Timing and Location of Reef Fish Spawning Activity in the Atlantic Ocean off the Southeastern United States

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South Atlantic Council Meeting
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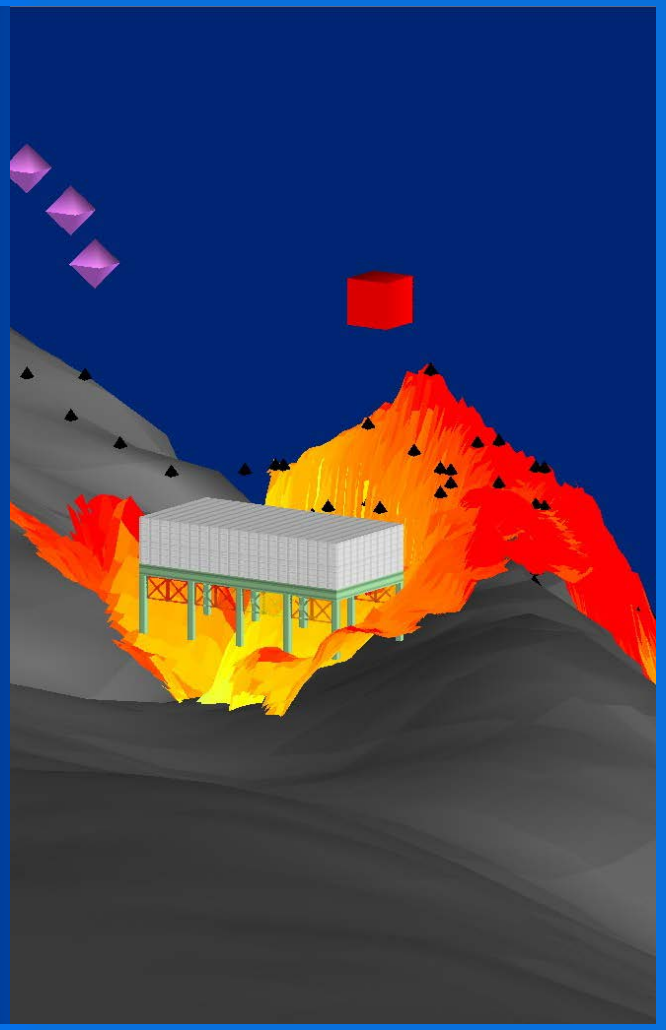
INTRODUCTION

Objectives:

- ✓ Synthesize what is known about timing of spawning for managed reef fish stocks relative to month and lunar phase
- ✓ Quantitatively test what variables are predictive of spawning activity
- ✓ Verify predicted spawning locations based on fisher local ecological knowledge and field validation studies
- ✓ Suggest needed data and methods for prediction and verification of the locations of spawning aggregations.



DATA SOURCES

Fishery-Independent Surveys:

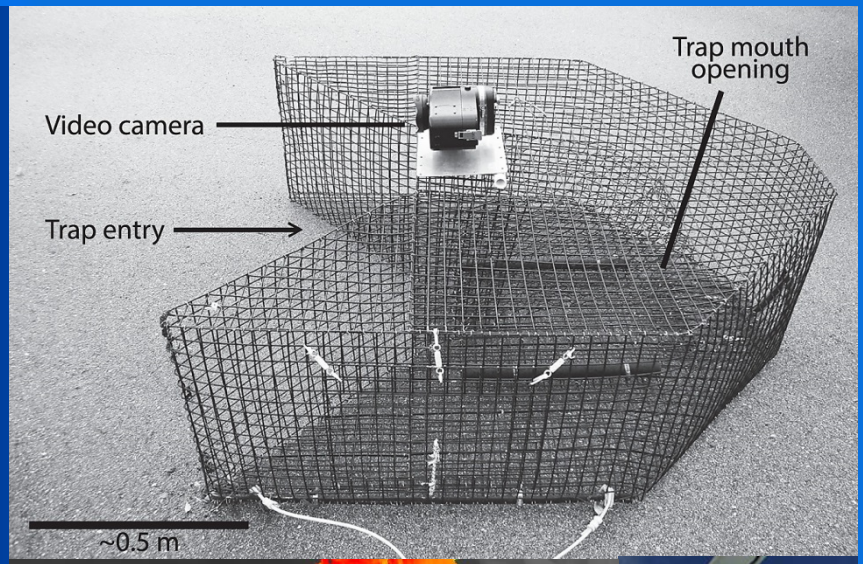
- ✓ MARMAP (1990-2012)
- ✓ SEAMAP-SA (2009)
- ✓ SEFIS (2010-2012)
- ✓ FWC (2012)

Bathymetry

- ✓ CRM: Coastal Relief Model (90 m)
- ✓ MB: Side-scan and Multi-beam (3-50 m)

Fishery-Dependent Validation

- ✓ MARMAP (1990-2014)
- ✓ LGL (2014-2015)
- ✓ Tishler Meadows (2012)
- ✓ FWC (2012-2013)



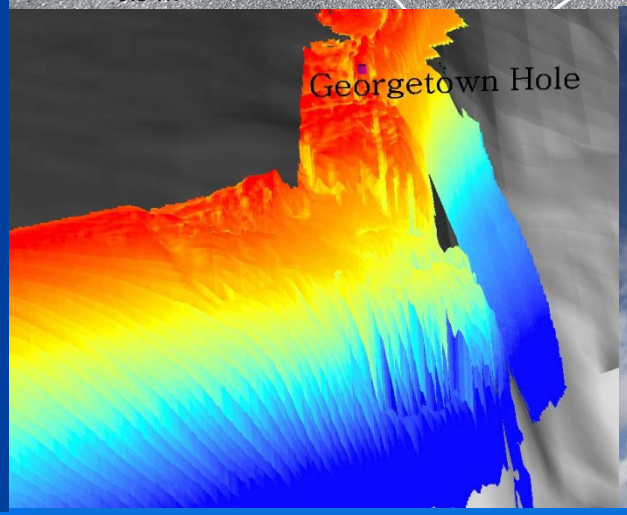
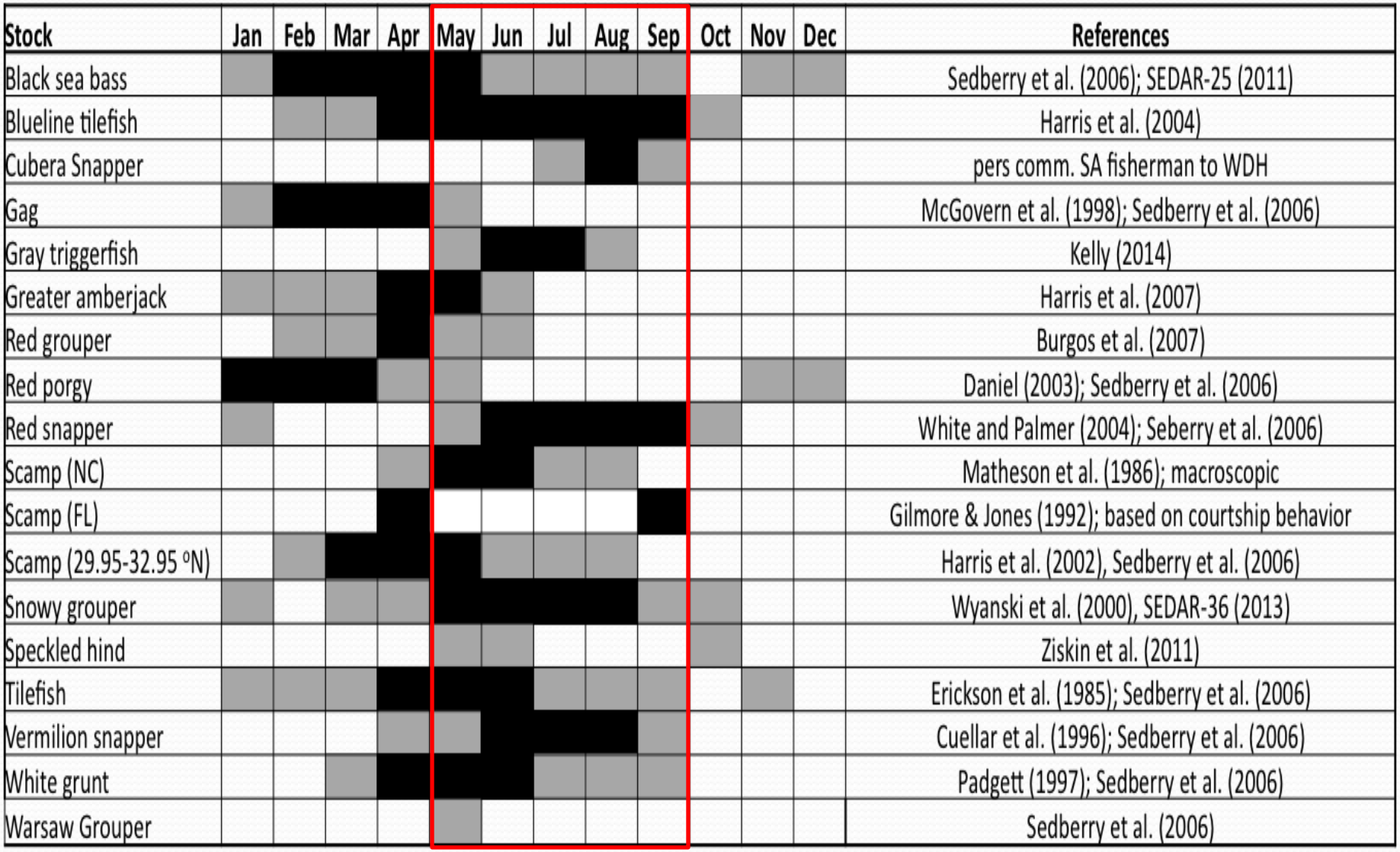


Table 6. Timing of spawning (gray shading) and peak spawning (black shading) for exploited Atlantic Ocean reef fish stocks off the southeastern United States. Red box denotes core SERFS core fishery-independent sampling months (Wyanski, pers. comm.).



