Beyond the Matrix: Assessing recovery of endangered smalltooth sawfish, *Pristis pectinata*, using stochastic individual-based model population viability analysis

Nicholas A. Farmer, John K. Carlson, Michael J. Schram, Dominic G. Swift, Brian J. Moe, Adam B. Brame, Andrew K. Wooley, R. Dean Grubbs, Tonya R. Wiley, David S. Portnoy, Brittany Troast, Enrique Montes, Gregg R. Poulakis

AES Conference, New Orleans

Spinning Fish Symposium, July 11, 2026

Goals & Objectives

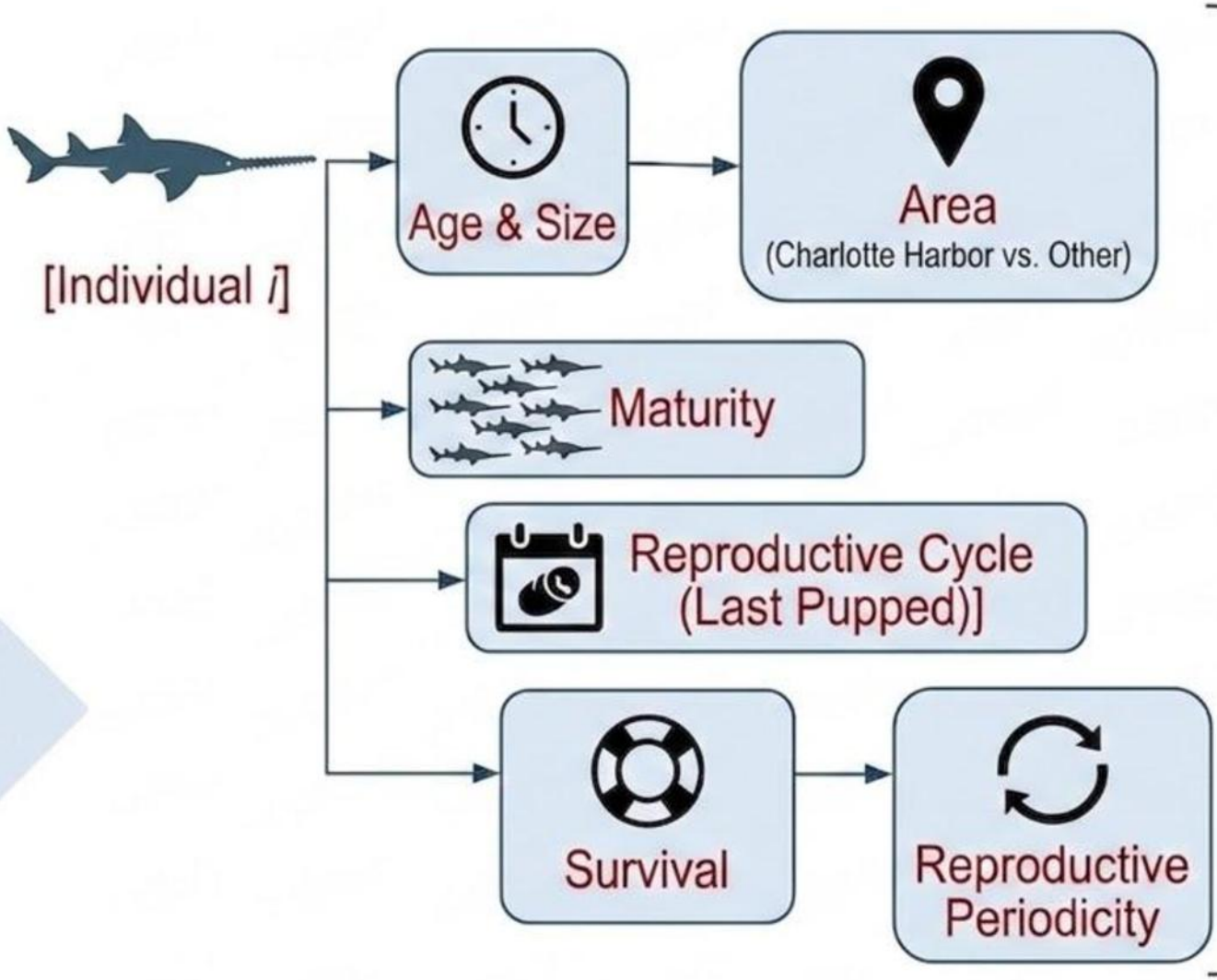
Develop a population viability model of the smalltooth sawfish population

- → Updated life history parameters and bycatch estimates
- → Capture uncertainty
- → Calibrate to empirical data
- → Eliminate unrealistic scenarios
- → Account for historical declines

Evaluate extinction risk

- → Impact of 2024/25 UME
- → Shrimp bycatch mortality
- → Recreational fishing mortality
- → Other fishery mortality
- → Juvenile survivorship through habitat alteration
- → Stochastic UMEs

Individual-Based Architecture



Emergent Population Properties OVER pool-based average rates

This IBM: Spatial tracking; individual-level demographic and environmental stochasticity; Transient Initial Age Distribution (TAD); empirically calibrated to field-derived abundance indices.

Dynamic Reproductive Periodicity and Density-dependent Litter Scaling

[Pupping Event] → [Gestation/Rest] → [Pupping]

Sample New Periodicity:
1, 2, or 3 Years
(Ave: Approx. 90% of and 3 years)

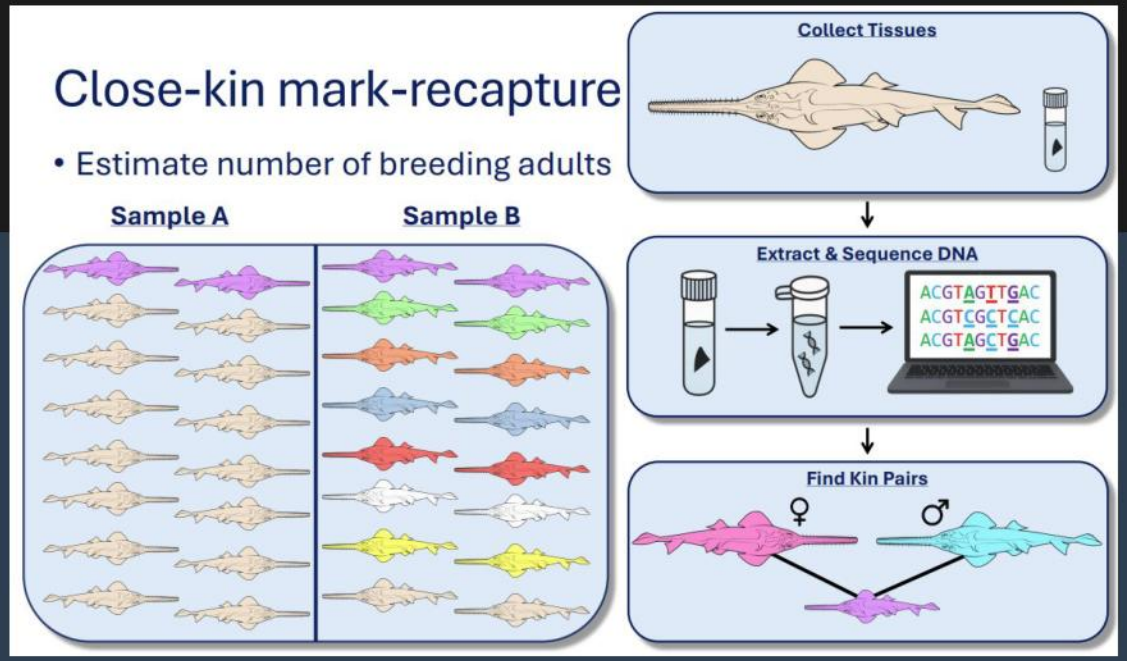
*Note: Approx. 90% **of reproductive** events are **biennial** (2 years).

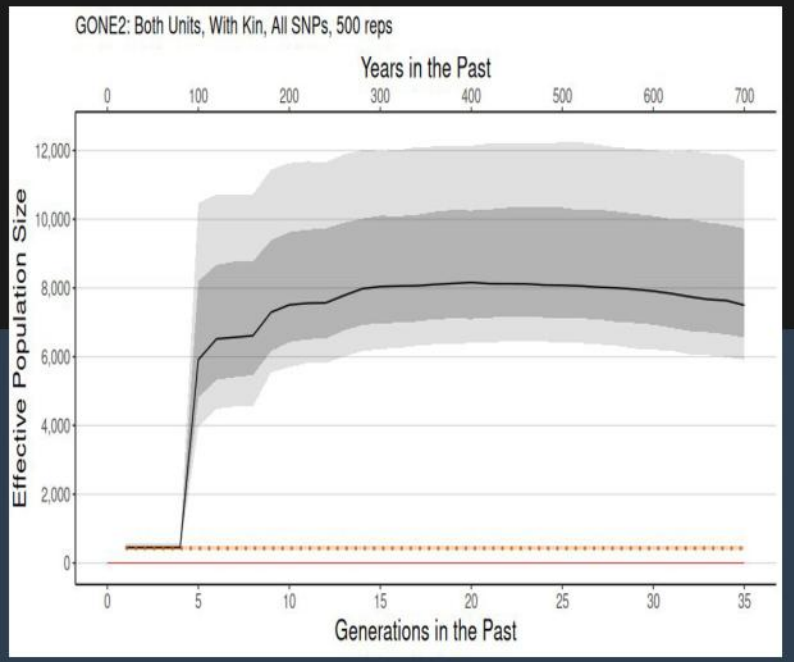
Stochastic Litter Allocation Equation (Litter Size)

$$Pups_{\_female} = Round(U|_{7,14}| \times Density_{\_Scalar} \times Sex_{\_Ratio})$$

Parameter Summary: Abundance Benchmarks

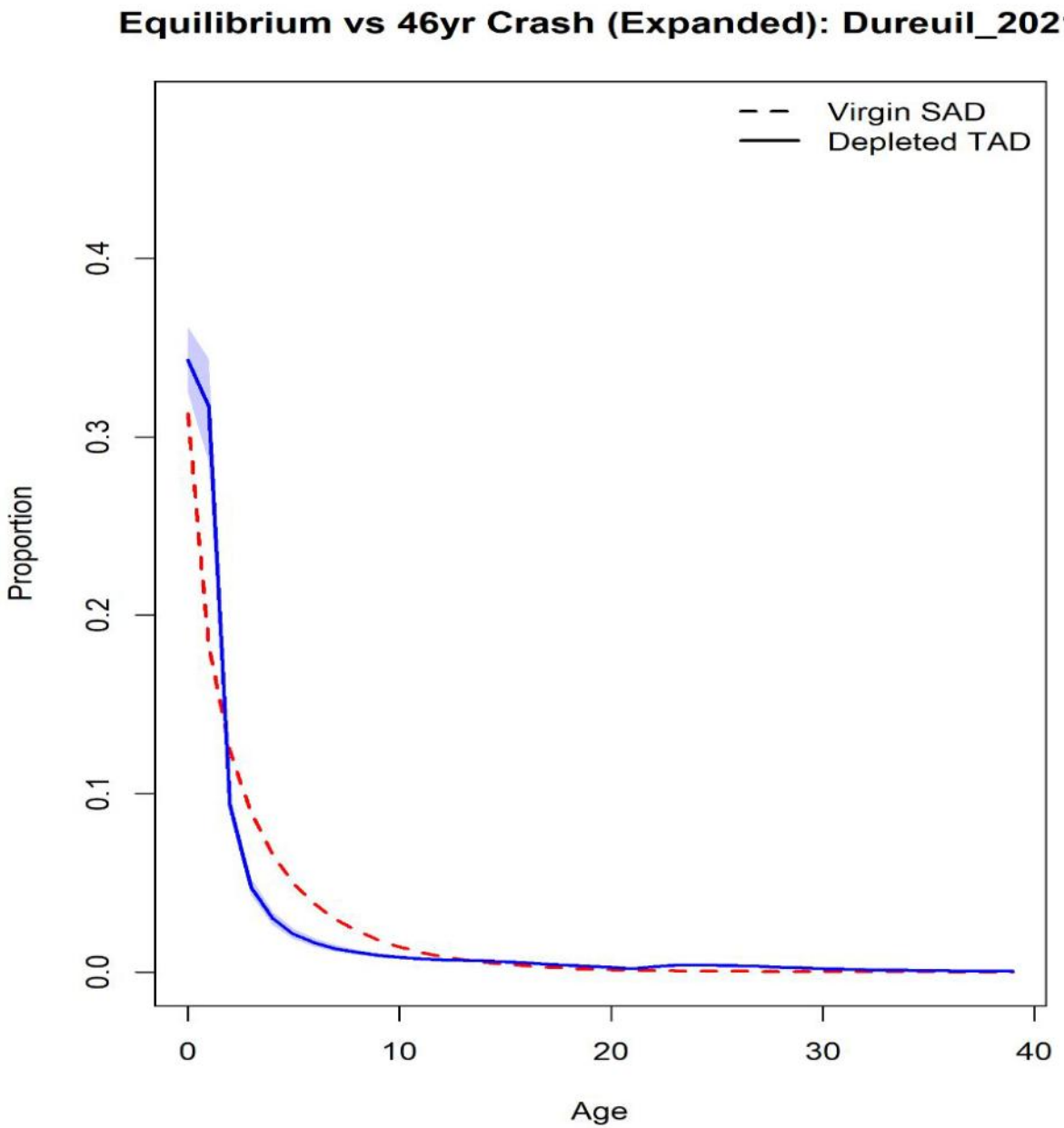
Parameter	Central Tendency	Range / Distribution	Source / Attribution
Historical Decline (1950-1996)	94.4%	Trunc. Normal (85% - 99%)	IAD Builder reconstruction anchor
2015 CKMR Window (Breeder N_c)	Varies by Model	ABC: 975 (407-1898)	Mixture models (Log-Normal draws)
		PSL_IA: 1284 (682-2175)	
		PSL_CC: 717 (385-1154)	

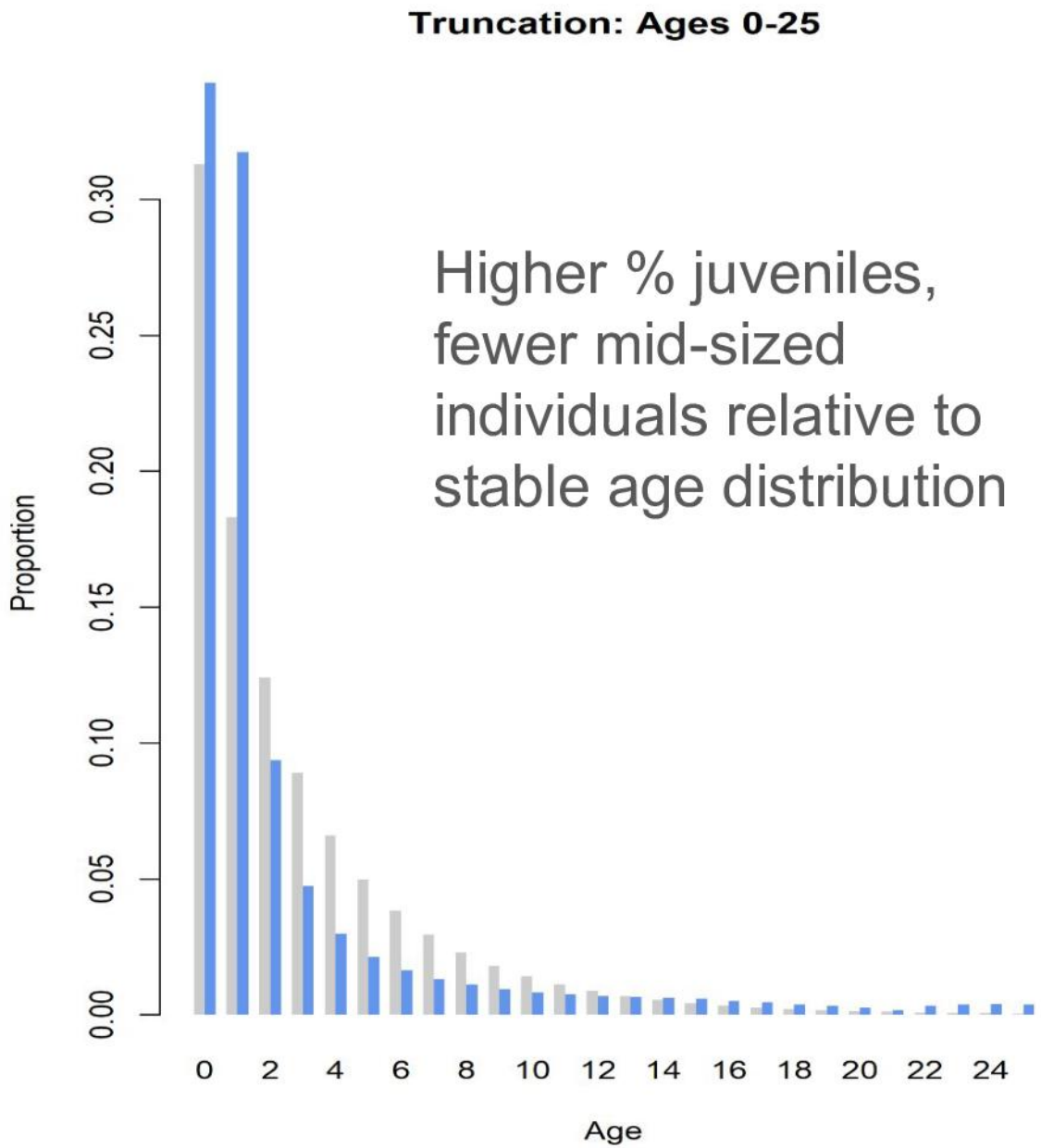




from Swift et al. (unpublished)

