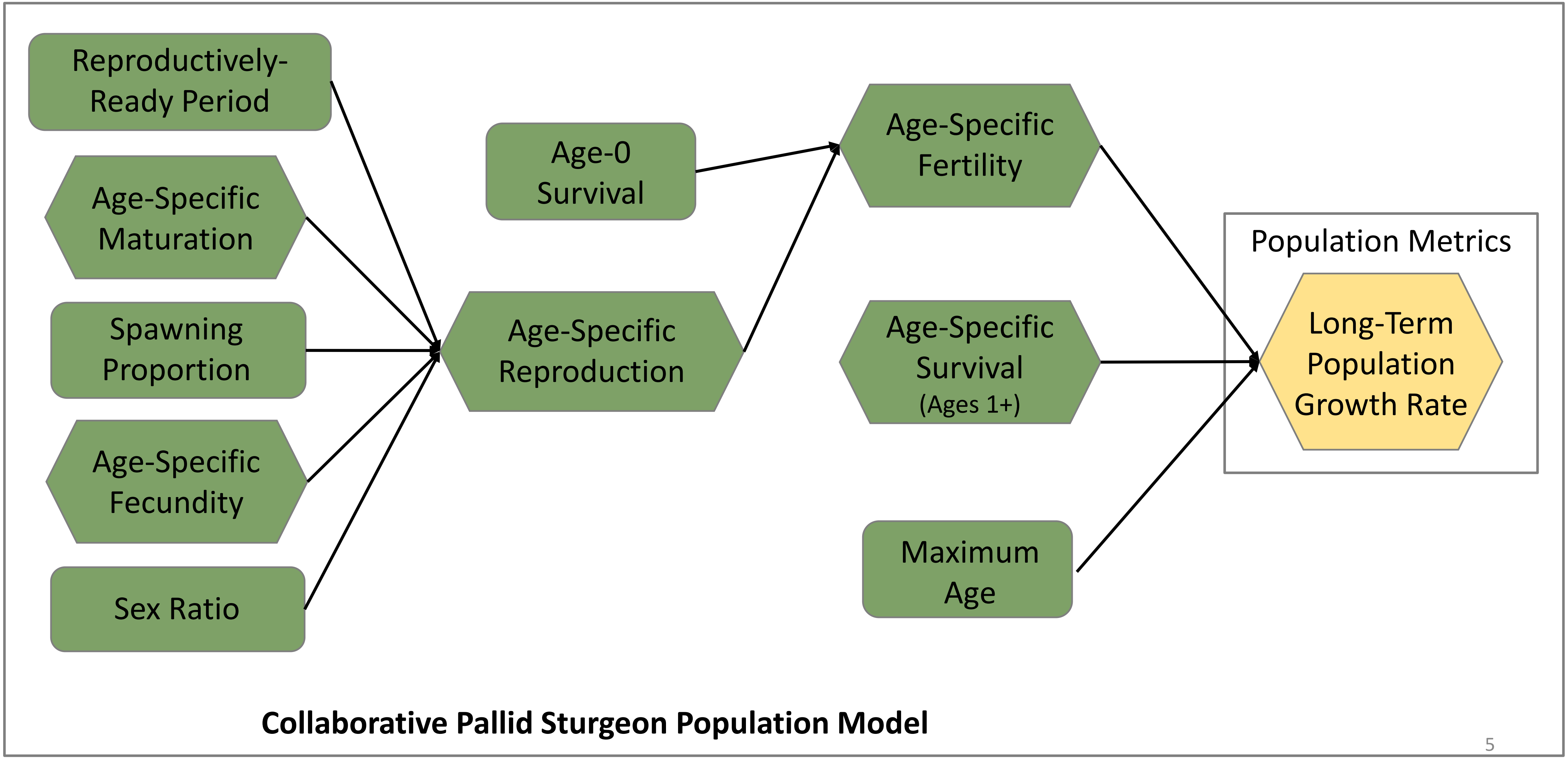
maximum age

$$\begin{pmatrix} F_1 & F_2 & F_3 & \cdots & F_{A_{max}-1} & F_{A_{max}} \\ \phi_1 & 0 & 0 & \cdots & 0 & 0 \\ 0 & \phi_2 & 0 & \cdots & 0 & 0 \\ 0 & 0 & \phi_3 & \ddots & 0 & 0 \\ \vdots & \vdots & \ddots & \ddots & \vdots & \vdots \\ 0 & 0 & 0 & \cdots & \phi_{A_{max}-1} & 0 \end{pmatrix}$$

Age-Specific Fertilities

Age-Specific Survivals

Deterministic CPSPM: Leslie Matrix Model



Deterministic CPSPM: Parameterization

Parameter	Summary Notes	Sources
maximum age	• 41 years old	Keenlyne et al. (1992), Steffensen et al. (2013), and Wildhaber et al. (2017)
	• Will look at 34-49	Hamel et al. (2020)
age-specific survivals	• computed from RPMA 4 IPSPM stage-specific survival estimates and a growth model fit to PSPAP data	PSPAP/IPSPM Estimates
age-specific maturation	• minimum age: 8	Keenlyne & Jenkins (1993) and Steffensen et al. (2013)
	• minimum length: 800mm	
	• computed from growth model fit to PSPAP data	
reproductively-ready period	• distribution generated from data in the literature	DeLonay et al. (2016) and Fuller et al. (2008)
	• range: 2-5 years mean: 2.95 years	
spawning proportion	• 1 (all reproductively-ready females spawn) • Analyses will look at a range	Assumed no atresia
age-specific fecundity	• used an age-length growth model and a length-fecundity model to simulate fecundity at age	PSPAP data Rob Holm, unpublished data
	• models were fit with RPMA 4 pallid sturgeon PSPAP data and data provided by the hatcheries, respectively	
sex ratio	• 0.5 (1:1)	Assumed equal sex ratio
age-0 survival	• 0.000075 (75 in 1 million)	Pine et al. (2001)
	• ≤0.0004 in gulf sturgeon	

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Deterministic CPSPM: Leslie Matrix Model

Age-Specific Survivals

- Utilize recent stage-specific survival estimates from PSPAP and the IPSPM
  - Juveniles: Age-2 fish, Age-3+ fish that are <600mm 0.780
  - SubAdults: Age-3+ fish that are 600-800mm 0.932
  - Adults: Age-4+ fish that are >800mm 0.976

