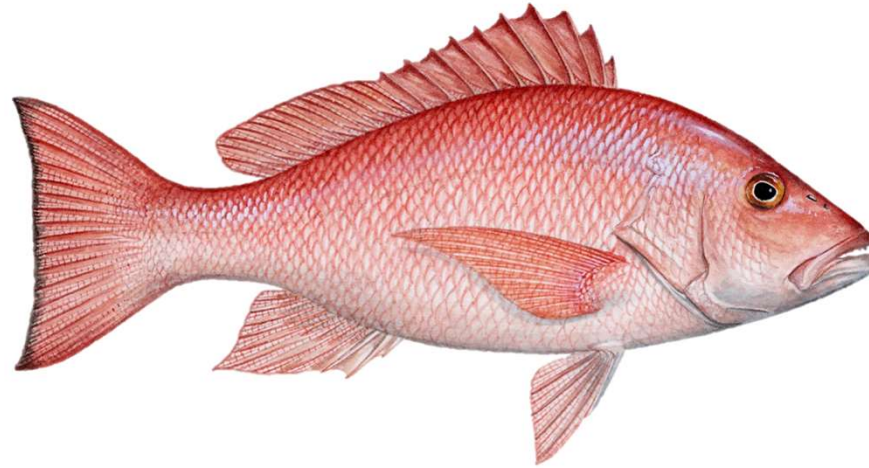


Estimation of US Atlantic Red Snapper Abundance



Study Team



Will Patterson Joe Tarnecki Miaya Taylor Dave Chagaris Liam Kehoe Dave Portnoy Chris Hollenbeck Alison Monroe Kat Lanoue Lizz Dolan Nick Weber Andrew Fields



Jeff Buckel Paul Ruderhausen Nathan Hostetter Krishna Pacifici Viviane Zulian Erin Schliep Brian Reich Chris Custer Ben Goldstein Matt Damiano



Kyle Shertzer Nate Bachelor Eric Anderson Matt Vincent Paul McLaughlin Chris Taylor Wally Bubley Dawn Franco Bev Sauls Ted Switzer Ellie Corbett

Study Dedication: Kyle Shertzer

This study and final report are dedicated to the memory of our colleague, Kyle Shertzer, who passed away just prior to its completion. Kyle was a brilliant scientist, a valued collaborator, and a generous friend. His passing leaves a tremendous hole in the scientific capacity of our region. As significant as that loss is, it is nowhere near as acute as the one felt by his family and friends. Kyle is greatly missed by all who knew him.



Grants Administration at South Carolina Sea Grant



Susan Lovelace



Emily Osborne



Ryan Bradley



Jocelyn Juliano



Matthew Gorstein



Crystal Narayana

Congressman Rutherford and His Staff



Congressman John Rutherford



Katie Ramos



Amber Nejjari

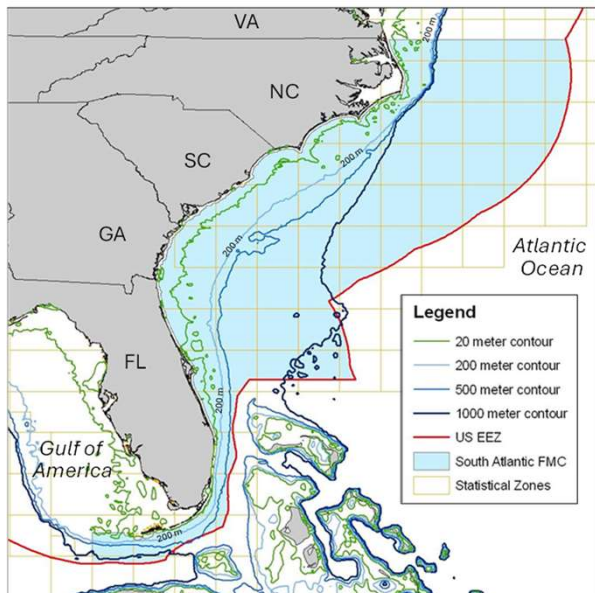
South Atlantic Red Snapper Research Program (SARSRP)



SOUTH ATLANTIC RED SNAPPER RESEARCH PROGRAM (SARSRP) "The South Atlantic Red Snapper Count"

REQUEST FOR PROPOSALS

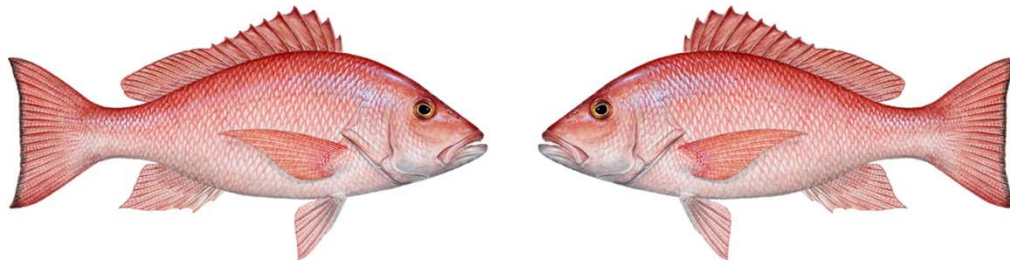
Letter of Intent Deadline: November 16, 2020 at 5 pm ET
Full Proposal Deadline: February 1, 2021 at 5 pm ET



- Produce an estimate of absolute abundance of age-2+ red snapper in U.S. Atlantic with a CV <0.3
- Estimate to serve as a benchmark for future stock assessments
- Utilize CKMR, optical data from video surveys, or a combination of acoustics and optical data like the GRSC in the Gulf
- “Fisheries managers wish to know the total number of red snapper and where they are, regardless of where the fishery operates.”

SARSRP Study Objectives

- 1) Estimate the distribution and density of red snapper across the US Atlantic shelf from North Carolina through the Florida Keys with ROVs in unknown or unconsolidated habitats
- 2) Develop a hierarchical Bayesian hierarchical integrated model to estimate age-2+ red snapper population size based on Southeast Reef Fish Survey trap-camera and ROV survey data
- 3) Conduct genetic close-kin mark recapture (CKMR) analysis to estimate age-2+ red snapper population size
- 4) Integrate/reconcile study results with the Atlantic red snapper stock assessment model



Appendix Chapters

Appendix I

Canadian Journal of Fisheries and Aquatic Sciences
OPEN ACCESS | Research Article

Applying mark-resight, count, and telemetry data to estimate effective sampling area and fish density with stationary underwater cameras

Viviane Zulian¹, Krishna Pacifici², Nathan M. Bachelier³, Jeffrey A. Buckel⁴, William F. Patterson, III⁵, Brian J. Reich⁶, Kyle W. Shertzer⁶, and Nathan J. Hostetter⁶

¹North Carolina Cooperative Fish and Wildlife Research Unit, Department of Applied Ecology, North Carolina State University, Raleigh, NC, USA; ²Department of Forestry and Environmental Resources, North Carolina State University, Raleigh, NC, USA; ³Southeast Fisheries Science Center, National Marine Fisheries Service, Beaufort, NC, USA; ⁴Department of Applied Ecology, Center for Marine Sciences and Technology, North Carolina State University, Morehead City, NC, USA; ⁵University of Florida, School of Forest, Fisheries, and Geomatics Sciences, Gainesville, FL, USA; ⁶Department of Statistics, North Carolina State University, Raleigh, NC, USA; ⁷U.S. Geological Survey, North Carolina Cooperative Fish and Wildlife Research Unit, Department of Applied Ecology, North Carolina State University, Raleigh, NC, USA

Corresponding author: Viviane Zulian (email: zulian.v@gmail.com)

Abstract

Accurate estimates of abundance and density for geographically open populations must account for the effective sampling area (ESA) of sampling gears. We describe a Marked N-Mixture model to estimate ESA and density (number of individuals/unit area) from repeated counts of unmarked and marked individuals, integrating mark-resight, camera counts, and telemetry data of red snapper (*Lutjanus campechanus*) at a 1.6 km² reef off North Carolina, USA. Cameras recorded observations of unmarked and marked individuals, whereas telemetry data indicated the number of tagged fish present on the reef. We estimated density (95 individuals/km², 95%CI: 58–149), ESA (which was lower when current direction was towards the camera), detection probability (0.06, 95%CI: 0.03–0.09), and covariate relationships. Simulation studies under different scenarios of data quality and space use identified positive bias in density estimates from N-mixture models due to fish movement. In contrast, the Marked N-Mixture model returned unbiased estimates of density, ESA, and detection parameters, and appears to be a more robust method for modeling density given the data available for this analysis. This approach can be applied to other populations where count and telemetry data overlap in space and time.