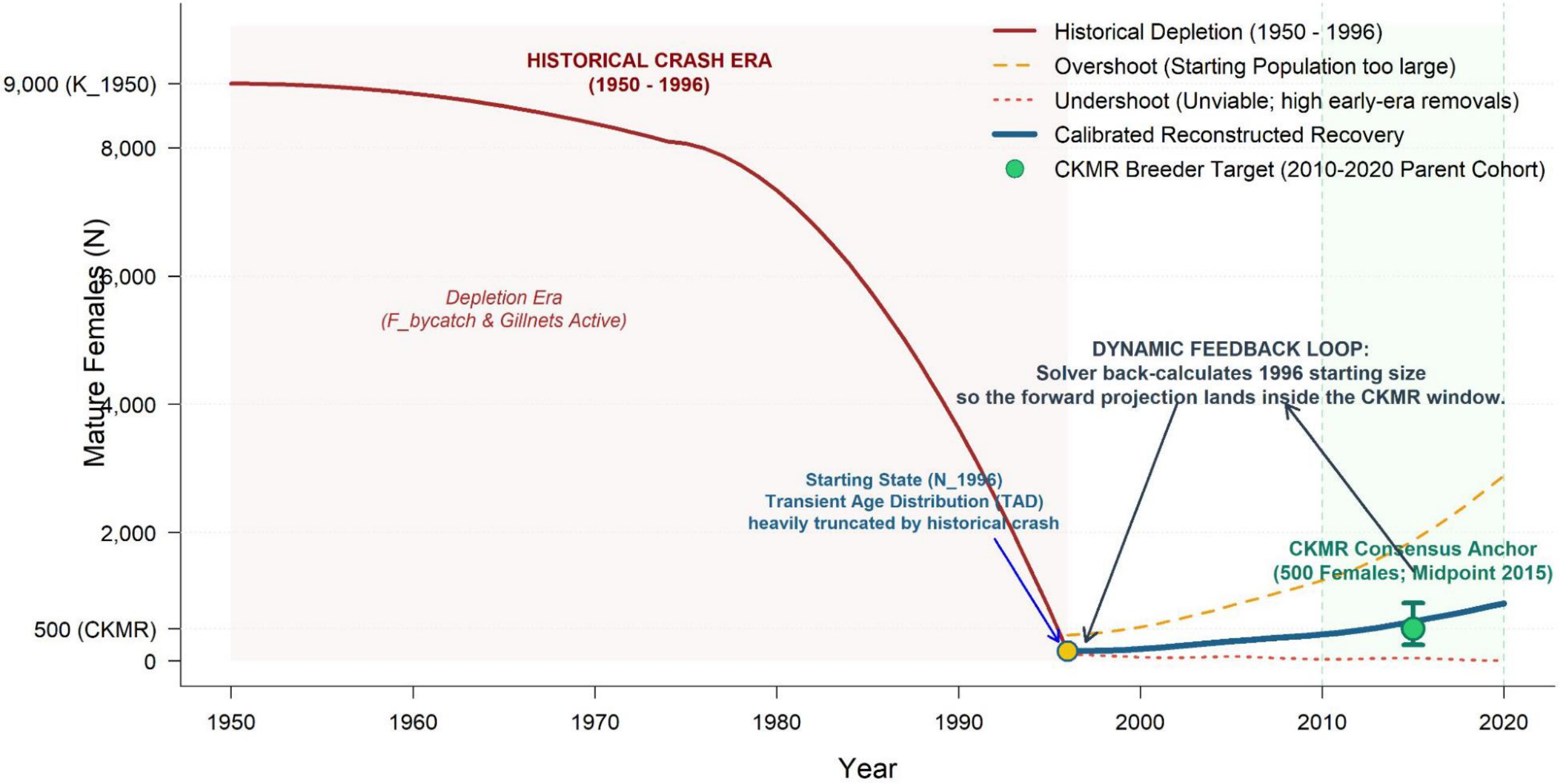
Capturing Demographic Momentum via Transient Age Distributions





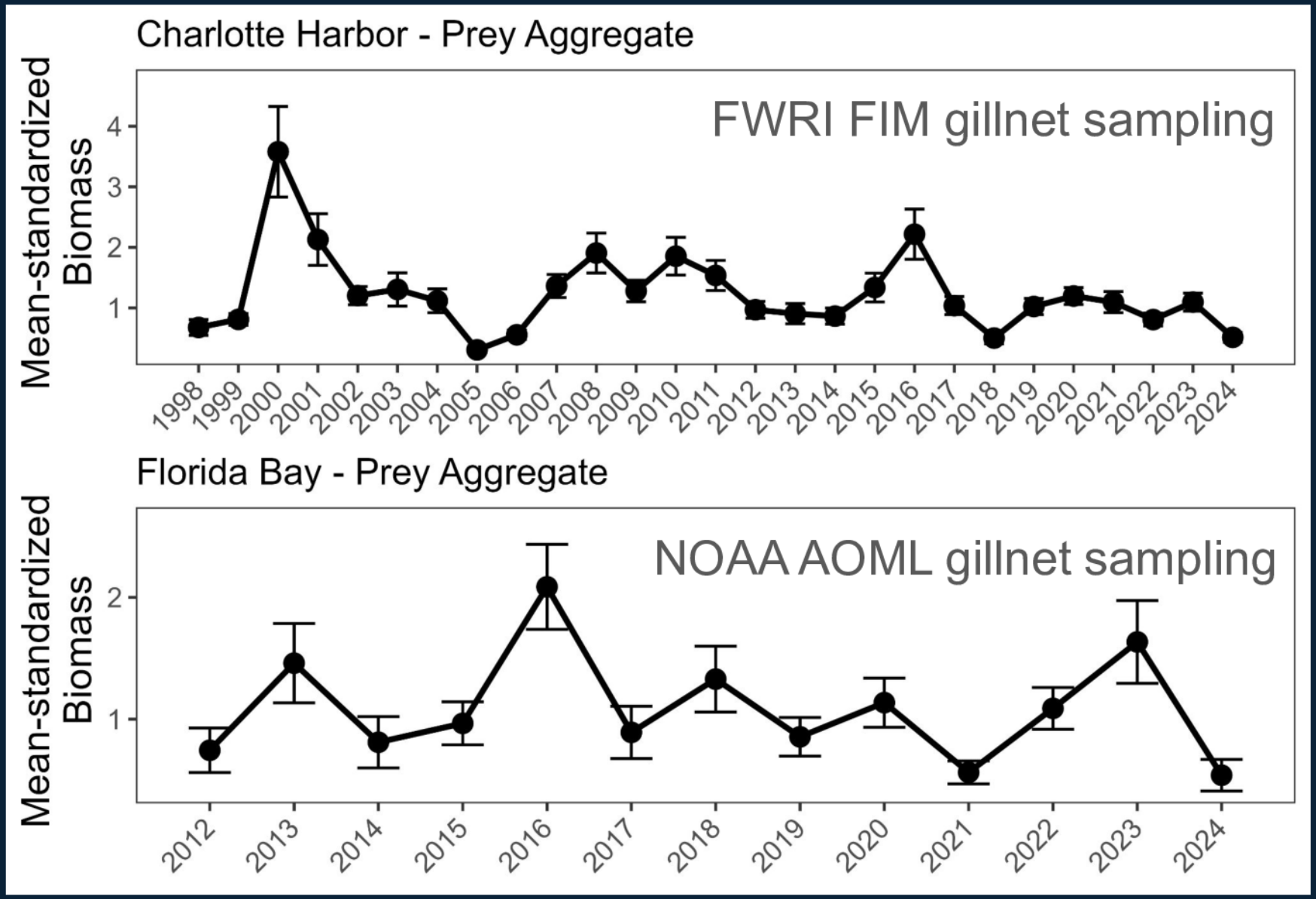
Higher % juveniles, fewer mid-sized individuals relative to stable age distribution

Developing an “Initial Age Distribution”



Spatial Nursery Tracking & Regional Asymmetry

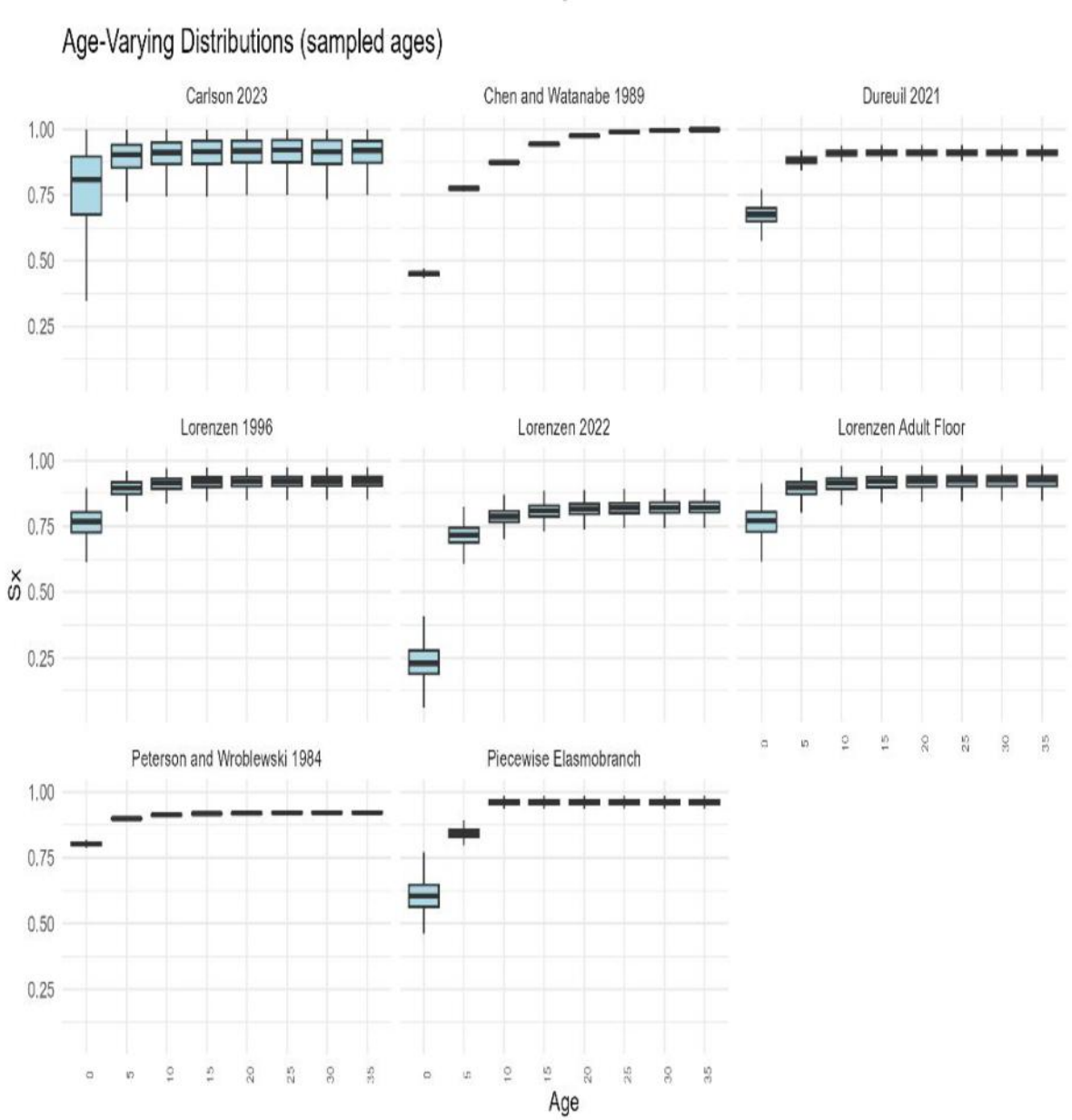
Allows generation of age- and area-specific indices along with variable juvenile survivorship