Stock	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	References
Black sea bass													Sedberry et al. (2006); SEDAR-25 (2011)
Blueline tilefish													Harris et al. (2004)
Cubera Snapper													pers comm. SA fisherman to WDH
Gag													McGovern et al. (1998); Sedberry et al. (2006)
Gray triggerfish													Kelly (2014)
Greater amberjack													Harris et al. (2007)
Red grouper													Burgos et al. (2007)
Red porgy													Daniel (2003); Sedberry et al. (2006)
Red snapper													White and Palmer (2004); Seberry et al. (2006)
Scamp (NC)													Matheson et al. (1986); macroscopic
Scamp (FL)													Gilmore & Jones (1992); based on courtship behavior
Scamp (29.95-32.95 °N)													Harris et al. (2002), Sedberry et al. (2006)
Snowy grouper													Wyanski et al. (2000), SEDAR-36 (2013)
Speckled hind													Ziskin et al. (2011)
Tilefish													Erickson et al. (1985); Sedberry et al. (2006)
Vermilion snapper													Cuellar et al. (1996); Sedberry et al. (2006)
White grunt													Padgett (1997); Sedberry et al. (2006)
Warsaw Grouper													Sedberry et al. (2006)

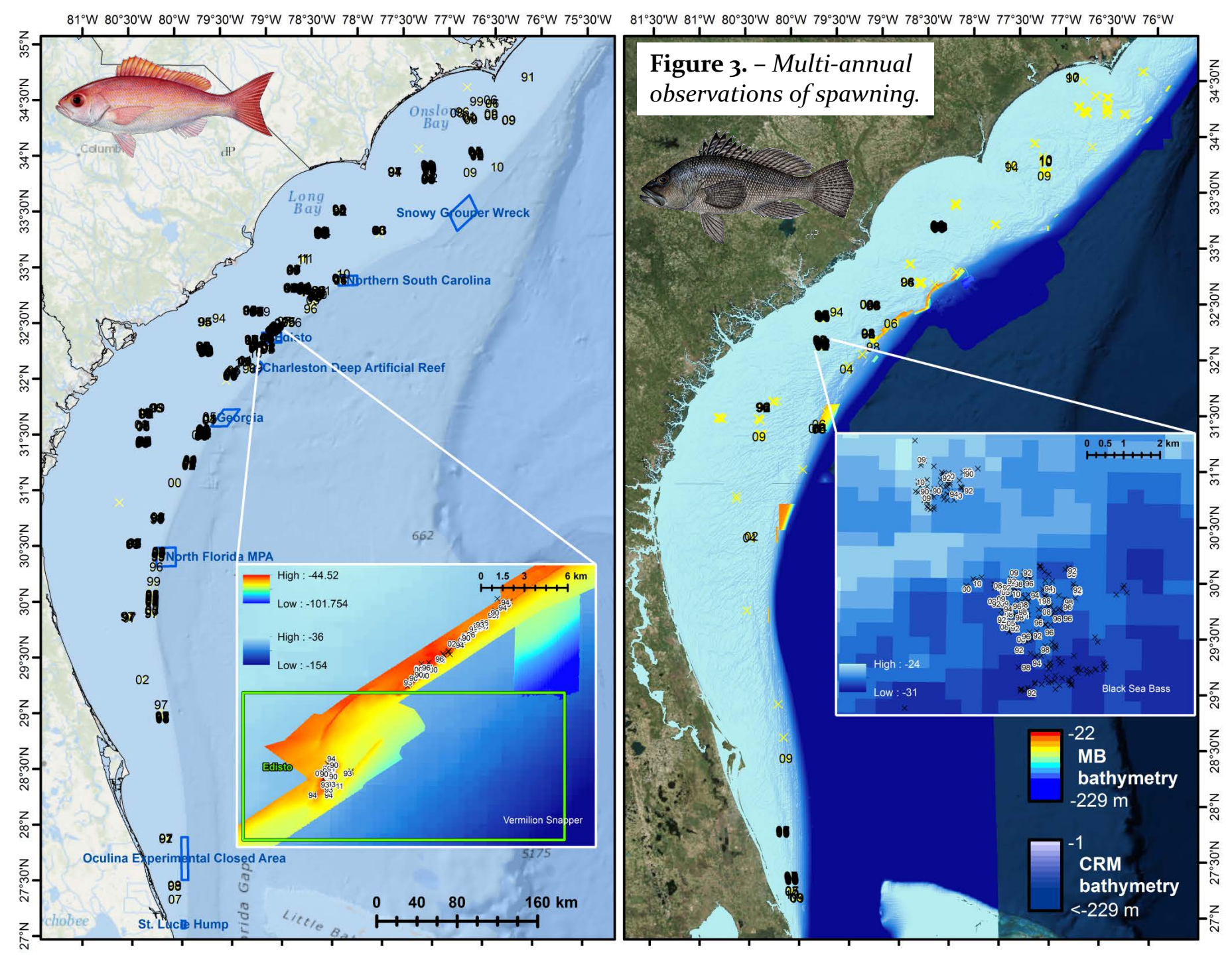


Figure 3. – Multi-annual observations of spawning.
Snowy Grouper Wreck
Northern South Carolina
Edisto
Charleston Deep Artificial Reef
Georgia
North Florida MPA
Oculina Experimental Closed Area
St. Lucie Hump
Onslow Bay
Long Bay
High : -44.52
Low : -101.754
High : -36
Low : -154
Edisto
Vermilion Snapper
0 1.5 3 6 km
0 40 80 160 km
High : -24
Low : -31
Black Sea Bass
0 0.5 1 2 km
-22
MB
bathymetry
-229 m
-1
CRM
bathymetry
<-229 m

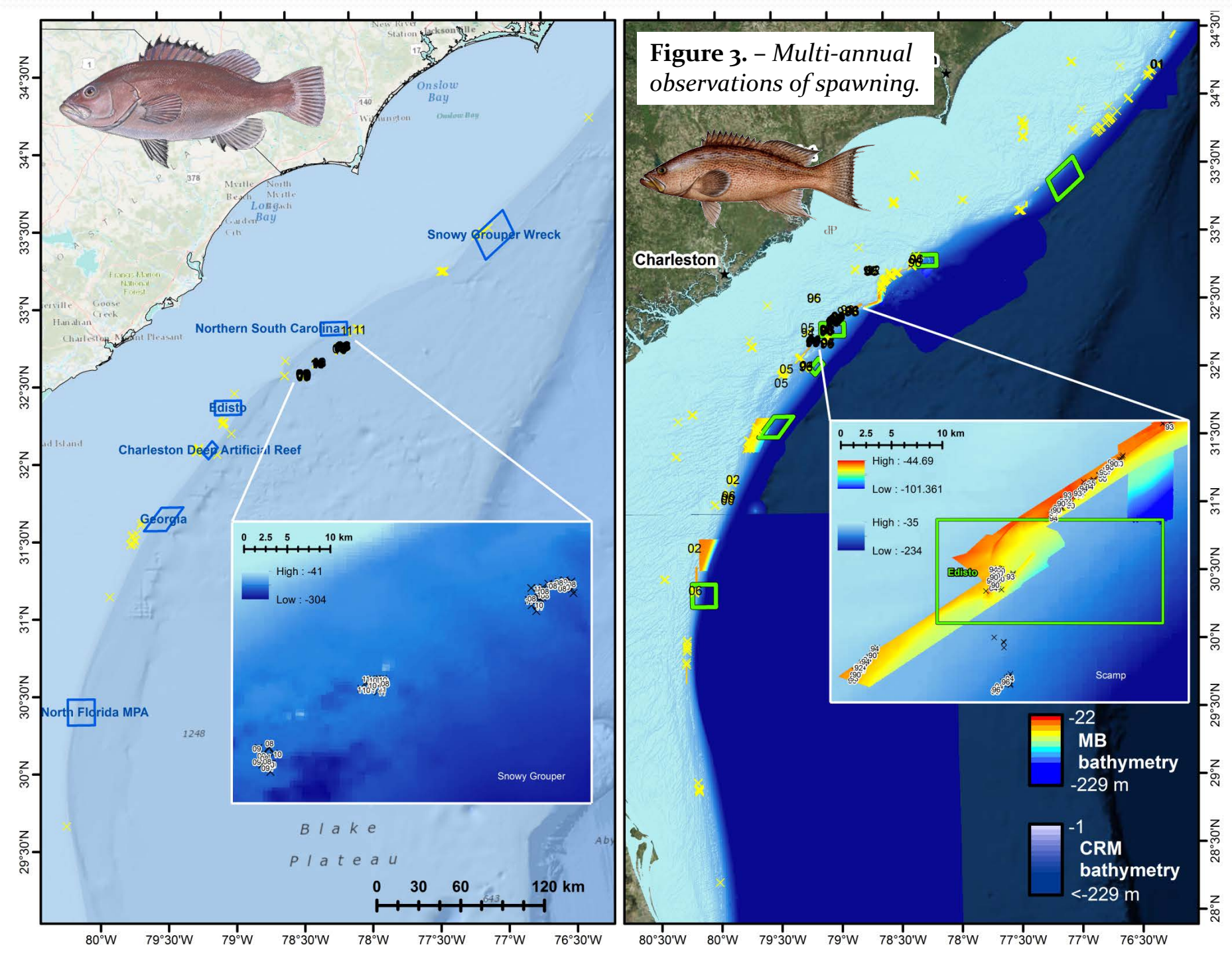


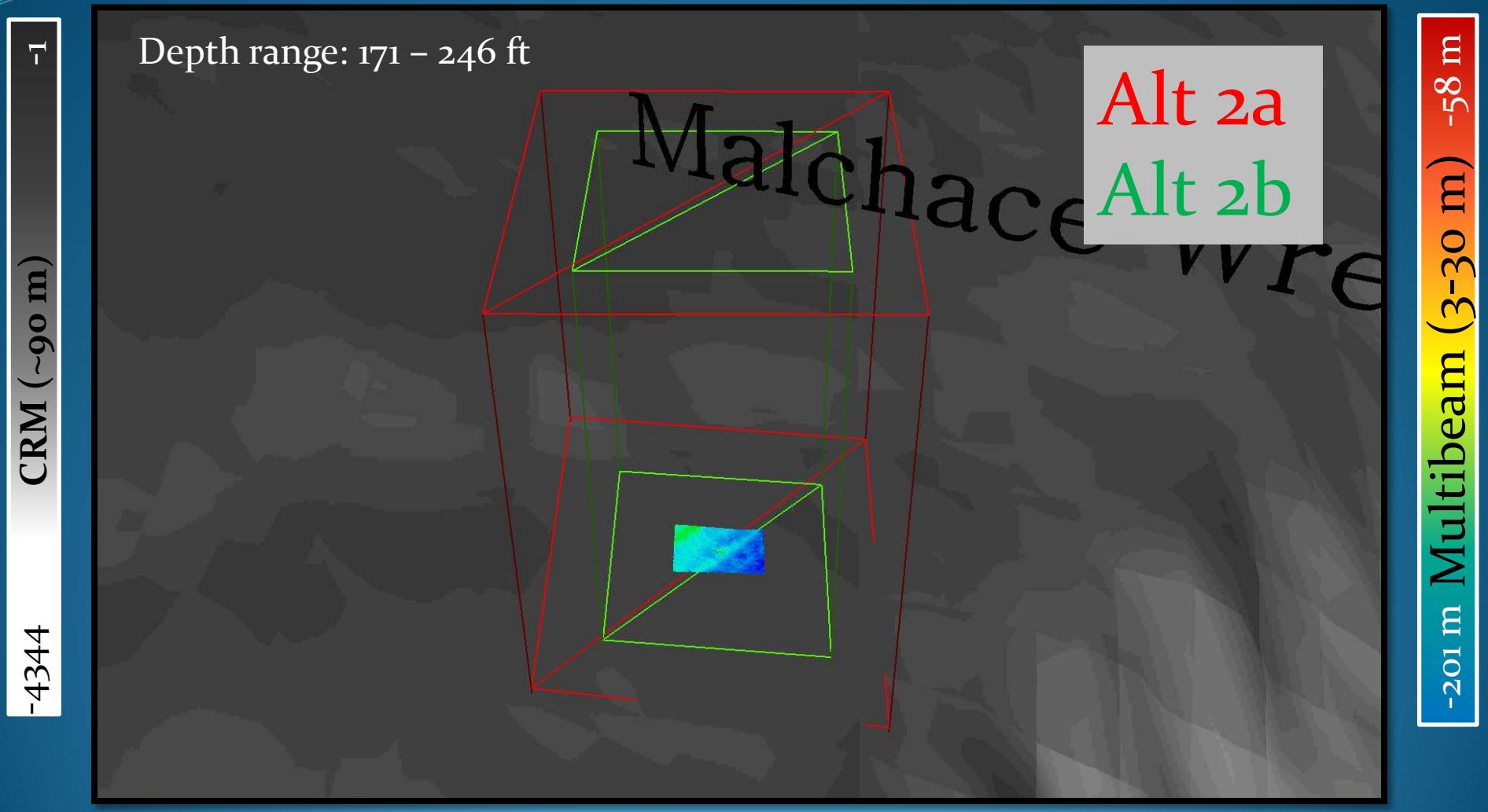
Figure 3. – *Multi-annual observations of spawning.*

MULTI-ANNUAL USE OF SPAWNING LOCATIONS

Table 5. Summary statistics for apparent use of multi-annual spawning locations.