Key words: effective sampling area, mark-resight, N-mixture models, batch mark, red snapper, telemetry

Introduction

Accurate estimates of abundance and density are critical for species conservation and management. Multiple sampling methods have been developed to obtain high-quality data for abundance estimates based on spatial and temporal sampling (Nichols et al. 2000; Katsanevakis et al. 2012; Dénès et al. 2015; Howe et al. 2017; Delisle et al. 2023). Recently, the increase in remote sampling methods using stationary cameras in aquatic (Cappo et al. 2006; Stobart et al. 2007; Katsanevakis et al. 2012; Baker et al. 2022) and terrestrial environments (Burton et al. 2015; Steenweg et al. 2017; Delisle et al. 2021; Kays et al. 2022) has created new opportunities for sampling large areas in short periods of time. However, estimation of abundance and density from stationary camera counts is notoriously difficult in studies of mobile organisms that are not uniquely identifiable (reviewed by Gilbert et al. 2021). Specifically, movement of animals entering and

leaving the field of view of the camera results in an unknown effective sampling area (ESA) that can bias estimates of abundance and density (Chandler et al. 2011; Katsanevakis et al. 2012; Burton et al. 2015). Further, the regular inclusion of bait during camera studies exacerbates the challenge of density estimation, as bait can attract individuals to the camera view (Stoner 2004; Cappo et al. 2006; Bachelier et al. 2022).

Due to relatively straightforward implementation, N-Mixture models are a common approach to analyze count data collected in terrestrial environments (e.g., Royle 2004; Kéry et al. 2005; Keever et al. 2017), and more recently, aquatic environments (Flowers and Hightower 2015; Som et al. 2018; Acre et al. 2021). However, these models are sensitive to assumption violations, especially the requirement of a closed population within and across sampling occasions (e.g., Kéry et al. 2005; Chandler et al. 2011; Barker

Appendix II

Appendix II
Do not cite. This manuscript is in peer review at a scientific journal. Once published in a journal, a link to the paper will be provided on the South Atlantic Red Snapper Research Program webpage.

An Integrated Approach to Estimating the Effective Sampling Area of Baited Underwater Camera Traps

Benjamin R. Goldstein¹, Krishna Pacifici¹, Jeffrey A. Buckel², Nathan M. Bachelier³, Erin M. Schliep⁴, Brian J. Reich⁵, Kyle W. Shertzer⁶, William F. Patterson III⁷, Joseph H. Tarnecki⁸, Nathan J. Hostetter⁶

¹Department of Forestry and Environmental Resources, North Carolina State University, Raleigh, NC, USA

²Department of Applied Ecology, Center for Marine Sciences and Technology, North Carolina State University, Raleigh, NC, USA

³Southeast Fisheries Science Center, National Marine Fisheries Service, Beaufort, NC, USA

⁴Department of Statistics, North Carolina State University, Raleigh, NC, USA

⁵School of Forest, Fisheries, and Geomatics Sciences, University of Florida, Gainesville, FL, USA

⁶U.S. Geological Survey, North Carolina Cooperative Fish and Wildlife Research Unit, Department of Applied Ecology, North Carolina State University, Raleigh, NC, USA

Corresponding author Email: njhostet@ncsu.edu

Appendix III

Contents lists available at ScienceDirect
Fisheries Research
journal homepage: www.elsevier.com/locate/fishres

Spatiotemporal dynamics and habitat use of red snapper (*Lutjanus campechanus*) on the southeastern United States Atlantic continental shelf

Nathan M. Bachelier¹, William F. Patterson III², Joseph H. Tarnecki³, Kyle W. Shertzer⁴, Jeffrey A. Buckel⁵, Nathan J. Hostetter⁶, Krishna Pacifici⁷, Viviane Zulian¹, Walter J. Buble⁸

¹Southeast Fisheries Science Center, National Marine Fisheries Service, Beaufort, NC, USA
²University of Florida, School of Forest, Fisheries, and Geomatics Sciences, Gainesville, FL, USA
³Department of Applied Ecology, Center for Marine Sciences and Technology, North Carolina State University, Morehead City, NC, USA
⁴U.S. Geological Survey, North Carolina Cooperative Fish and Wildlife Research Unit, Department of Applied Ecology, North Carolina State University, Raleigh, NC, USA
⁵Department of Forestry and Environmental Resources, North Carolina State University, Raleigh, NC, USA
⁶North Carolina Cooperative Fish and Wildlife Research Unit, Department of Applied Ecology, North Carolina State University, Raleigh, NC, USA
⁷Marine Resources Research Unit, South Carolina Department of Natural Resources, Charleston, SC, USA
⁸Marine Resources Research Unit, South Carolina Department of Natural Resources, Charleston, SC, USA

ARTICLE INFO

Handled by Alejandra Yaxina Velasco

Keywords:
Red fish
Abundance index
Relative abundance
ROV
GAM

ABSTRACT

Red snapper (*Lutjanus campechanus*) is an iconic marine fish species along the southeast United States coast. Despite its ecological and economic importance, surprisingly little is known about red snapper biology and habitat use on the southeast United States Atlantic continental shelf (SEUS). We used data from a long-term baited trap and video survey (2011–2022), as well as from remotely operated vehicle (ROV) sampling (2021–2022), to quantify temporal changes in relative abundance, patterns of spatial distribution, and habitat use of red snapper in the SEUS. Using generalized additive models, we showed that red snapper increased in relative abundance from 2011 to 2022 by ~1000% in both trap and video samples. Red snapper relative abundance was highest in mid-shelf waters off the east coast of Florida, Georgia, and, to a lesser extent, off the Outer Banks of North Carolina; red snapper were less common off southern North Carolina and South Carolina. Highest relative abundance of red snapper occurred in locations with a moderate amount of natural structured habitat and high seafloor complexity and were never observed at randomly selected ROV stations (n = 197) lacking structured habitat. These results increase our understanding of the spatial and temporal distribution of red snapper, improve our knowledge of red snapper habitat use, and can be used when scaling local density estimates to the entire SEUS.

1. Introduction

Red snapper (*Lutjanus campechanus*) is a large, early maturing (–age-2), long-lived (maximum observed age = 51 years), predatory fish species that occurs from Cape Hatteras, North Carolina, to the Yucatan Peninsula, including the Gulf of Mexico (Mansueti and Potts, 1997; Hesse and Moore, 1998; SEDAR, 2021). Red snapper are found across a wide range of water depths on the continental shelf and shelf-break, from relatively shallow coastal habitats to deep mesopelagic habitats (Camber, 1955), but they are most commonly found in depths of 20–100 m (Callaway et al., 1999; Mitchell et al., 2014; Bachelier et al., 2016). Benthic juveniles are mainly found over substrates consisting of shell hash and sand (Callaway et al., 1999; Geary et al., 2007), while

adults tend to associate with natural and artificial structure such as coral reefs, rocky outcroppings and ledges, oil rigs, and shipwrecks (Moseley, 1966; Poulos and Barans, 1980; Williams-Grove and Szedlmayer, 2016; Dance and Booker, 2019; Chatterjee et al., 2024).

Red snapper are an iconic species in the southeast United States (Cowan Jr. et al., 2011), and significant recreational and commercial fisheries for red snapper have operated in the region for many decades (White and Palmer, 2004; SEDAR, 2018, 2021). On the southeast United States Atlantic continental shelf (hereafter, SEUS), red snapper commercial landings increased throughout the 1950s and 1960s and peaked at 473,000 kg in 1968, followed by a long decline through the 1990s (Johnson III et al., 1998). Recreational landings temporarily lagged behind the commercial harvest, peaking at 280,800 kg in 1985, but also

* Correspondence to: National Marine Fisheries Service, Southeast Fisheries Science Center, 101 Pivers Island Road, Beaufort, NC 28516, USA.
E-mail address: nate.bachelier@noaa.gov (N.M. Bachelier).