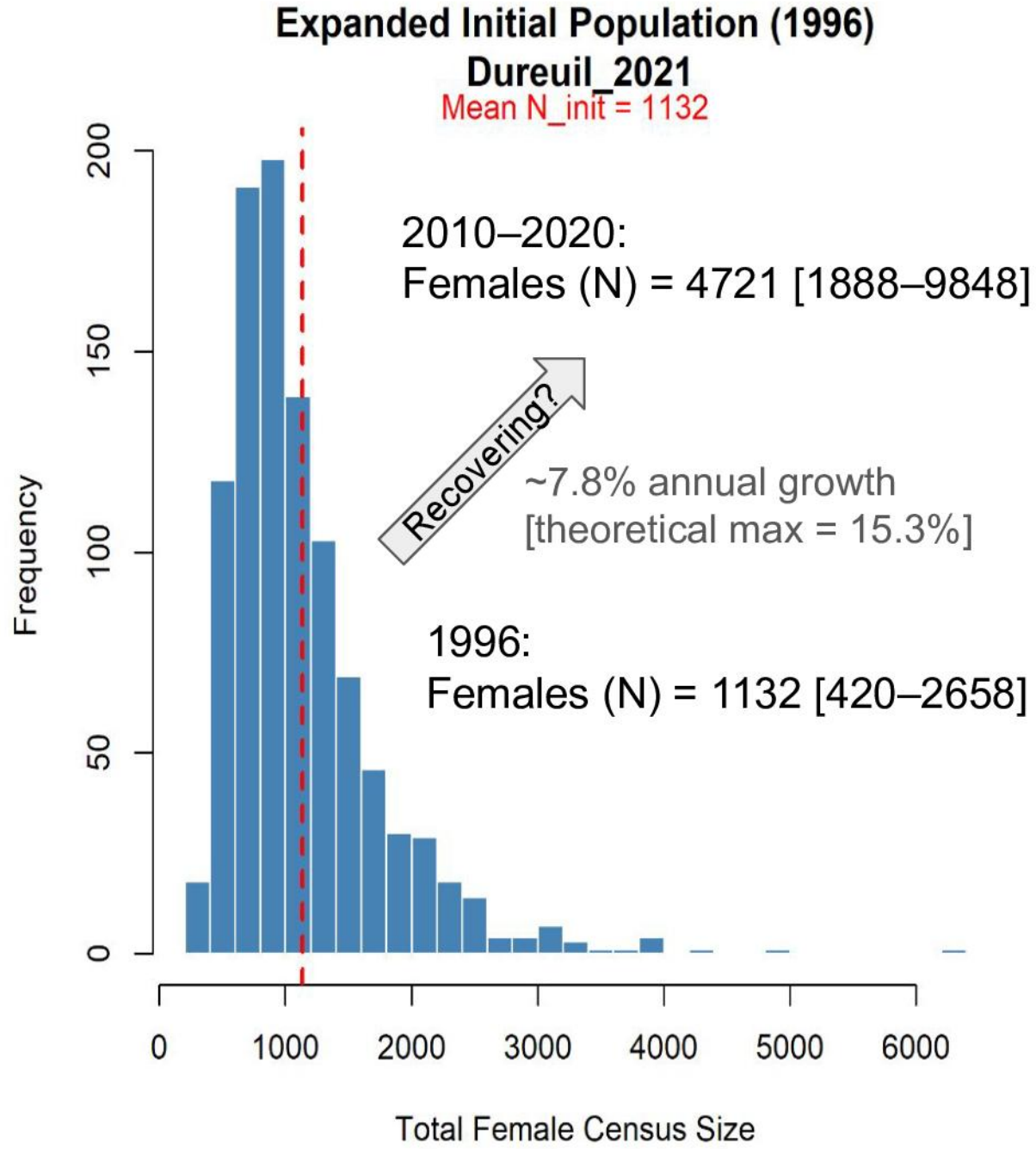


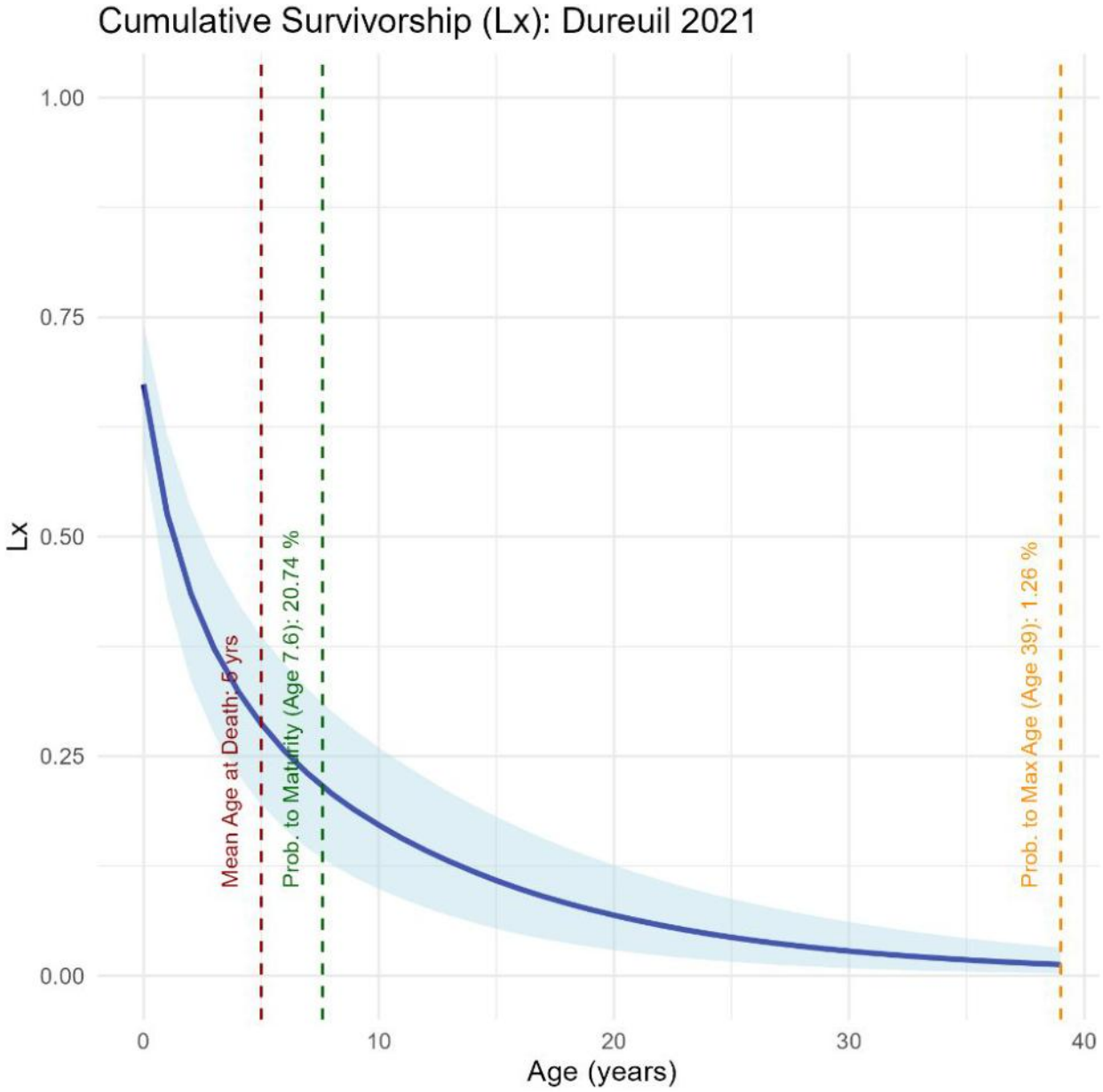
Lagodon rhomboides
Mugil cephalus
Trinectes maculatus
Anchoa mitchilli
Bairdiella chrysoura
Menticirrhus americanus
Cynoscion arenarius
Fundulus spp.
Eucinostomus spp.
Eucinostomus gula
Eucinostomus harengulus
Menidia spp.
Hypanus sabinus

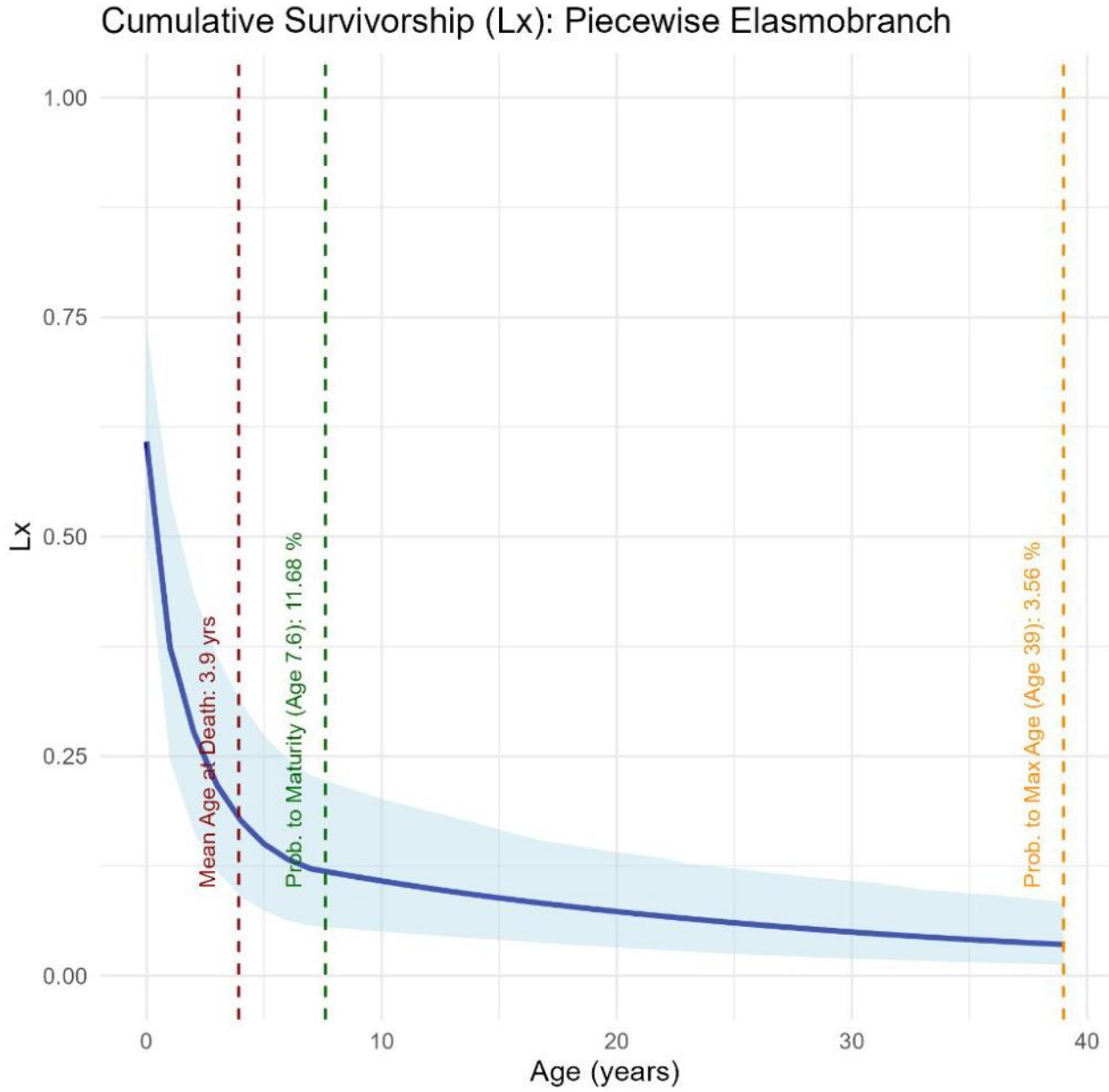
Lagodon rhomboides
Anchoa mitchilli
Bairdiella chrysoura
Eucinostomus spp

Multiple Survivorship Models



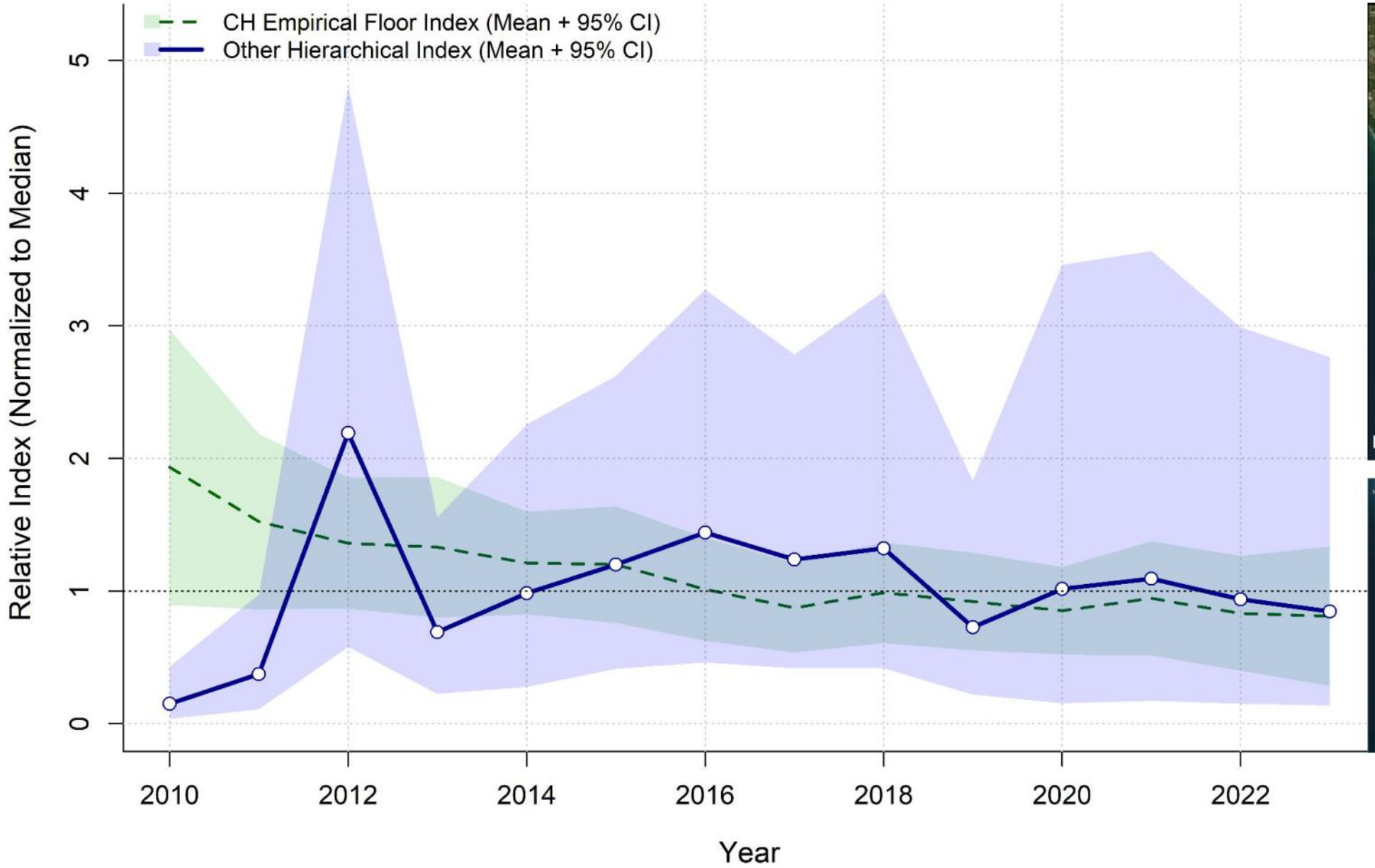


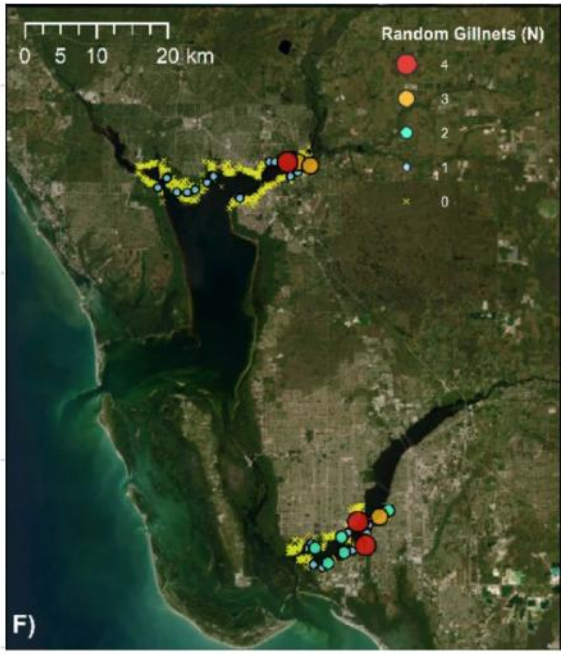

Cumulative Survivorship (Lx): Dureuil 2021
1.00
0.75
0.50
0.25
0.00
Lx
Mean Age at Death: 5 yrs
Prob. to Maturity (Age 7.6): 20.74 %
Prob. to Max Age (Age 39): 1.26 %
0
10
20
30
40
Age (years)


Cumulative Survivorship (Lx): Piecewise Elasmobranch
1.00
0.75
0.50
0.25
0.00
Lx
Mean Age at Death: 3.9 yrs
Prob. to Maturity (Age 7.6): 11.68 %
Prob. to Max Age (Age 39): 3.56 %
0
10
20
30
40
Age (years)