- Use a growth model to estimate the proportion of each age class that is in each stage and weight stage-specific survival estimates to obtain age-specific estimates

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  - SubAdults: Age-3+ fish that are 600-800mm 0.932
    Age-3 to age-7 fish that are >800mm
  - Adults: Age-8+ fish that are >800mm 0.976

    minimum maturation age of a Lower River female pallid sturgeon

- Use a growth model to estimate the proportion of each age class that is in each stage and weight stage-specific survival estimates to obtain age-specific estimates

Deterministic CPSPM: Leslie Matrix Model

Age-Specific Survivals: Growth model fits to PSPAP data

	TMB HOPS LOG(VBGF) FIT	JAGS HOPS + Unknown Age Growth Data VBGF FIT
L_∞	1065.684	1051.872
k	0.09023894	0.1008206
t_0	-2.166103	-1.830915
σ	0.1286695	47.56881
Model	$L \sim \exp\left(\mathcal{N}(\ln L_a, \sigma)\right)$	$L \sim \mathcal{N}(L_a, \sigma)$

$$L_a = L_\infty\left(1 - e^{-k(a-t_0)}\right)$$

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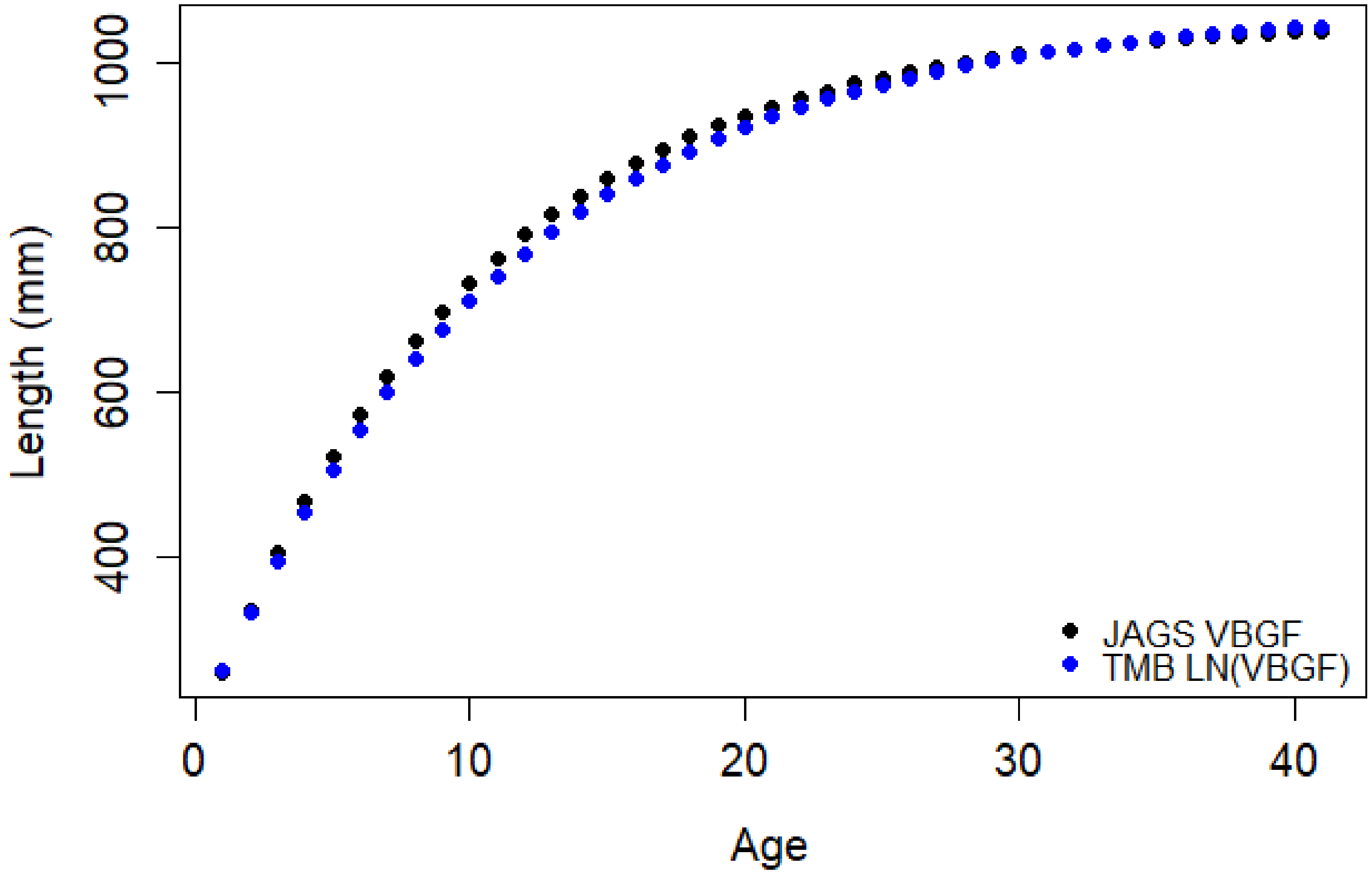
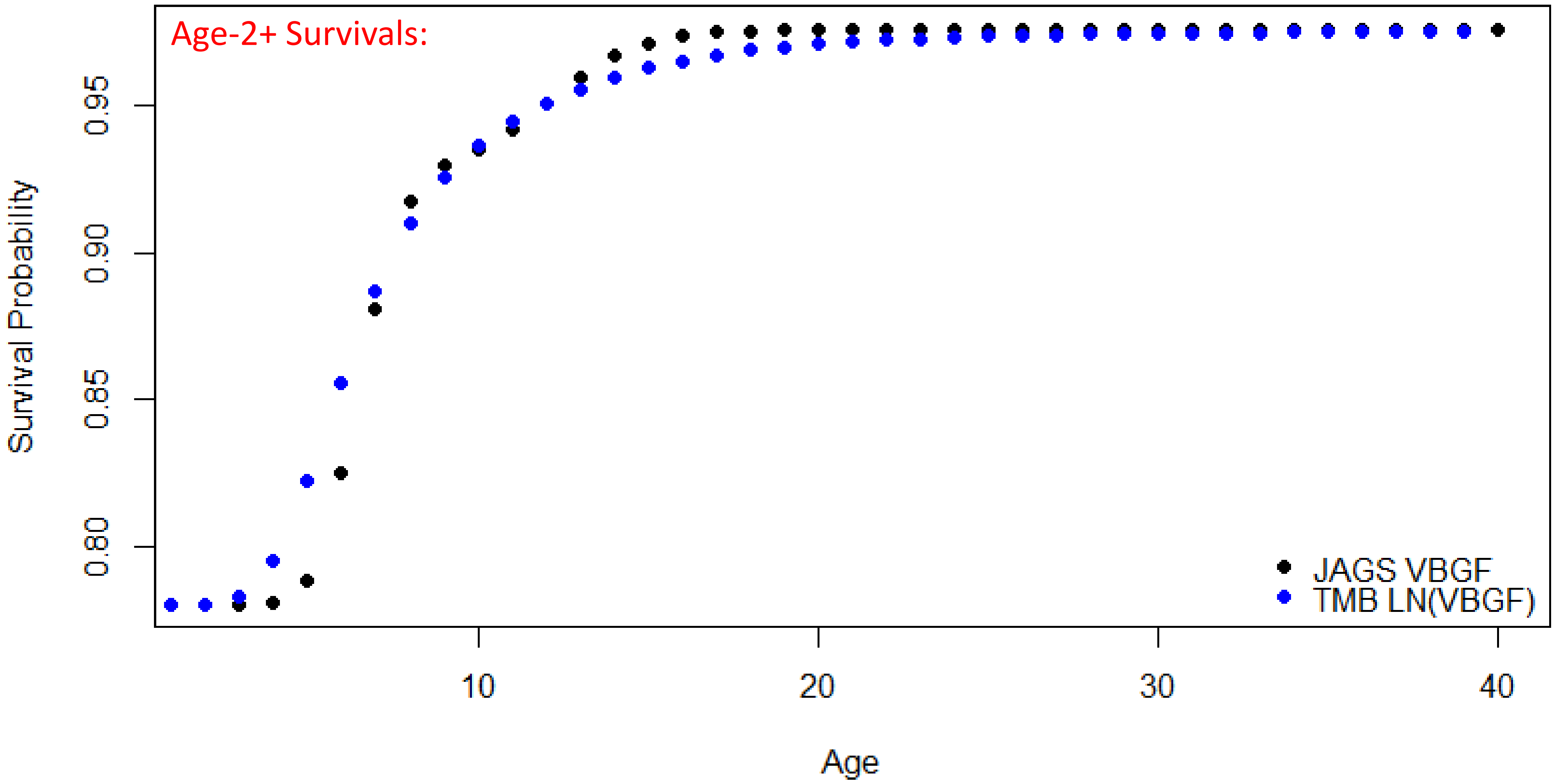