<https://doi.org/10.1016/j.fishres.2024.107200>

Received 20 February 2024; Received in revised form 10 September 2024; Accepted 3 October 2024

Available online 14 October 2024

0165-7836/ Published by Elsevier B.V. This is an open access article under the CC BY-NC license (<http://creativecommons.org/licenses/by-nc/4.0/>).

Appendix Chapters

Appendix IV

Appendix IV

Do not cite. This is a draft manuscript. Once published in a scientific journal, a link to the paper will be provided on the South Atlantic Red Snapper Research Program webpage.

Genetic Population Structure of Red Snapper, *Lutjanus campechanus*, in the U.S. Atlantic and Eastern Gulf of America

Alison Monroe¹, Christopher M. Hollenbeck¹, Catherine L. Lanoue¹,
William F. Patterson III², and David S. Portnoy¹

¹Marine Genomics Laboratory, Department of Life Sciences, Texas A&M University–Corpus Christi, 6300 Ocean Drive, Corpus Christi, TX 78412, USA

²School of Forest, Fisheries, and Geomatics Sciences, University of Florida, 7922 NW 71st Street, Gainesville, Florida 32653, USA

Appendix V

Appendix V

Do not cite. This manuscript is in peer review at a scientific journal. Once published in a journal, a link to the paper will be provided on the South Atlantic Red Snapper Research Program webpage.

Sensitivity of CKMR Population Estimates to Uncertainty in Life History

Liam Kehoe^{1,2,*}, Eric C. Anderson³, Christopher M. Hollenbeck⁴, David Chagaris²,
Kyle Shertzer⁵, William F. Patterson III¹, and David S. Portnoy⁴

¹School of Forest, Fisheries, and Geomatics Sciences, University of Florida, Gainesville, Florida, USA

²Nature Coast Biological Station, University of Florida, Cedar Key, FL 32625, USA

³Department of Biology and Department of Fish, Wildlife, and Conservation Biology, Colorado State University, Fort Collins, Colorado, USA.

⁴Marine Genomics Laboratory, Department of Life Sciences, Texas A&M University–Corpus Christi, 6300 Ocean Drive, Corpus Christi, TX 78412, USA

⁵National Marine Fisheries Service, Beaufort, NC, 28516

* correspondence: LKehoe@ufl.edu

Key Words: CKMR; Fisheries; Genomics; Life History; Mark-Recapture; Recruitment Variation; Age Composition

Appendix VI

Appendix VI

Do not cite. This is a draft manuscript. Once published in a scientific journal, a link to the paper will be provided on the South Atlantic Red Snapper Research Program webpage.

Incorporating Close-Kin Mark-Recapture Data into an Integrated Stock Assessment Model for Southeast United States Atlantic Red Snapper (*Lutjanus campechanus*).

Paul S. McLaughlin¹, Eric C. Anderson^{2,3}, Paul B. Conn⁴, Matthew D. Damiano^{5,*}, Christopher M. Hollenbeck⁶, Alison A. Monroe⁶, William F. Patterson III⁷, David S. Portnoy⁶,
Kyle W. Shertzer⁵, Matthew T. Vincent⁵

¹Cooperative Institute for Marine and Atmospheric Studies, University of Miami, Miami, FL, USA

²Southwest Fisheries Science Center, National Marine Fisheries Service, Santa Cruz, CA, USA

³Department of Biology, Colorado State University, Fort Collins, Colorado, USA

⁴Marine Mammal Lab, Alaska Fisheries Science Center, National Marine Fisheries Service, Seattle, WA, USA

⁵Southeast Fisheries Science Center, National Marine Fisheries Service, Beaufort, NC, USA

⁶Department of Life Sciences, Texas A&M University-Corpus Christi, Corpus Christi, TX, USA

⁷School of Forest, Fisheries, and Geomatics Sciences, University of Florida, Gainesville, FL, USA

*Current affiliation: North Carolina Division of Marine Fisheries, Morehead City, NC, USA

Appendix Chapters

Appendix VII

Appendix VII

Do not cite. This manuscript is in peer review at a scientific journal. Once published in a journal, a link to the paper will be provided on the South Atlantic Red Snapper Research Program webpage.

Estimating Reef Fish Exploitation Rates in Catch-and-Release Fisheries with Conventional and Genetic Tags

Liam Kehoe^{1,2*}, Kyle W. Shertzer³, Matthew V. Lauretta³, Jeffrey A. Buckel⁴, David S. Portnoy⁵, William F. Patterson III¹, and David D. Chagaris^{1,2}

¹School of Forest, Fisheries, and Geomatic Sciences, University of Florida, Gainesville, Florida, USA

²Nature Coast Biological Station, University of Florida, Cedar Key, Florida USA

³Southeast Fisheries Science Center, National Marine Fisheries Service, Beaufort, North Carolina or Miami, Florida, USA

⁴Department of Applied Ecology, Center for Marine Sciences and Technology, North Carolina State University, Morehead City, North Carolina, USA

⁵Marine Genomics Laboratory, Department of Life Sciences, Texas A&M University–Corpus Christi, Corpus Christi, Texas, USA

*corresponding author: lkehoe@ufl.edu

Appendix VIII

Appendix VIII

Do not cite. This manuscript has been accepted for publication in *Regional Studies in Marine Science*. Once the published paper is available a link will be provided on the South Atlantic Red Snapper Research Program webpage

Stakeholder Insights Corroborate Habitat and Reef Fish Abundance on the Southeastern U.S. Atlantic Continental Shelf

P.J. Rudershausen^{1*}, C.M. Schobernd², N.M. Bachelier², K. Pacifici³, W.F. Patterson III⁴, B.J. Runde⁵, and J.A. Buckel¹

¹North Carolina State University, Department of Applied Ecology, Center for Marine Sciences and Technology, 303 College Circle, Morehead City, NC 28557 USA

²Southeast Fisheries Science Center, National Marine Fisheries Service, Beaufort, NC 28516 USA

³Department of Forestry and Environmental Resources, North Carolina State University, Raleigh, North Carolina USA

⁴University of Florida, School of Forest, Fisheries, and Geomatics Sciences, 7922 NW 71st St., Gainesville, FL 32653 USA

⁵The Nature Conservancy, 652 Peter Jefferson Pkwy STE 190, Charlottesville, VA 22911 USA

*corresponding author email: pjruders@ncsu.edu

Appendix IX

North American Journal of Fisheries Management, 2025, 45, 270–282
https://doi.org/10.1093/najfm/vqaf012
Advance access publication: April 29, 2025
Article



Discard mortality rates of Red Snapper after barotrauma and hook trauma: Insights from using acoustic telemetry in the U.S. South Atlantic

P. J. Rudershausen^{1*}, B. J. Runde², R. M. Tharp³, J. H. Merrell⁴, N. M. Bachelier², W. F. Patterson III¹, and J. A. Buckel¹

¹Center for Marine Sciences and Technology, Department of Applied Ecology, North Carolina State University, Morehead City, North Carolina, USA

²The Nature Conservancy, Charlottesville, Virginia, USA

³National Marine Fisheries Service, Southeast Fisheries Science Center, Beaufort, North Carolina, USA

⁴Fisheries and Aquatic Sciences, University of Florida, Gainesville, Florida, USA

*Corresponding author: P.J. Rudershausen. Email: pjruders@ncsu.edu.

ABSTRACT

Objective: We studied discard mortality of Red Snapper *Lutjanus campechanus*, a reef species that experiences barotrauma and hook trauma in its U.S. hook-and-line fisheries. Annual numbers of discarded Red Snapper far exceed those harvested in federal fisheries management regions, a phenomenon that emphasizes the importance of quantifying discard fates.