Incorporate Indices of Abundance

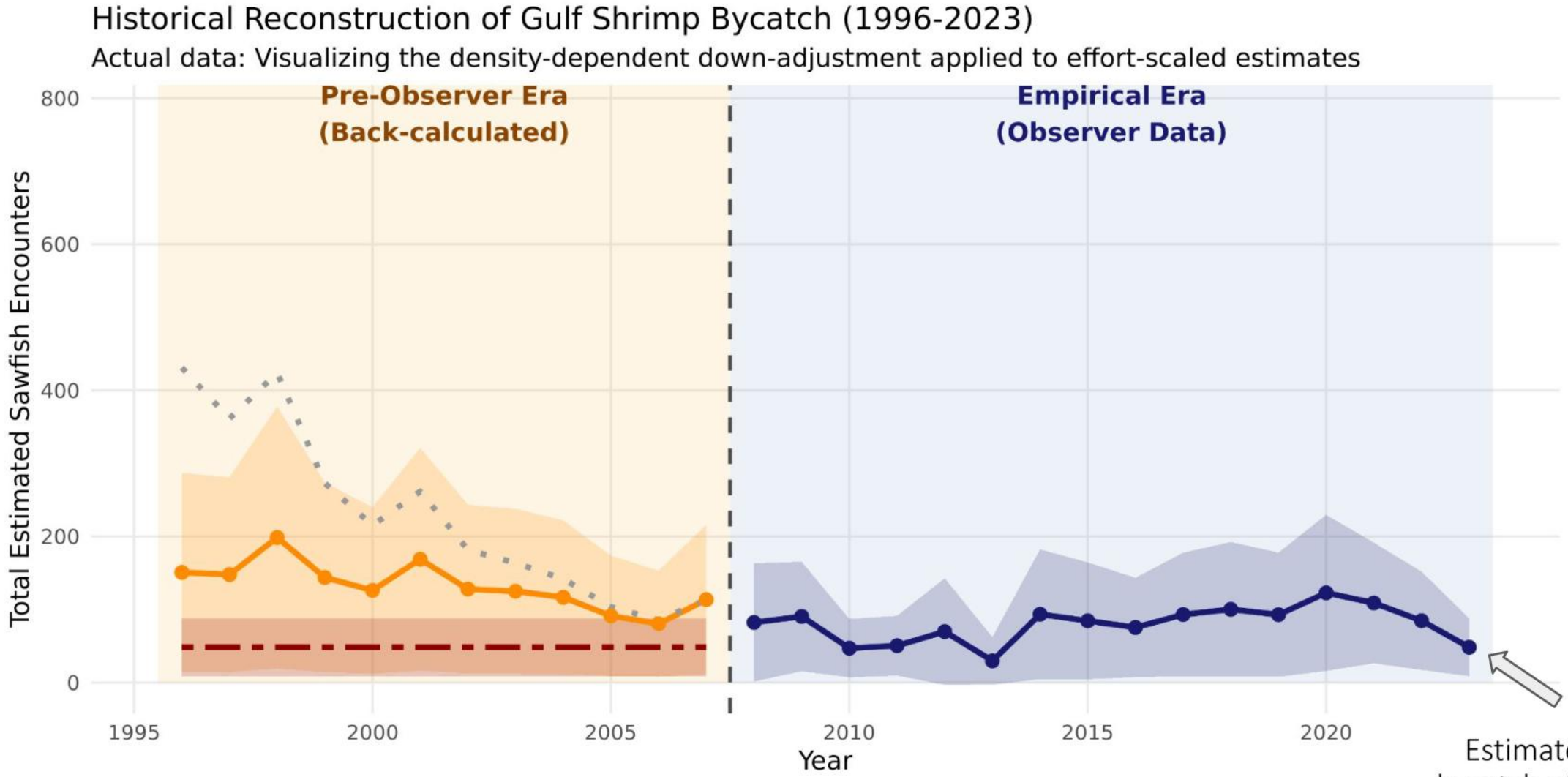
Farmer et al. (2026)
Sci. Reports





Kroetz et al. (2025)
Eco & Evol. +
Carlson unpublished

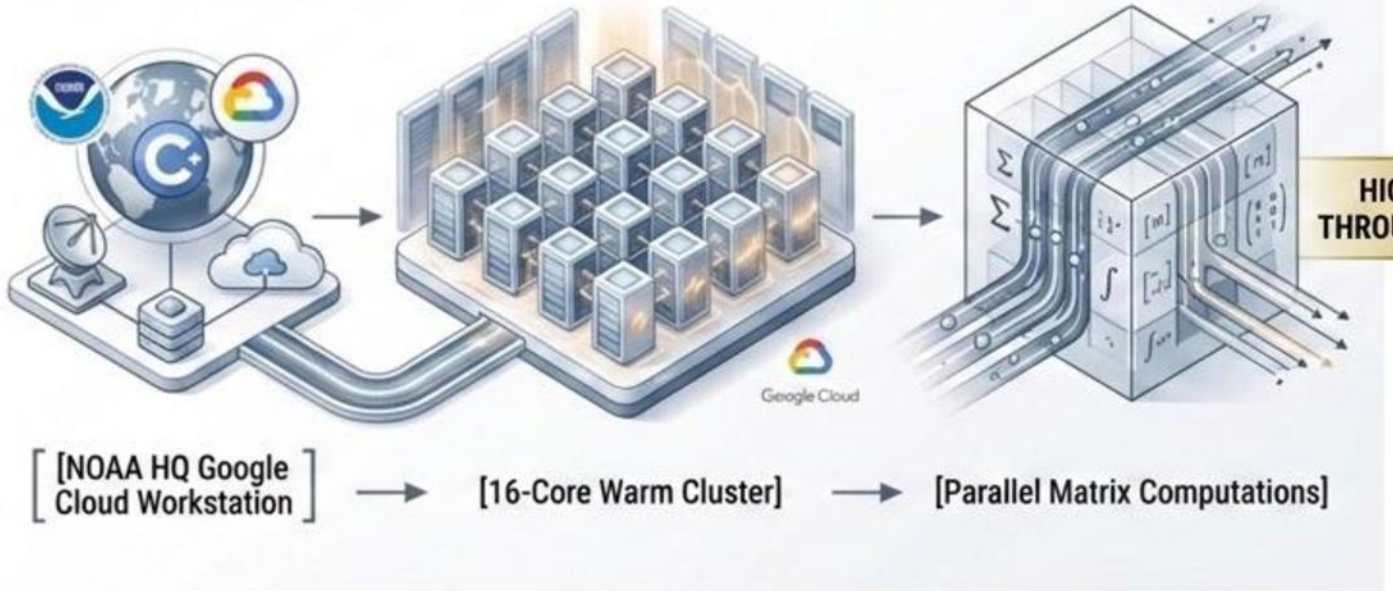
Updated Bycatch Data



Source:
Estimates of shrimp trawl bycatch of smalltooth sawfish and giant manta ray in the Southeast USA

Effort data from K. Detloff (pers. comm.)

Cheston Peterson[1], Elizabeth A. Babcock[2], Daniel Woods[2]



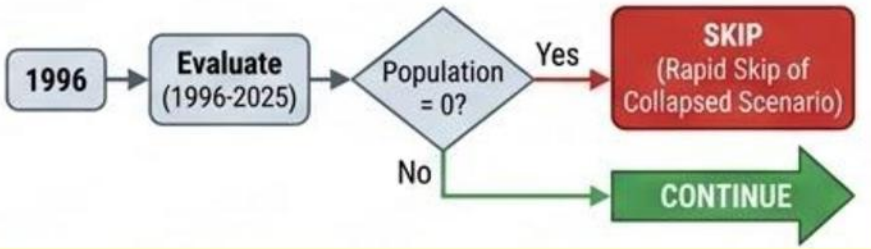
HIGHER THROUGHPUT

Optimization Highlight

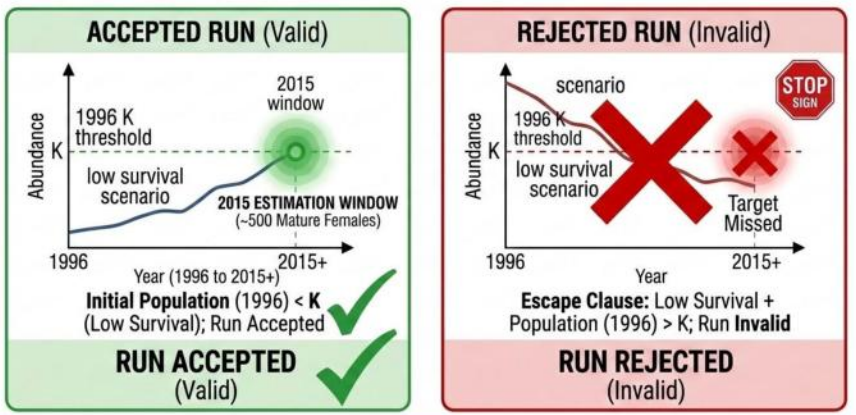
[OPTIMIZATION KEY POINTS]

- >3000 scenarios x 500 bootstraps = **> 15,000 runs**
- Replaced S3 Dataframes with primitive, **memory-contiguous Numeric Matrices**
- Vectorized survival checks (runif(n_alive) instead of individual loop draws)

[Pilot Batch Escape Clause]



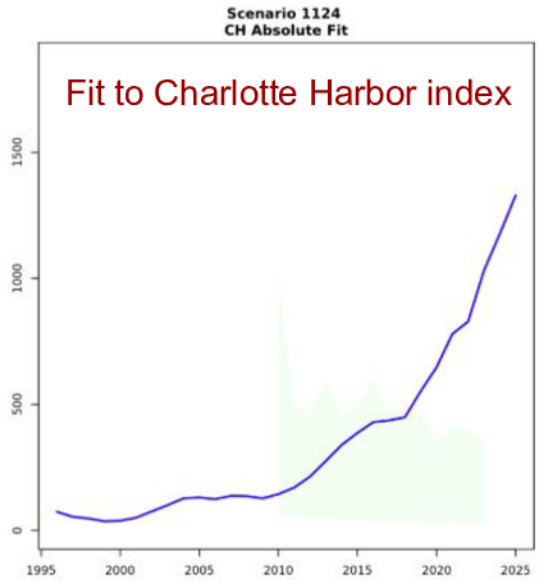
VALIDITY CHECK CRITERIA:
ESCAPE CLAUSE & RUN REJECTION

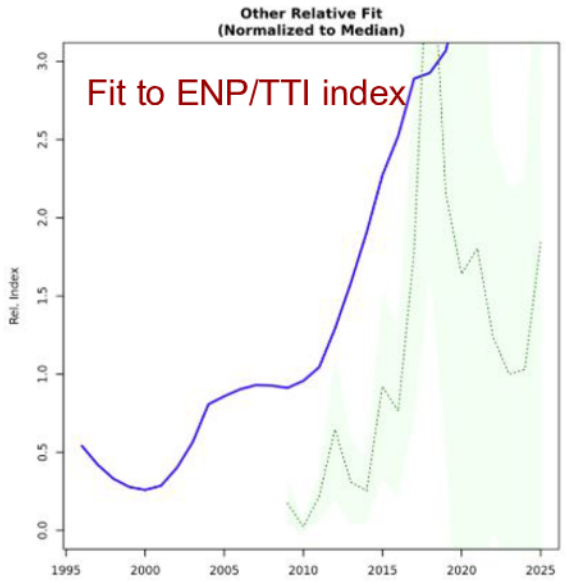


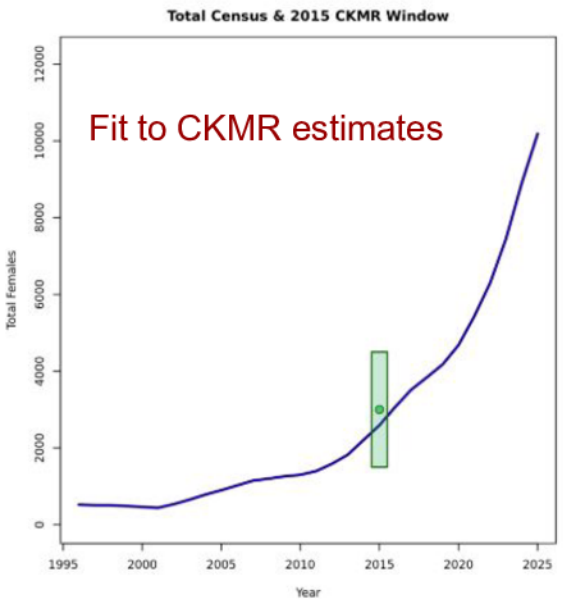
Implementation: Cloud-Native High-Performance Architecture

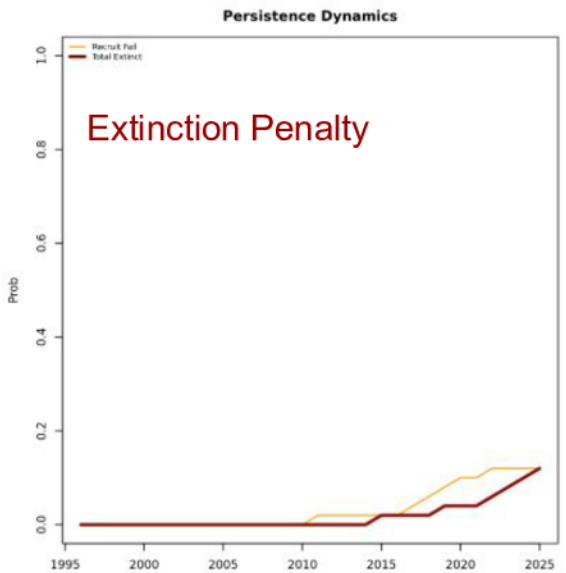
- 500 individual 30-year replicates / minute
- Approach:
  - Broad sweep 3000 scenarios x 50 reps
  - Filter top 10 best-fitting models
  - Forward project to 2056 x ~~500~~ 100 reps

Empirical Calibration & Multi-Population Goodness-of-Fit









Empirical Anchoring: Scored against three independent benchmarks: Charlotte Harbor absolute abundance (Ages 0-1), broader regional relative trends (Ages 0-2), and a 2015 Close-Kin Mark-Recapture (CKMR) total population target.

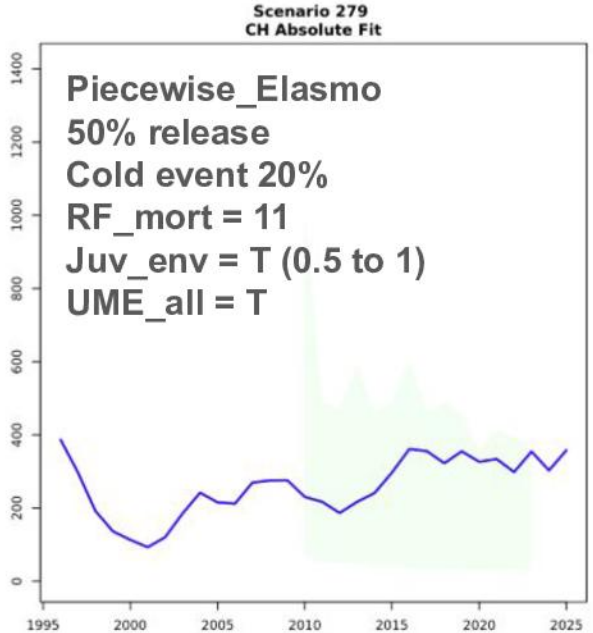
Statistical Metrics: Evaluates both trend shape and absolute scale using Log-Likelihood, Normalized Root Mean Squared Deviation (NRMSD), and Pearson correlation.

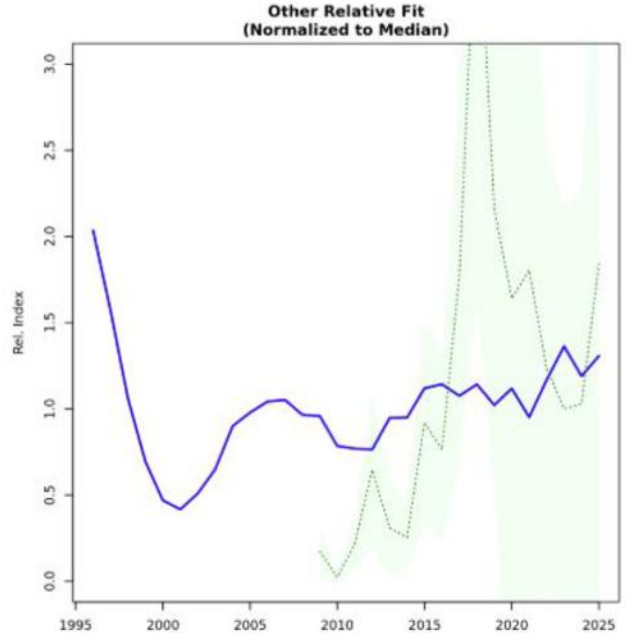
Strict Gated Filters: Immediately disqualifies biologically unviable scenarios, specifically those exhibiting >10% extinction risk, missing the 2015 CKMR target window (1,500–4,500 females), or spending >50% of the time series outside empirical bounds.