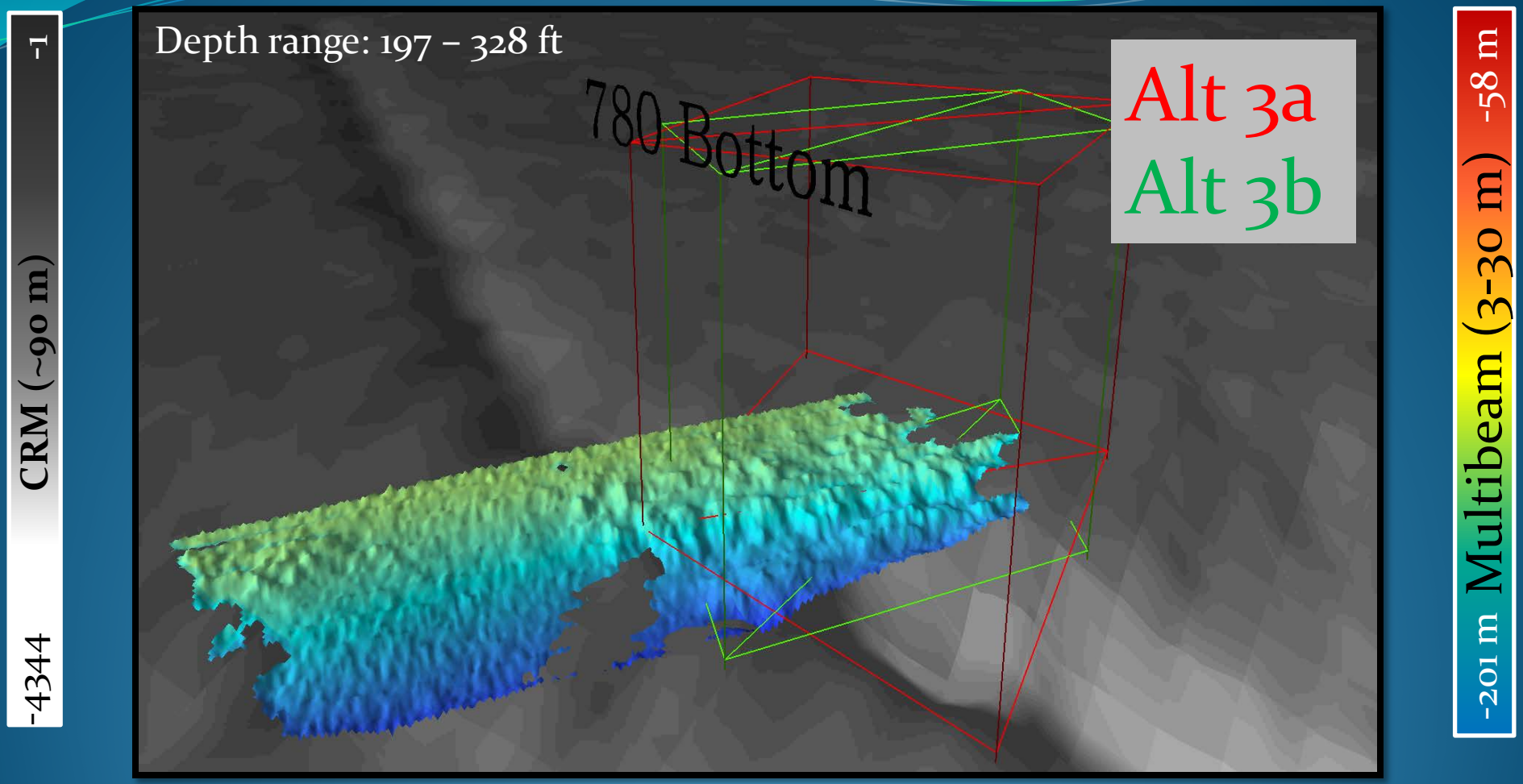
Stock	Multi-annual Spawning Locations	Years Sampled	Years with Spawning Condition Females	% Years with Spawning Condition Females	MCP (mi^2)
Black Sea Bass	14	12.8 ± 6.1	5.9 ± 3.3	51% ± 22%	1.6 ± 1.6
Gray Triggerfish	17	9.9 ± 6.2	3.9 ± 1.6	51% ± 24%	1.0 ± 1.5
Red Snapper	9	2.9 ± 1.2	2.9 ± 1.2	100% ± 0%	0.4 ± 0.8
Scamp	11	8.2 ± 4.2	3.5 ± 2.7	47% ± 19%	0.7 ± 1.0
Snowy Grouper	3	3.3 ± 0.6	3.3 ± 0.6	100% ± 0%	1.2 ± 0.5
Vermilion Snapper	42	9.1 ± 6.2	7.7 ± 5.2	89% ± 16%	2.5 ± 5.3
White Grunt	14	6.7 ± 4.2	3.1 ± 1.6	53% ± 27%	0.6 ± 0.7

NC Alt 2: Malchace Wreck



Fisher info of historic catches of speckled hind at this location.