Methods: To estimate discard mortality, three-dimensional movement data were collected using acoustic telemetry tags and a 3-km² array of receivers deployed in 2019 and 2023 at a natural reef area (38 m deep) off North Carolina. Release treatments were jaw-hooked or deep-hooked fish, all fish were returned to depth with a recompression device. We assigned a fate for each released Red Snapper based on movement profiles revealed by the acoustic detection data; fates included discard mortality, lost tag, emigrated/harvested, or alive within the array when the receivers were retrieved. A Kaplan–Meier survivorship analysis was used to estimate the rates of discard survival for each release treatment.

Results: Mean proportional rates of discard mortality (1 – survival) were 0.063 (95% CI = 0.001–0.122) for jaw-hooked recompressed fish and 0.875 (0.543–0.966) for deep-hooked recompressed fish.

Conclusions: Our study provides estimates of discard mortality for Red Snapper at a depth where the species is often captured in U.S. South Atlantic commercial and recreational fisheries. Our estimate of discard mortality for deep-hooked Red Snapper is among the highest published rates for fish in this release condition and demonstrates that deeply hooked Red Snapper will likely die.

KEYWORDS: acoustic telemetry, discard mortality, Red Snapper

LAY SUMMARY

The results from using acoustic telemetry to study discard mortality rates of recompressed Red Snapper highlight the need for aggressive outreach regarding the benefits and requirements of fishing with conservation gears, such as circle hooks and recompression tools, to reduce deep hooking and effects of barotrauma and thus facilitate recovery of the U.S. Atlantic Red Snapper stock.

INTRODUCTION

The Red Snapper *Lutjanus campechanus* is a prized reef species that aggregates on low- and medium-relief reef habitats in tropical and subtropical waters on the western Atlantic and Gulf of Mexico continental shelf (Bachelier et al., 2016; Dance & Rosker, 2019; Karamoukas et al., 2017; Mitchell et al., 2014). Management approaches to address overfishing and the overfished status of Red Snapper in the U.S. Gulf of Mexico and

Appendix Chapters

Appendix X

Contents lists available at ScienceDirect

Fisheries Research

journal homepage: www.elsevier.com/locate/fishres

Full length article

Post-release mortality of red snapper, *Lutjanus campechanus*, in US Atlantic waters off northeast Florida estimated with three-dimensional acoustic telemetry

Selia Zimmermann^{a,*}, Liam Kehoe^a, Miaya Taylor^a, Joseph H. Tarnecki^a, Nathan M. Bacheler^a, Zachary A. Siders^a, William F. Patterson III^a

^a Fisheries and Aquatic Sciences, School of Forest, Fisheries, and Geomatics Sciences, University of Florida, Gainesville, FL, USA
^b Southeast Fisheries Science Center, National Marine Fisheries Service, Beaufort, NC, USA

ARTICLE INFO

Keywords:
Release mortality
Barotrauma
Acoustic telemetry

ABSTRACT
Regulatory discards contribute upwards of 80% of the total recreational fishing mortality for red snapper (*Lutjanus campechanus*) in US Atlantic waters, contributing to the stock's overfished status and resulting in restrictive management actions. Accurate estimates of discard mortality and the impact of mitigation measures are paramount for evaluating management options. Toward that end, we deployed a three-dimensional positioning acoustic telemetry array of 100 receivers between 21 and 28 m depths at a 20 km² study site off Pomme Hater, Florida in summer 2024. Red snapper ($n = 65$) were captured via hook and line, tagged with external acoustic transmitters, and released at the surface or using a descender device. Movement patterns of tagged fish were used to infer individual fate. Three-quarters of the mortalities occurred acutely post-release (within 6 h) with 46.8% dead for surface released and 12.9% dead for descender released fish. No mortalities occurred 48 h post-release with a $D = 29.0\%$ for descender fish, $D = 46.9\%$ for surface-released fish, and $D = 38.3\%$ combined at this time. Results from a Bayesian hurdle proportional hazards model showed descending fish significantly increased acute survival but did not affect delayed survival. Instead, larger fish and shorter times out of water significantly increased delayed survival but these improvements were small relative to the acute descender effects. Our results show that using a descender device to release fish is paramount for increasing survival at our study depths but that minimizing air exposure can decrease delayed post-release mortality if fish cannot be descended.

1. Introduction

Discard mortality is a symptom of catch-and-release fisheries for numerous species around the globe and is one of the more pervasive marine conservation and sustainable fisheries issues in the U.S. This is a particularly acute issue for reef fishes along the Atlantic coast of the southeastern U.S. (SEUS), for which regulatory discards in the recreational sector are estimated to greatly exceed the landed catch (Kunde et al., 2019, 2021; Shertzer et al., 2024; Fadenhausen et al., 2025). Regulatory discards are generated by catching fishes that are under a seasonal closure, bag and size limits, or fishing moratorium. Discards are a particularly problematic issue in regions and habitat hosting mixed-species aggregations (e.g. SEUS snapper-grouper complex) for which fishing has the chance of capturing a variety of species besides the targeted ones (Campbell et al., 2014; Chagaris et al., 2019; Shertzer et al., 2024).

Red snapper (*Lutjanus campechanus*) is one of the more popular reef fish targets in the SEUS but has long been at the center of contentious management, with repeated fishing moratoriums driven by high levels of regulatory discards. High discard rates are driven by management measures such as minimum size limits, seasonal closures, and low recreational bag limits. Limited harvest, recreational seasons less than 5 days open, has been allowed intermittently when red snapper total removals remain within the acceptable biological catch (ABC), but high discard estimates have frequently caused the ABC to be exceeded, prompting repeated closures and even shorter recreational seasons, including a single-day season in 2024 (89 FR 50530; SEDAR 2021). While discarding is intended to facilitate escapement of fish from fishery removals, benefits depend on the survival of released fish. Estimated Atlantic red snapper recreational discard rates are among the highest of

* Correspondence to: Fisheries and Aquatic Sciences, University of Florida, 7922 NW 71st Street, Gainesville, FL 32653, USA.
E-mail address: sellazimmermann@ufl.edu (S. Zimmermann).

<https://doi.org/10.1016/j.fishres.2026.107703>
Received 29 August 2025; Received in revised form 26 February 2026; Accepted 26 February 2026
Available online 12 March 2026
0165-7836/© 2026 Elsevier B.V. All rights are reserved, including those for text and data mining, AI training, and similar technologies.

Appendix XI

Appendix XI

Do not cite. This is a draft manuscript. Once published in a journal, a link to the paper will be provided on the South Atlantic Red Snapper Research Program webpage.

Sensitivity of CKMR-Derived Atlantic Red Snapper Population Estimates to Uncertainty in Life History Parameters

Liam Kehoe,^{1,2,*} Eric C. Anderson,³ Christopher M. Hollenbeck,⁴ David Chagaris,² Kyle Shertzer^{5†}, William F. Patterson III¹, and David S. Portnoy⁴

¹School of Forest, Fisheries, and Geomatics Sciences, University of Florida, Gainesville, Florida, USA

²Nature Coast Biological Station, University of Florida, Cedar Key, FL 32625, USA

³Department of Biology and Department of Fish, Wildlife, and Conservation Biology, Colorado State University, Fort Collins, Colorado, USA.