Deterministic CPSPM: Leslie Matrix Model

Age-Specific Survivals

Age-1 Survival: 0.151 (directly from PSPAP/IPSPM estimates)

Age-2+ Survivals:



Deterministic CPSPM: Leslie Matrix Model

Age-Specific Fertilities: Female maturation age

1. Use the proportion of each age class that are in each stage
   - Same proportions just computed from the growth models and age requirements when estimating survivals
   - Proportion of age-i fish that are adults (age-8+ and >800mm) minus the surviving proportion of age-i fish that were age-$(i-1)$ adults the previous time step

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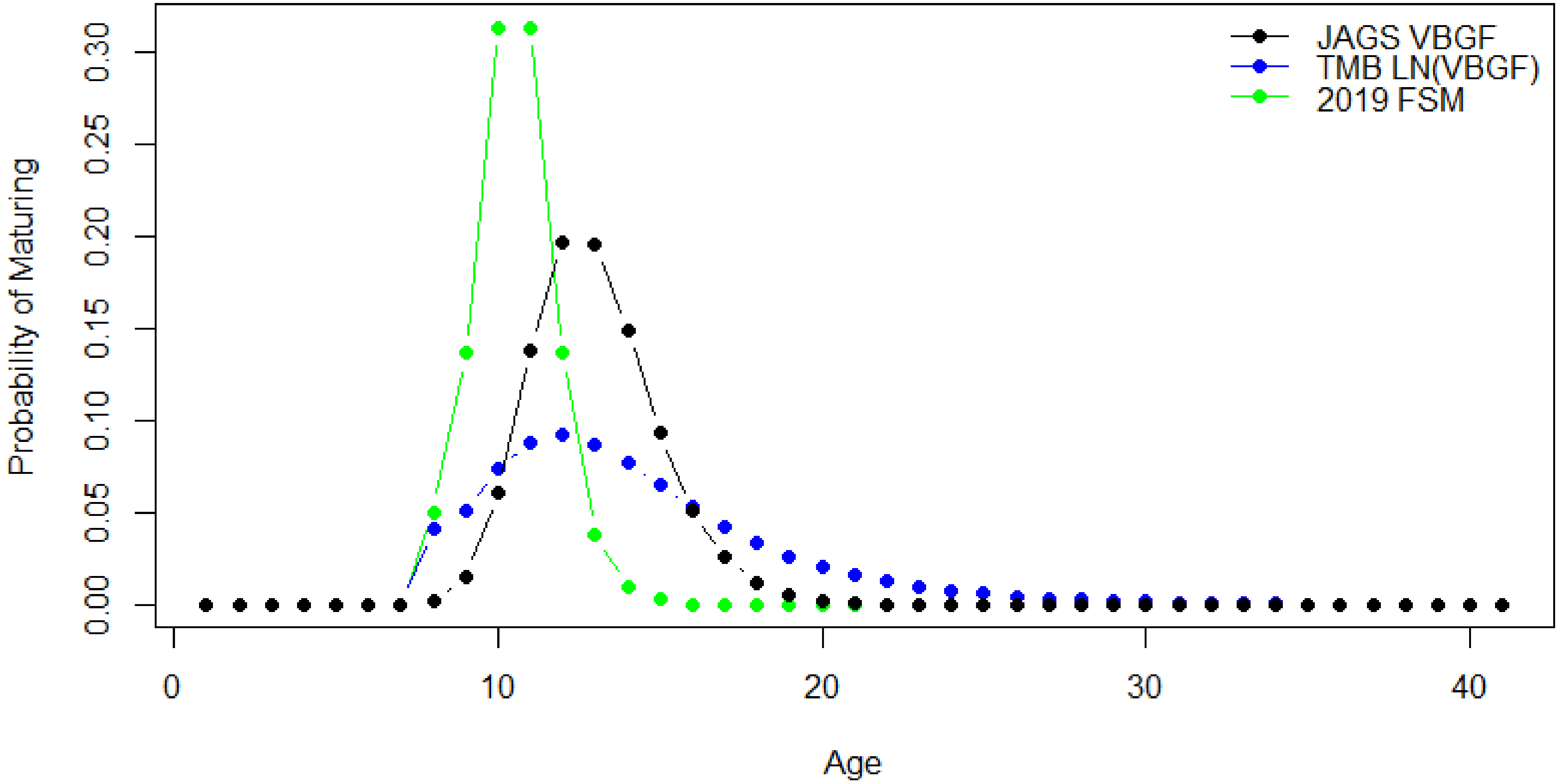
2. Compare with the maturation distribution curve presented at the 2019 FSM
   - Cumulative distribution as a logistic function with half saturation age $a_h = 10$ and maturation rate parameter $k = 1.47$
   - Discretized between a minimum age of maturation of 8 and a maximum age at which a female matures of 15