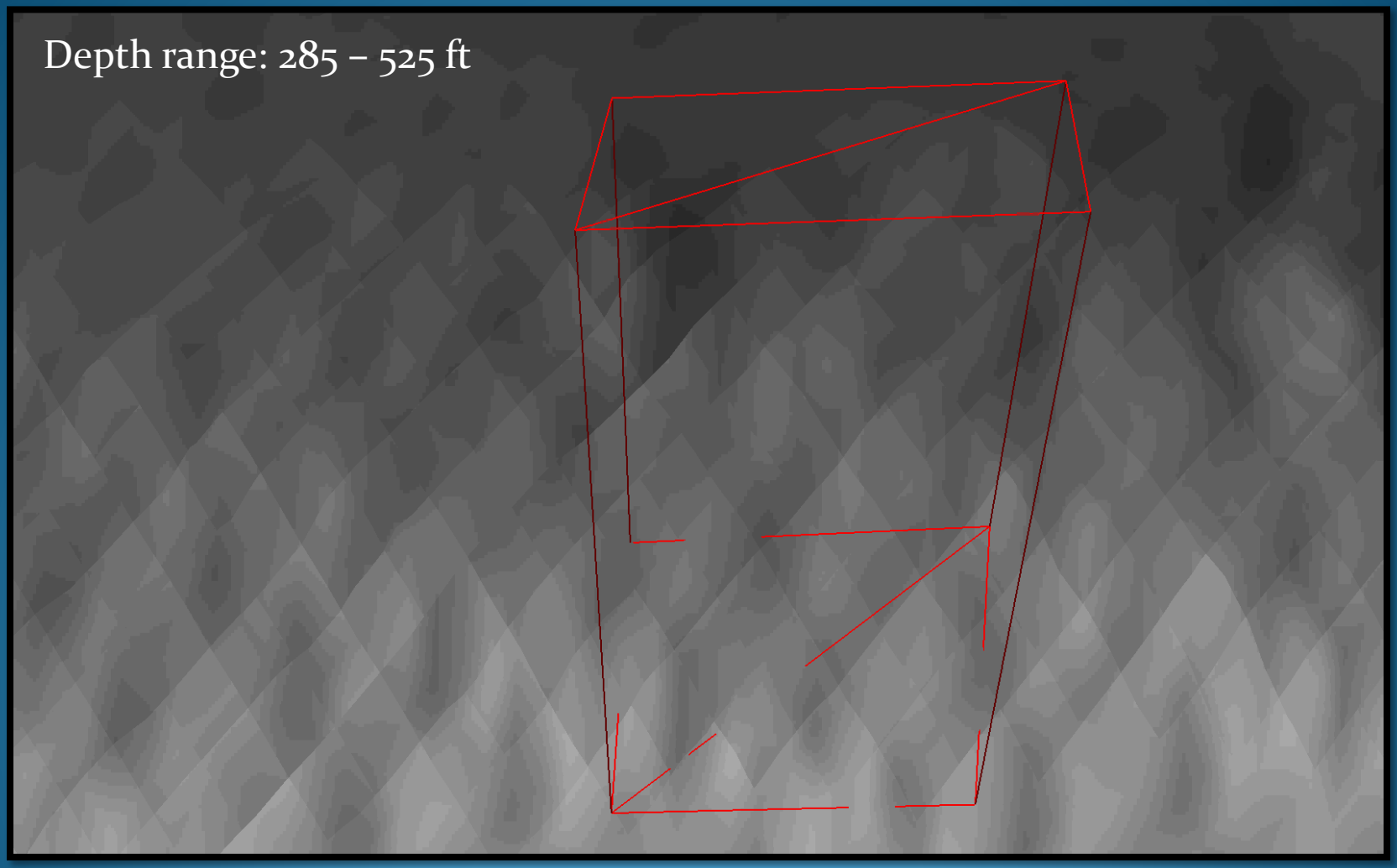
NC Alt 3: 780 Bottom



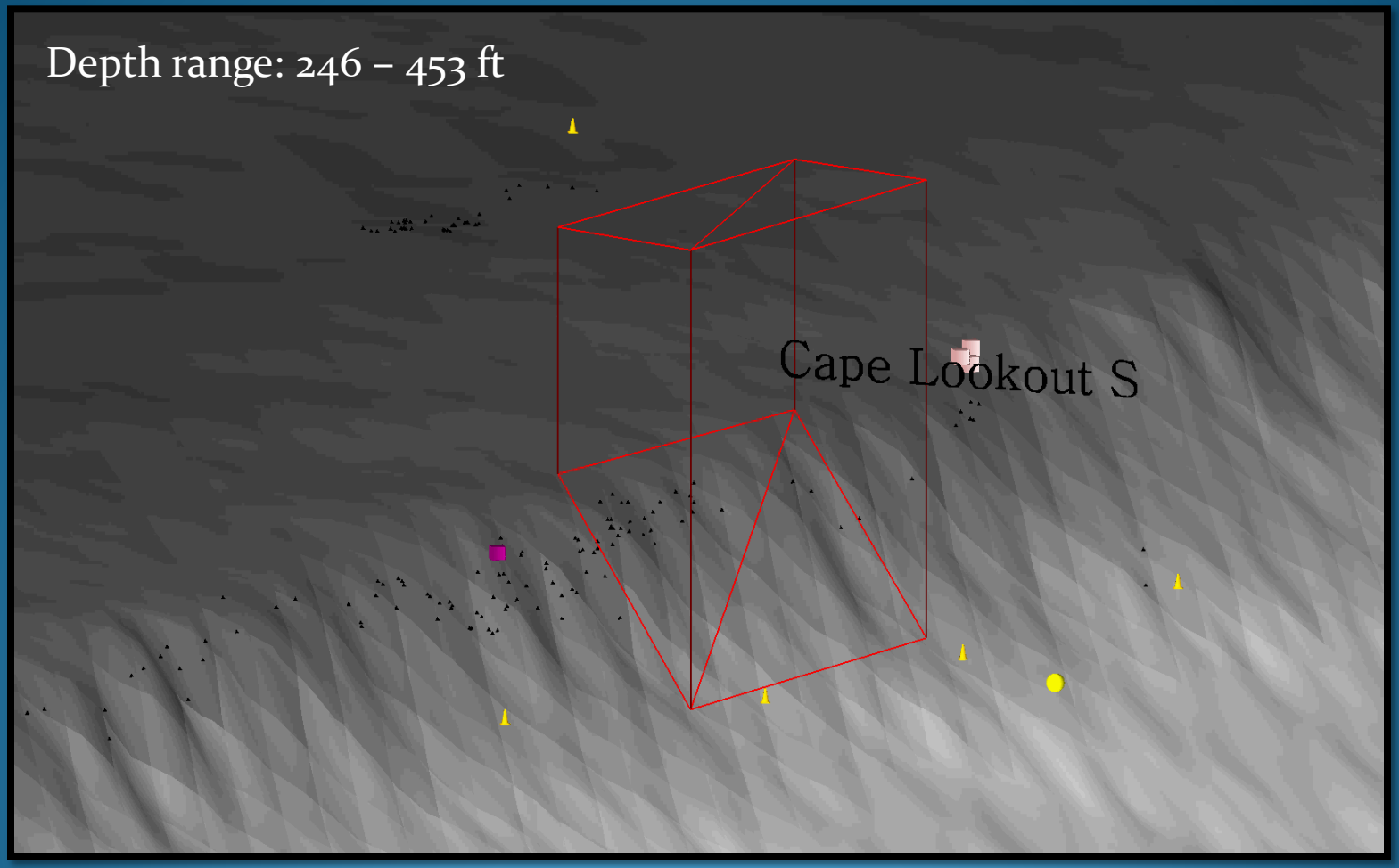
The terrain feature in the CRM is a data artifact and is not a real feature.

Fisher info of historic catches of speckled hind at this location.