⁴Marine Genomics Laboratory, Department of Life Sciences, Texas A&M University–Corpus Christi, 6300 Ocean Drive, Corpus Christi, TX 78412, USA

⁵National Oceanic and Atmospheric Administration, Southeast Fisheries Science Center, Beaufort Laboratory, Beaufort, NC, 28516

[†]deceased

* correspondence: LKehoe@ufl.edu

Key Words: CKMR; Fisheries; Genomics; Life History; Mark-Recapture; Recruitment Variation; Age Composition

Bayesian Hierarchical Integrated Modeling

Objective:

Estimate Atlantic red snapper population size with a CV of ≤ 0.3 from trap-camera, ROV, and habitat data

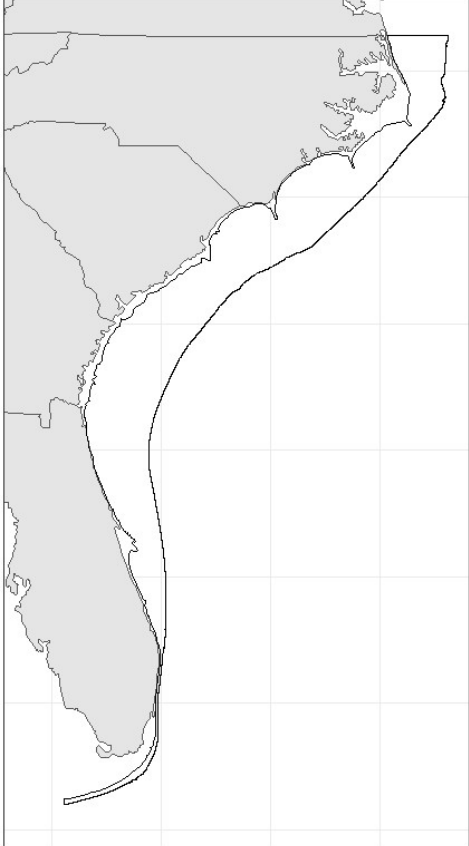
Approach:

- 1) Integrate red snapper density estimates from multiple survey methods to jointly estimate red snapper abundance at three spatial scales: i) survey site ($\sim 10^3 \text{ m}^2$), ii) grid cell (25 km^2), and iii) study area ($\sim 100 \times 10^3 \text{ km}^2$)
- 2) Habitat suitability informed by study video data, fishery-dependent data, and informed priors from previous studies and mapping
- 3) Separate observation models to account for different detection probabilities and effective sampling area of ROV, traps, and cameras mounted to traps

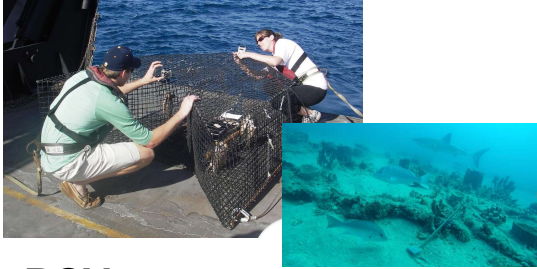


Bayesian Hierarchical Integrated Modeling

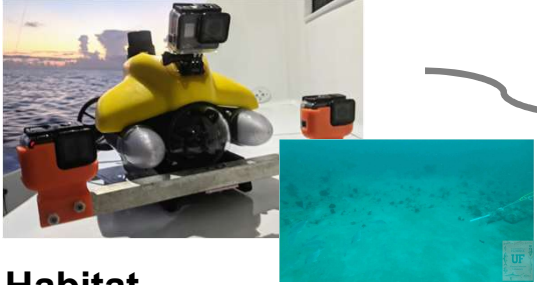
Study area



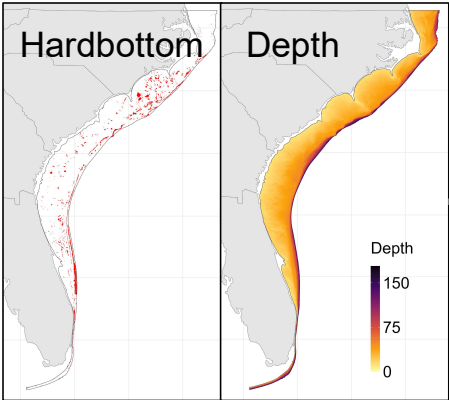
Camera counts



ROV counts

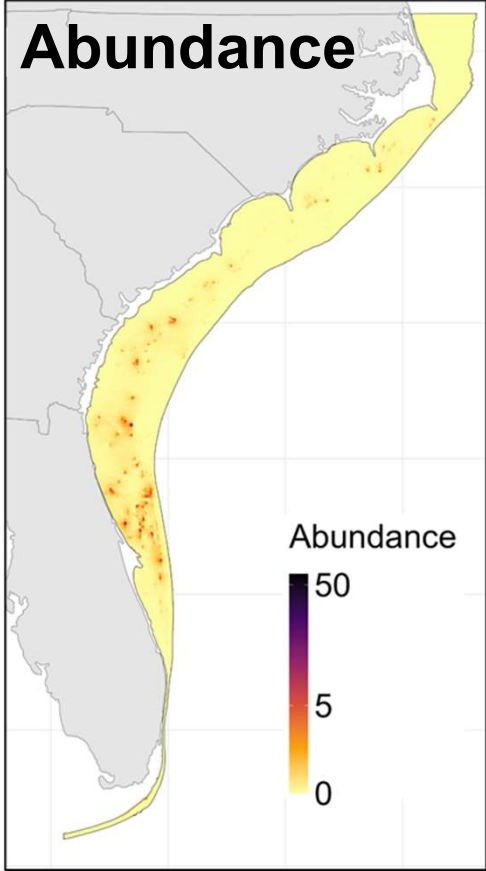


Habitat

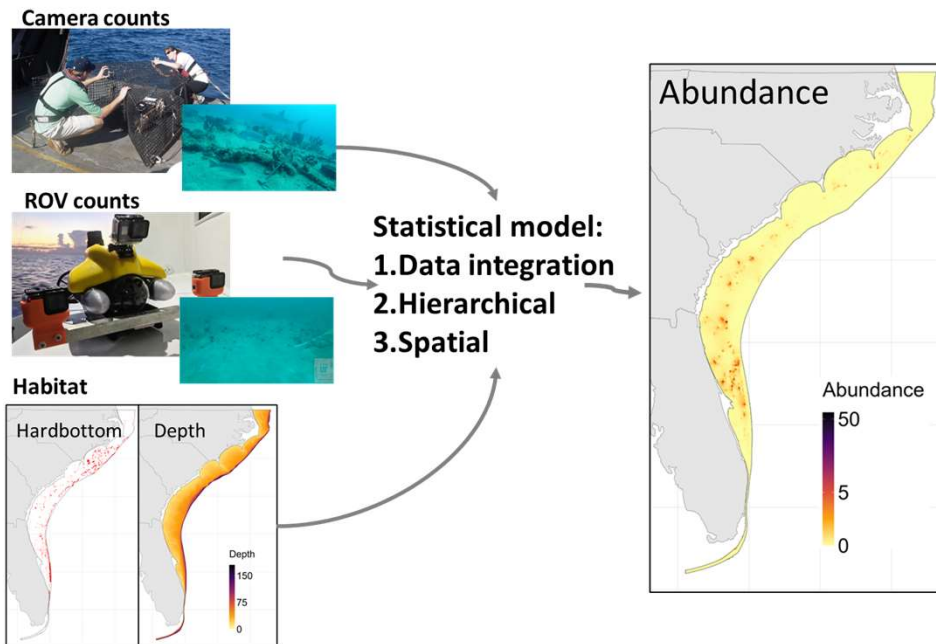


Statistical model:
1.Data integration
2.Hierarchical
3.Spatial

Abundance

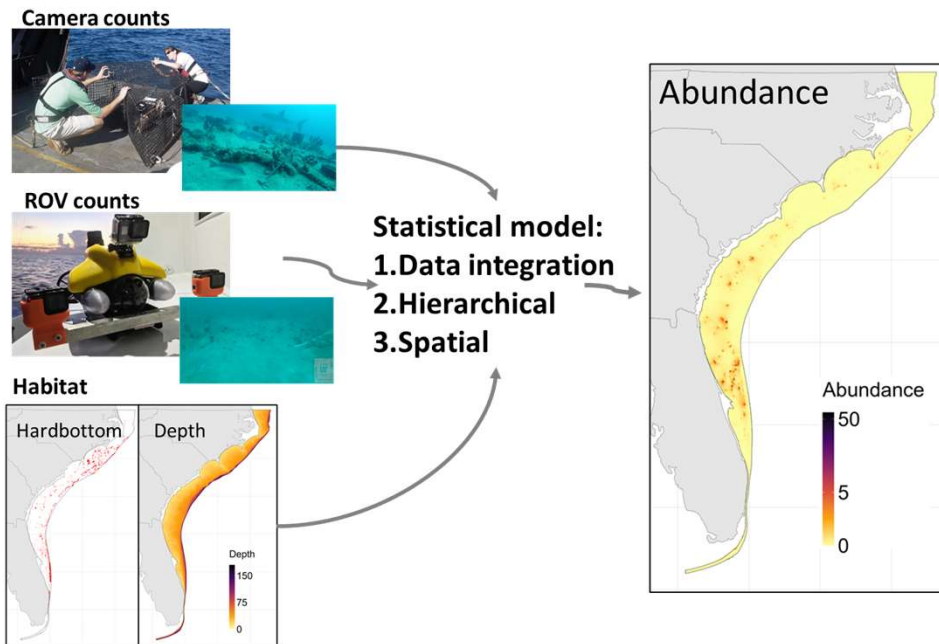


Bayesian Hierarchical Integrated Modeling



- Single abundance process jointly estimated from all data
- Reduce bias in any single dataset
- Propagate uncertainty
- Sub-models connect observed counts to latent abundance
- Address survey-specific sampling biases