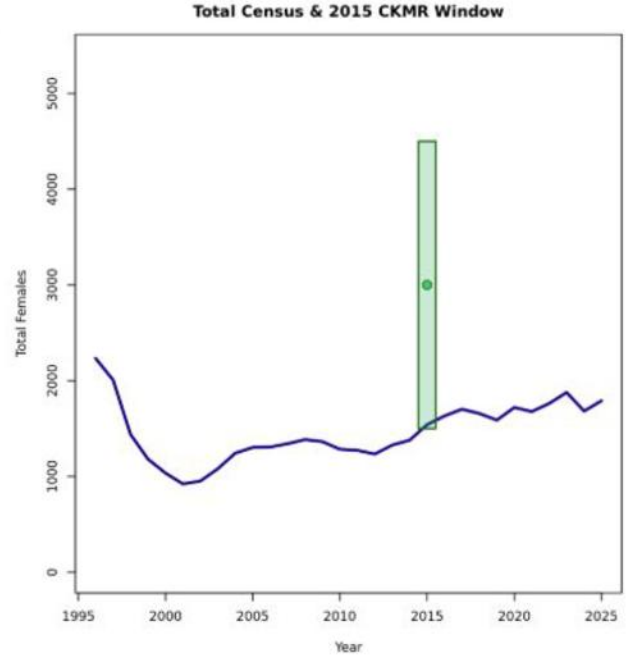
Weighted Ranking: Calculates a definitive `RankSum` by applying explicit multipliers to decoupled ordinal ranks, heavily prioritizing the CKMR contemporary anchor and Charlotte Harbor absolute abundance fits.

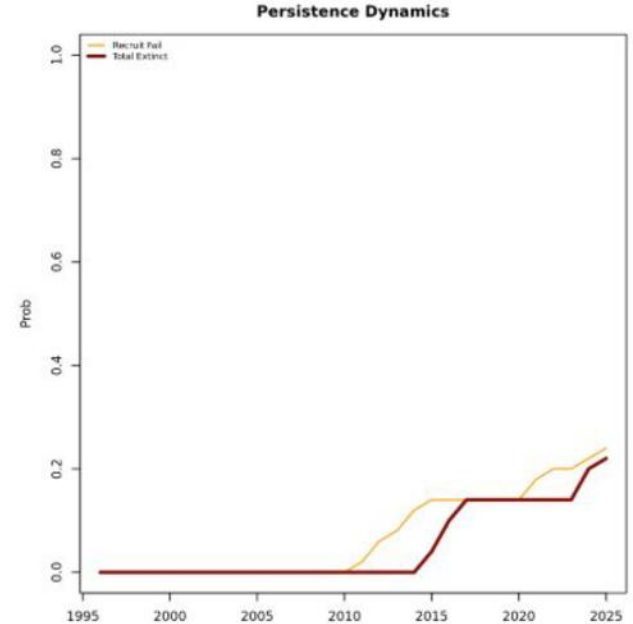
Top-fitting Models

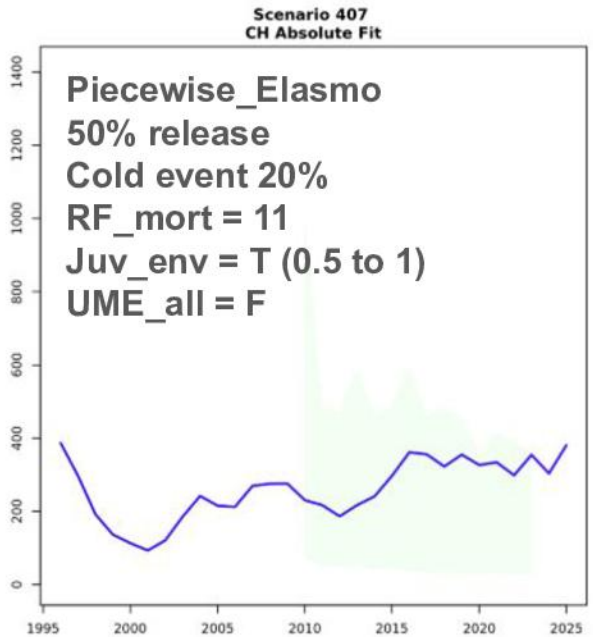
Preliminary Results for Demonstration Purposes Only

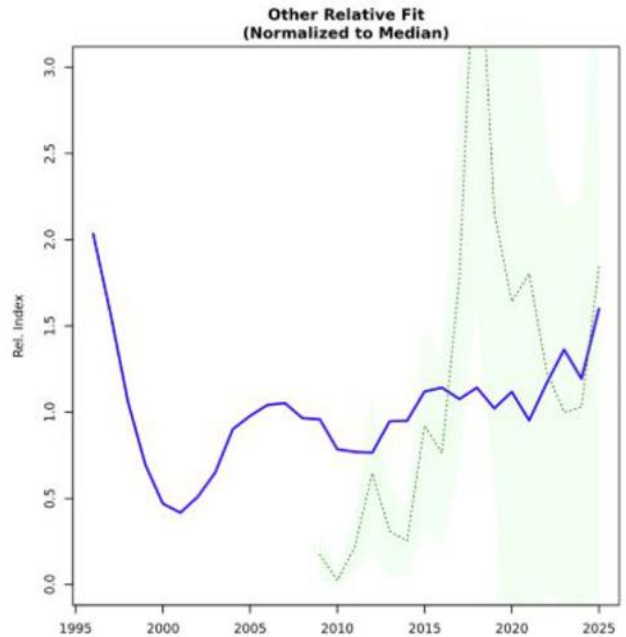


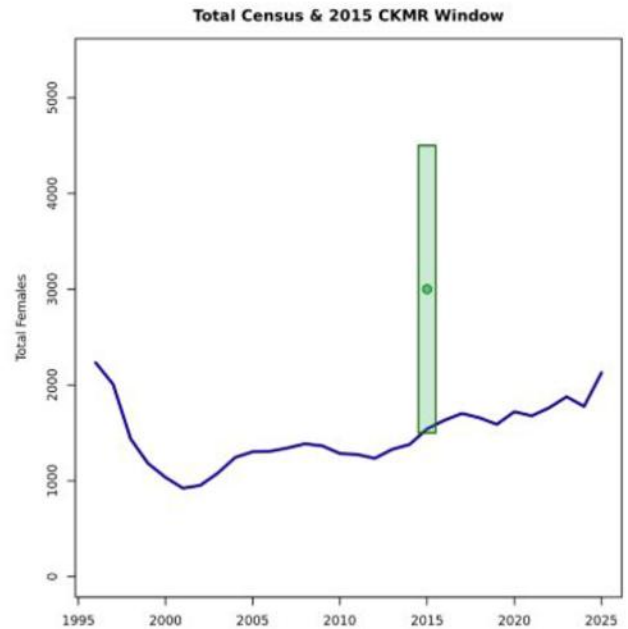


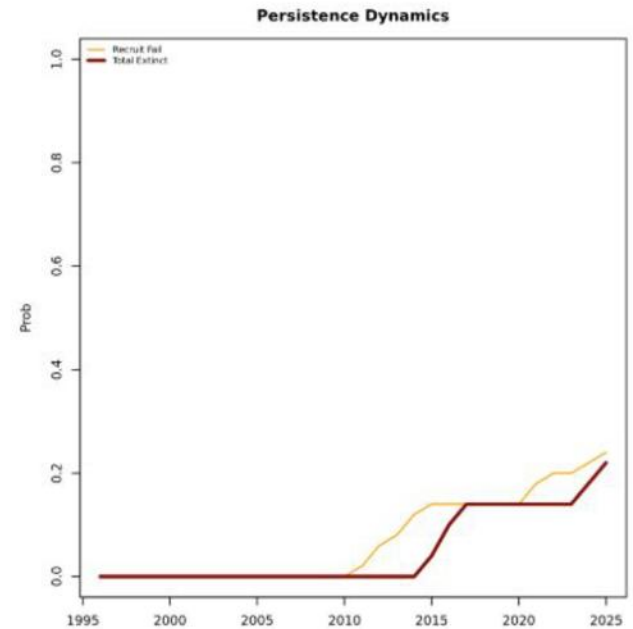




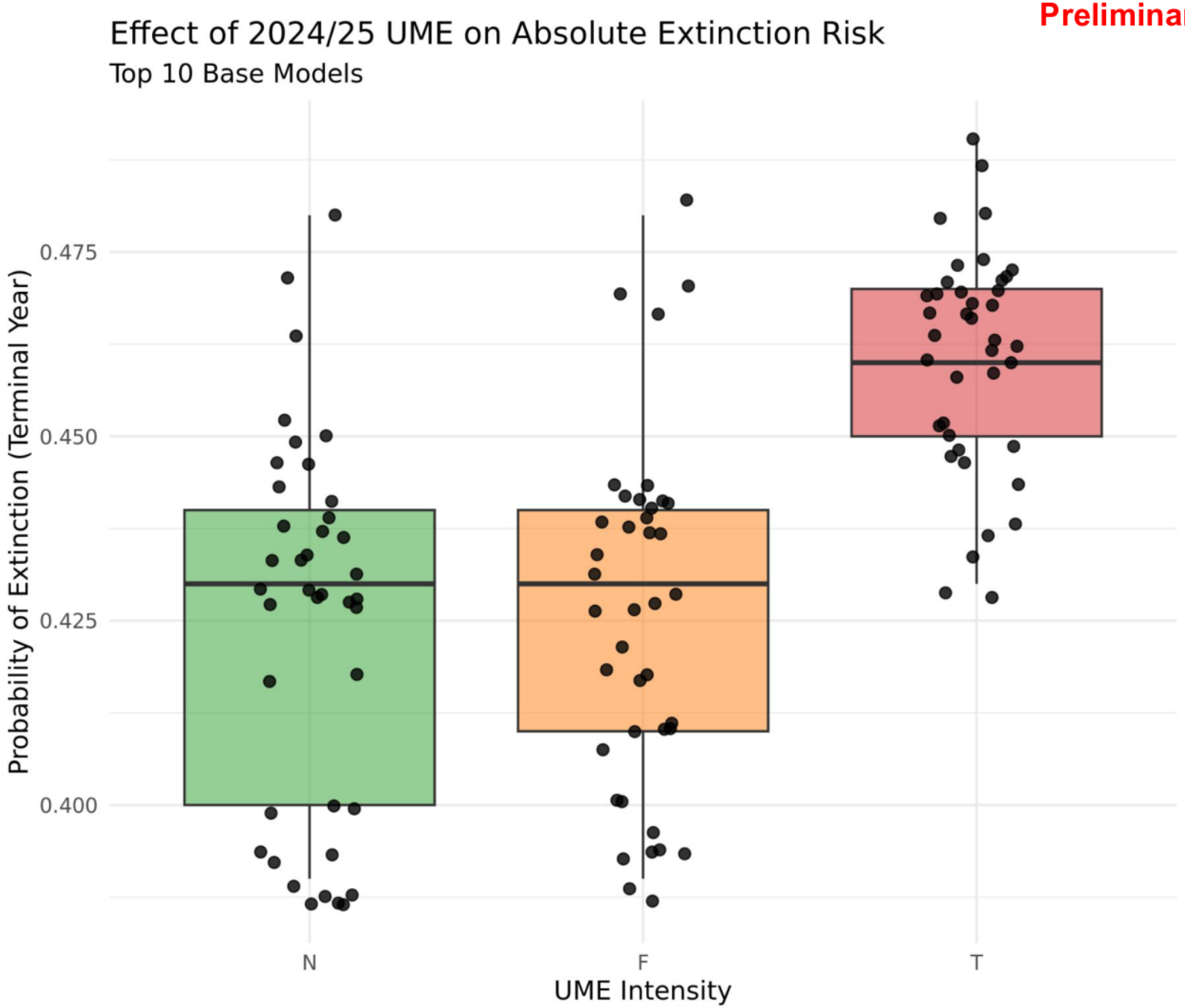








Preliminary Results for Demonstration Purposes Only



What is the effect of the 2024/25 UME on sawfish population extinction risk?