Deterministic CPSPM: Leslie Matrix Model

Age-Specific Fertilities: Female maturation age



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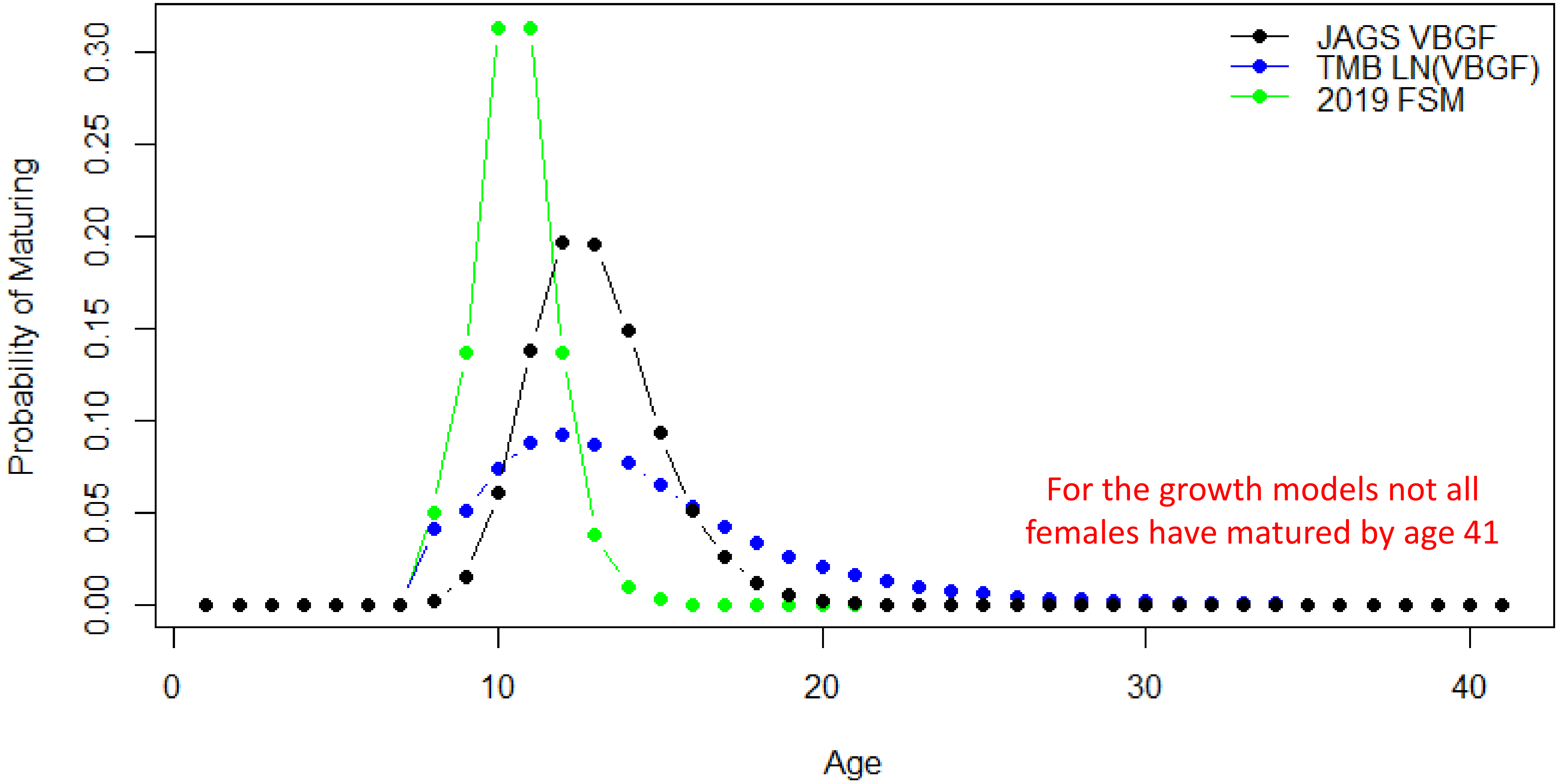
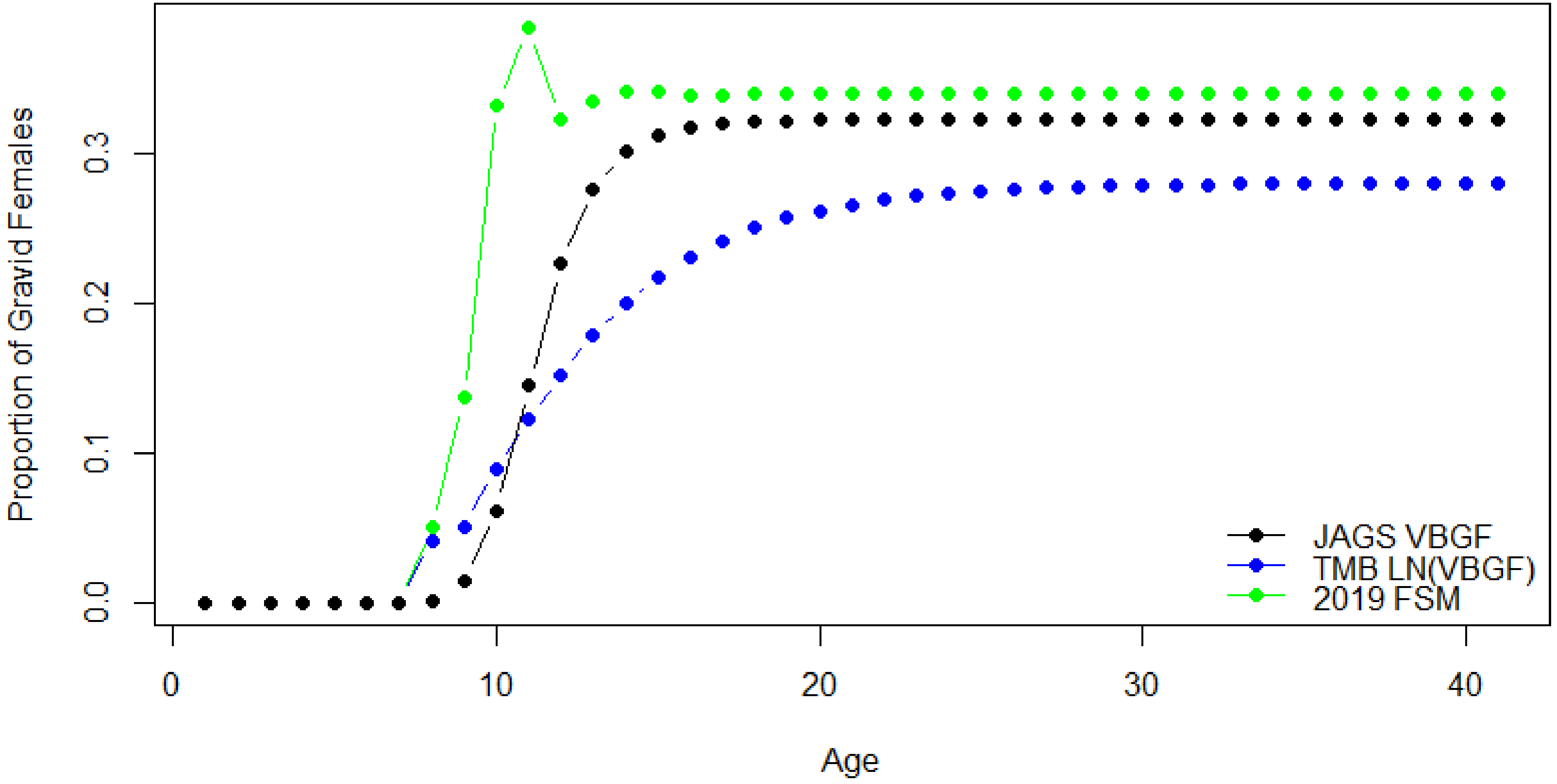