NC Alt 4: NC Deep Wreck



NC Alt 5: S Cape Lookout

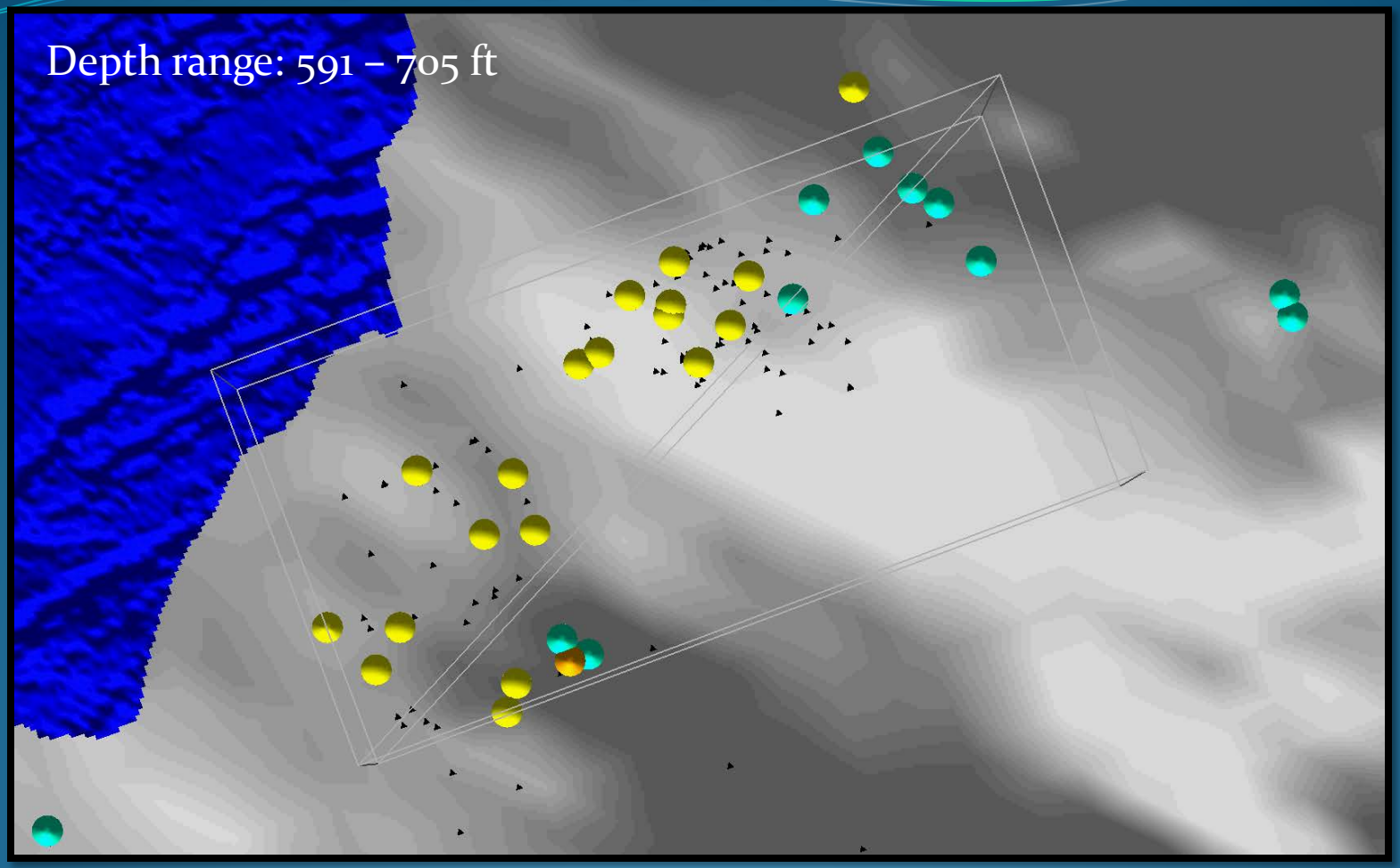


-1
CRM (~90 m)
-4344

-201 m Multibeam (3-30 m) -58 m

Vermilion snapper Snowy grouper Greater amberjack

SC Alt 2e: SC South



Snowy grouper

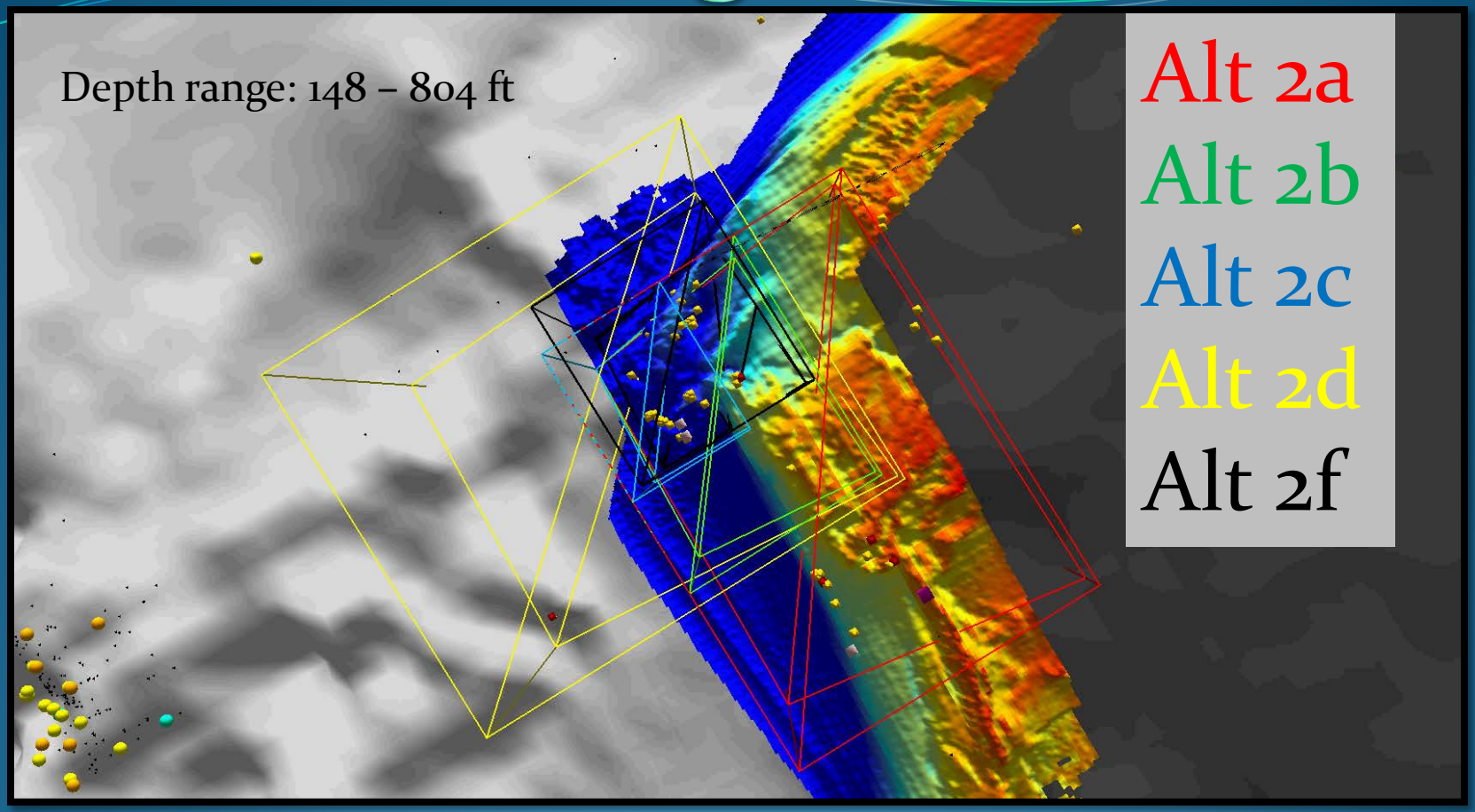
Golden tilefish

Blueline tilefish

-58 m Multibeam/Sidescan (3-30 m) -201 m

-1 m Coastal Relief Model (~90 m) -4344 m

SC Alt 2: Georgetown Hole

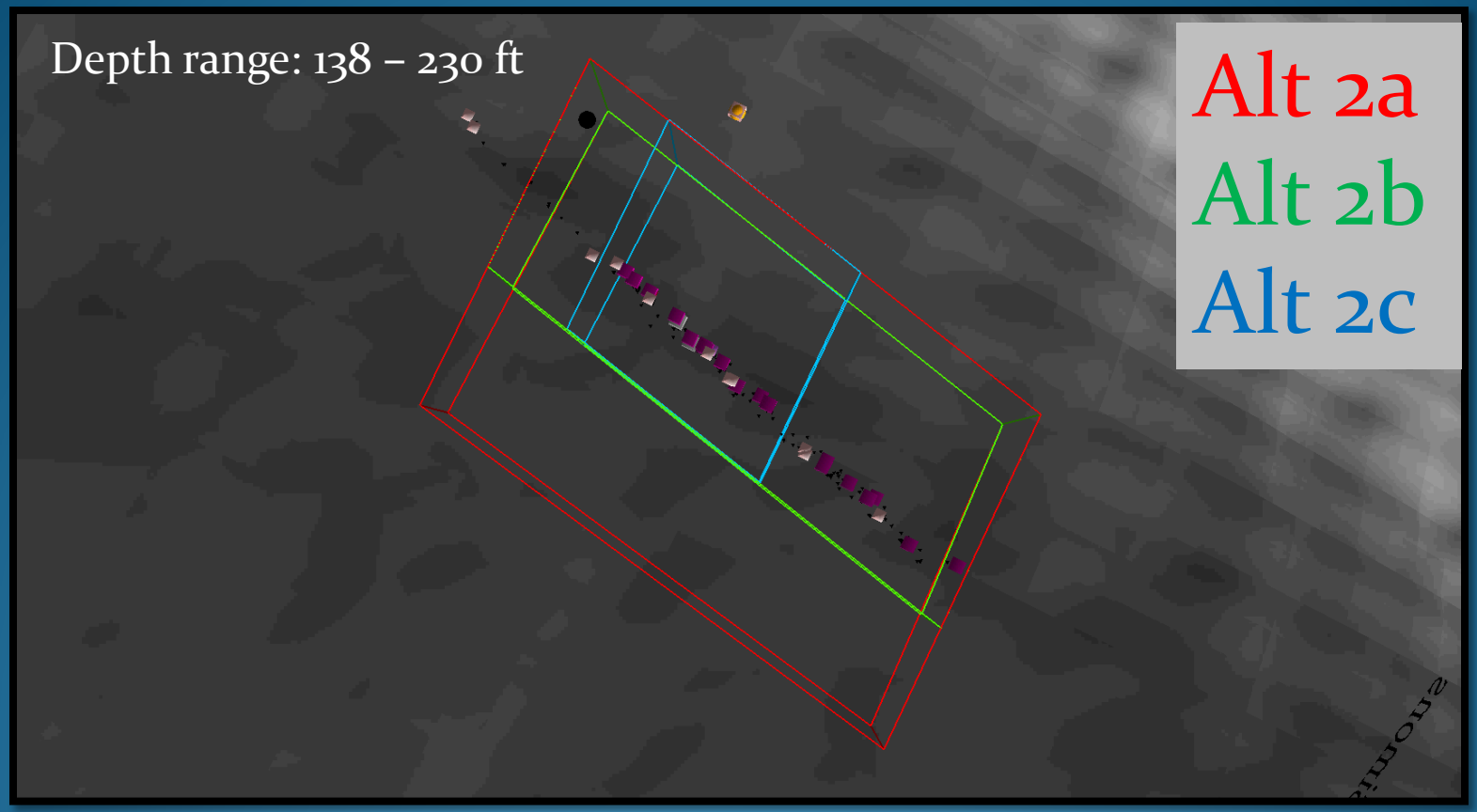


-1
CRM (~90 m)
-4344

-58 m
Multibeam (3-30 m)
-201 m

Gray triggerfish
Vermilion snapper
Red snapper
Golden tilefish
Greater amberjack
Snowy grouper
Black sea bass
Red porgy
Blueline tilefish

GA Alt 2: St. Simons

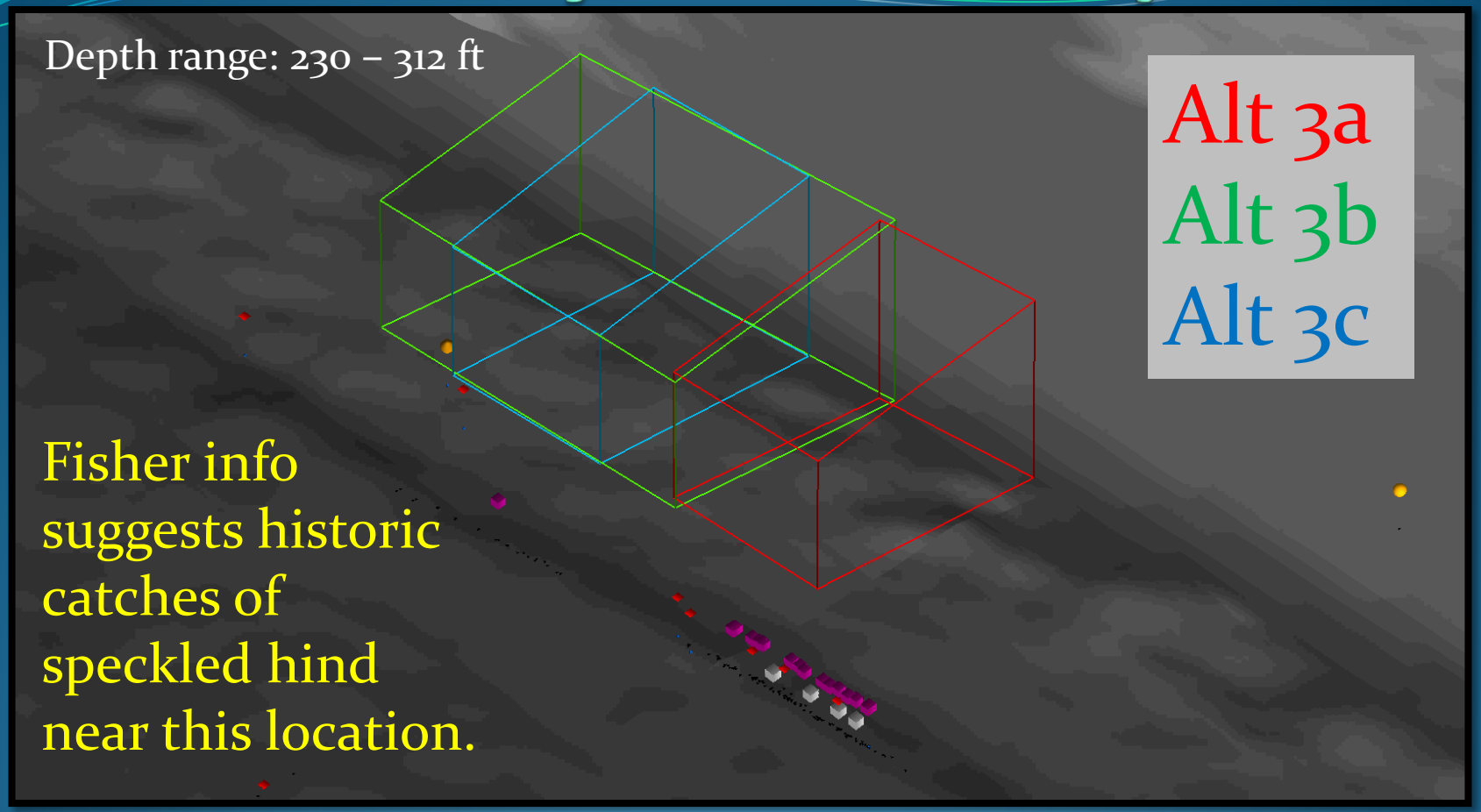


-1
CRM (~90 m)
-4344

-58 m
Multibeam (3-30 m)
-201 m

Gray triggerfish
Vermilion snapper
Red snapper
Golden tilefish
Greater amberjack
Black sea bass
Red porgy
Artificial Reef

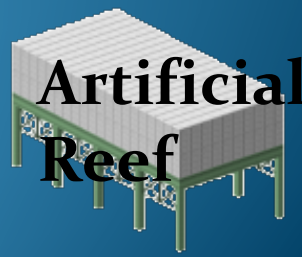
FL Alt 3: Daytona Steeples



-1
CRM (~90 m)
-4344

-58 m
Multibeam (3-30 m)
-201 m

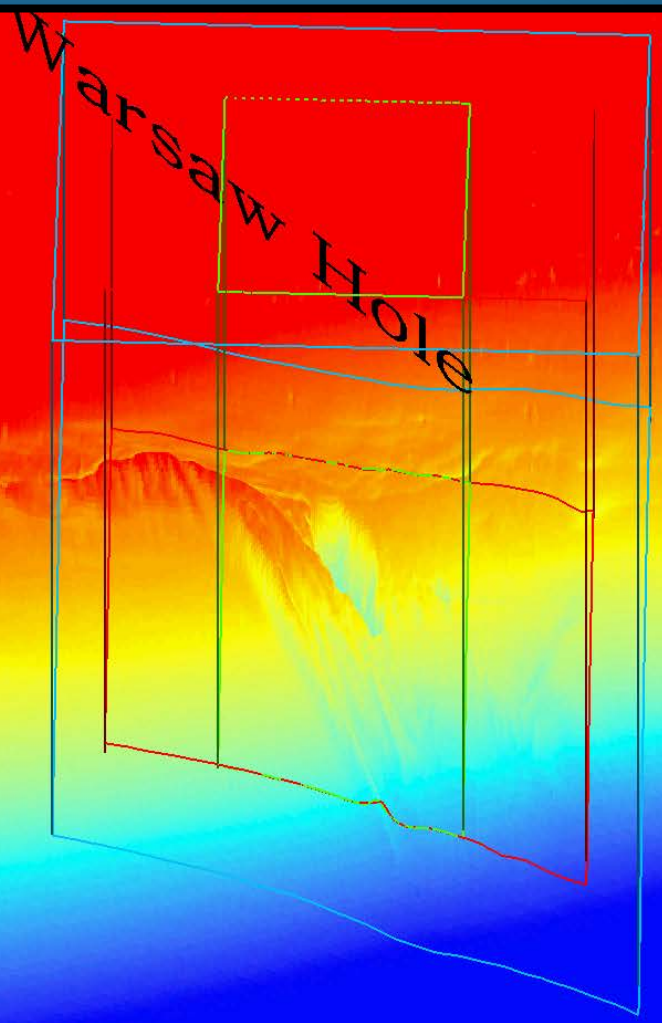
Gray triggerfish
Vermilion snapper
Red snapper
Golden tilefish
Greater amberjack
Black sea bass
Gag



FL Alt 2: Warsaw Hole

Depth range: 187 – 443 ft

Fisher info suggests substantial historic catches of Warsaw grouper at this location; possible aggregation site?