Bayesian Hierarchical Integrated Modeling

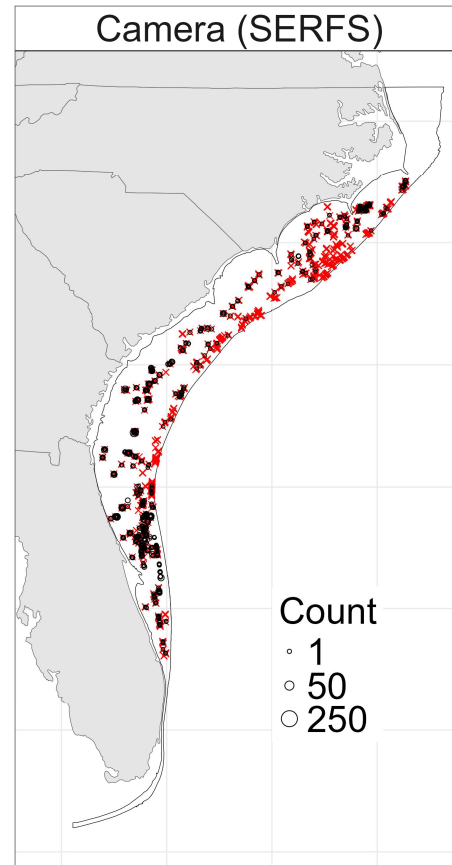


- + Integrate results from separate studies via informative priors
- + Vague priors when information is unavailable
- Markov chain Monte Carlo can be slow

Bayesian Hierarchical Integrated Modeling: Data

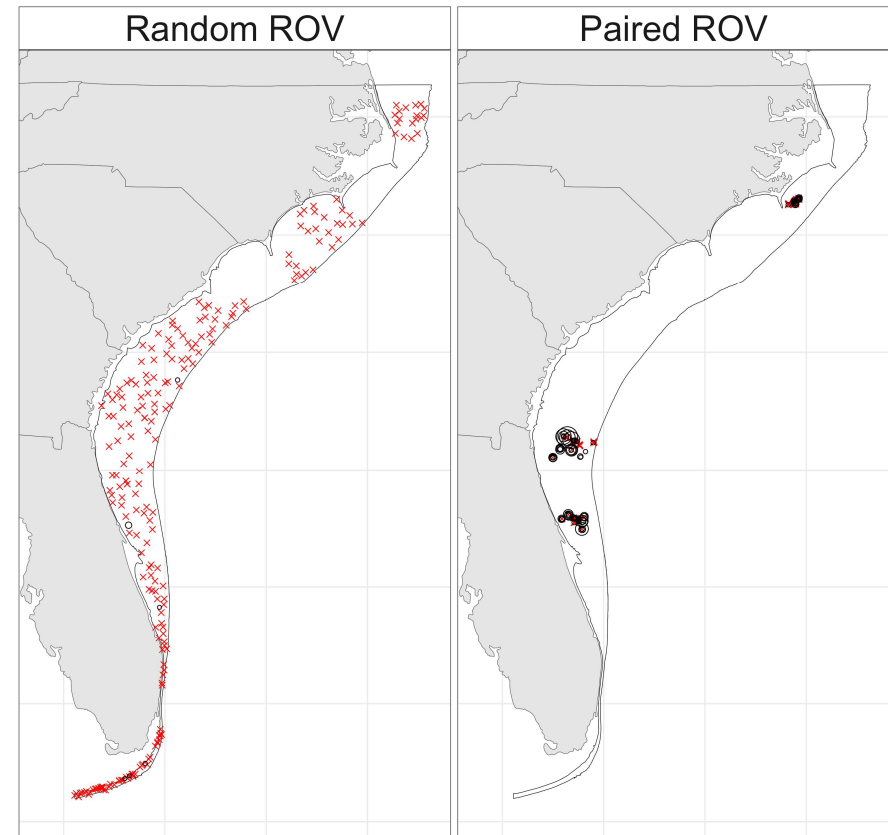
SERFS

- 2,434 sites; SRS from ~4,300 sites
- Cape Hatteras to St. Lucie Inlet
- April – Oct 2021 (n = 1,384) and 2022 (n = 1,050)



ROV

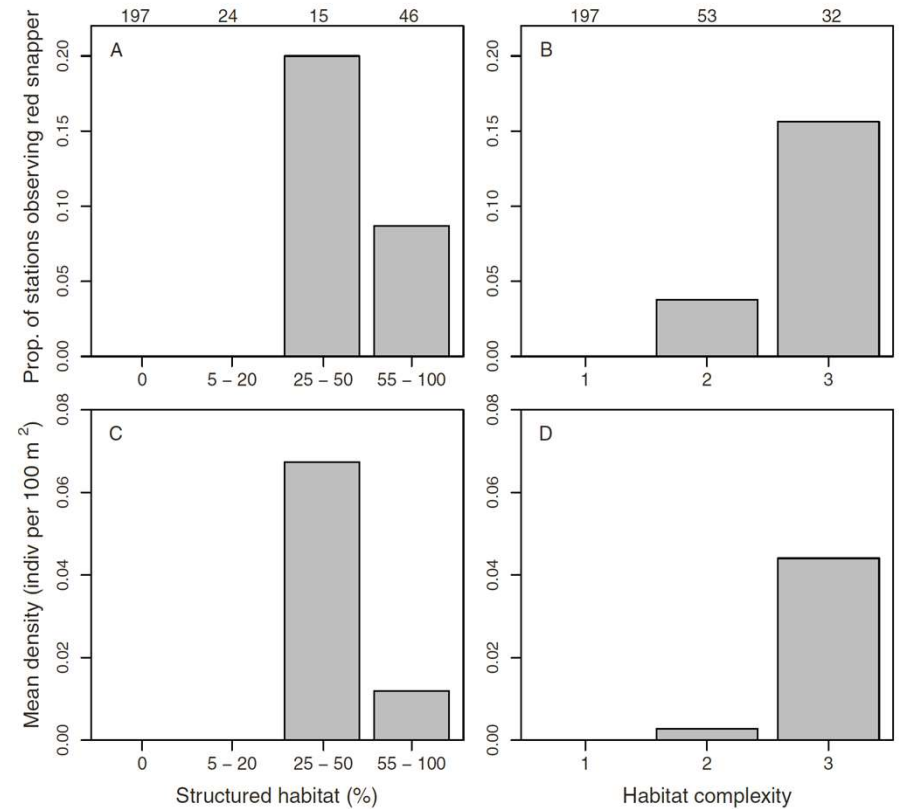
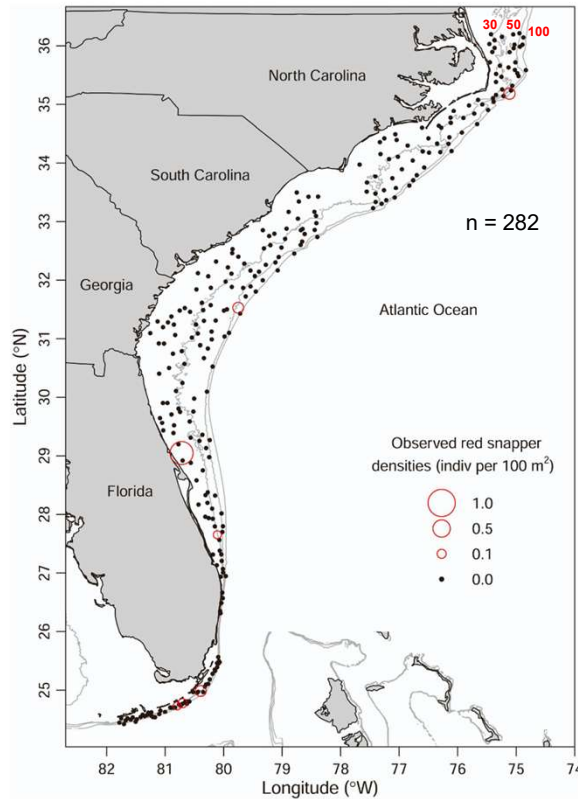
- SRS: n = 231 sites; paired with SERFS: n = 205