For the growth models not all females have matured by age 41

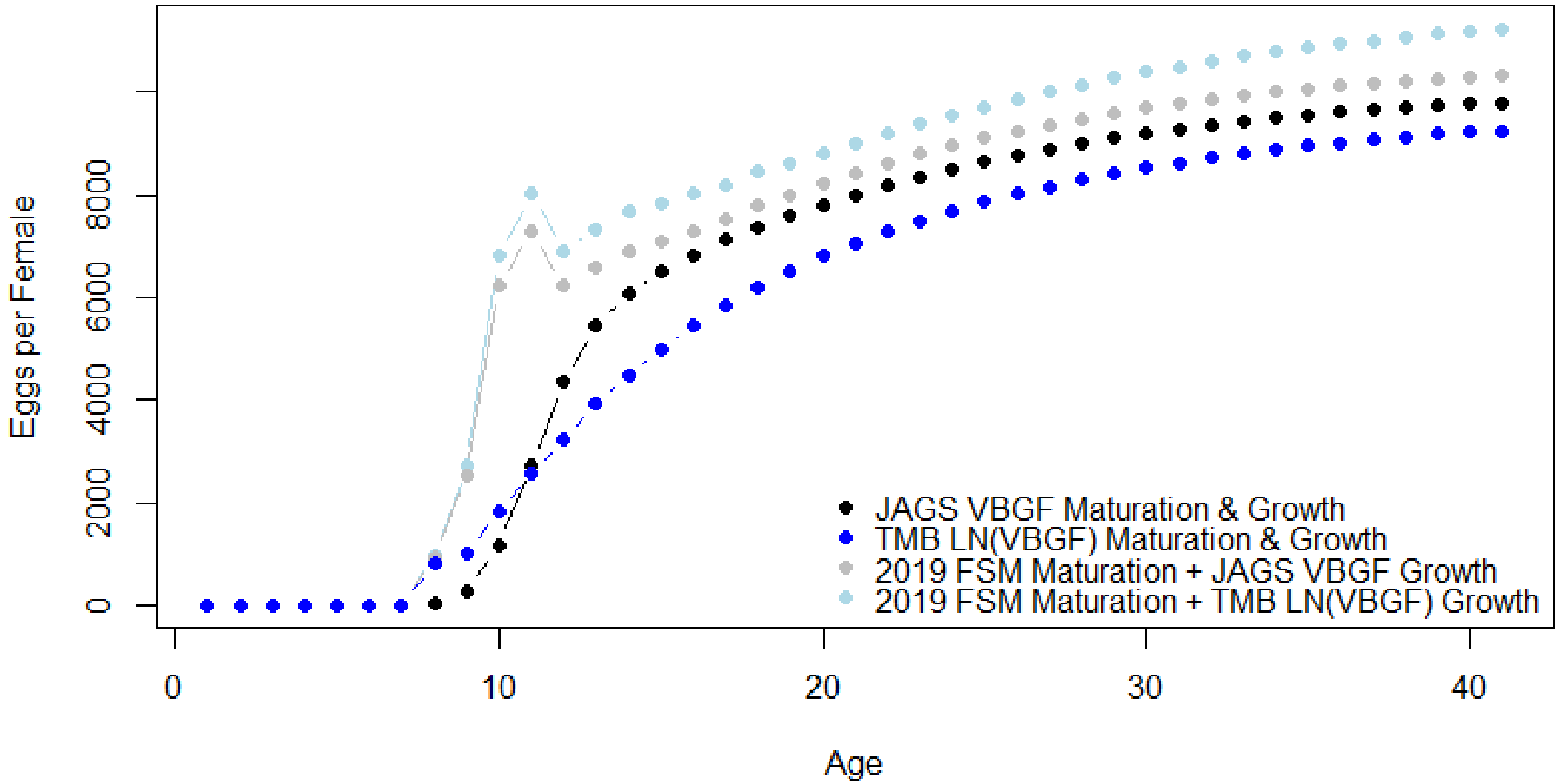
Deterministic CPSPM: Leslie Matrix Model