Alt 2a
Alt 2b
Alt 2c

Red grouper

-58 m Multibeam/Sidescan (3-30 m) -201 m

-1 m Coastal Relief Model (~90 m) -4344 m

Data Limitations

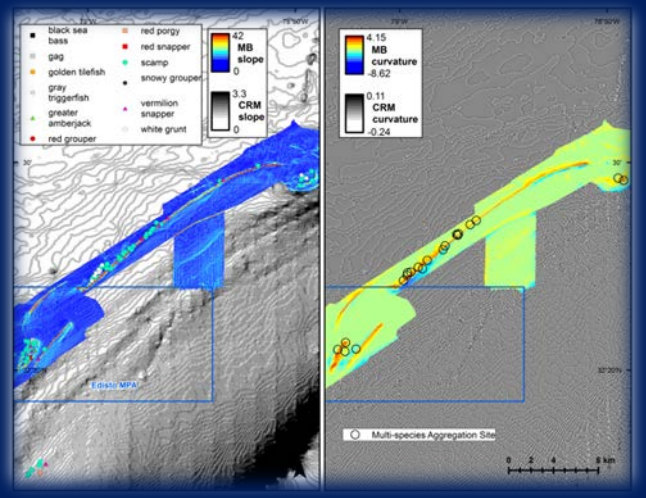
- Observations of spawning were influenced both by the spatiotemporal sampling domain and the distribution of the stocks of interest.
- For the small- and medium-bodied species best represented by the SERFS data, group or pair spawning may be the more common spawning behavior as opposed to the formation of large transient spawning aggregations.
- The SERFS and FWC fishery-independent data contained limited information on larger, longer-lived species of groupers and snappers in the U.S. South Atlantic
- 90 m resolution of the CRM bathymetry may be too coarse to register any meaningful trends to which a reef fish might respond
- Best model fits to bathymetry were in the MB bathymetric layer, which was spatially-limited
- It is important to note that an absence of sampling does not imply an absence of spawning activity – there are many areas and months that remain poorly sampled:
  - **Steep, high-current zones**
  - **Deeper areas**
  - **Winter months**
  - **South of 27° N**

Application to Management

- Black Sea Bass, Gray Triggerfish, Vermilion Snapper, and White Grunt appear to spawn frequently at numerous, small, broadly-distributed sites. It will be challenging to protect a substantial portion of spawning biomass for these species using SMZs.
- Red Snapper may be a simple migratory or resident spawner at a vast number of locations. SMZs that contain their spawning locations have value, but the stock spawns over a broad range.
- Red Snapper were the most common species at multispecies spawning sites and may be indicators of favorable spawning habitat.
- Several multiannual spawning (aggregation?) sites for Scamp and Snowy Grouper were identified offshore of existing MPAs; these species are vulnerable to sperm limitation and overfishing, and their peak spawning season is not covered by the Jan-Apr grouper spawning closure in SAFMC waters. These locations are excellent candidates for SMZ protection.

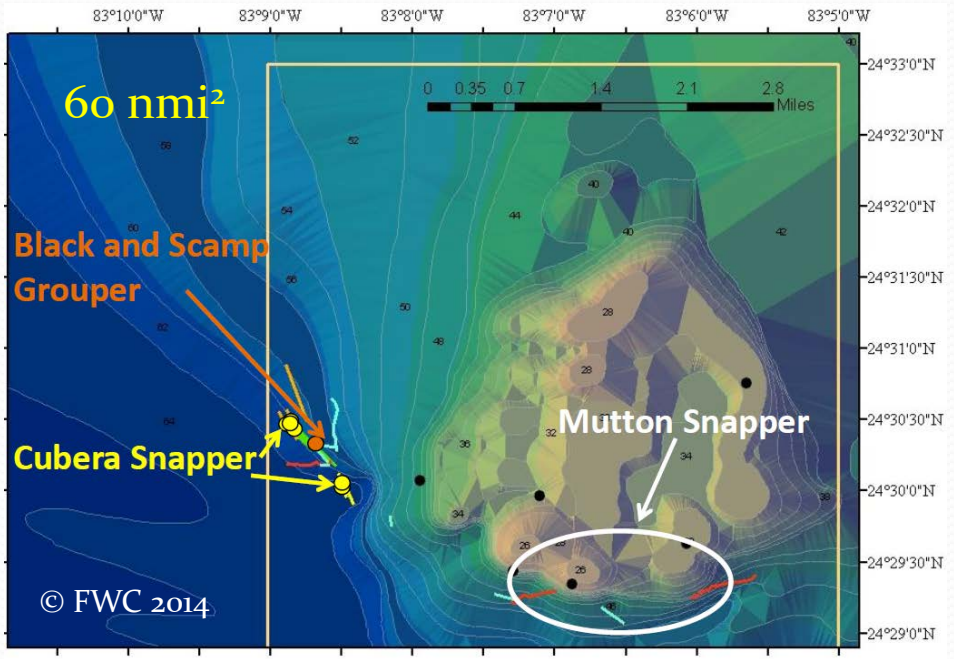
Future Improvements

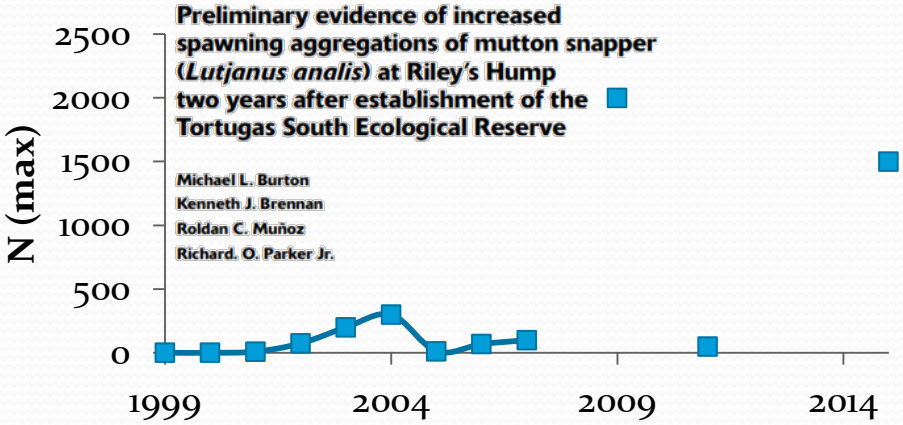
- Use cooperative research with commercial fishermen to collect video and biological samples for under-represented species/areas/times
- Integrate these monitoring approaches into the SAFMC MPA System Management Plan as a required monitoring protocol for existing and newly implemented MPAs and SMZs.
- Complete high-resolution (5-10 m) mapping of the shelf-edge throughout the SAFMC jurisdiction
- Increase SERFS funding or cooperative research to facilitate:
  - Increased histological sampling
  - Expanded sampling south of 27° N
  - Increased winter sampling
  - Increased use of hook-and-line gears at high-relief, high current locations



Regional Success Stories

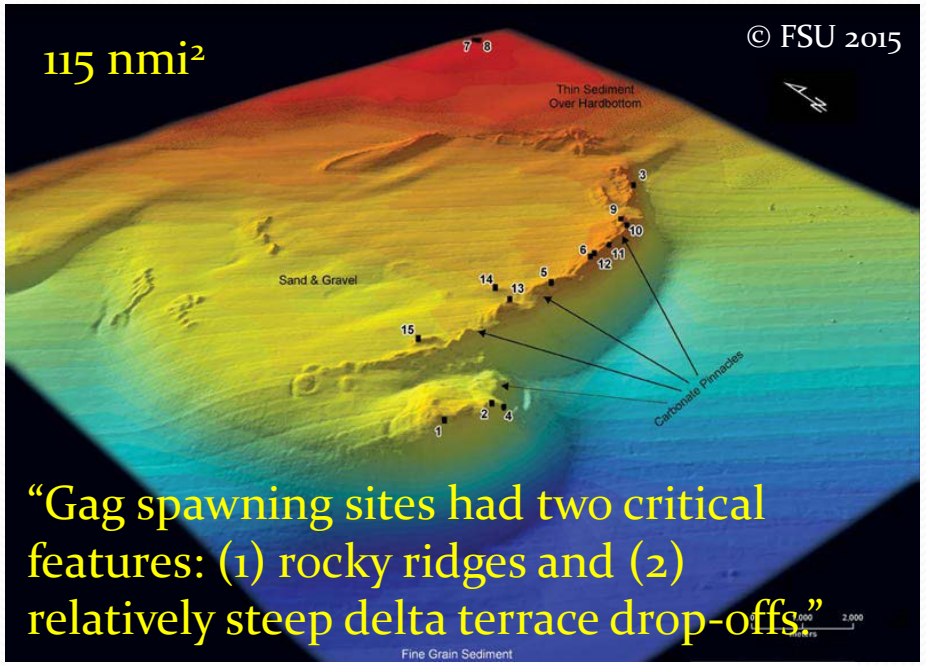
Riley's Hump, FL (2001)





Mutton Snapper SEDAR-15A Update (2014): Not overfished, not overfishing

Madison-Swanson, FL (2000)



Groupers on the Edge: Shelf Edge Spawning Habitat in and Around Marine Reserves of the Northeastern Gulf of Mexico*

Felicia C. Coleman
Florida State University Coastal and Marine Laboratory

Kathryn M. Scanlon
United States Geological Survey

Christopher C. Koenig
Florida State University Coastal and Marine Laboratory

Gag SEDAR-10 (2006): Overfishing
SEDAR-10 Update (2009): Overfished/Overfishing
SEDAR-33 (2014): Not Overfished/Not Overfishing

Questions?

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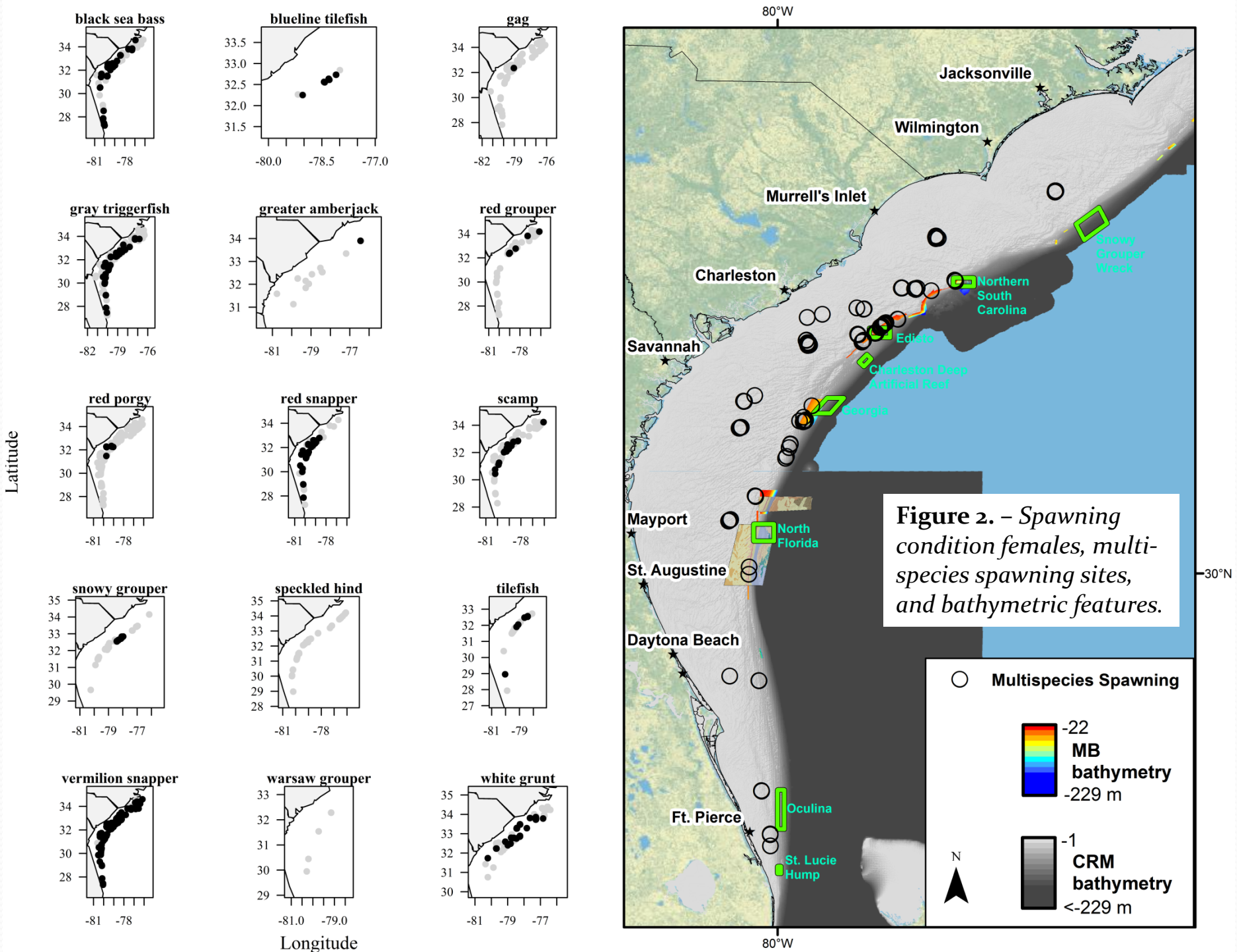


