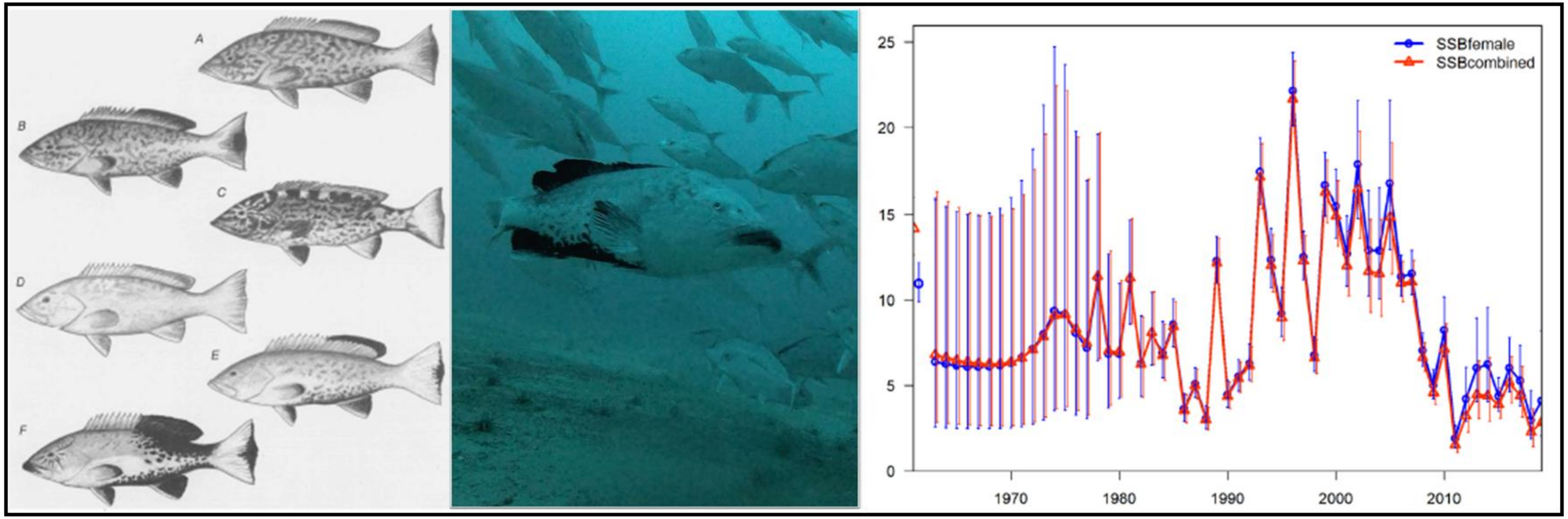
Reproductive resilience in the protogynous gag grouper



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What is reproductive resilience?

The reproductive resilience paradigm (RRP): Reproductive resilience is the capacity of a population to maintain the reproductive success needed to result in long-term population stability despite disturbances such as climate change and fishing.

- Teleost fishes exhibit the largest array of reproductive strategies among vertebrates

Casas and Saborido-Rey 2021

- Their spawner-recruit systems are complex and made up of fixed, behavioral, and varying traits (dependent on ecological context) with fitness and density dependent feedback loops.


FISH and FISHERIES

Reproductive resilience: a paradigm shift in understanding spawner-recruit systems in exploited marine fish

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ORIGINAL ARTICLE

FISH and FISHERIES WILEY

Reproductive resilience or sweepstakes recruitment? Assessing drivers of lifetime reproductive success in exploited marine fish

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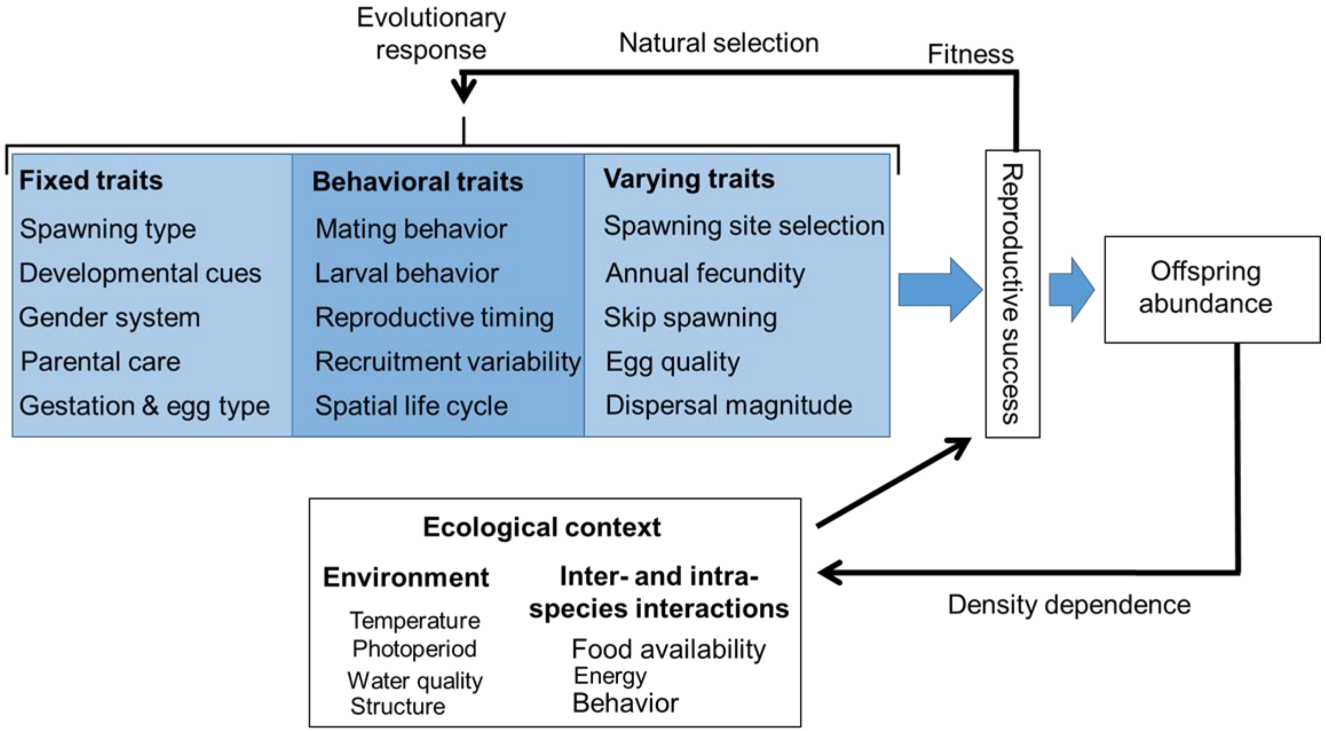


Lowerre-Barbieri et al., 2017

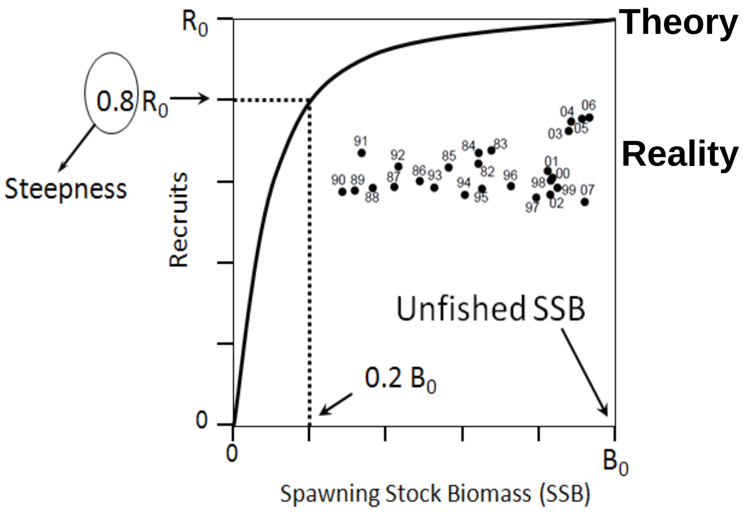
Why does this matter for fisheries assessment and management?

Our conceptual model of population growth is based on terrestrial vertebrates

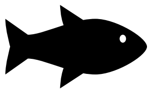
- But for most fish species, there is little relationship between recruitment and adult abundance

Vert-pre et al. 2013; Szuwalski et al. 2015; Sharma et al. 2019

- And fish reproductive strategies are very different from terrestrial vertebrates