Age-Specific Fertilities: Expected proportion of females that are reproductively-ready to spawn



Deterministic CPSPM: Leslie Matrix Model

Age-Specific Fertilities: Expected eggs per female by age

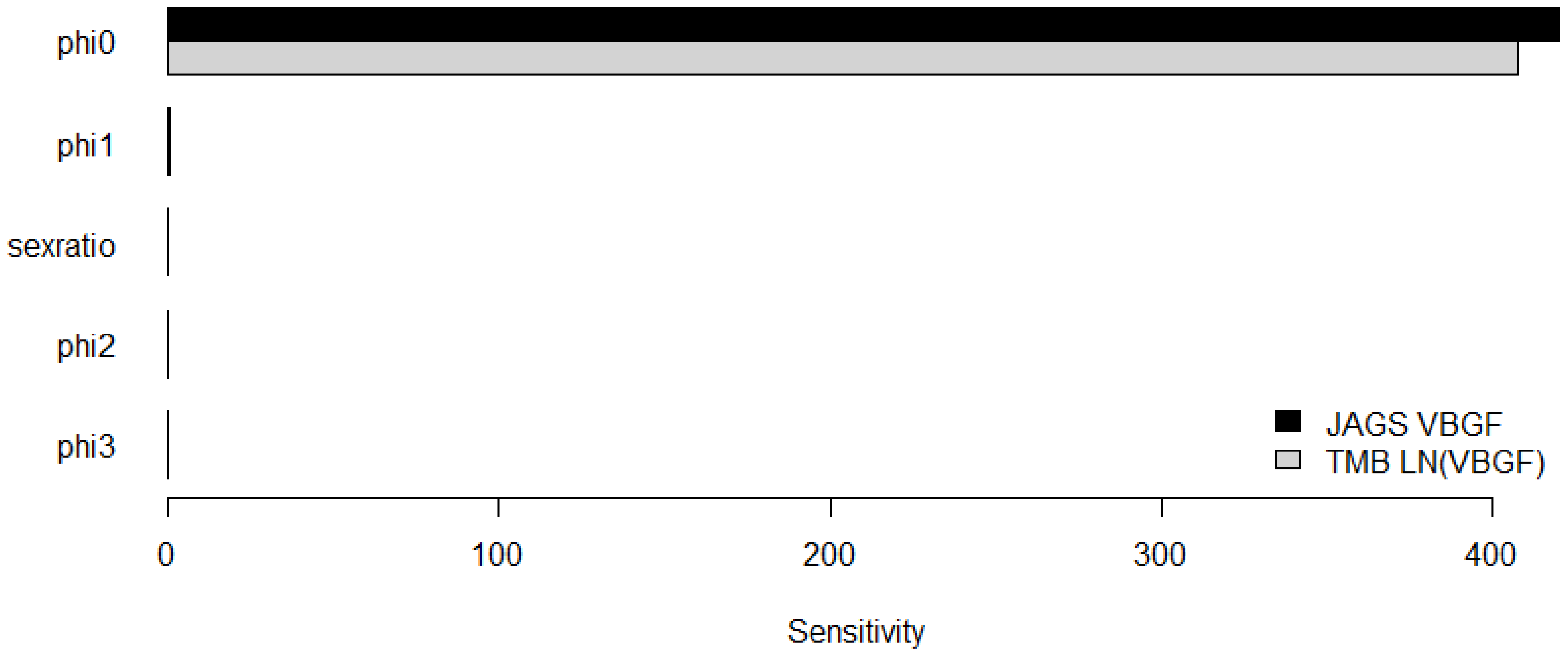


Deterministic CPSPM: Analyses

1. Sensitivity analyses
2. Age-0 survival needed for stability
3. Growth-decline boundary in terms of age-0 and age-1 survival
4. Harvest analyses