Figure 2. – *Spawning condition females, multi-species spawning sites, and bathymetric features.*

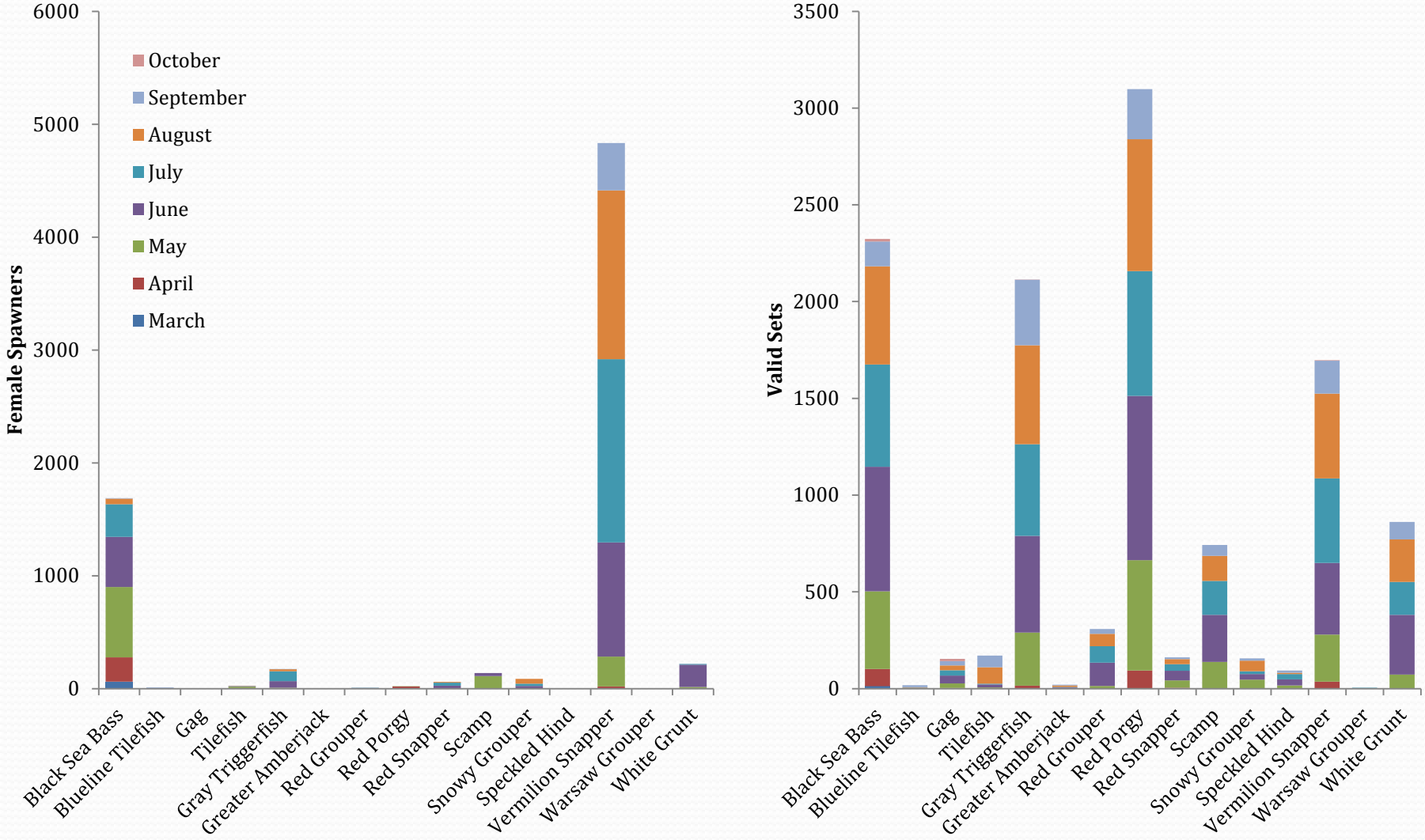


Figure 1. – *Spawning condition females and valid sets by month.* Number of SERFS samples of females within 48 hours of spawning (left) and number of sets where a histological sample was taken, by species and sampling month.

Table 2. Number of gear deployments ('sets') from MARMAP/SERFS and FWC fishery-independent data with histological sampling ('Samples'), with number of sets containing females within 48 hours of spawning ('Female Spawners'), number of sets containing females and males within 48 hours of spawning ('All Spawners'), number of sets with three or more histologically-sampled fish for the species ('Valid Sets'), and number 'Valid Sets' within the high-resolution multibeam bathymetry ('MB Valid Sets'). Species in gray had insufficient samples to be statistically modeled.

Common Name	Samples	Female Spawners	All Spawners	Valid Sets	MB Valid Sets
Black Sea Bass	2324	338	1185	1499	10
Blueline Tilefish	18	8	14	2	0
Gag	154	1	4	3	1
Gray Triggerfish	2114	122	956	799	212
Greater Amberjack	20	3	5	1	0
Red Grouper	308	6	19	70	0
Red Porgy	3098	17	965	1710	361
Red Snapper	421	159	309	158	8
Scamp	743	105	150	143	94
Snowy Grouper	156	48	53	56	5
Speckled Hind	93	0	0	4	1
Tilefish	171	12	32	87	1
Vermilion Snapper	1697	1124	1288	878	159
Warsaw Grouper	5	0	0	0	0
White Grunt	861	97	231	375	37

Table 4. Number of gear deployments with multispecies observations of spawning females from SERFS.

Stock	Black Sea Bass	Gray Triggerfish	Red Porgy	Red Snapper	Scamp	Vermilion Snapper	White Grunt
Black Sea Bass		0	4	1	1	40	4
Gray Triggerfish	0		0	6	0	25	7
Red Porgy	4	0		0	1	0	0
Red Snapper	1	6	0		3	12	2
Scamp	1	0	1	3		15	3
Vermilion Snapper	40	25	0	12	15		16
White Grunt	4	7	0	2	3	16	

MULTISPECIES SPAWNING SITES

Regression modeling

P(Spawning Condition Female):

- ✓ Stepwise logistic regression
- ✓ Best model = lowest AIC
- ✓ Bathymetric variables fit last

Cross-Validation:

- ✓ 10-fold
- ✓ ROC curve
- ✓ AUC >80% = "Good"
- ✓ Spurious if FPR or FNR >33%

Randomization Test:

- ✓ Randomize bathymetric variables, refit model 1000X
- ✓ If >33% randomized bathymetric variable models lower AIC below "best" model, variable deemed useless

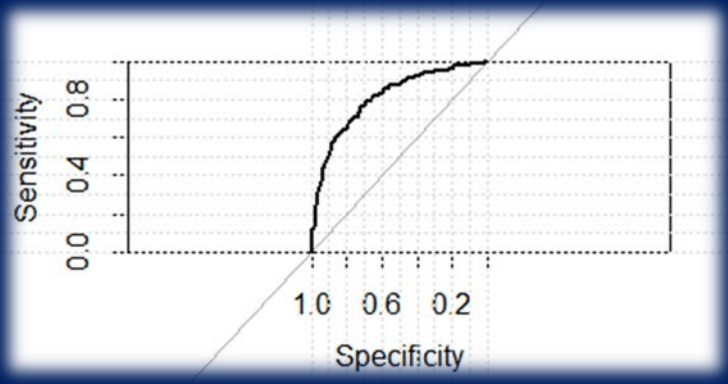


Table 1. Input variables considered in logistic regression model.

Variable	Description	Treatment	Coverage
MAXBCURVE	Maximum curvature value from MB bathymetry	Continuous	Limited
MEANBCURVE	Mean curvature value from MB bathymetry	Continuous	Limited
MAXBASPECT	Maximum aspect value from MB bathymetry	Continuous	Limited
MEANBASPEC	Mean aspect value from MB bathymetry	Continuous	Limited
MAXBSLOPE	Maximum slope value from MB bathymetry	Continuous	Limited
MEANBSLOPE	Mean slope value from MB bathymetry	Continuous	Limited
MAXBBSBPI	Maximum broad-scale (18 cell) BPI value from MB bathymetry	Continuous	Limited
MEANBBSBPI	Mean broad-scale (18-cell) BPI value from MB bathymetry	Continuous	Limited
MAXBFSBPI	Maximum fine-scale (9 cell) BPI value from MB bathymetry	Continuous	Limited
MEANBFSBPI	Mean fine-scale (9-cell) BPI value from MB bathymetry	Continuous	Limited
MAXCBSBPI	Maximum broad-scale (18 cell) BPI value from CRM bathymetry	Continuous	Comprehensive
MEANCBSBPI	Mean broad-scale (18-cell) BPI value from CRM bathymetry	Continuous	Comprehensive
MAXCFSBPI	Maximum fine-scale (9 cell) BPI value from CRM bathymetry	Continuous	Comprehensive
MEANCFSBPI	Mean fine-scale (9-cell) BPI value from CRM bathymetry	Continuous	Comprehensive
MAXCASPECT	Maximum aspect value from CRM bathymetry	Continuous	Comprehensive
MEANCASPEC	Mean aspect value from CRM bathymetry	Continuous	Comprehensive
MAXCCURVE	Maximum curvature value from CRM bathymetry	Continuous	Comprehensive
MEANCCURVE	Mean curvature value from CRM bathymetry	Continuous	Comprehensive
MAXCSLOPE	Maximum slope value from CRM bathymetry	Continuous	Comprehensive
MEANCSLOPE	Mean slope value from CRM bathymetry	Continuous	Comprehensive
Gear_ID	Sampling gear	Categorical	All records
Month	Month	Categorical	All records
Year	Year	Categorical	All records
Latitude	Latitude for gear set (1° bins from 30.5°-34.5°)	Categorical	All records
Depth	Depth of gear set (20 m bins from 10-70 m)	Categorical	All records
Temperature	Temperature at depth of gear deployment	Continuous	Some errors
Salinity	Salinity at depth of gear deployment	Continuous	Some errors
Lunar3	Lunar phase	Both	All records
Habitat	Habitat type	Categorical	Limited

Table 7. Logistic regression model fit statistics for probability of encountering a fish within 48 hours of spawning, with percent deviance explained (i.e. percent variability explained by inclusion of additional variable); cross-validation results for area under the curve (AUC), false positive rate (FPR) and false negative rate (FNR); and percentage of 500 runs where random variable inclusion in model outperformed model-selected bathymetric variable ('Random test'). See Methods for additional details.