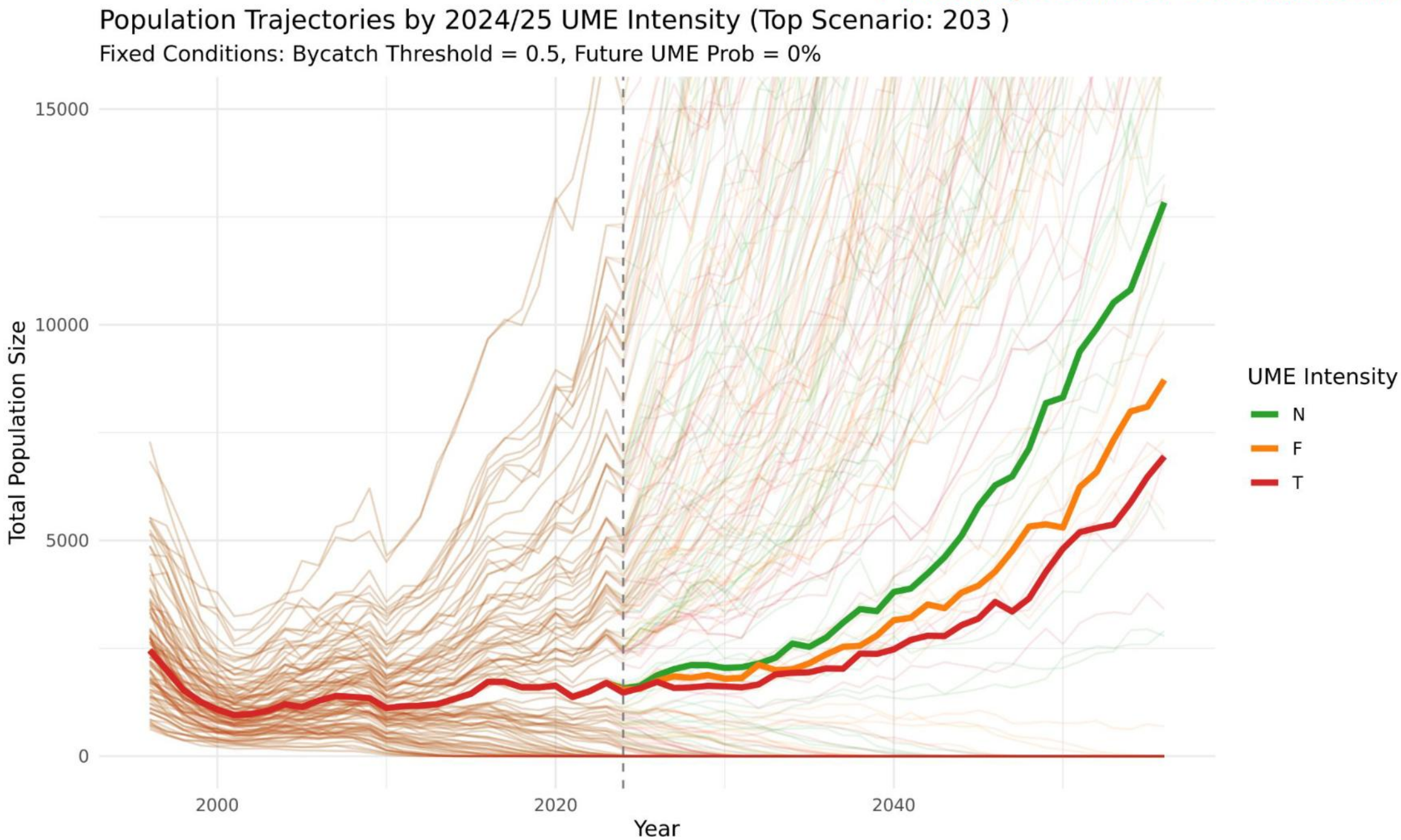
N = no 24/25 UME

F = only observed deaths

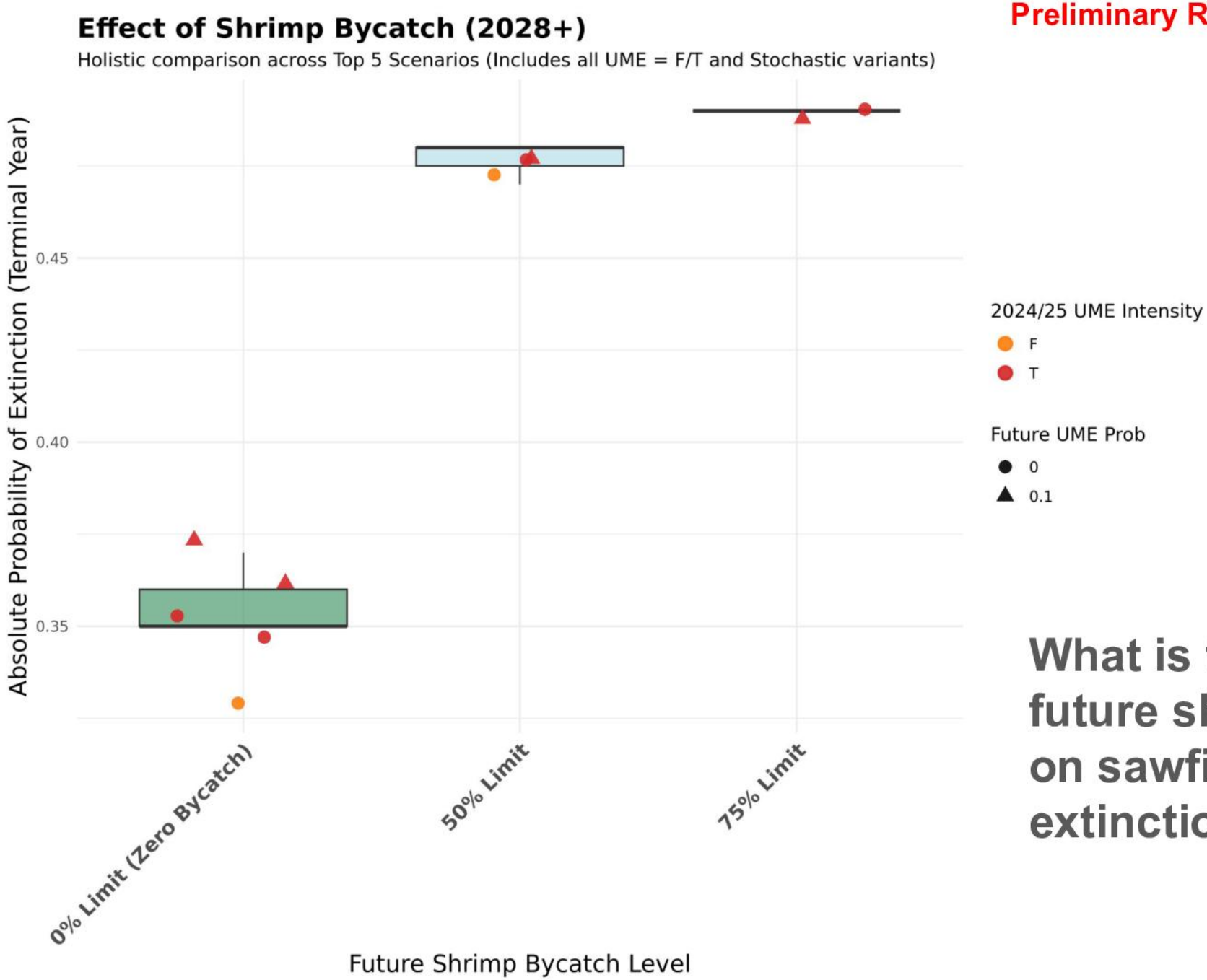
T = all reported “spinning” sawfish died

Assumptions:
Bycatch_thres = 0.5 to 0.75
UME_stoch = 0 to 0.1

Preliminary Results for Demonstration Purposes Only



Preliminary Results for Demonstration Purposes Only



What is the effect of the future shrimp trawl bycatch on sawfish population extinction risk?

Thank You Symposium Sponsors!

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All activities performed under authorization and guidance of NOAA Fisheries Emergency Section 7 Consultation #SERO-2024-00402

and

ESA Section 10 permits to Gregg Poulakis, Tonya Wiley, John Carlson, and Colin Simpfendorfer

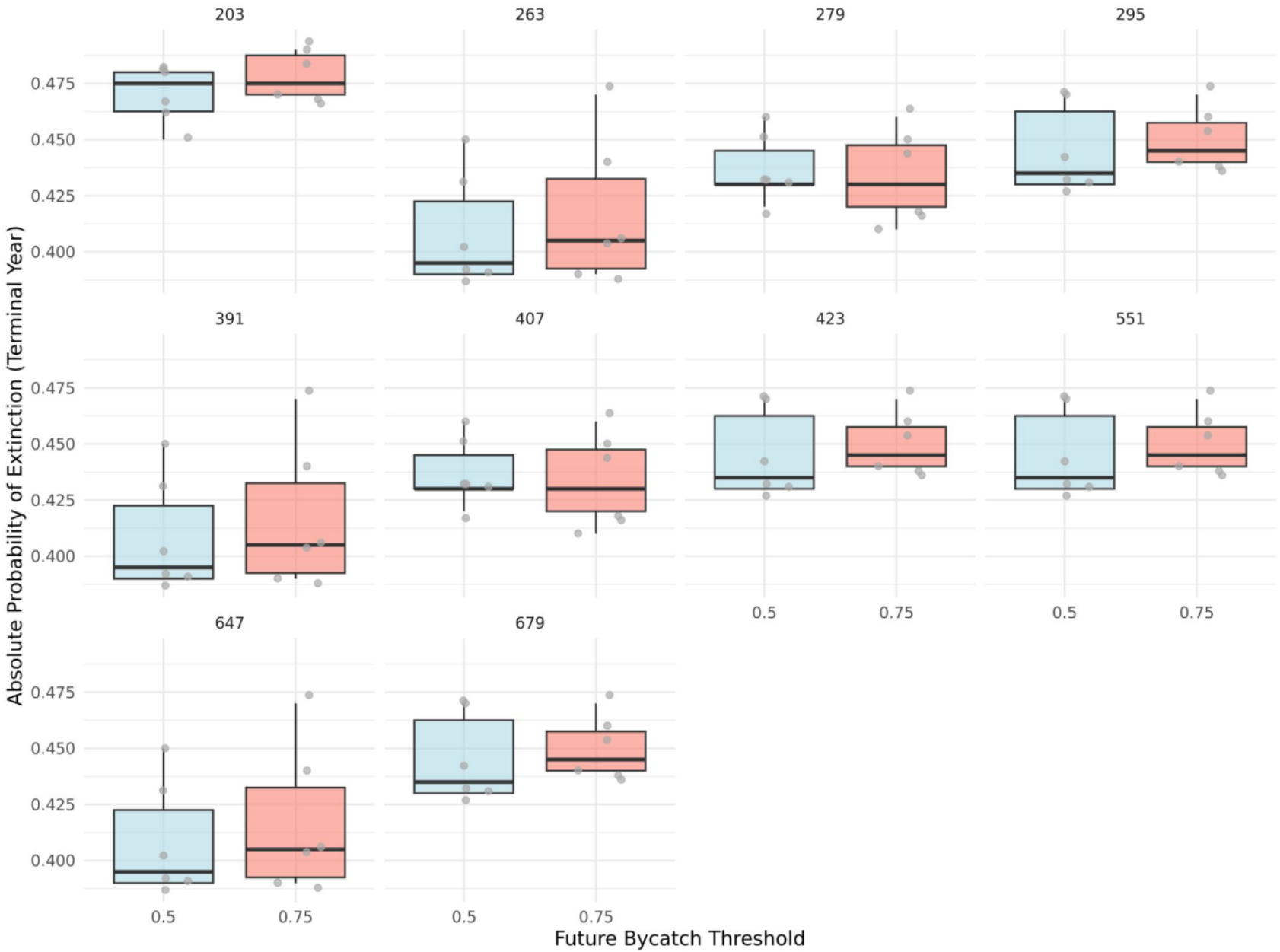
Questions?

nick.farmer@noaa.gov

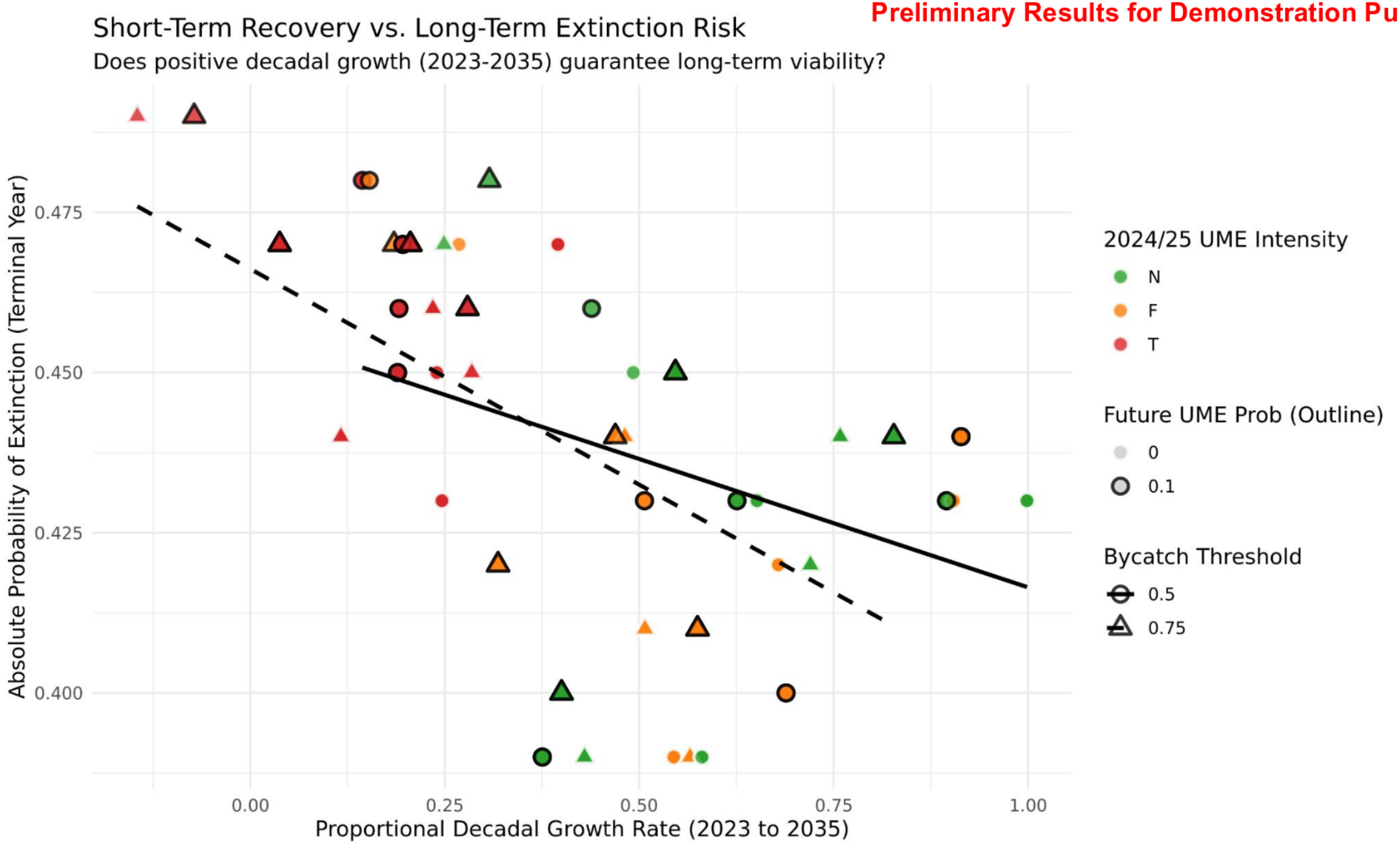
NOAA-AOML Florida Bay Sampling

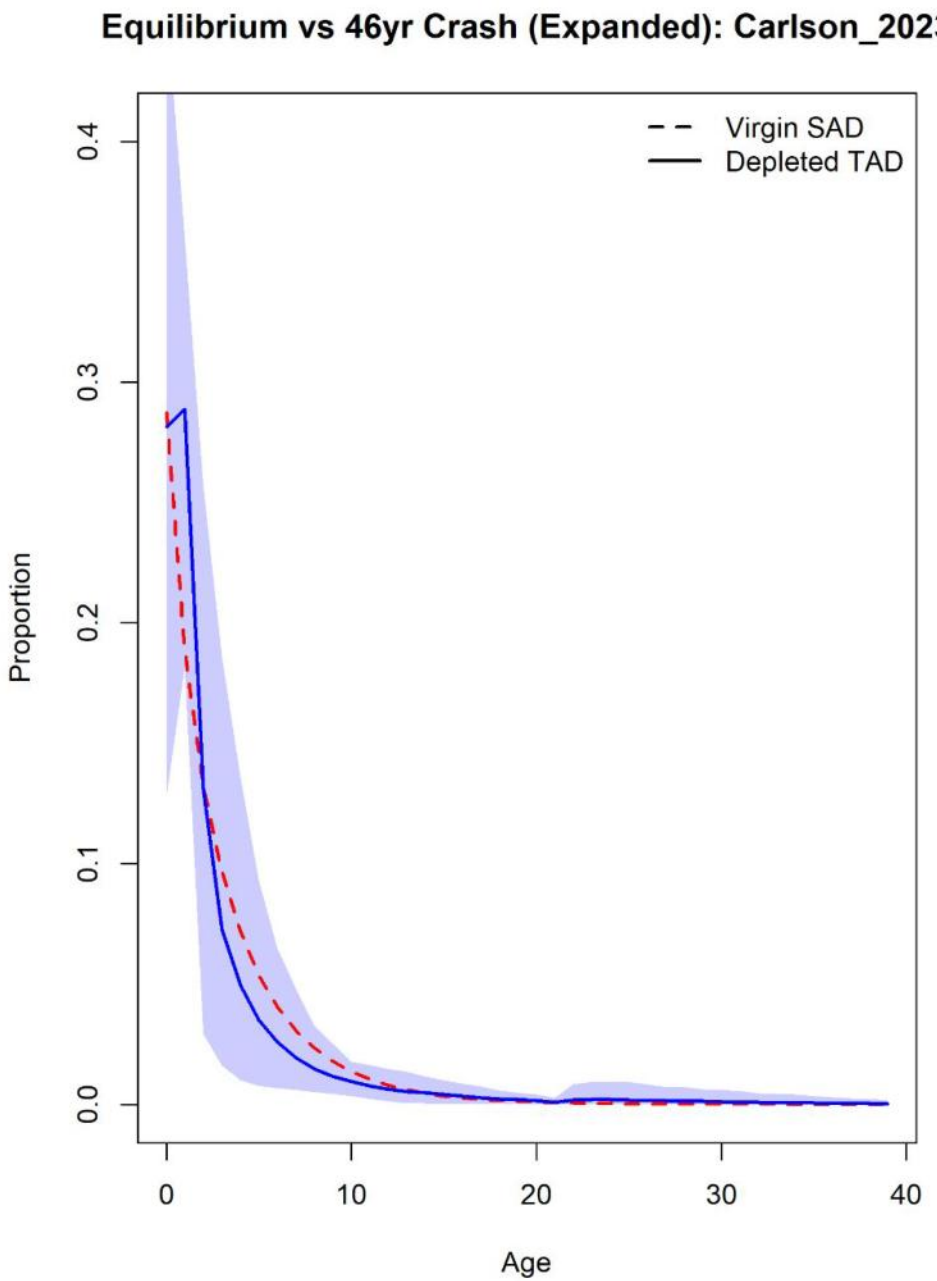
Retained sites (green) consistently sampled May–Nov near sawfish sampling locations from Kroetz et al. (2025):