Deterministic CPSPM: Sensitivity Analyses

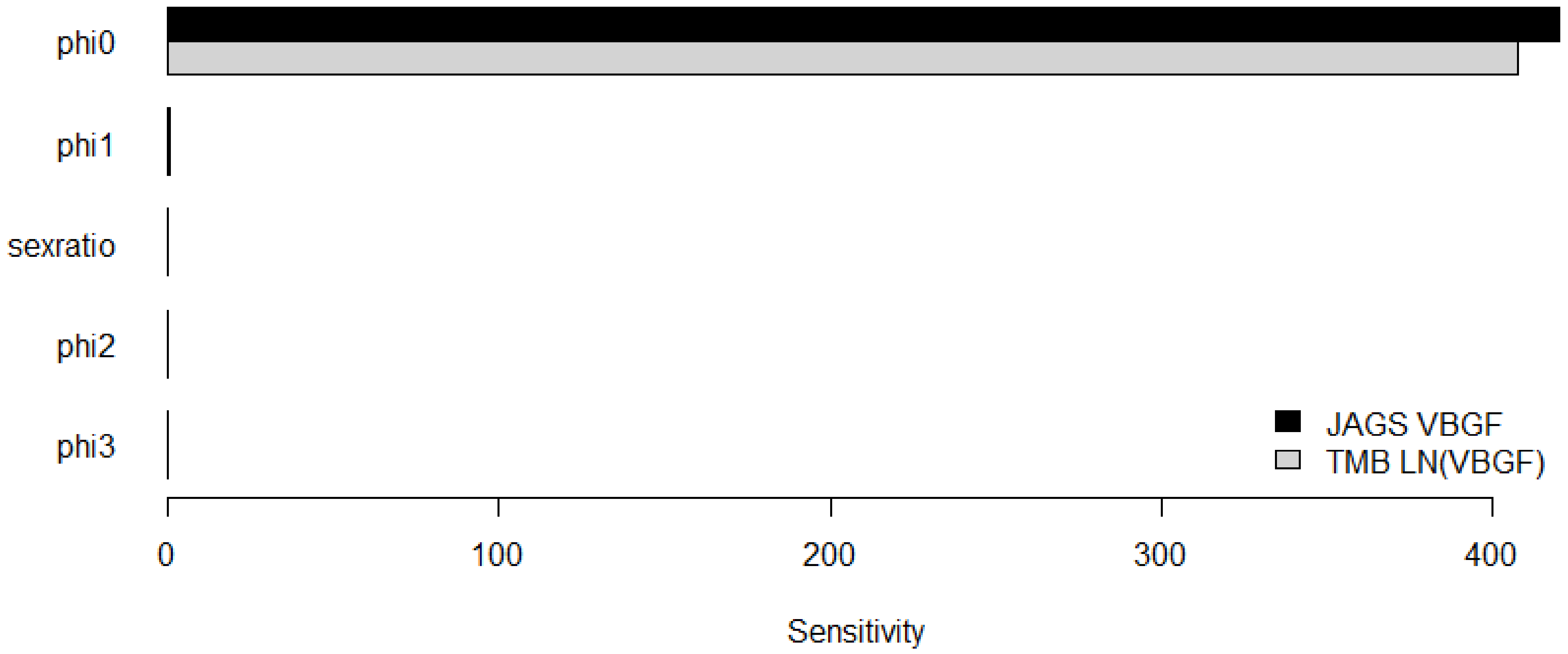
One-way sensitivity values: change in long-term lambda with a unit parameter change



Deterministic CPSPM: Sensitivity Analyses

One-way sensitivity values: change in long-term lambda with a unit parameter change

Most sensitive parameter (phi0: age-0 survival) is also one of the most uncertain!



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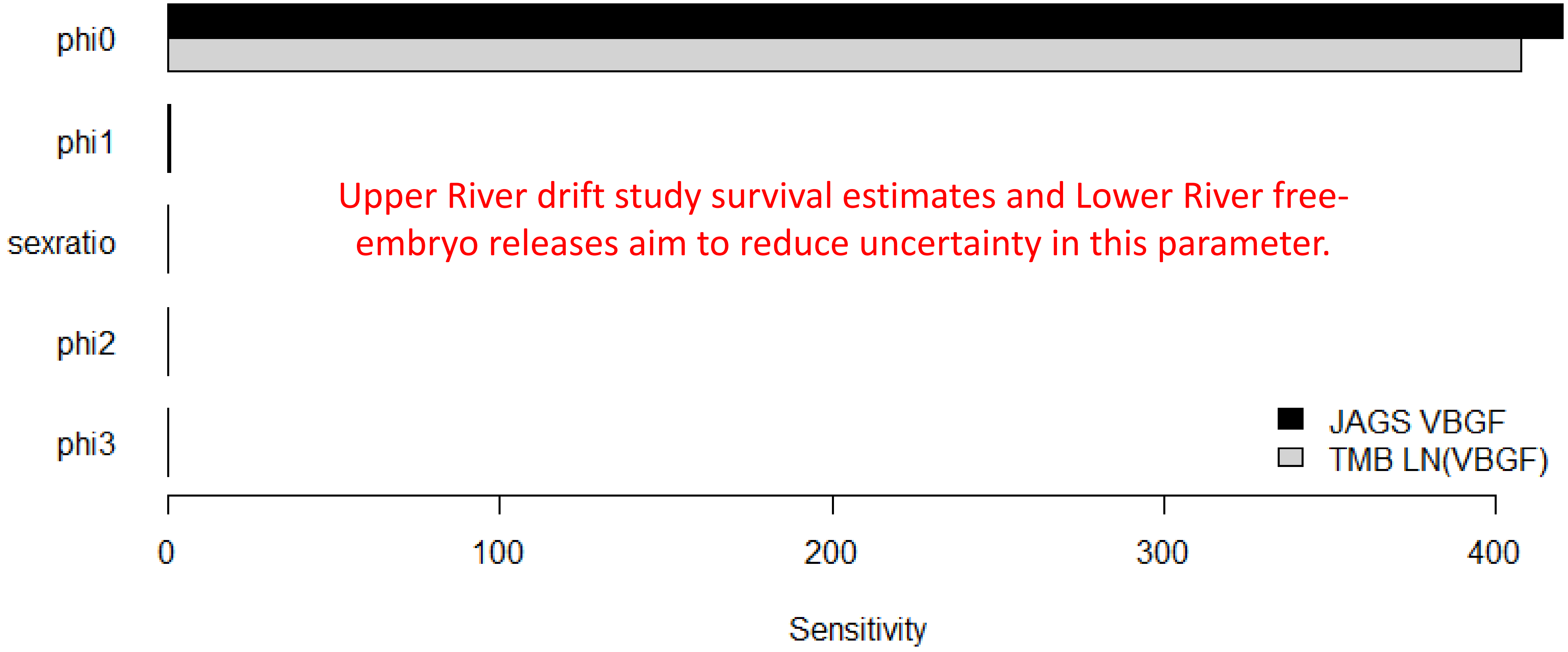

Upper River drift study survival estimates and Lower River free-embryo releases aim to reduce uncertainty in this parameter.

Deterministic CPSPM: Sensitivity Analyses

One-way elasticity values: proportional change in long-term lambda with a proportional change in a parameter value

Parameter	Elasticity Value JAGS VBGF	Elasticity Value TMB ln(VBGF)
Maximum Age	0.081456	0.089307
Age-0 thru Age-7 Survivals Sex Ratio	0.033442	0.032743

*Note: Due to the discrete nature of the maximum age parameter, its elasticity value was computed from an average rate of change as compared to all other values which were computed from an instantaneous rate of change.