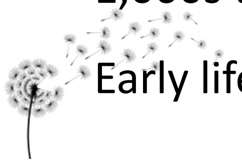
Small eggs strategy



Eggs: 1 mm

Max ~800,000,000:1

Annual fecundity:
1,000s to 1,000,000s



Early life dispersal

Fixed ratio strategy

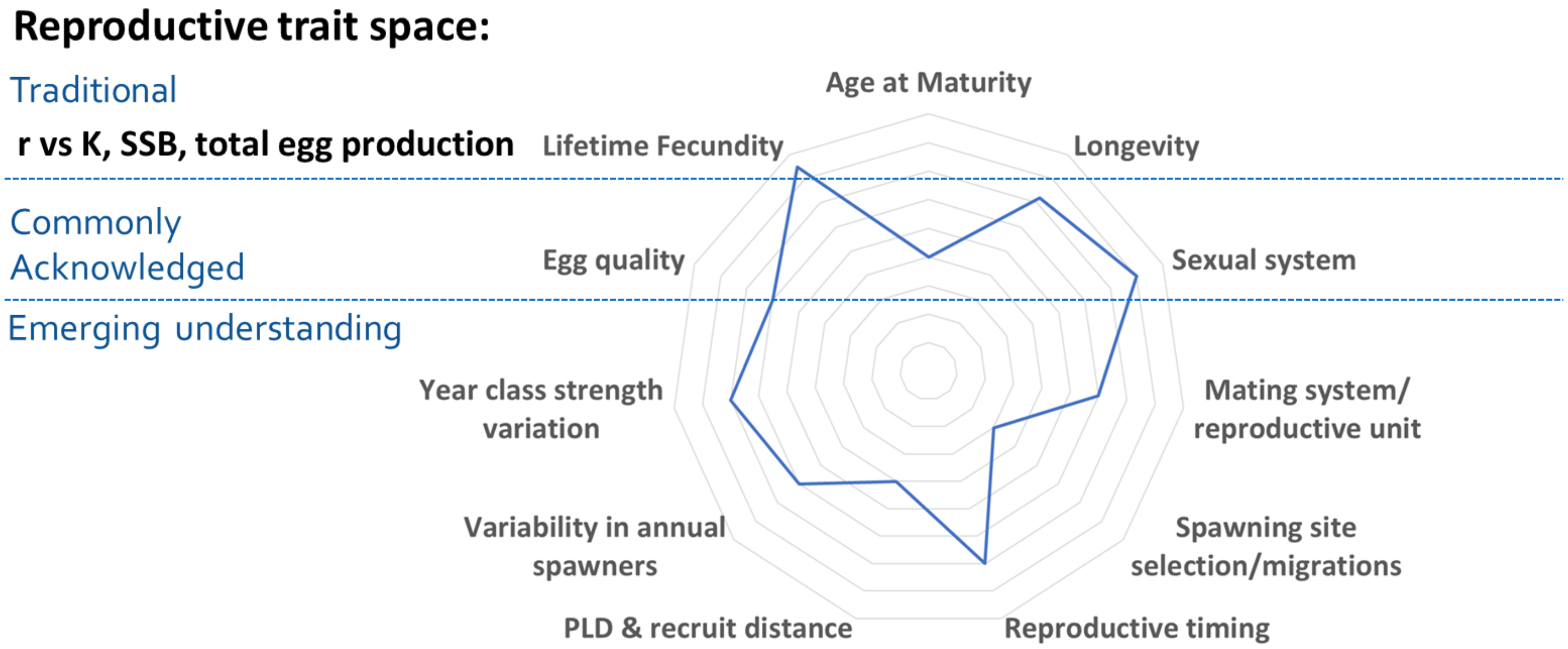
40:1 45:1 50:1

Max # offspring per year:
84 <1 1-15

Babies stay put

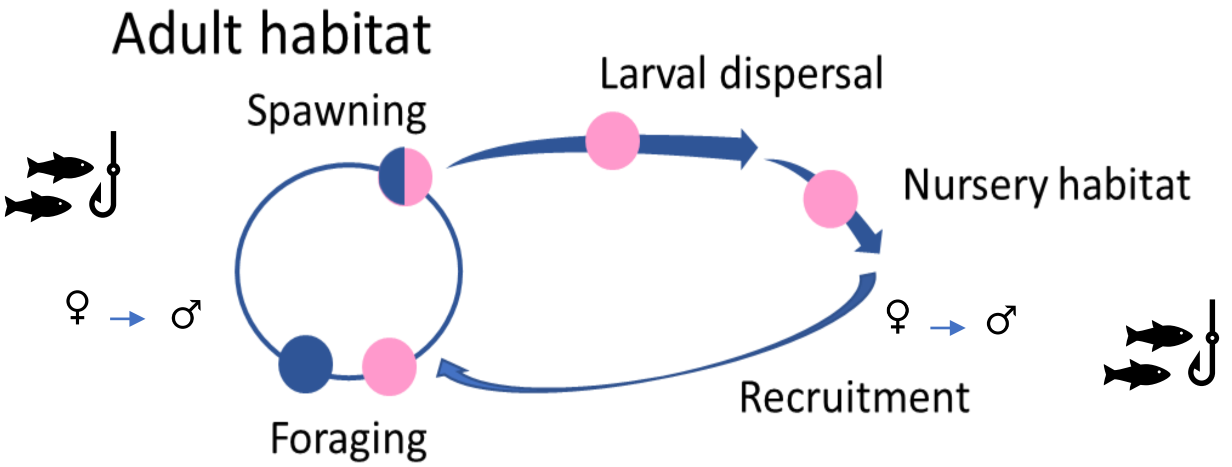
RRP uses fish reproductive trait space to assess vulnerability and productivity

- Movement and reproductive strategies in marine fish are linked and current conceptual models of life history do not capture this because they do not integrate movement
- As an example, small pelagic fish are r-selected, yet they are some of the most common stocks to collapse Pinsky et al. 2011



Especially important for protogynous species ♀→♂

- As the only location ensured to have both sexes is the spawning grounds, with only females in nursery and subadult habitat
- When spawning and nursery grounds do not overlap, all females must undergo ontogenetic habitat shifts
- Where and when sex change occurs and how this intersects with fishing mortality will affect male recruitment;



Applying this to Gag

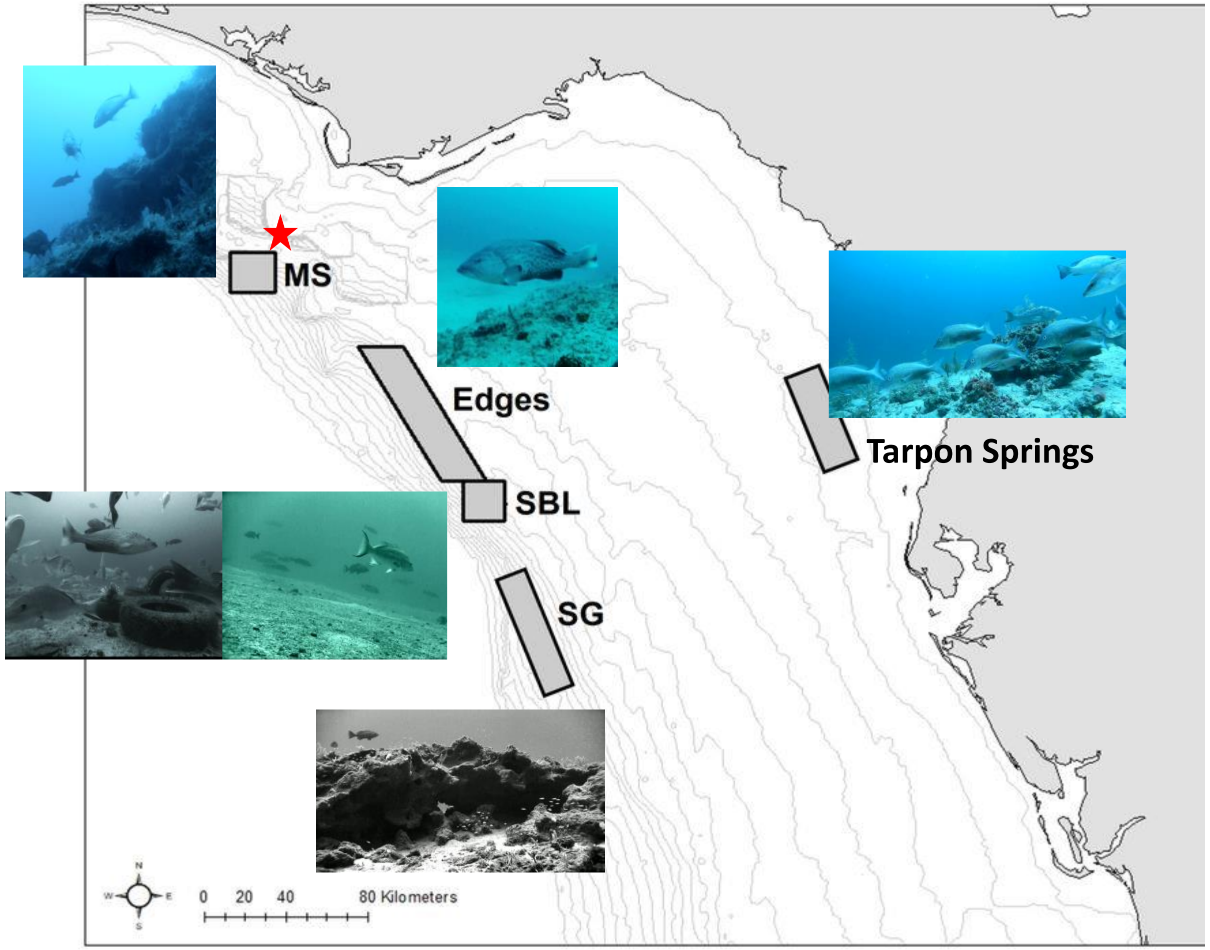
What was known before we got started (2015)

Accepted ecology:

- Protogynous (Koenig et al., 1996)
- Long pelagic larval duration (35-45 d), and distance from offshore spawning to estuarine nursery habitat (Fitzhugh et al., 2005)
- Subadult Gag select nearshore habitat with relief/structure exhibiting strong density-dependent habitat selection and ontogenetic habitat shifts (Lindberg et al. 2006)
- Gag form pre-spawning aggregations in late fall/early winter in 20-40 m depth and spawning aggregations at 50 m depth or deeper (Koenig et al., 1996; Coleman et al. 1996)
- Males remain in these deeper waters (~50 m or deeper) year-round; females use shallower water and undergo spawning migrations (Heppell et al., 2006)
- Sex change occurs on the spawning grounds, mediated by social interactions (male abundance or size of fish in the spawning aggregations), during the spawning season or just after it (Koenig et al., 1996; Ellis and Powers 2012)
- Spawning reserves will increase male sex ratios (Heppell et al., 2006; Ellis and Powers 2012)

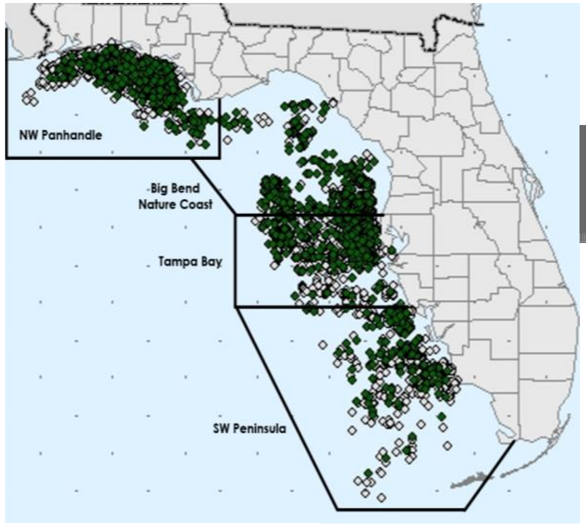
What we have done since 2015: two studies on Gag reproductive potential

- Steamboat Lumps study sampled the MPA (SBL), the Sticky Grounds (SG), & exploratory sampling off Tarpon Springs; 2019-2021 (n=753)
- Original Madison Swanson study sampled the MPA (MS), an open area (★) and the seasonally closed Edges; 2016-2018 (n=615)
- These data were pooled with FWC/FDM data 2016-2021 (n=1,156) and FWC/FIM data 2009-2018 (n=346)
- Same methods for both studies and fishermen were chartered for H& L and video sampling

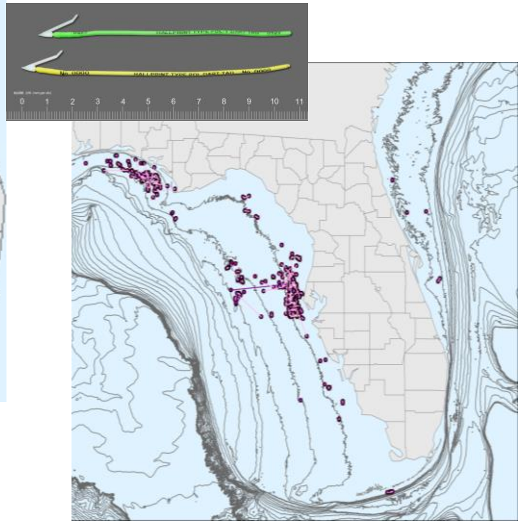


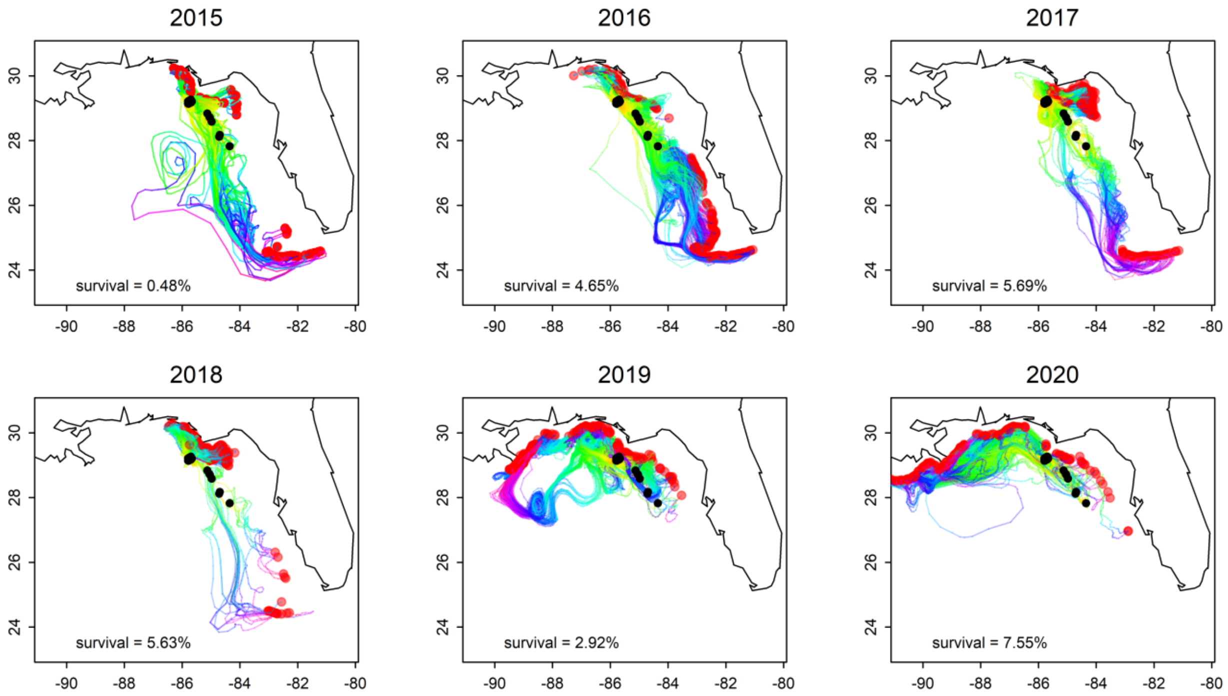
Graduate student research & a new study focused on sex change, movement, catchability, & connectivity (2022-2024)