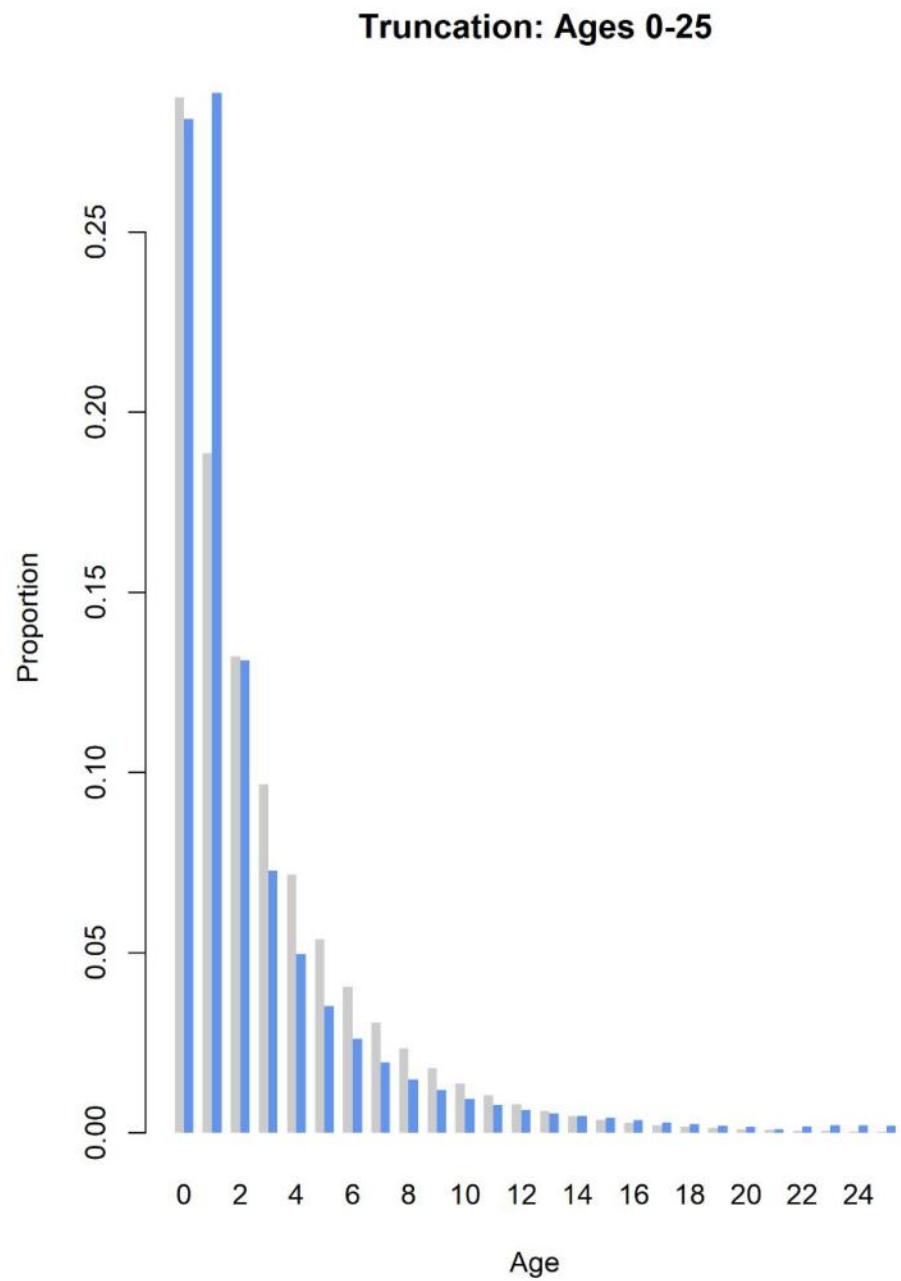
Preliminary Results for Demonstration Purposes Only

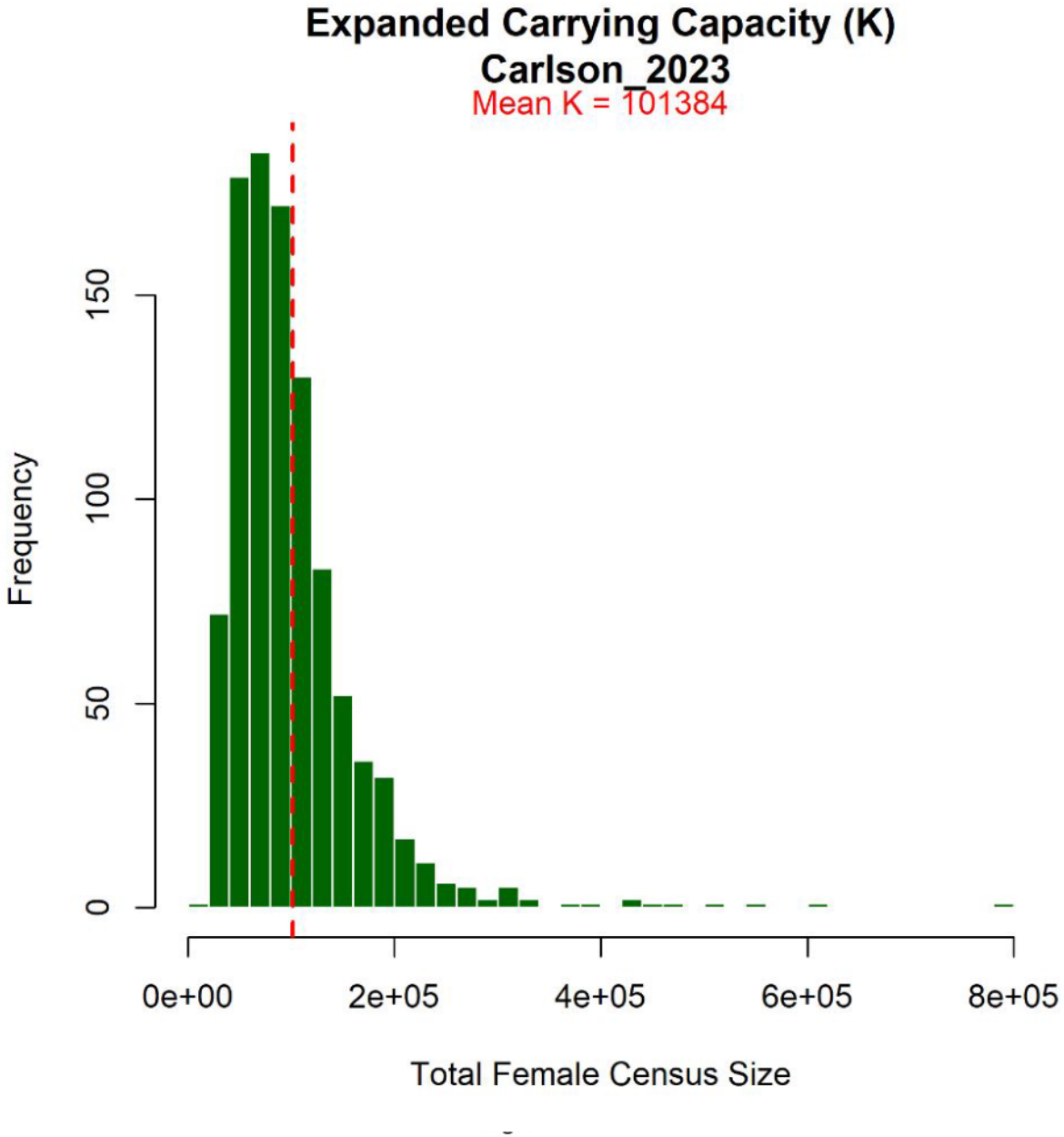


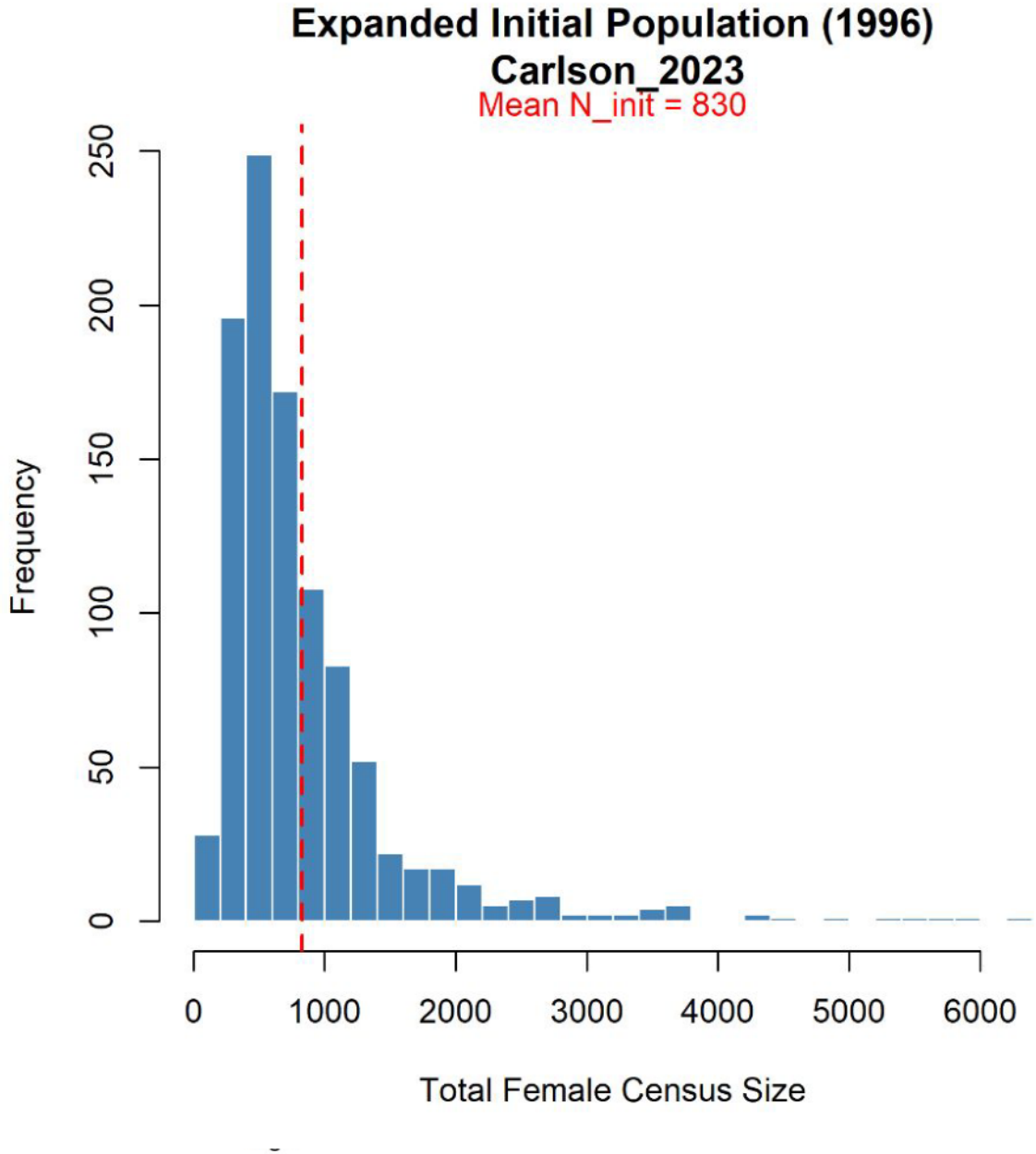
Preliminary Results for Demonstration Purposes Only




Equilibrium vs 46yr Crash (Expanded): Carlson_2023
Virgin SAD
Depleted TAD
Proportion
0.0
0.1
0.2
0.3
0.4
0
10
20
30
40
Age


Truncation: Ages 0-25
Proportion
0.00
0.05
0.10
0.15
0.20
0.25
0
2
4
6
8
10
12
14
16
18
20
22
24
Age


Expanded Carrying Capacity (K)
Carlson_2023
Mean K = 101384
Frequency
0
50
100
150
0e+00
2e+05
4e+05
6e+05
8e+05
Total Female Census Size


Expanded Initial Population (1996)
Carlson_2023
Mean N_init = 830
Frequency
0
50
100
150
200
250
0
1000
2000
3000
4000
5000
6000
Total Female Census Size

Parameter Summary: Spatial Allocation & Effective Size

Parameter	Central Tendency	Range / Distribution	Source / Attribution
Charlotte Harbor Effective Size (Ne_{CH})	$\mu = 196$	Truncated Normal (158 - 253)	Derived from empirical genetics/kinship
Other Region Effective Size (Ne_{Oth})	$\mu = 335$	Truncated Normal (279 - 412)	Derived from empirical genetics/kinship
Other Undersampling Scalar (U_{scalar})	1.5	Uniform (1.0 - 2.0)	Assumption due to geographic undersampling
Charlotte Harbor Allocation (CH_{ratio})	$\approx 28.2\%$	Dynamically Calculated	$Ne_{CH}/(Ne_{CH} + Ne_{Oth} \times U_{scalar})$

Parameter Summary: Life History & Reproduction

Parameter	Central Tendency	Range / Distribution	Source / Attribution
Maximum Age (Age_{max})	39.66 years	Fixed	Kroetz et al. (2025); 99.9% of Linf
Age at Maturity (Age_{mat})	7.6 years	Uniform (7 - 11)	Forward PVA individual assignment
Female Litter Size	5.25 pups	$U[7, 14] \times 0.5$ sex ratio	Simulated physical litter constraints
Reproductive Periodicity	2 years	1, 2, or 3 years (probs: 5%, 90%, 5%)	Dynamic individual tracking assumption
Sex Ratio	0.5	Fixed	Standard biological assumption

Parameter Summary: Somatic Growth (Von Bertalanffy)

Parameter	Central Tendency	Range / Distribution	Source / Attribution
Asymptotic Length (L_∞)	484 cm	Normal ($\mu = 484, \sigma = 14.89$)	Kroetz et al. (2025) 90% Credible Intervals
Growth Coefficient (k)	0.17 yr^{-1}	Normal ($\mu = 0.17, \sigma = 0.0082$)	Kroetz et al. (2025) 90% Credible Intervals
Age at Length Zero (t_0)	-0.972 years	Normal ($\mu = -0.972, \sigma = 0.03$)	Kroetz et al. (2025) 90% Credible Intervals