Stock	Response	Bathy	Deviance Explained	AUC	FPR	FNR	Random Test	Percent Deviance Explained					
								Bathymetric	Month	Year	Latitude	Depth	Lunar Phase
Black Sea Bass	Females	CRM	69.42%	92%	17%	10%	48%	MAXCSLOPE (1.0)	27.7	16.1	38.7	12.9	4.7
Gray Triggerfish	Females	CRM	38.16%	82%	23%	30%	n/a		19.6		5.3	10.5	9.3
Red Snapper*	Females	CRM	63.91%	81%	35%	19%	5%	MEANCFSBPI (7.8)	42.4	6.1	4.0	3.6	
Scamp	Spawners	MB	59.90%	86%	16%	50%	23%	MEANBSLOPE (15.2)	41.7			18.9	
Snowy Grouper	Females	CRM	40.06%	74%	>50%	10%	37%	MEANCSLOPE (7.5)	35.2				
Vermilion Snapper	Females	MB	52.60%	82%	29%	28%	27%	MAXBCURVE (3.4), MAXBSLOPE (0.1), MAXBCURVE* MAXBSLOPE (5.3)	13.9	25.7		6.4	13.5
White Grunt	Females	CRM	62.40%	89%	24%	13%	>50%	MEANCBSBPI (1.5)	17.9	28.3		6.2	30.9

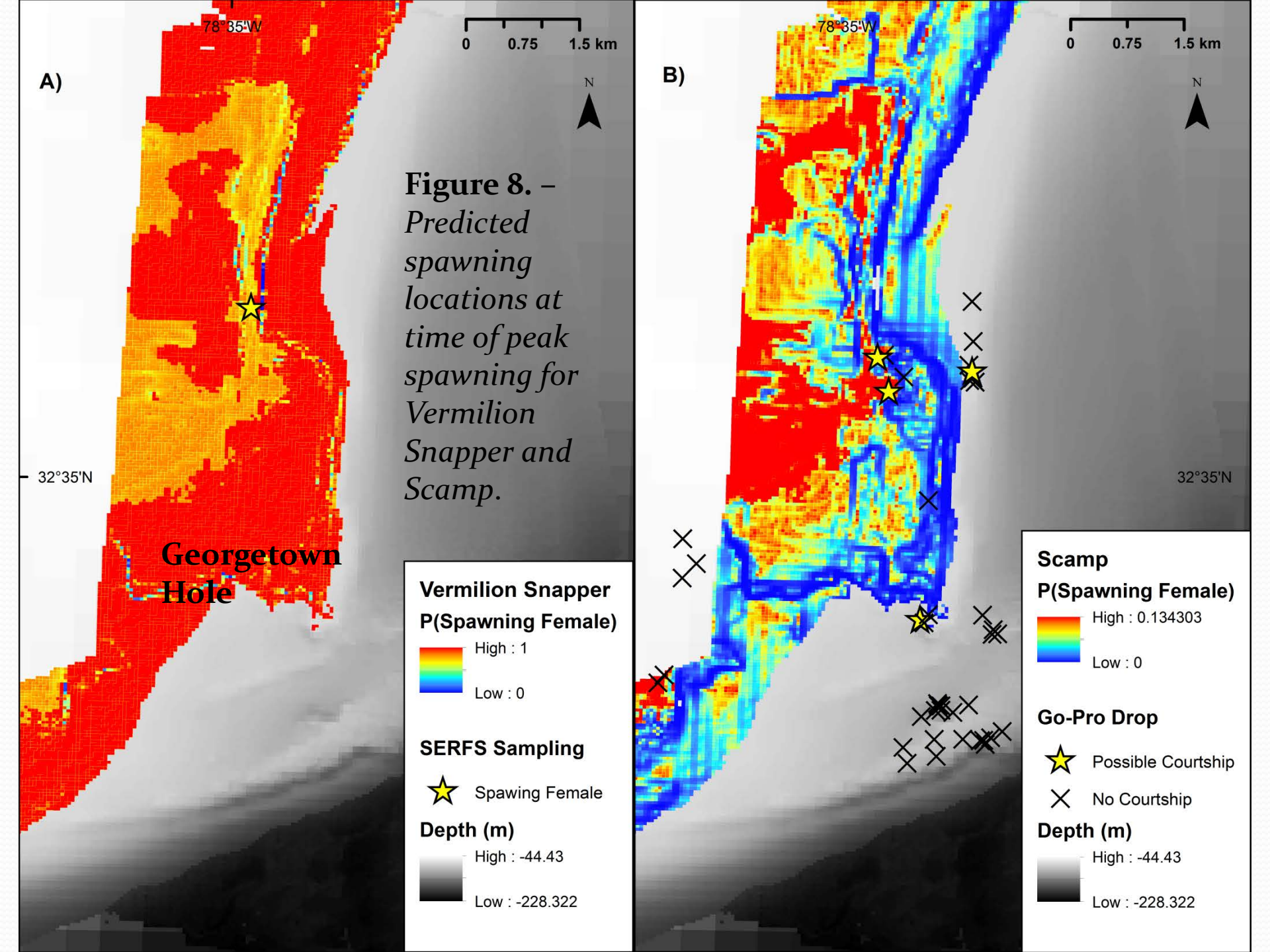


Figure 8. – *Predicted spawning locations at time of peak spawning for Vermilion Snapper and Scamp.*

Gray Triggerfish

Life History

- ✓ Small-bodied
- ✓ Gonochoristic
- ✓ Demersal nests in the sediment either in or around reef structure
- ✓ Elaborate courtship, nest-guarding
- ✓ Non-aggregating species?

Findings

- ✓ Spawn at numerous, broadly distributed locations along and just inshore of the shelf-edge.
- ✓ Model fits were good, but explained a relatively low percentage of the overall variability (38%).
- ✓ Peak spawning months were identified as June-July, which agrees with previously published studies.
- ✓ Peak spawning was predicted around the new moon in the 30-70 m depth range, which corresponds to the shelf-edge in most locations.

White Grunt

Life History

- ✓ Small-bodied
- ✓ Gonochoristic
- ✓ Reproduce throughout the year

Findings

- ✓ Spawn at numerous, broadly distributed, relatively small locations along and just inshore of the shelf-edge.
- ✓ Model fits were good, with a reasonably high proportion of the total variability in encounters of spawning condition females explained by lunar phase, year, month, depth.
- ✓ Peak spawning was predicted inshore of the shelf-edge (30-50 m depth) during May and June.

Vermilion Snapper

Life History

- ✓ Small-bodied
- ✓ Gonochoristic
- ✓ Spawn approximately every five days from April - September

Findings

- ✓ Spawn at numerous sites along the shelf-edge throughout the SERFS sampling domain.
- ✓ Spawning condition females encountered on most shelf-edge habitats.
- ✓ A good model fit in the high-resolution bathymetry indicated that spawning condition females are more likely to be found at sites with high slope and high curvature.
- ✓ Model predictions indicated peak spawning following the full moon in June-August in the 30-70 m depth range.

Red Snapper

Life History

- ✓ Moderately-sized
- ✓ Gonochoristic
- ✓ Spawn May-October

Findings

- ✓ Peak spawning takes place in July in the 50-70 m depth range at valleys at the base of ridges.
- ✓ These sites appear broadly distributed and the predictive model appears to confirm anecdotal observations that Red Snapper will spawn on or beside any appreciable hardbottom habitat.
- ✓ This contrasts with findings in the Gulf of Mexico that Red Snapper spawn on rocky ridges and relatively steep delta terrace drop-offs.
- ✓ Our model had a relatively high percentage of false negatives when compared to fisher information, which may indicate the bathymetric variable was insufficiently resolved to generate spatial predictions.

Black Sea Bass

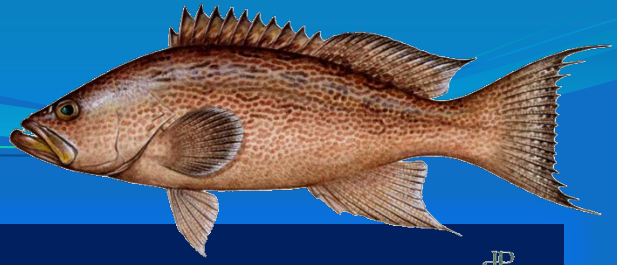
Life History

- ✓ Moderately-sized
- ✓ Protogynous hermaphrodite
- ✓ Generally associated with live-bottom or inshore sponge-coral patch reef habitats

Findings

- ✓ Black Sea Bass spawning condition females were observed numerous sites across decades of sampling.
- ✓ Very good model fit with latitude (less certain south of 31.5° N), month, year, depth, and lunar phase.
- ✓ Bathymetric variable, maximum slope, appeared to have little predictive utility.
- ✓ Peak spawning predicted March-April [limited SERFS FID sampling in winter]
- ✓ Predictive maps performed well under external validation.

Scamp



Life History

- ✓ Large-bodied
- ✓ Protogynous hermaphrodite
- ✓ Known to aggregate in deep water (>40 m) to spawn at high-relief sites on the shelf-edge, with or without a drop-off
- ✓ "Grayhead" Scamp reported at Georgetown Hole, Julians Ridge, Sebastian Pinnacles, Jacksonville Scarp, and St. Augustine Scarp

Findings

- ✓ Good model fit in the MB bathymetry suggested spawning condition females were most likely to be encountered in May in deep water (mean 52 ± 13 m) at the base of high slope sites.
- ✓ The finding regarding the flat slope of spawning sites tested as potentially spurious and may not be biologically relevant: Logistically, in areas of high relief / high current, SERFS sets traps in flat areas just inshore or offshore of the ledge.

Snowy Grouper

Life History

- ✓ Large-bodied
- ✓ Protogynous hermaphrodite
- ✓ Adults are generally associated with the upper continental slope (>75 m) in habitats characterized by rocky ledges, cliffs, and swift currents.

Findings

- ✓ Observed spawning condition female Snowy Grouper at depths from 175-223 m.
- ✓ Fair model fit suggested spawning condition females were more likely to be encountered at the base of high slope sites, but results were potentially spurious.
- ✓ Peak spawning was predicted in July.
- ✓ Three multiannual spawning sites offshore and south of the existing Northern South Carolina MPA were identified.