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Deterministic CPSPM: Age-0 Survival for Stability

JAGS VBGF Baseline Parameters	TMB LN(VBGF) Baseline Parameters
0.000384	0.000507

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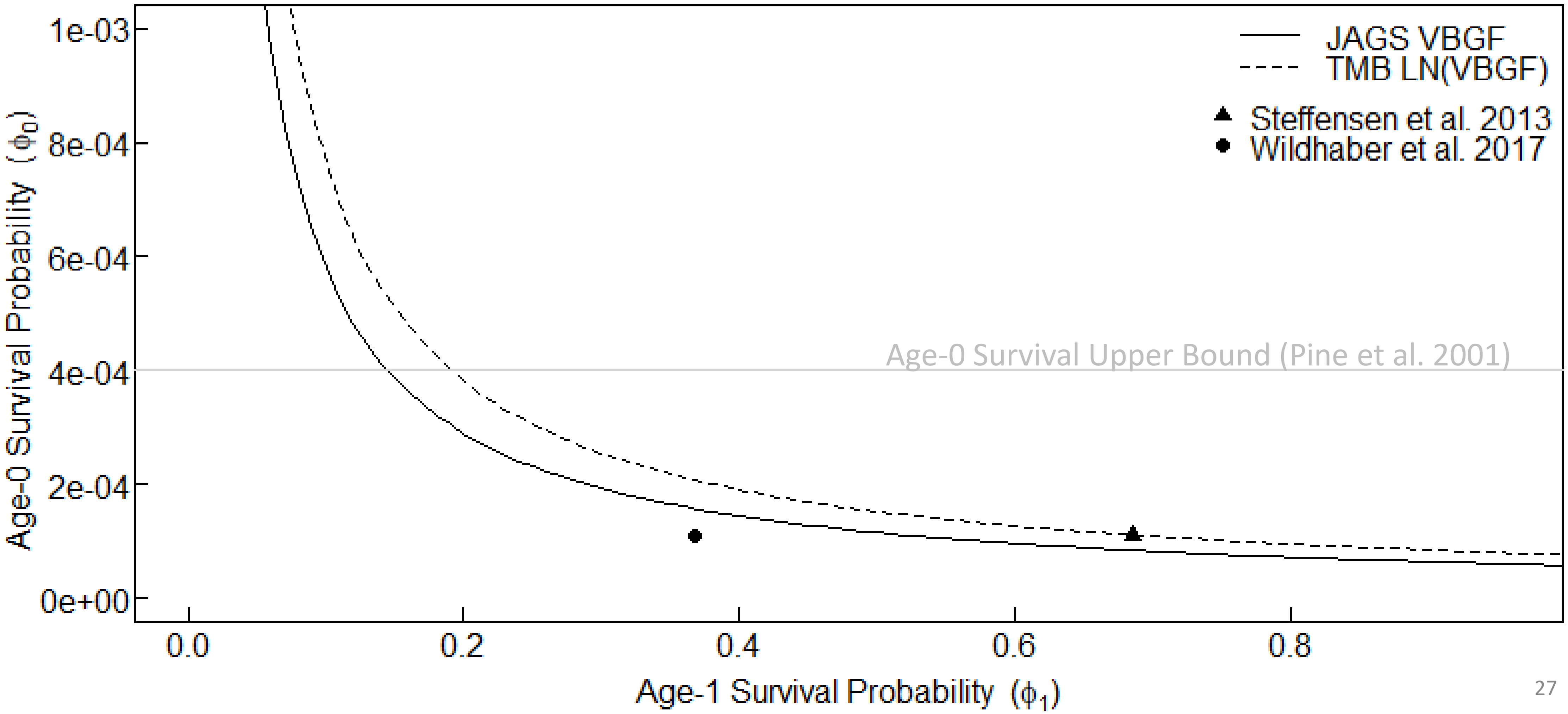
- Within the Pine et al. (2001) estimate of 0.0000-0.0004 for gulf sturgeon.
- Stabilizing age-0 survivals might be reasonably attainable for the Lower Missouri River pallid sturgeon population.

Deterministic CPSPM: Growth-Decline Boundaries

Age-0 and Age-1 Survival Combinations Above and to the Right of the Curves Support Population Growth (assuming baseline parameter values for all other variables)



Deterministic CPSPM: Harvest Analyses

- Motivation: How has past harvesting impacted recovery (e.g., time to recovery)?
- Approach: Caviar harvesting of females that are reproductively-ready to spawn occurs annually at rate h
- For the deterministic model we can analyze how different harvest levels alter
  - age-0 survival needed for long-term stability
  - long-term growth decline boundaries
  - model sensitivities
- These will give a sense of how harvest has impacted recovery, but projecting a population forward in time under uncertainty will provide a more direct understanding

Lower River CPSPM Structure

4 Options, Adding in Layers of Uncertainty:

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4 Options, Adding in Layers of Uncertainty:

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2. Demographic Stochasticity
    - "Implicit Individual Variance" (Wildhaber et al. 2017)

3. Demographic Stochasticity and Environmental Stochasticity
    - Incorporates temporal changes and/or general temporal variance
    - "Unpartitioned Variance" (Wildhaber et al. 2017)

4. Demographic Stochasticity, Environmental Stochasticity, and Parameter Uncertainty
    - Incorporates both parameter variance (at the replicate level) and temporal variance (at the time-step level)
    - "Partitioned Variance" (Wildhaber et al. 2017)

Stochastic CPSPM: Harvest & Stocking Analyses

Potential Metrics

- Time to quasi-extinction/time to a z individuals
- Quasi-extinction probability in a set timeframe
- Age-0 survival needed for a probability of stability or growth $\geq x$ in a time period of y years
- Probability of obtaining/maintaining a population $\geq z$ in a time period of y years

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Timeframe, probability level, and population size vs. growth rate are all important considerations that impact the metrics

Summary

- The Lower River CPSPM has an updated parameterization that incorporates estimates from PSPAP and the IPSPM

- Structural uncertainty: the growth model used for the parameterization approach is important to model outcomes

- Sensitive Parameters:
  - Age-0 survival: updates from 2019 drift study and free-embryo learning to be incorporated
  - Maximum age of reproductive female: potential area for future modeling analyses/learning

- The CPSPM has been expanded to multiple stochastic versions that incorporate various levels of uncertainty
  - Various metrics possible with discussions surrounding importance planned

- Future modeling considerations:
  - Functional relationships between spawning cues, spawning habitat, IRCs, and the model parameters – science efforts from today will significantly aid in this
  - Drift into and migration to and from the Mississippi