Parameter Summary: Natural Mortality & Survivorship

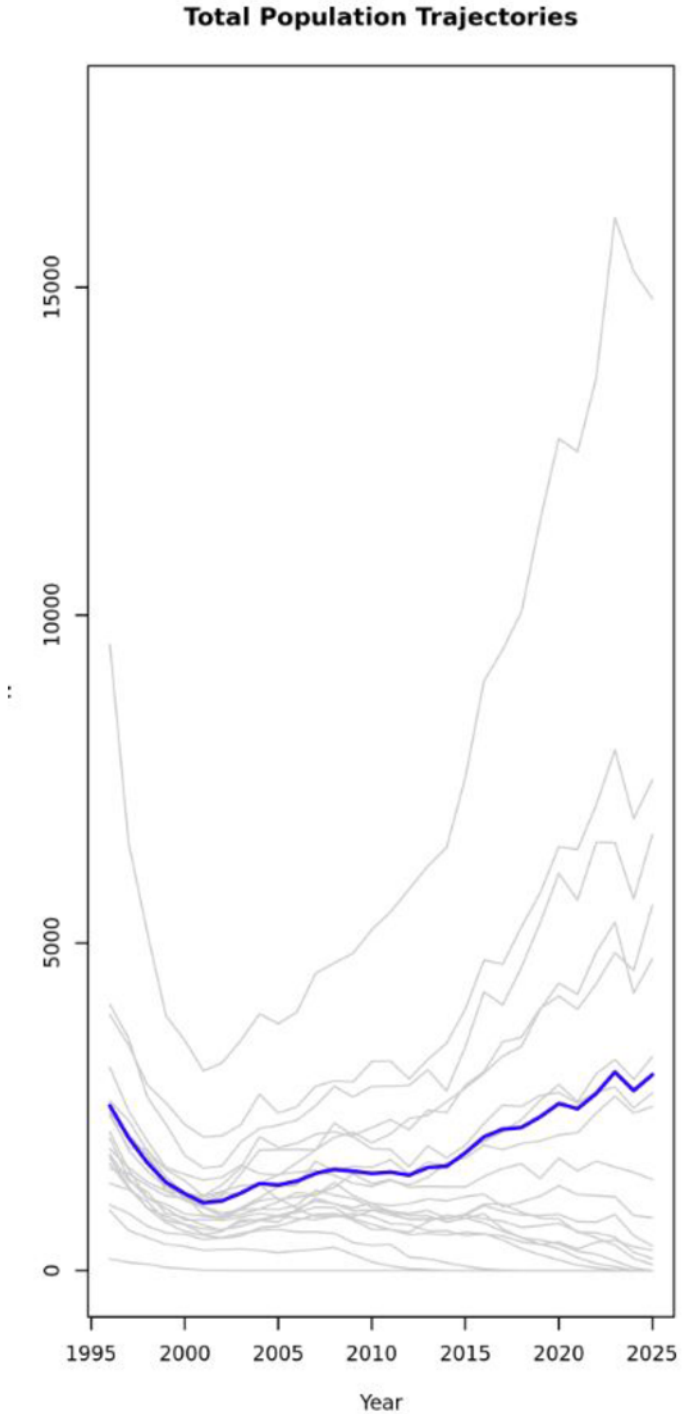
Parameter	Central Tendency	Range / Distribution	Source / Attribution
Piecewise Juv. Mortality (M_{juv})	0.55 yr^{-1}	Normal ($\mu = 0.55, \sigma = 0.10$)	Piecewise Elasmobranch framework
Piecewise Adult Mortality (M_{adult})	0.06 yr^{-1}	Normal ($\mu = 0.06, \sigma = 0.01$)	Piecewise Elasmobranch framework
Lorenzen Adult Floor (M_{floor})	0.03 yr^{-1}	Normal ($\mu = 0.03, \sigma = 0.01$)	Biological buffer for large K-selected taxa
Juv. Survivorship Stoch. (CH)	1.0 (scalar)	Trunc. Normal ($\mu = 1.0, \sigma = 0.05$)	Area-specific environmental variance
Juv. Survivorship Stoch. (Other)	1.0 (scalar)	Trunc. Normal ($\mu = 1.0, \sigma = 0.10$)	Higher variance in Everglades/Florida Bay

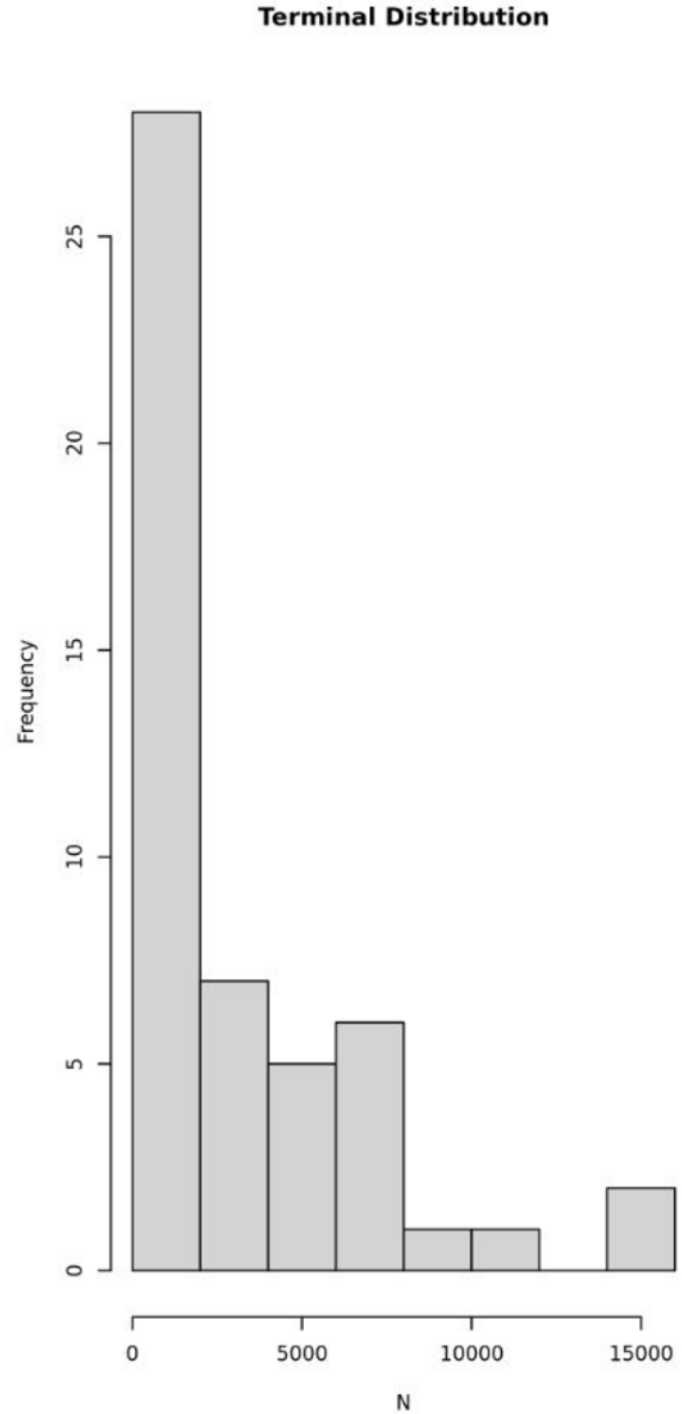
Parameter Summary: Anthropogenic Mortality & Stressors

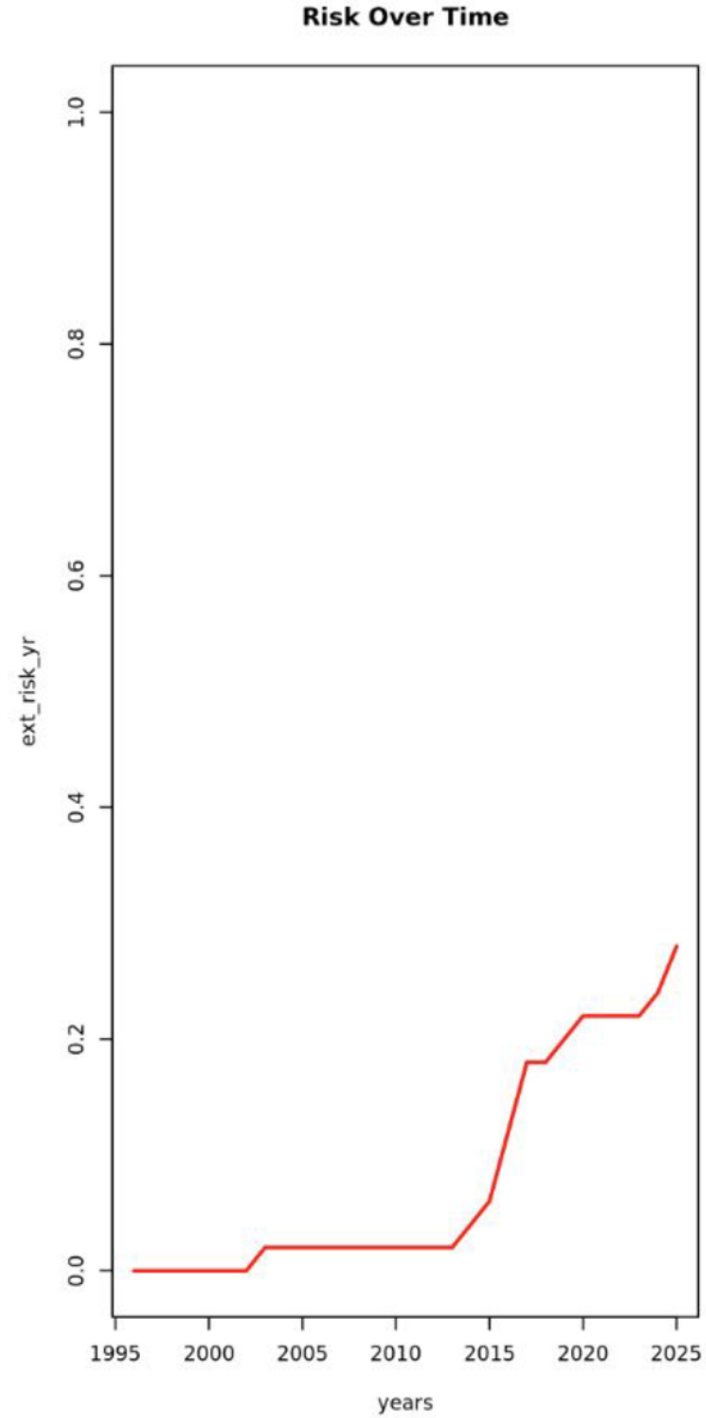
Parameter	Central Tendency	Range / Distribution	Source / Attribution
Recreational Fishing (Low)	11.0 deaths/yr	Normal ($\mu = 11.0, \sigma = 3.3$)	Historical recreational catch estimates
Recreational Fishing (High)	34.4 deaths/yr	Normal ($\mu = 34.4, \sigma = 32.54$)	Elevated catch/release scenario
Shrimp Bycatch Release Mortality	0.70 (70%)	Uniform (0.50 - 0.90)	Batch scenario variable
SBLL Removals (Ages 6+)	1.0 death/yr	Normal ($\mu = 1.0, \sigma = 0.3$)	Bottom Longline observer extrapolation
Cold Event Reduction (2010)	25% reduction	Batch scaled (10%, 20%, 40%, 80%)	Empirical mortality records
Stochastic UME (Post-2025)	50 deaths/yr	5% annual probability ($\sigma = 10$)	2024/2025 Keys UME benchmark

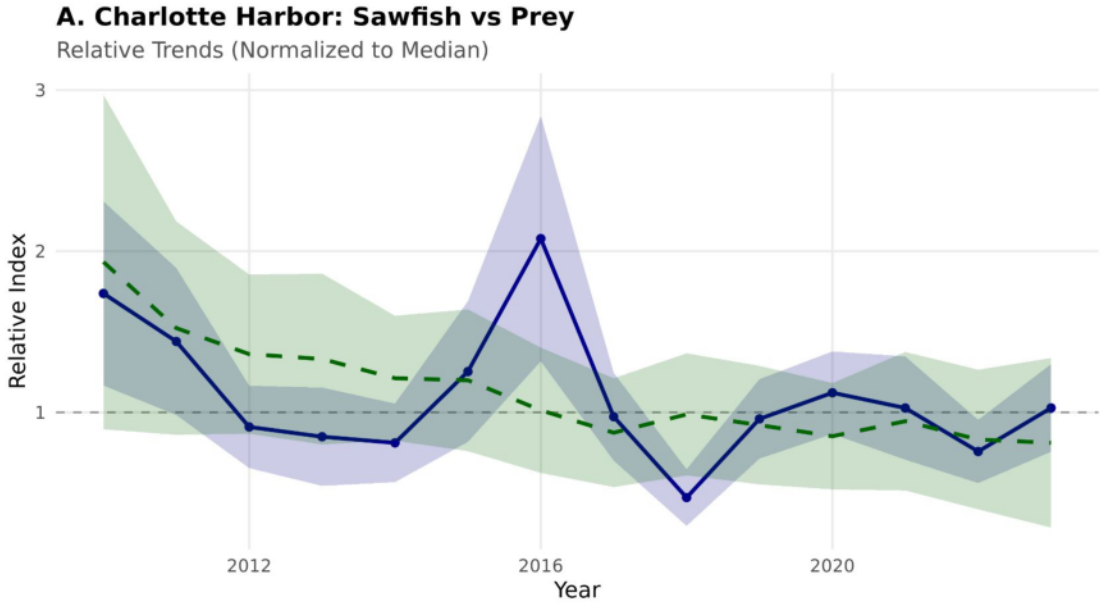
Example Output:

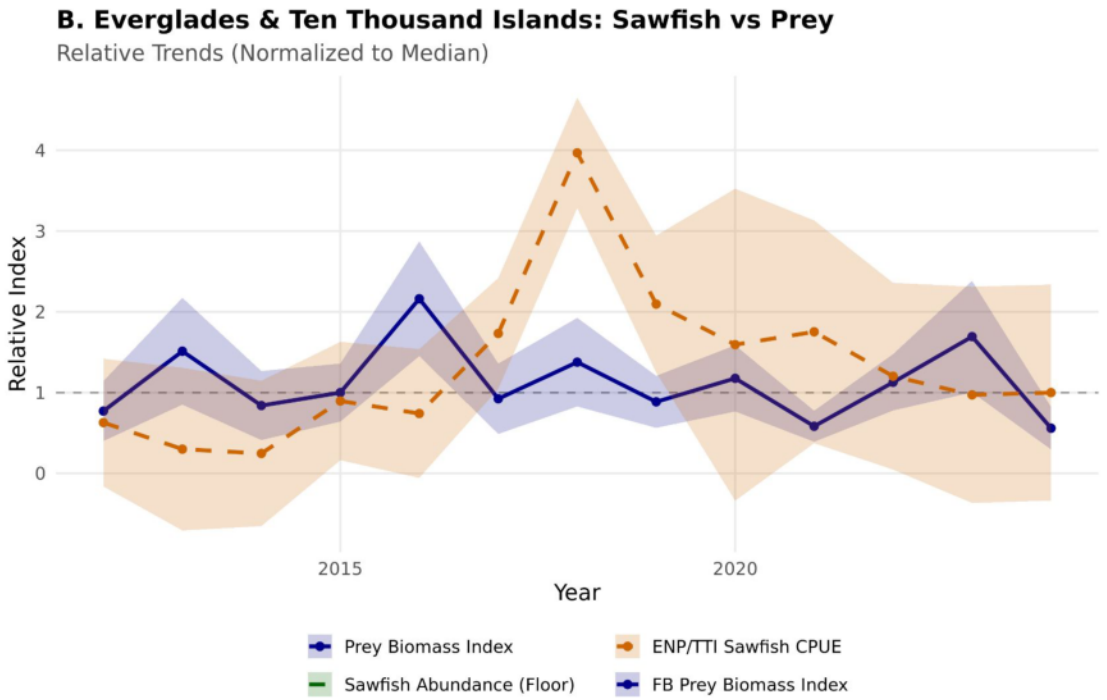
PARAMETERS:
survivorship_model
bycatchMortalityRate
bycatchThreshold
cold_event_2010_active
cold_event_2010_surv_reduction
UME_all
RF_mortality_mean
RF_mortality_sd
juv_env_scalar_active
env_scalar_floor
env_scalar_ceiling
density_dependence
use_iad_as_initial_pop
zero_future_shrimp_bycatch
use_terminal_yr
juvenile_survivorship_trend_active
juvenile_survivorship_trend_area_name
juvenile_survivorship_trend_rate
stochastic_ume_prob
stochastic_ume_mean
stochastic_ume_sd








A. Charlotte Harbor: Sawfish vs Prey
Relative Trends (Normalized to Median)
Relative Index
3
2
1
2012
2016
2020
Year


B. Everglades & Ten Thousand Islands: Sawfish vs Prey
Relative Trends (Normalized to Median)
Relative Index
4
3
2
1
0
2015
2020
Year
Prey Biomass Index
Sawfish Abundance (Floor)
ENP/TTI Sawfish CPUE
FB Prey Biomass Index