Bayesian Hierarchical Integrated Modeling: ROV Sampling

Objective:

Estimate the distribution and density of red snapper across the US Atlantic shelf from North Carolina through the Florida Keys with ROVs in unknown or unconsolidated habitats



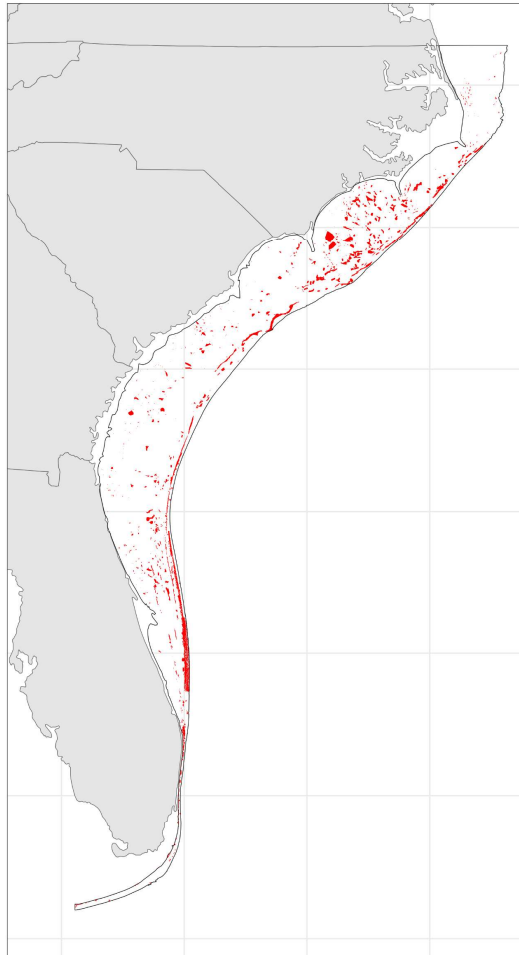
Bacheler et al. (2025); Appendix III

Bayesian Hierarchical Integrated Modeling: Hardbottom Distribution

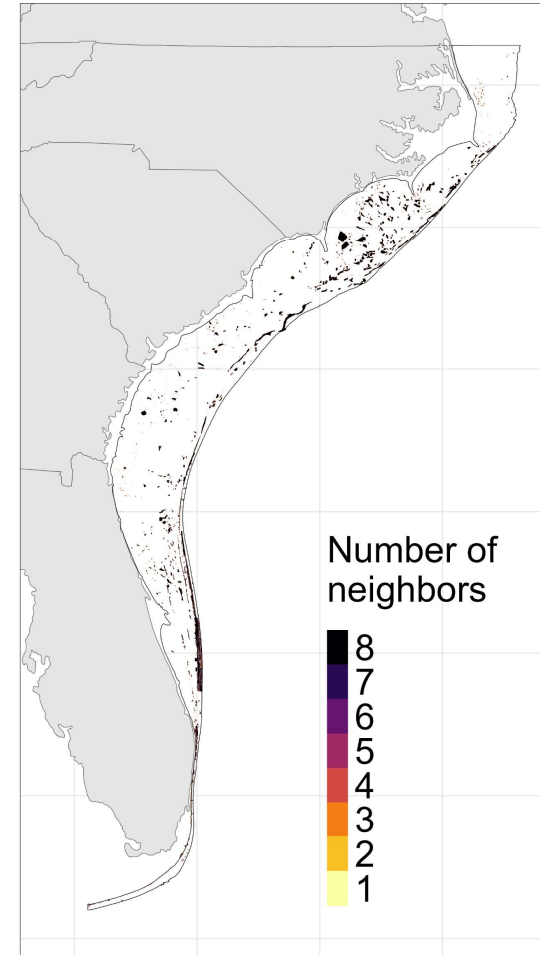
Working group evaluated:

- 1) Expert Opinion map [EO] (Steward et al. 2022)
- 2) TNC SAB map [TNC] (Conley et al. 2017)

Hardbottom



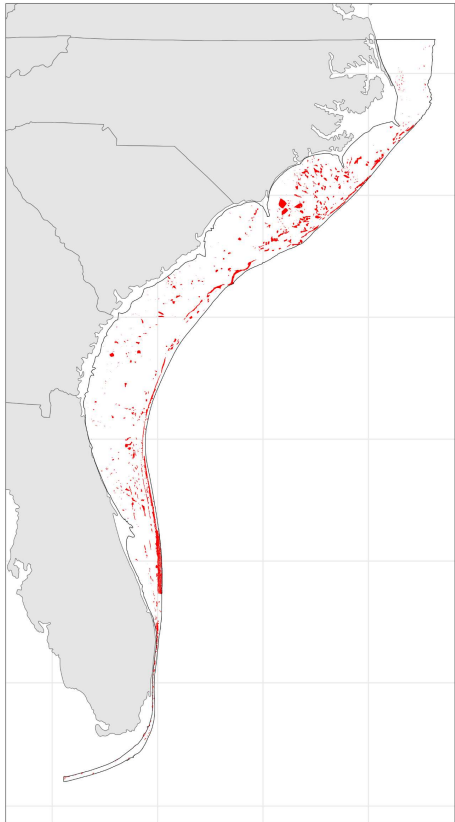
Hardbottom neighbors



Bayesian Hierarchical Integrated Modeling

Estimated population size under different hardbottom maps

Hardbottom



Map	% HB	Population size 10^6	CV
EO & TNC	~5%	5.31	0.39
TNC	~3%	99.95	0.28
TNC + Preferential sampling	~3%	0.79	0.46
EO & TNC (all)	~13%	7.22	0.32

Increased hardbottom \approx increased estimated abundance

Bayesian Hierarchical Integrated Modeling: CIE Review

Positives:

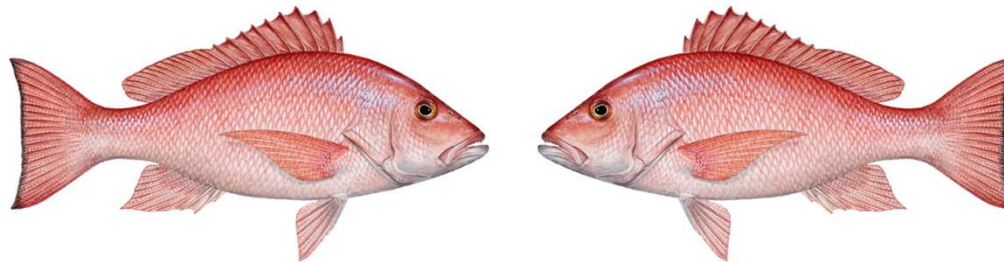
-methods applied appropriately, with several innovative approaches within BHIM

Concerns:

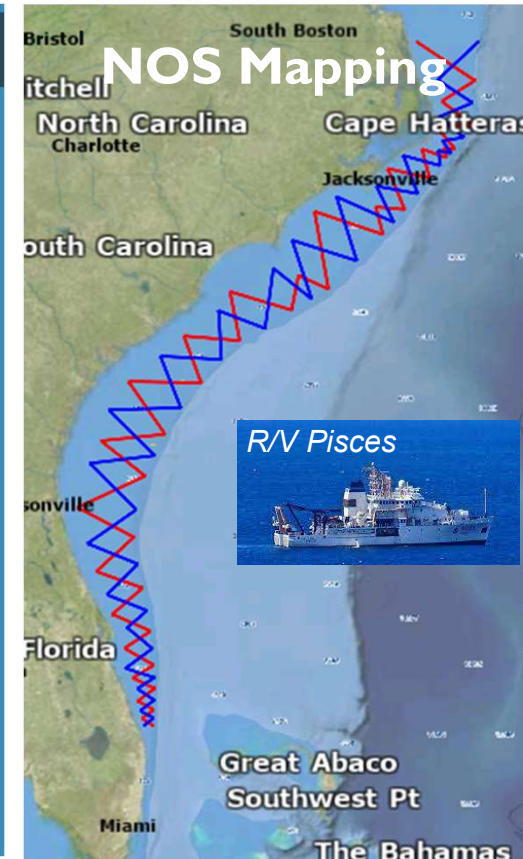
-BHIM estimate not independent of the RS stock assessment

-Camera-trap ESA estimation based on data from one region and perhaps is not applicable to others

-Bottom habitat information used by BHIM too uncertain to provide a sufficiently reliable estimate of age 2+ absolute abundance.