- Assessing Spatiotemporal Trends in Gag Grouper Spatial Ecology and Recreational Fishing Effort on the West Florida Shelf **Rachel Germeroth**, Masters; completed 2021
- Population Structure and Connectivity of a Sex-changing Marine Fish, West Florida Shelf Gag (*Mycteroperca microlepis*) **Hannah Gottesman**, PhD; on-going



No Gag Encountered
Gag Encountered





And we learned a lot from the experts…

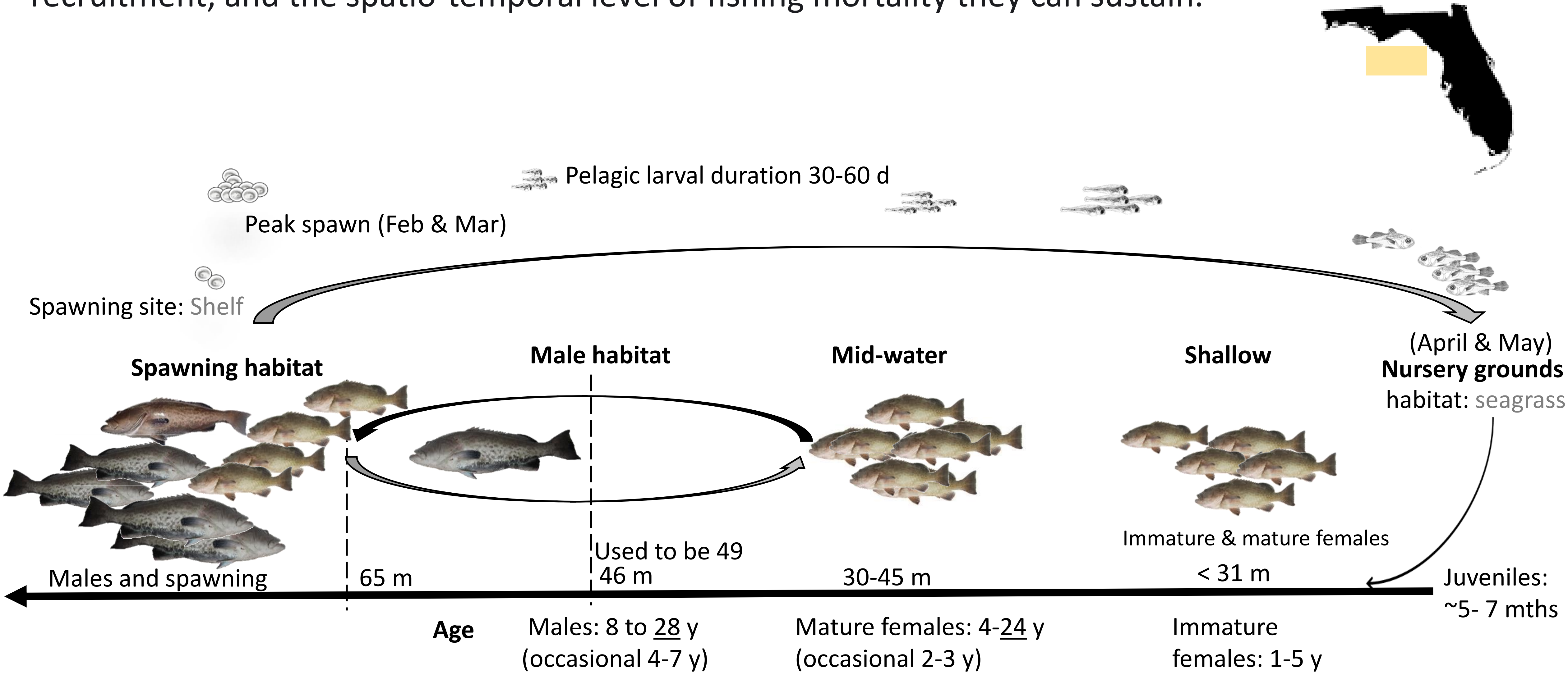
- Fishers
- Stock assessment scientists: Meghan Bryant, Skyler Sagarese, & Lise Ailloud
- Leading scientists on Gag grouper: Chris Koenig, Scott Heppell, and Bill Lindberg
- Hosting & listening at knowledge exchange workshops: (1) Captains’ meeting 2021; (2) 2023 SEDAR 72 results and research opportunities

What have we figured out?

- Spatial ecology and sex ratios
- Factors affecting male recruitment
- Sex change, movement, catchability, & connectivity

Our conceptual model:

Gag life cycle space use, their sexual system, and mating strategy all impact sex change, male recruitment, and the spatio-temporal level of fishing mortality they can sustain.

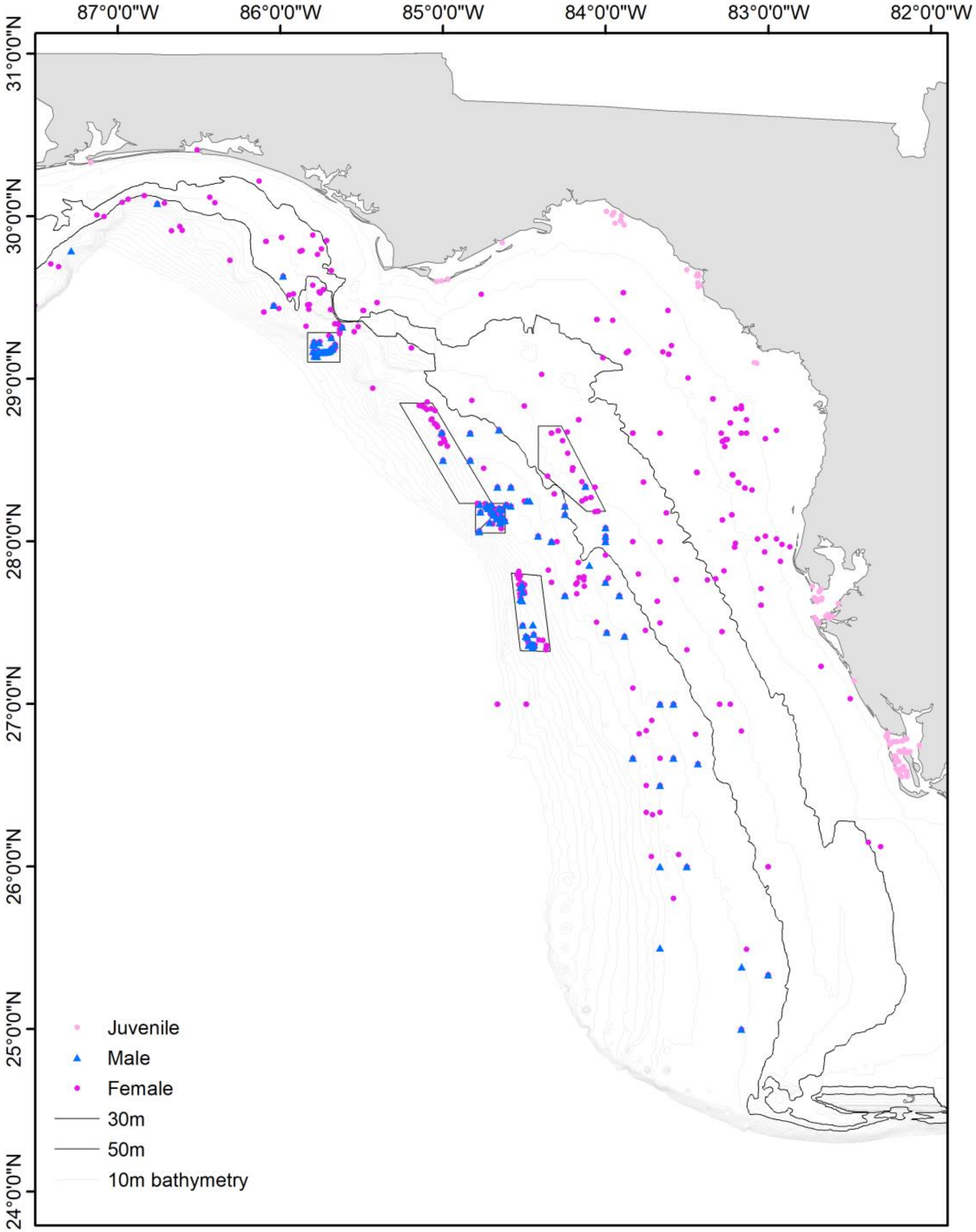


Spatial ecology and sex ratios

H_0 : **Gag exhibit sex-specific habitat use**

Results:

- Nursery habitat occurred over seagrass and in estuaries, all fish were female
- Immature females (n=38) were ages 2 through 5 yr and they occurred in water depths < 20 m (mean = 17.8 +/- 2.1 m)
- Actively spawning females were documented in water depths ranging from 65 to 138 m depth
- Most males occurred in depths > 50 m

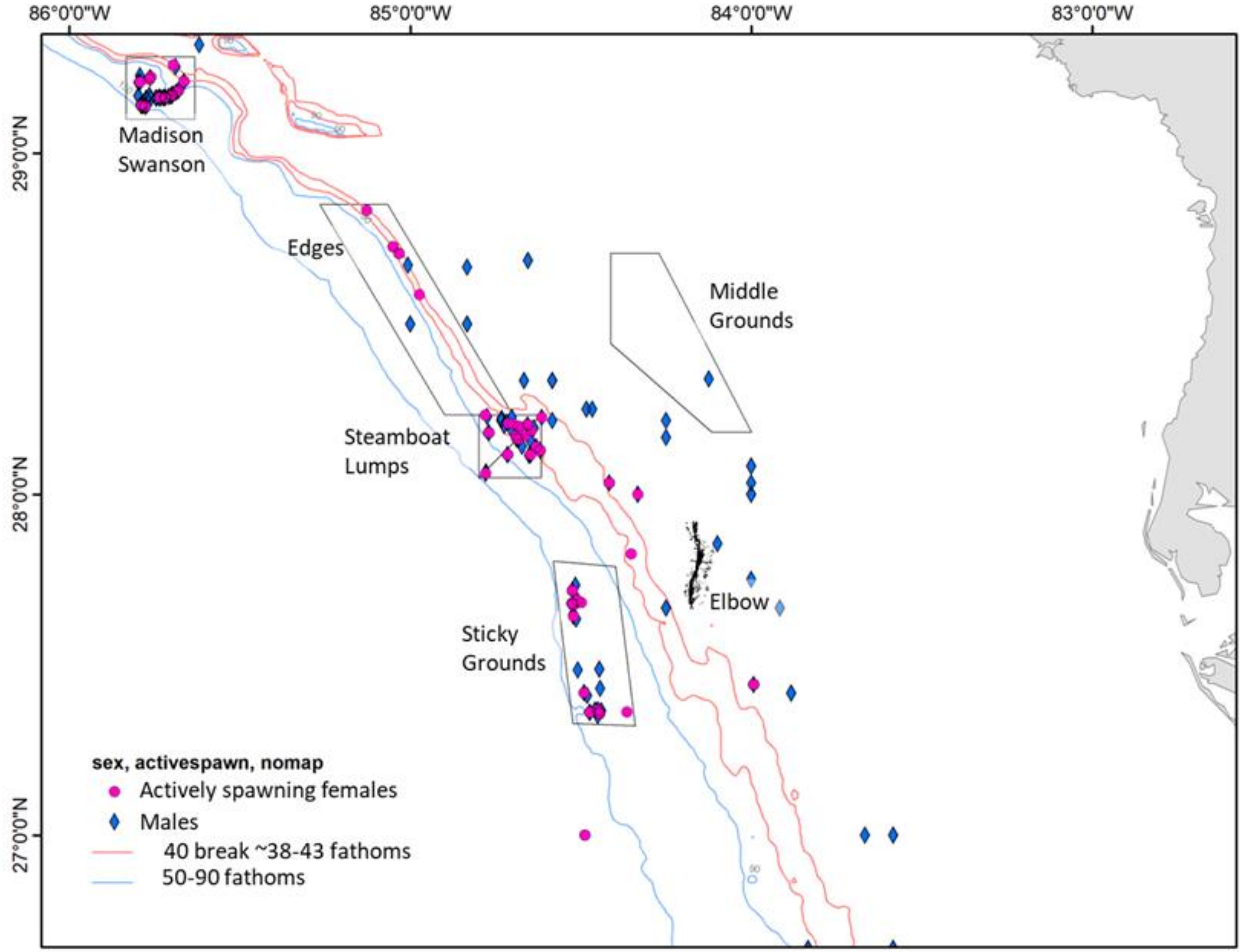


H_0 : Gag spawn only north of 28^0

- a data need identified in SEDAR 33

Results:

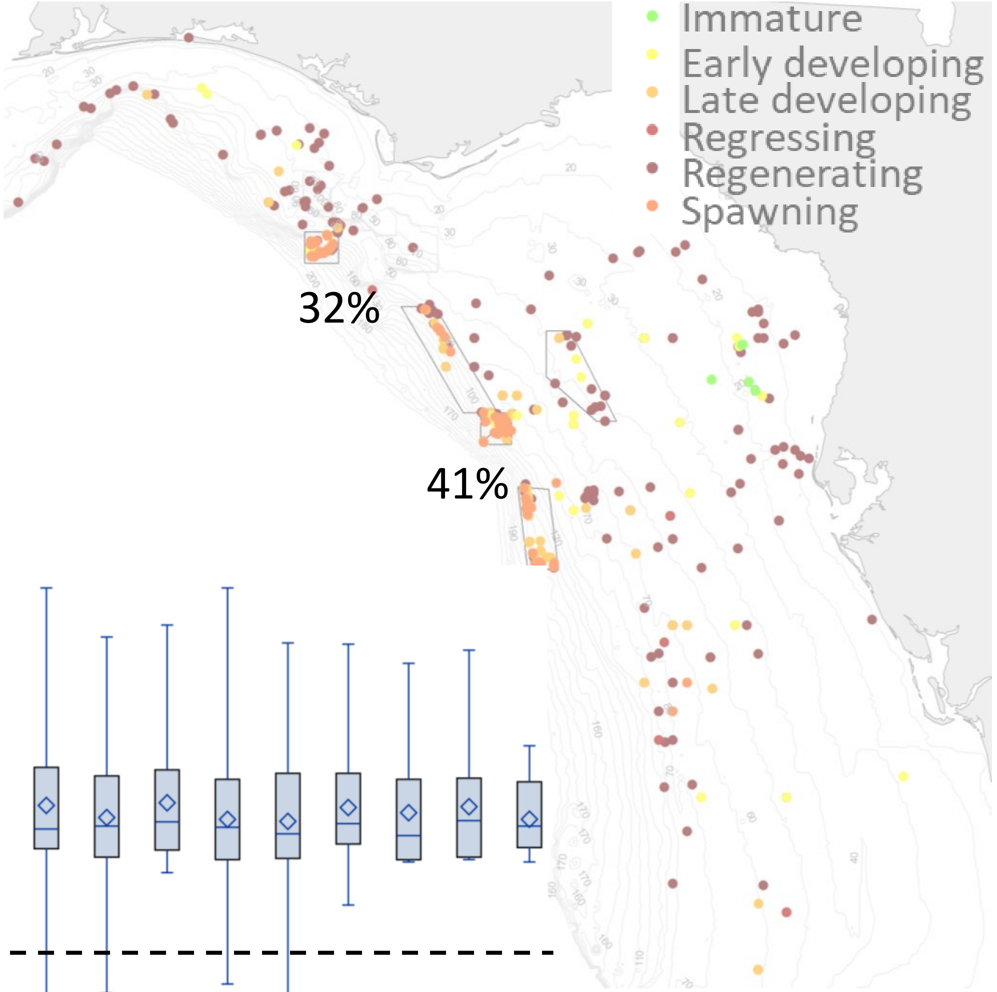
- In our first study we documented spawning in Madison Swanson and the Edges
- In the 2nd study we documented spawning in the Steamboat Lumpss MPA and the Sticky Grounds
- The spawning season was the same in both studies: February 1st - April 15th

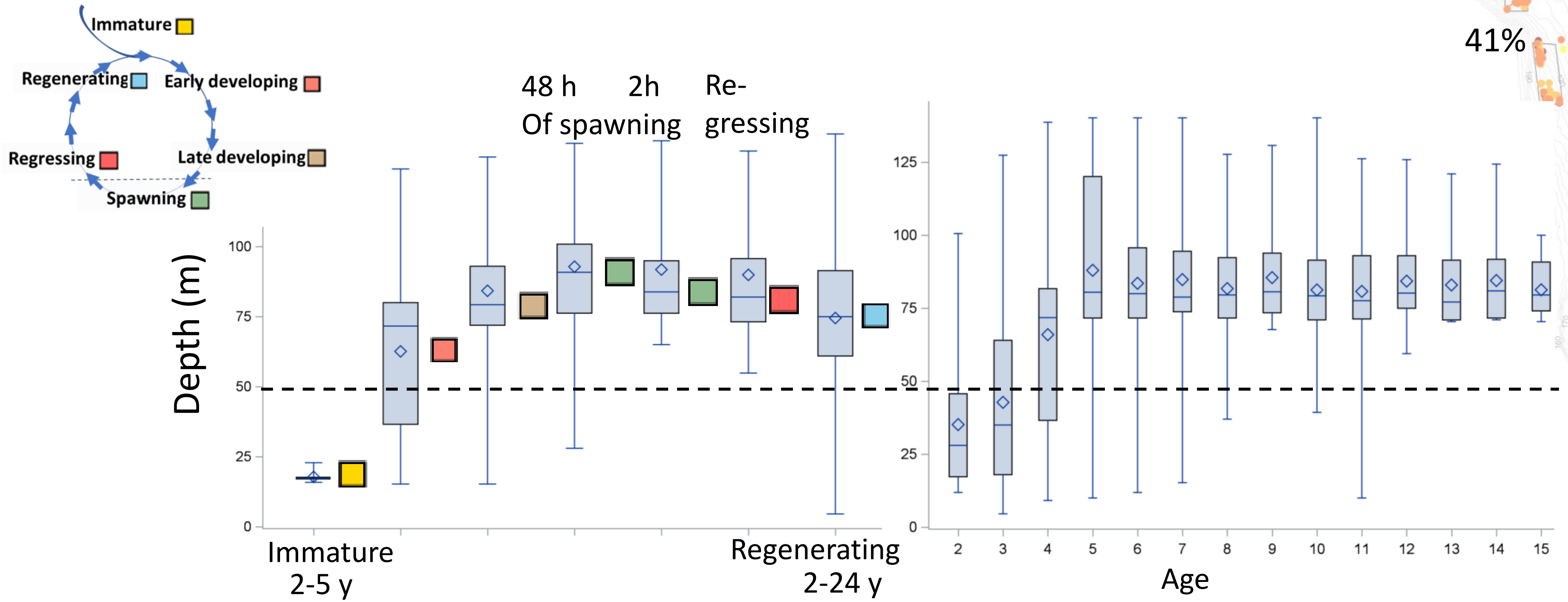


H_0 : Females exhibit spawning migrations, but males do not

Results:

- Mean depth at capture differed significantly with gonadal development and age for females, but not males
- Skip spawners were common in both studies 32%-41%





Measuring sex ratios in protogynous species is difficult, we need best practices

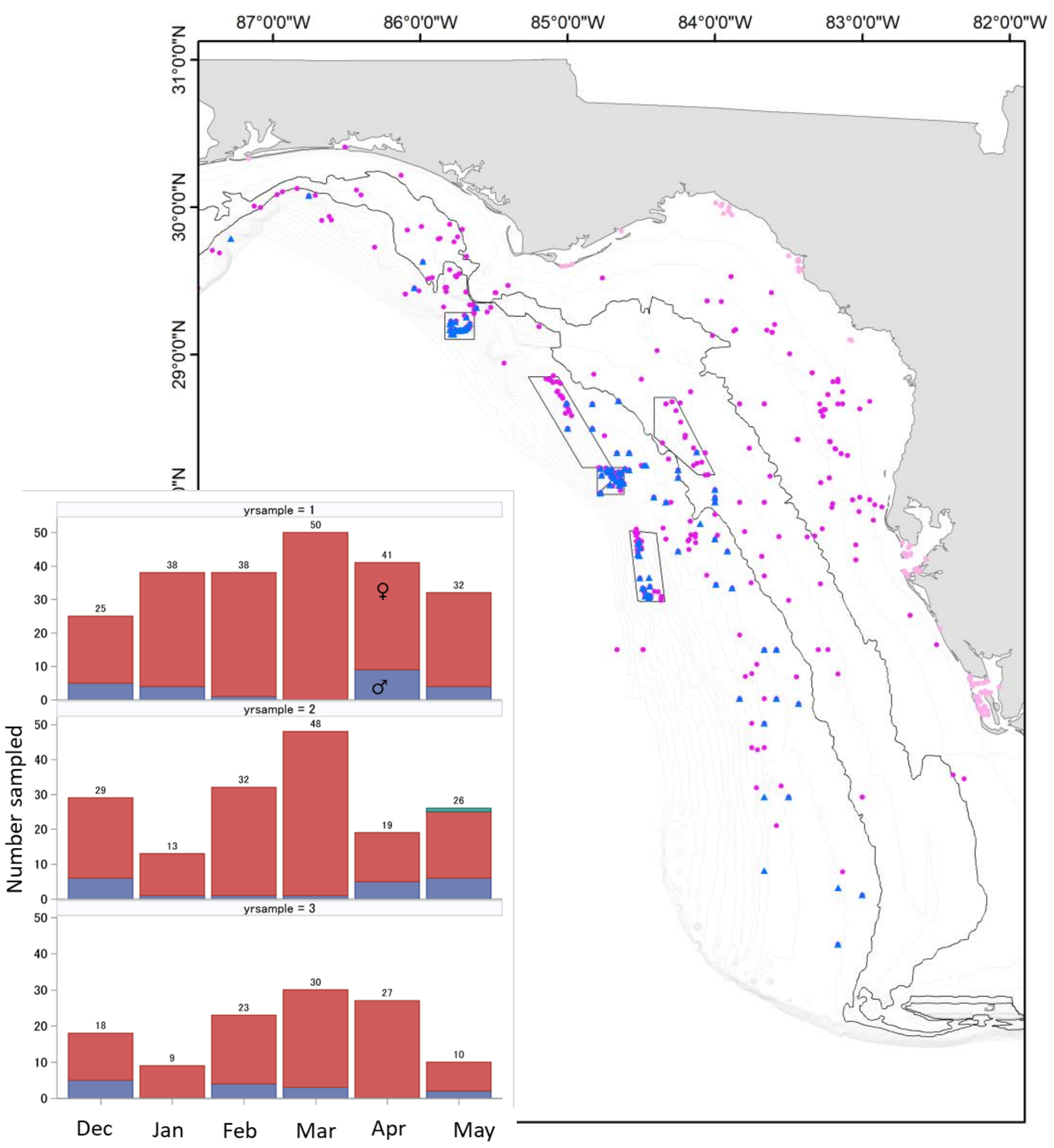
- Gonad histology needed to assign sex
- Accuracy based on pigmentation varies with location, training, and timing (i.e., it needs to be post-mortem to achieve 90% accuracy)

- The sexual segregation and Gag movement ecology means mature individuals of both sexes only occur on the spawning grounds
- And that female recruitment to the spawning population will affect sex ratios:
  - ➢ When there is a strong year class
  - ➢ Or if there is skip spawning and variable participation in spawning migrations in any given year

H_0 : Sex ratios in MPAs will recover to 15% (predicted Heppell et al. 2006)

Results:

- Neither did, with both being ~5%
- Steamboat Lumps MPA male sex ratio: 4.7%
  range: 3.9% in 2020 to 6.1% in 2019
- Madison Swanson MPA male sex ratio: 4.9%
  range: 2.5% in 2017 to 9.5% in 2018
- Unprotected areas had very different male sex ratios and sample sizes:
  - The seasonally-closed Edges: 0% (n=35)
  - The Sticky Grounds: 6.3% (n=144)
    range 4.4% in 2021 to 10% in 2019

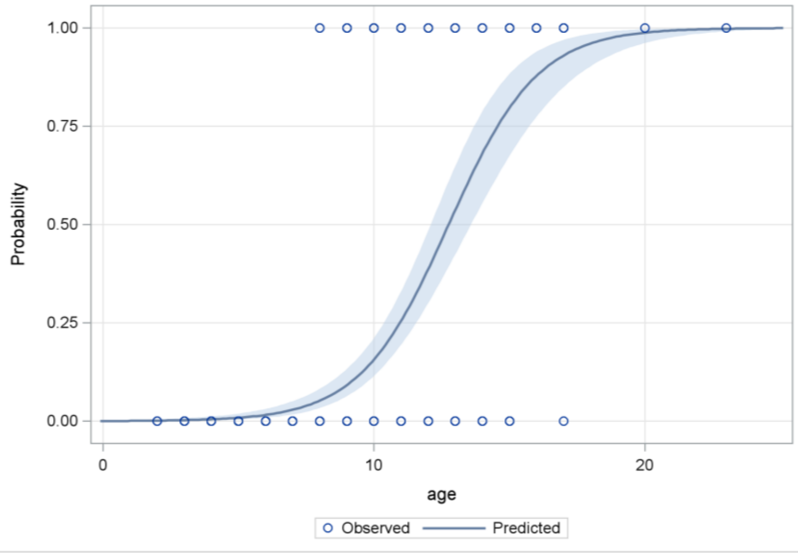


H_0 : Age at 50% male (A50) will be invariant

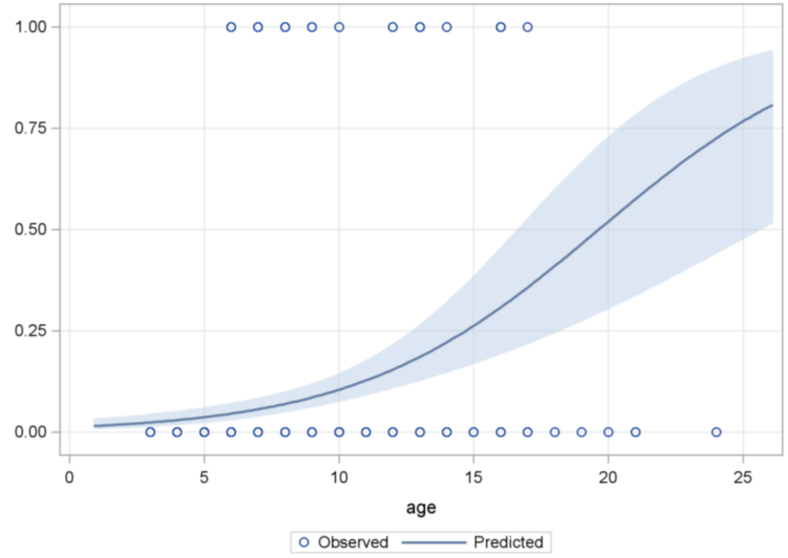
Results:

- A50 for previous assessments was estimated as 10.9 years (1977 & 2004)
- In MPAs
    - Madison Swanson A50=13 y
    - Steamboat Lumps A50=23 y, relationship was uninformative due to oldest fish being female
- Pooled data A50=12.3 years & without the MPAs, A50=10.4 y

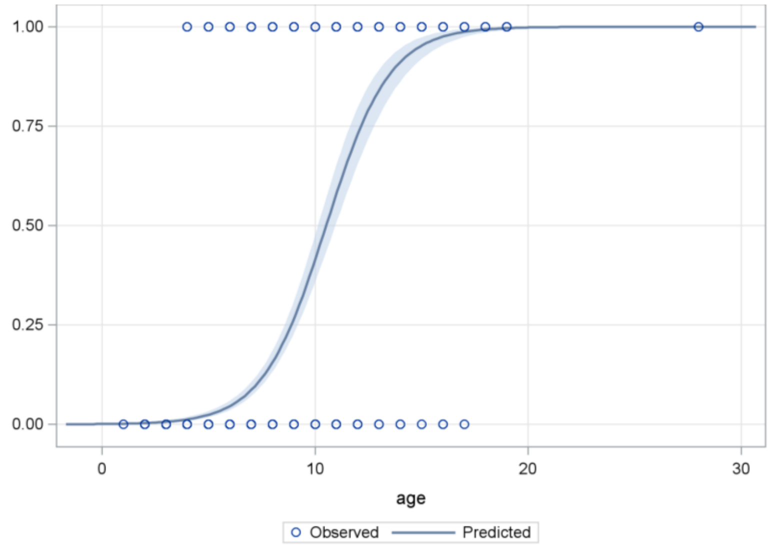
Madison Swanson A50= 13 y



Steamboat Lumps



Pooled, no MPAs A50=10.4 y



H_0 : These low sex ratio results are comparable to others

Results:

SEDAR 72: < 2% male sex ratio based on A50 of 11.6 years

- Virgin sex ratio estimated as 32%

Observed male sex ratios:

- Our pooled data sampled in the spawning season: 4.5% (n=733; 62% from MPAs, no FDM)

Koenig and Coleman 2011:

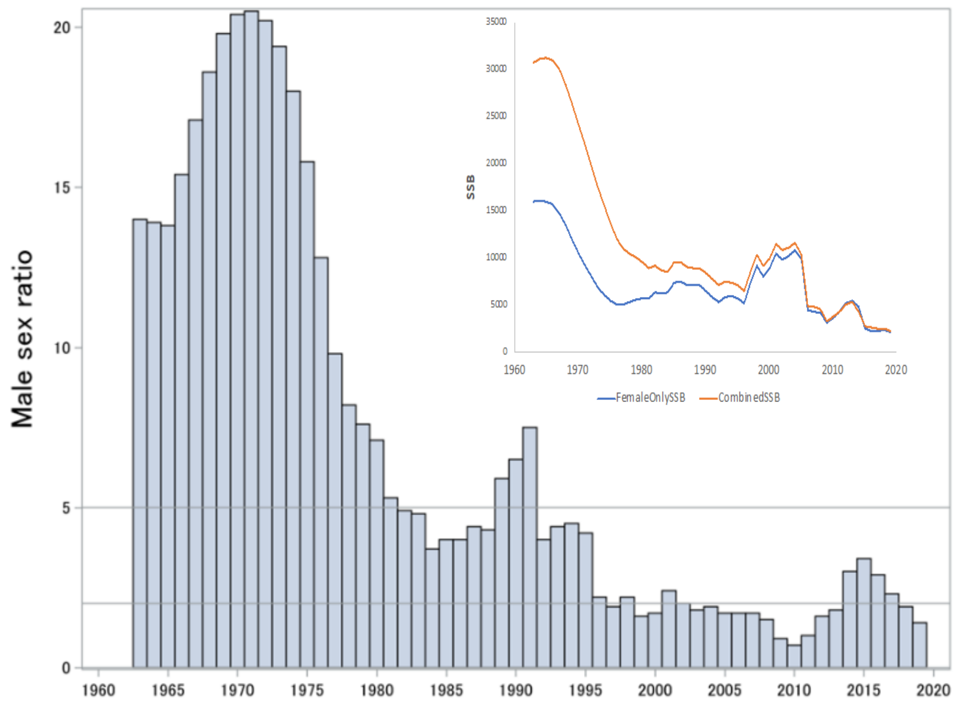
- 2007-2010, sampling Dec-May
  Madison Swanson ♂&→♂ : 5%, n=20
  Outside the MPA ♂&→♂: 1.1%, n=174

Burns and Robbins (2006)

- 2004-2005, sampling May, June & Jan
  NMFS grids 3-5 ♂&→♂: 1.8%, n=225 (all LL)

Hood and Schleider (1992)

- 1977-1980 December-March: 17%



Factors affecting male recruitment

Factors driving sex change

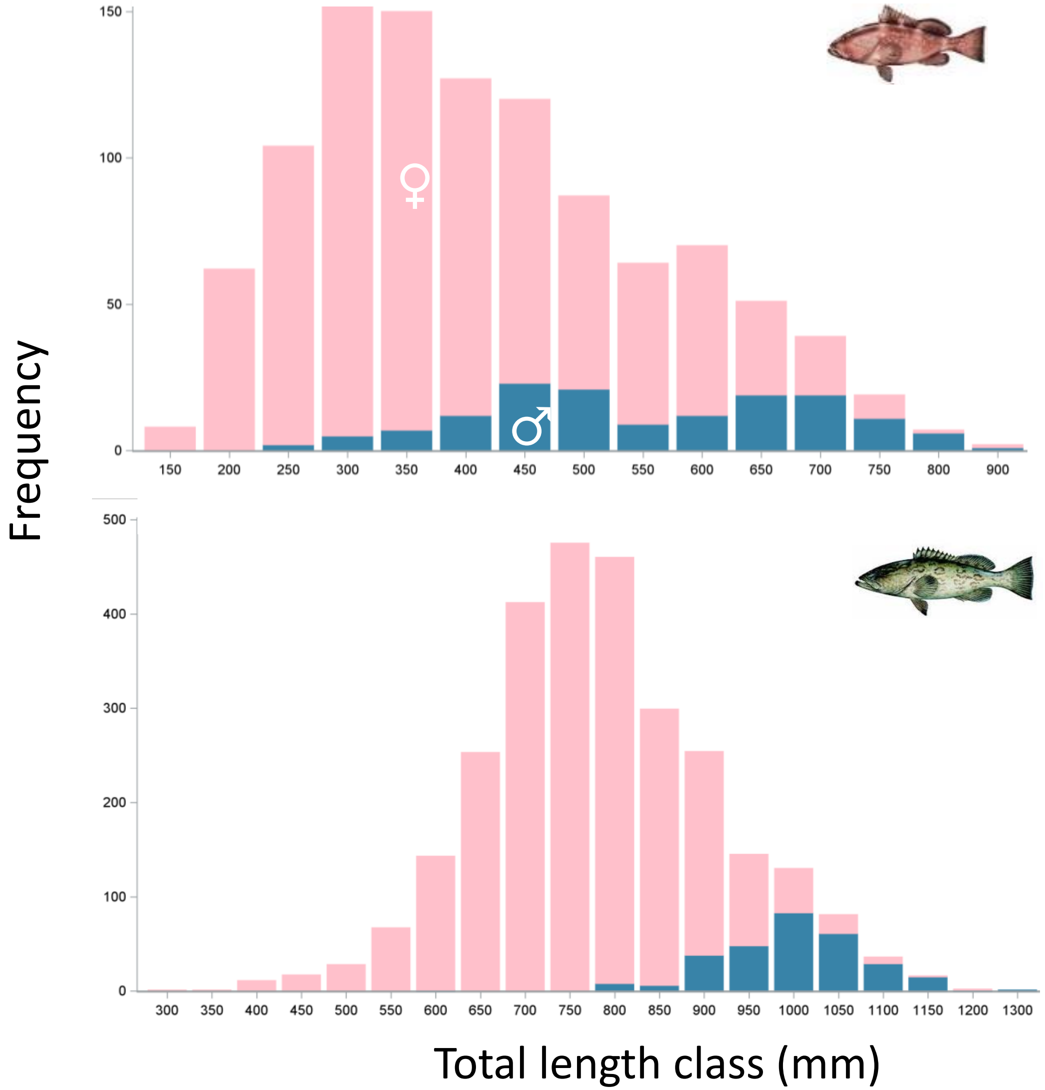
- The main theoretical model proposed to explain sex change is the size advantage model. It predicts sex change evolves when larger age/size of the terminal sex results in greater fitness

Theory	Triggers & mediators
• **The size advantage model > fitness due to increased reproductive success associated with larger size of terminal sex**	• **Population density** • **Local sex ratio**
• **Tightly linked to a species' mating system and social structure**	• **Relative size to others within "social group"** • **Threshold size or age**

H_0 : Sex-specific size distributions will be similar between Red and Gag grouper

Results: Red Grouper size distributions overlap more

- Gag males are significantly larger than females
- But Gag males are not as large as they used to be
- The largest male we sampled was 40 lbs in the Madison Swanson MPA compared to a 72 lb male captured in 1985



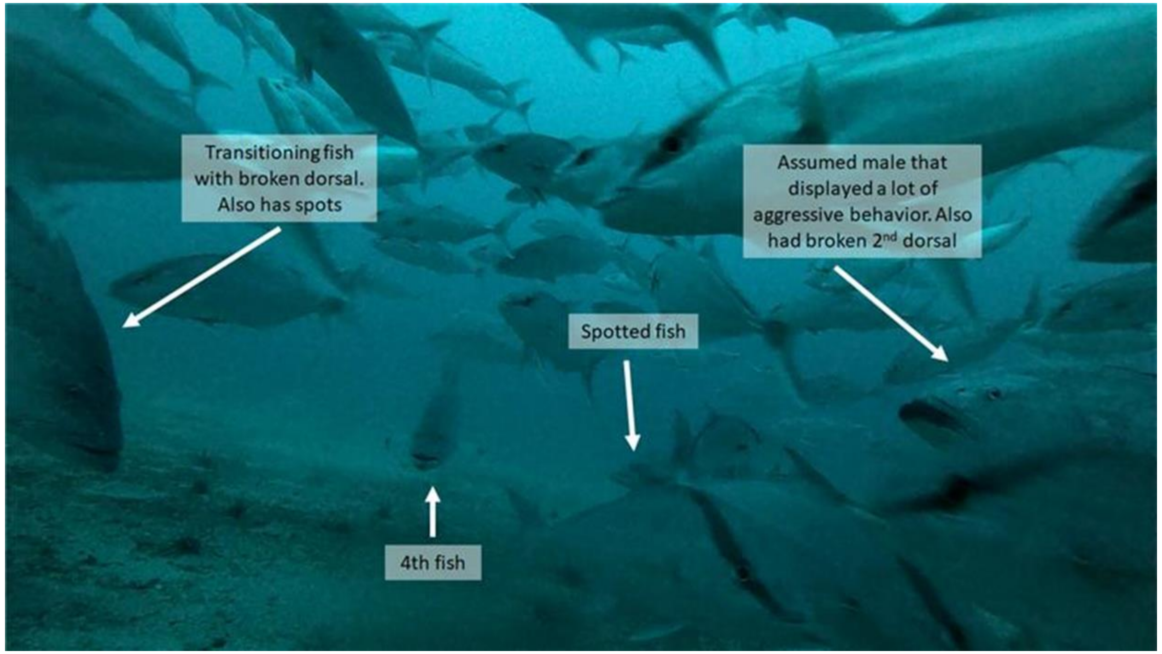
H_0 : The difference is due to mating strategy

Results: Red Grouper are haremic and Gag are not  

- The relative value of a male differs amongst fish which are haremic versus have multiple males in close proximity
- In well-dispersed harems, if the male is killed the largest female will change sex
- Male competition plays a role in male age at maturity in terrestrial vertebrates and may play a role in Gag, but this is unknown

Degree male competition	Young male maturation
(1) Promiscuous, form leks	Never/rarely
(2) Promiscious, dispersed males	Occasionally
(3) Pair bonding	Usually

Stearns 1992



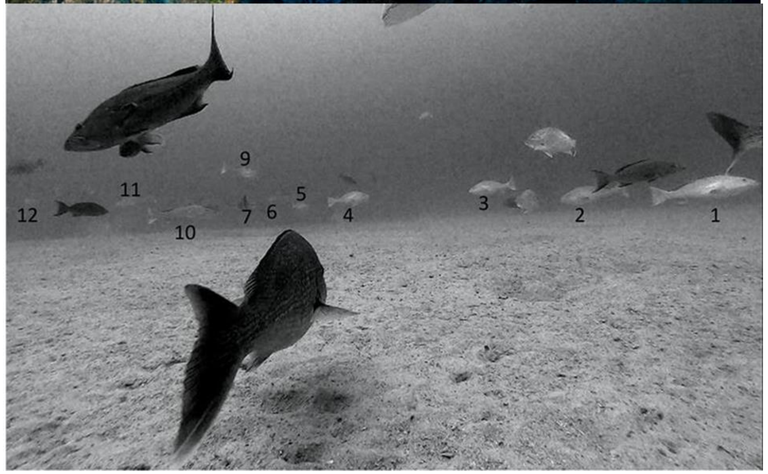
H_0 : The Gag mating strategy is to form spawning aggregations

Results: We do not have evidence of Gag aggregating to spawn

- Gag reported in the scientific literature to form small spawning aggregations from 50-100 fish
- A spawning aggregation is defined as having a four-fold increase in density in the spawning season. Our data does not support this. The maximum number observed on video during the spawning season was 12 in Steamboat Lumps and 18 in Madison Swanson

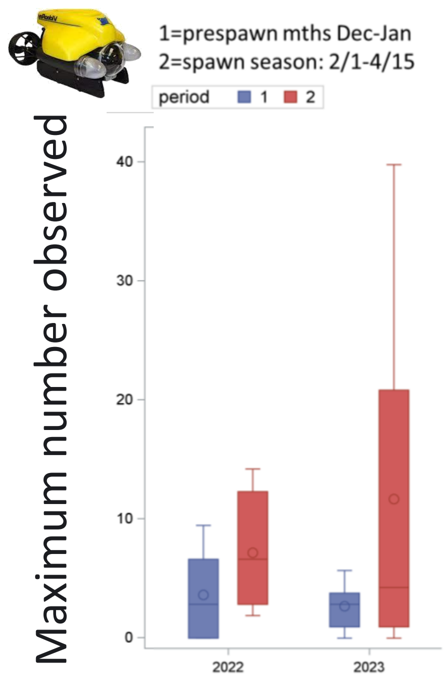
Study years	Area	Mean CPUE (S)	Mean CPUE (NS)	Max CPUE (S)	Max CPUE (NS)	MaxN Cap (S)	MaxN Cap (NS)	Max Nvid (S)	Max N Vid (NS)
2019-2021	Steamboat	3.3	2.9	29	18	12	9	12	18
	Sticky Grounds	1.4	0.9	30	10	17	20	2	0
2016-2018	Madison Swanson	1.9	1.4	38	8	17	10	14	4
	Edges	0.3	0.2	7	4	8	2	9	12*

*These fish are from 30 January 2016, i.e., just before the spawning season. The maximum number observed in the remainder of the non-spawning season was 8 fish



H_0 : Gag form spawning aggregations…

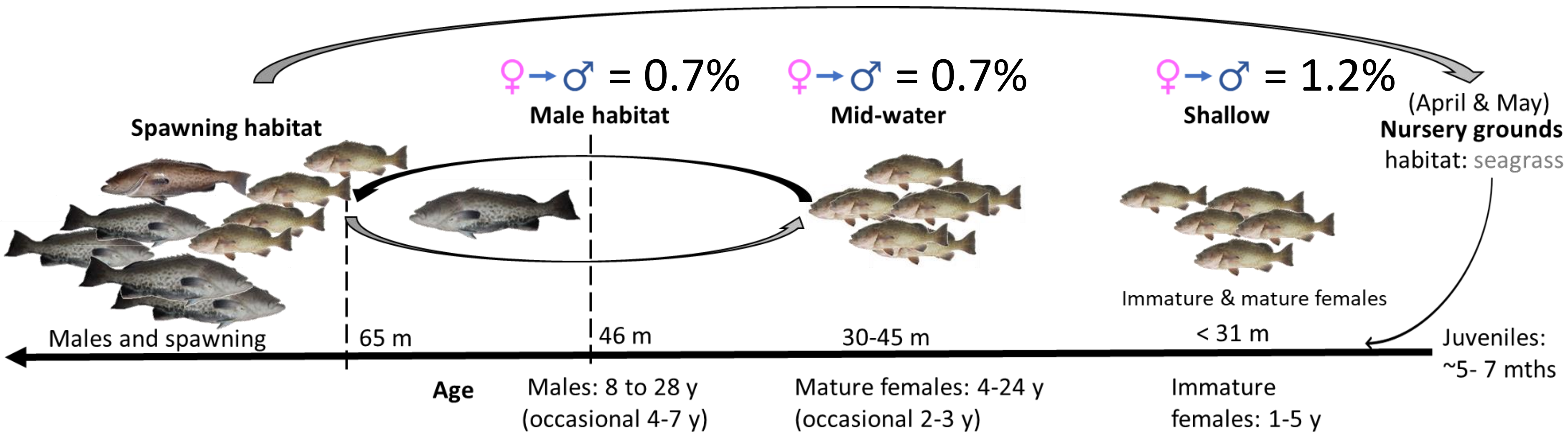
Results (continued): But on 4/4/2023 we observed 42 gag in Steamboat Lumps



H_0 : Sex change will occur primarily on the spawning grounds

Results: Sex change in shallow water was as or more common than on the spawning grounds

- Few transitionals sampled (22 out of 2,863) but sampled throughout most of the year
- Males are not needed for sex change, indicating sex ratio is not a driver
- Shallow-water transitionals were smaller and younger (mean: 765 +/- 116 mm TL and 4.6 +/- 0.89 years, n=4) than those from male habitat (941 +/- 107 mm TL and 8.2 +/-3.3 years, n=16)
- Suggesting size and age of Gag sex change is dependent on the relative size of others in the social group



Sex change, movement, catchability, & connectivity

H_0 : Fishing effort will increase in the fall when temperatures decline

Prelim results: High recreational effort in shallow water in pre-spawning months (Nov - Jan)

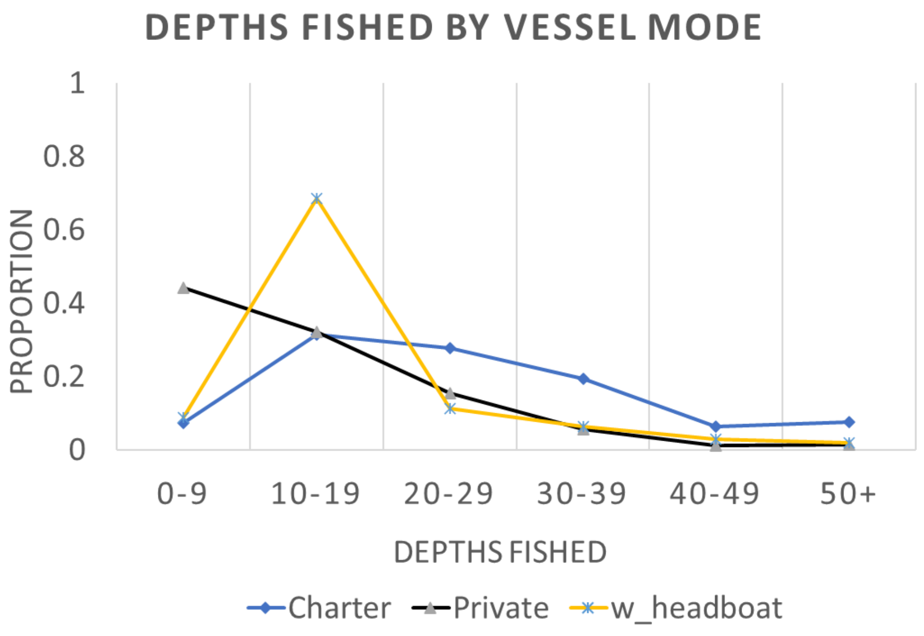
Gemeroth et al., 2021

- ~94% of sampled recreational fishing effort <=49 m
  - 92% of charter effort
  - 98% of headboat effort
  - 98.6% of private boat effort

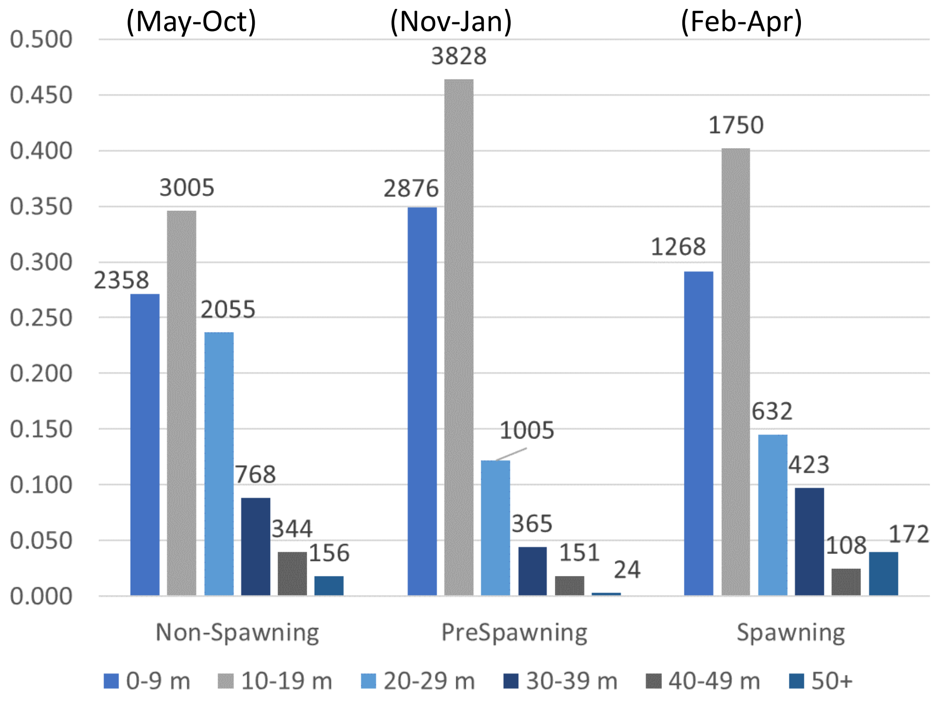
At-Sea Observer Program

SRFS STATE REEF FISH SURVEY

(2009-2019)

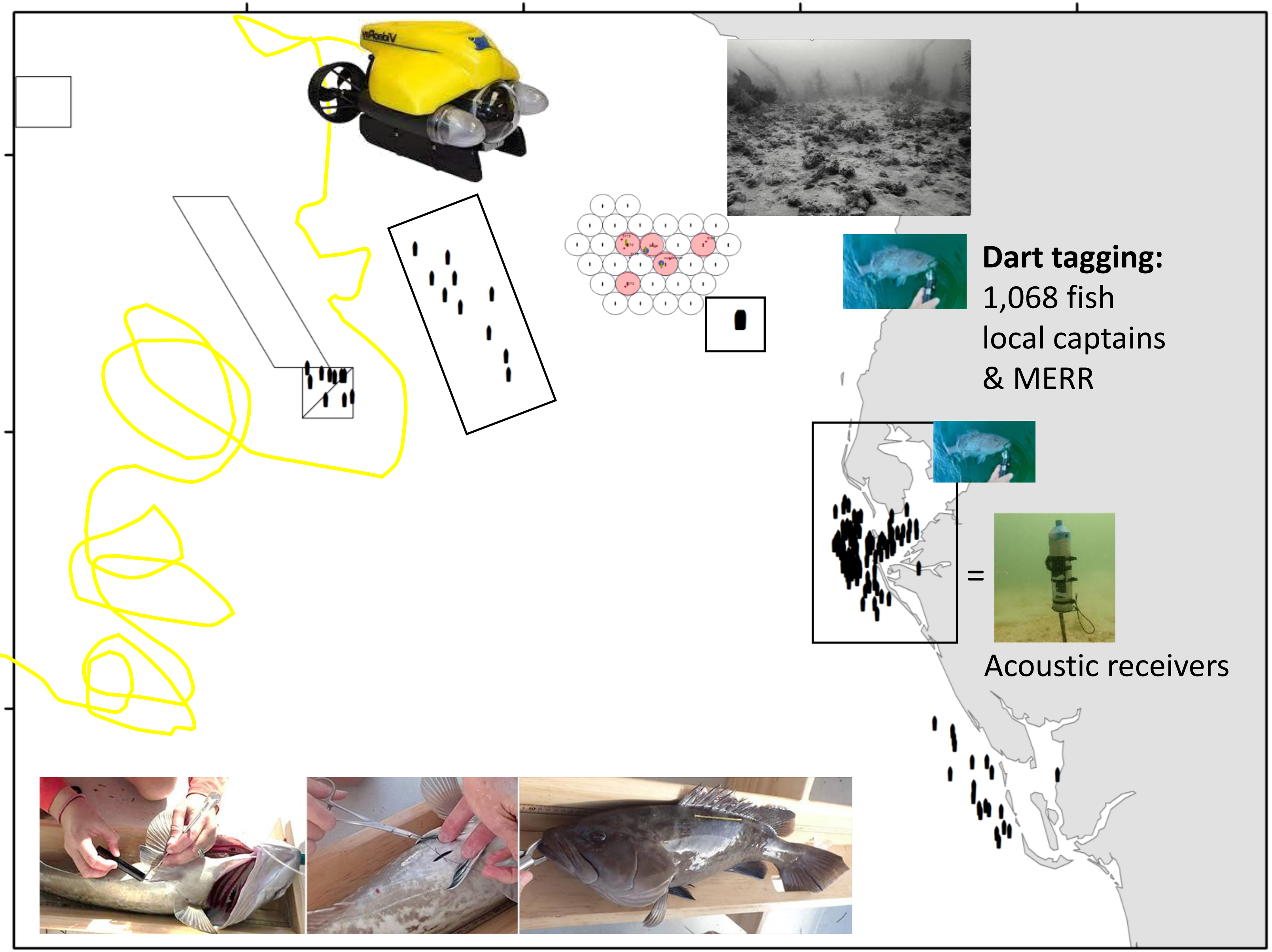


21-27% > gag caught in depths 0-19 m during pre-spawning season vs. non-spawning season.



On-going research

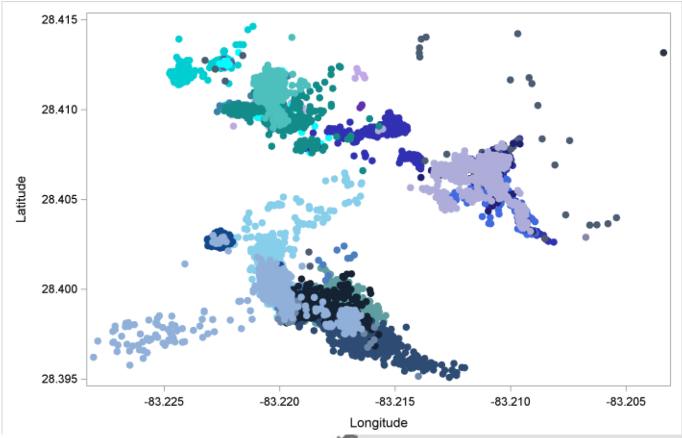
- Four sampling areas: estuarine, nearshore, mid-water & Steamboat Lumps
- ROV survey & hook and line sampling in pre-spawning months (Nov-Jan) & spawning months (Feb-March) to assess density
- Dart tags & acoustic tracking to assess movement

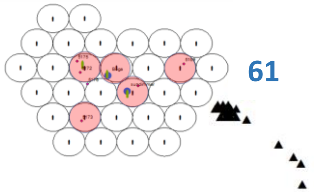


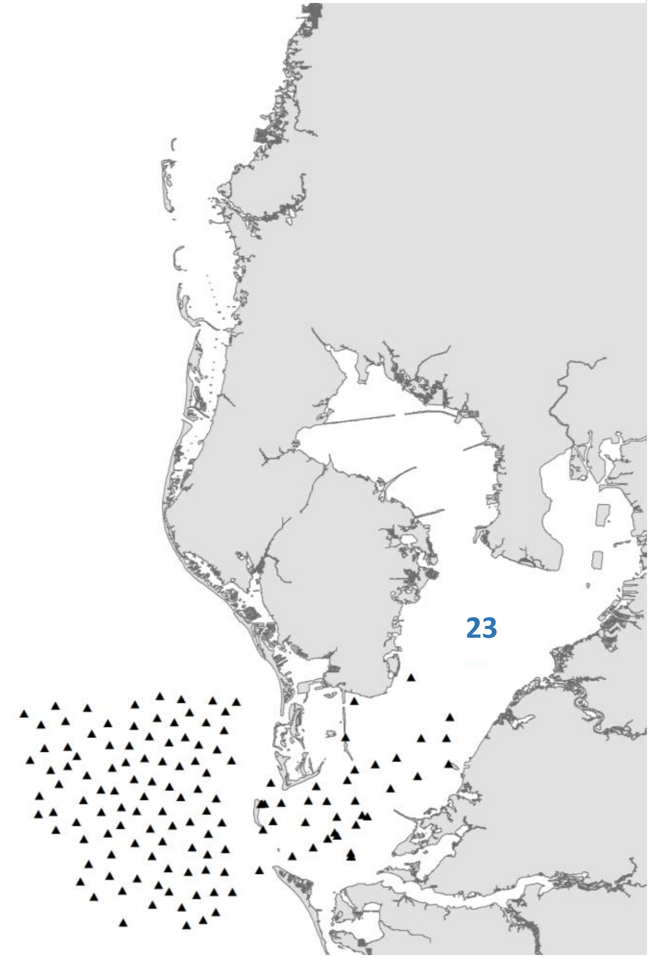
Prelim results: **84 Gag acoustically tagged**

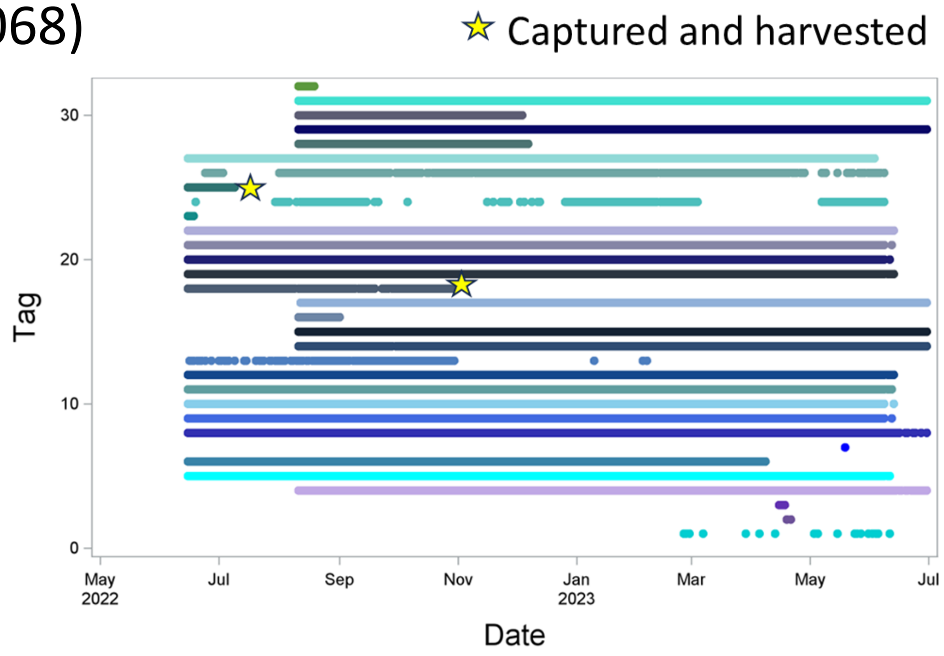
And 1,068 fish dart tagged

- Acoustic tracking helpful to assign nearshore fate: emigrated, predated, post-release mortality
- Dart tags, we hope to document offshore migration
- Offshore recaps low
  1 in our data & 2 in FDM dart tag database (n=7,540)
- 102 of our tags recaptured (n=1,068)
- 1 undersized fish captured & released 5x at a known hot spot over a year



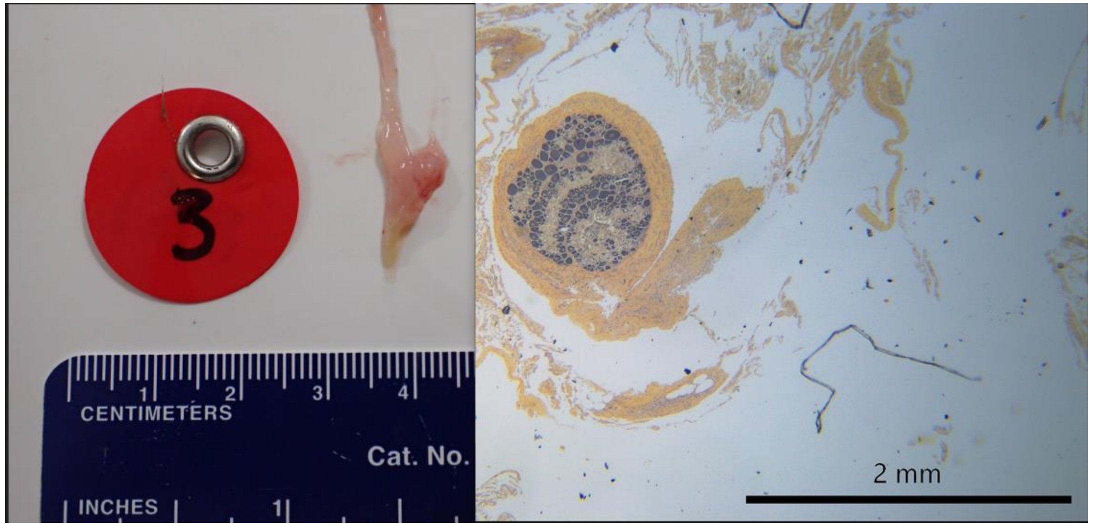






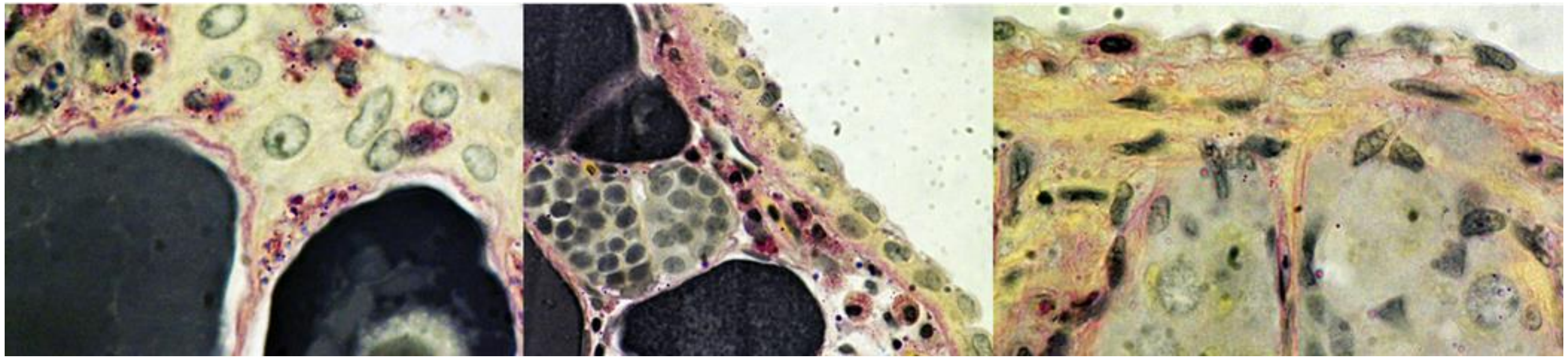
Analysis of maturity & transitionals sampled in shallow water is on-going

Lots of gonads, n=1,003



TL=666, age 4, captured 1/31/2020

Female regenerating | Transitional | Male regenerating



Main takeaways

Main takeaways for Gag:

- Male sex ratios are low
  - it takes ~ a decade to make a male
- Sex ratios did not recover to the expected 15% in either MPA
- Virgin sex ratio is estimated to be 32%
- The Edges, a seasonally-closed area, had the lowest male sex ratios
- Intense fishing effort in shallow, nearshore waters may represent a bottleneck to spawning population recruitment

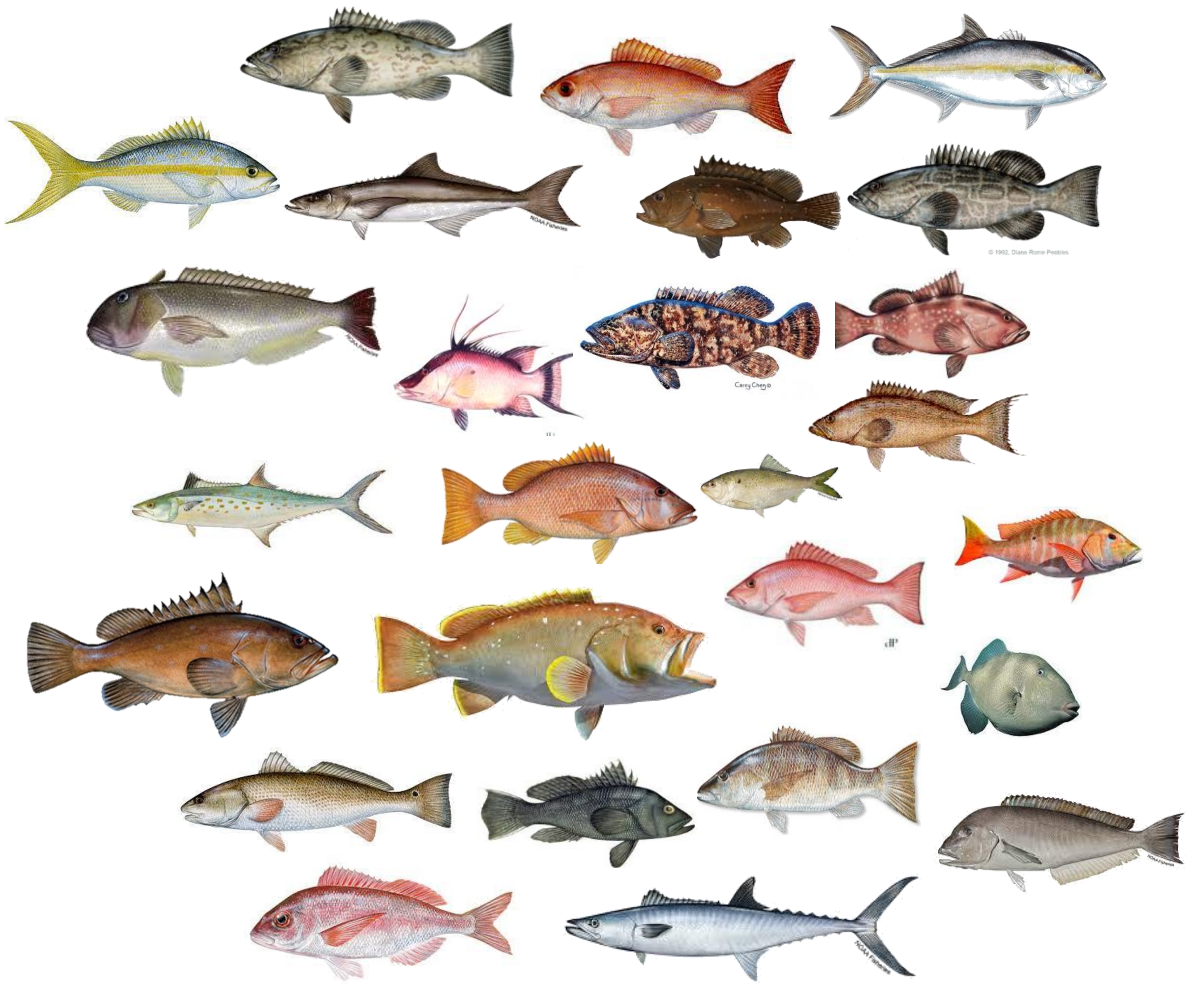
Looking forward: developing best practices for protogynous species

Factors affecting reproductive potential

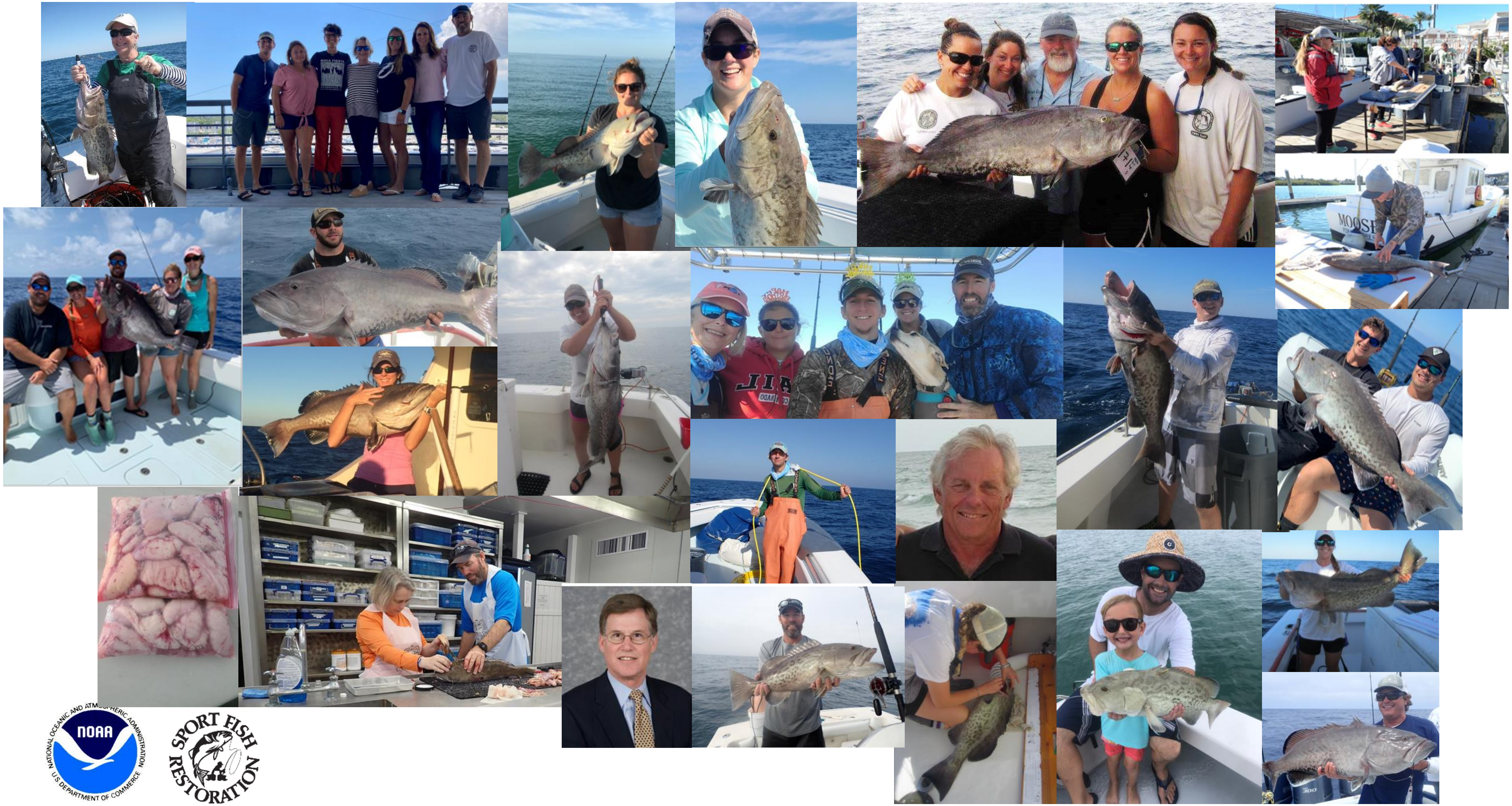
Assumption	Decision criterion
Gonochoristic	
Traditional: Productivity driven by abundance & fecundity	Data availability
Emerging: Spatial ecology & age distribution affects productivity	BOFFFs
	Sources and sinks
	Reproductive compensation
	Spatio-temporal reproductive behavior
Sequential hermaphrodite	
Productivity in protogynous fishes may be sperm limited	Sperm limitation affected by: size and age at transition & ability to adapt to fishing mortality

Modified from: Lowerre-Barbieri et al., 2017; SEDAR best practices

~a 1/3 of federally-managed species in SE are protogynous



Thanks everyone for your help!



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SPORT FISH RESTORATION