Atlantic Shelf Mapping



- Florida: LiDAR to a depth of 20+ meters along with multibeam sonar in shallow water to fill LiDAR data gaps and deeper bathymetry from 20 to 200 meters.

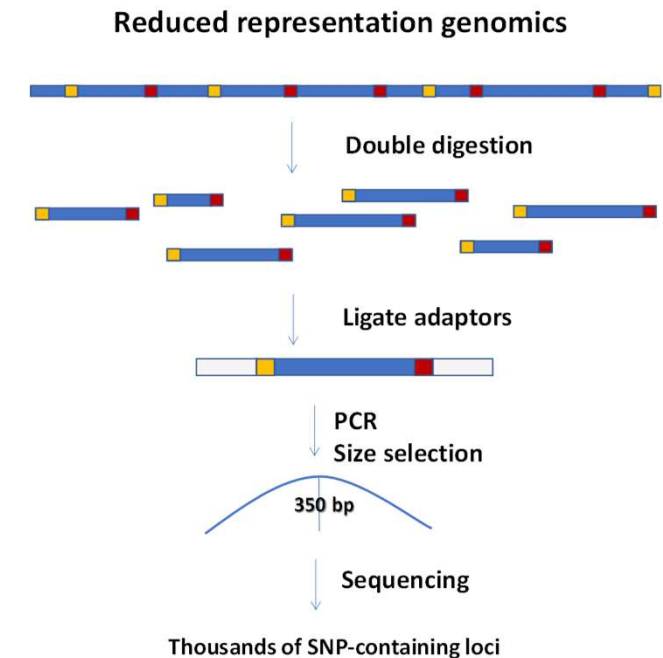
Close-Kin Mark-Recapture

Objectives:

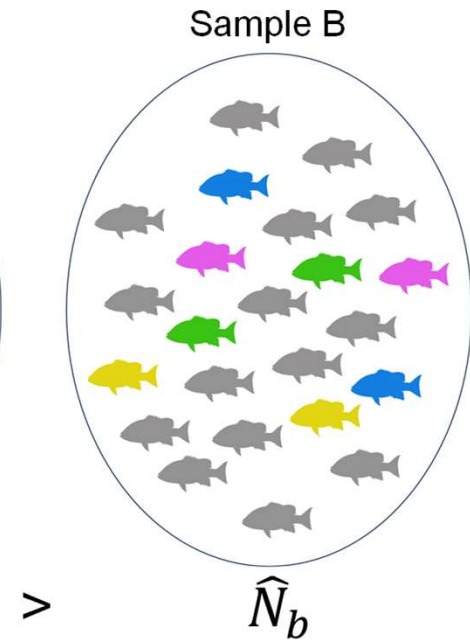
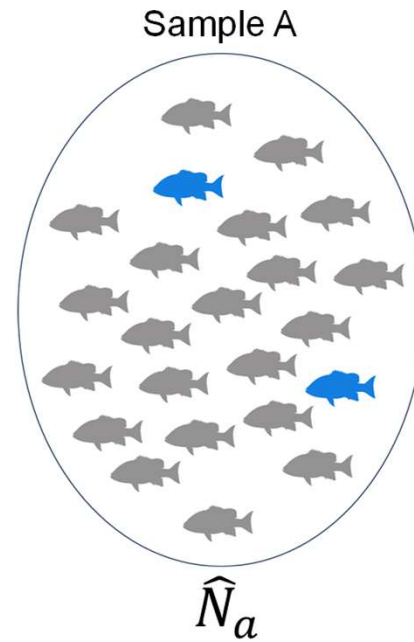
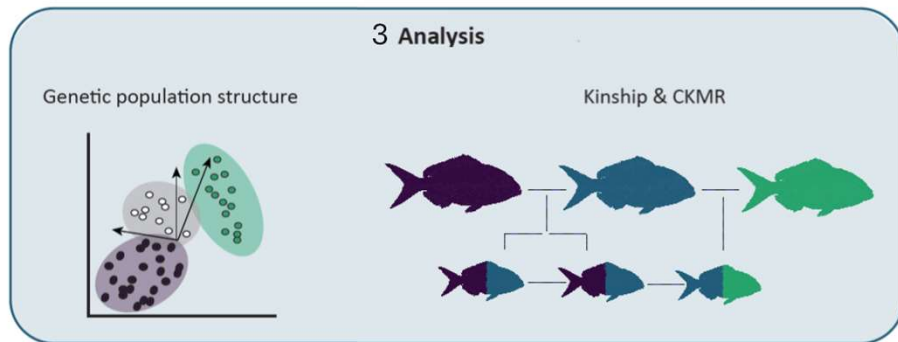
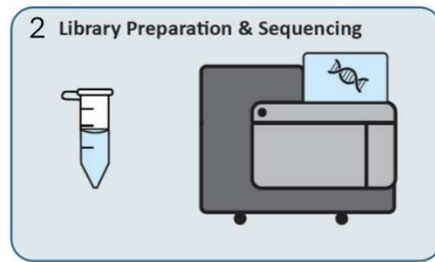
- 1) To estimate red snapper population size in US Atlantic
- 2) To estimate red snapper genetic population structure

Approach:

- 1) Fin clip sampling of Atlantic red snapper; up to 5k per year for 3 years
- 2) Development of genotyping in the thousands (GT-seq) panels to allow high through-put sequencing of 400 microhaplotypes (SNP-containing loci)
- 3) Sequencing of fin clip samples and population size estimation with CKMR model



Close-Kin Mark-Recapture: Conceptual Approach



>

Atlantic Red Snapper Population Structure

Portnoy et al. (2022)

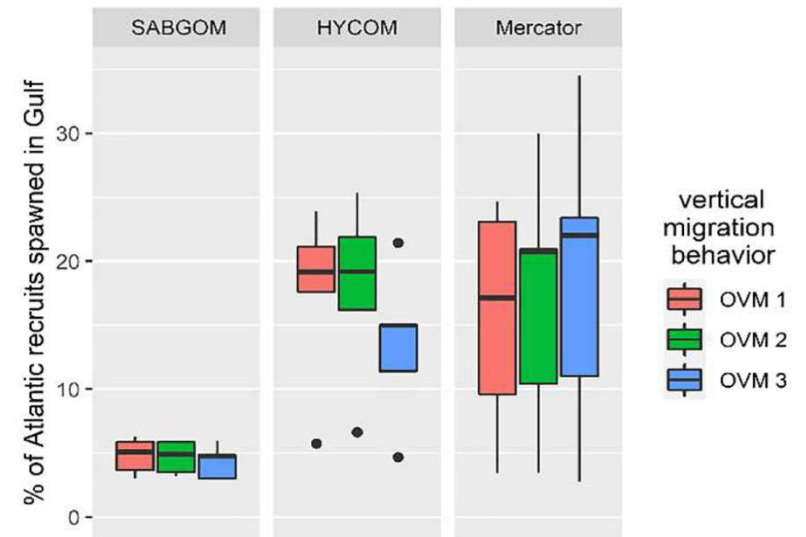
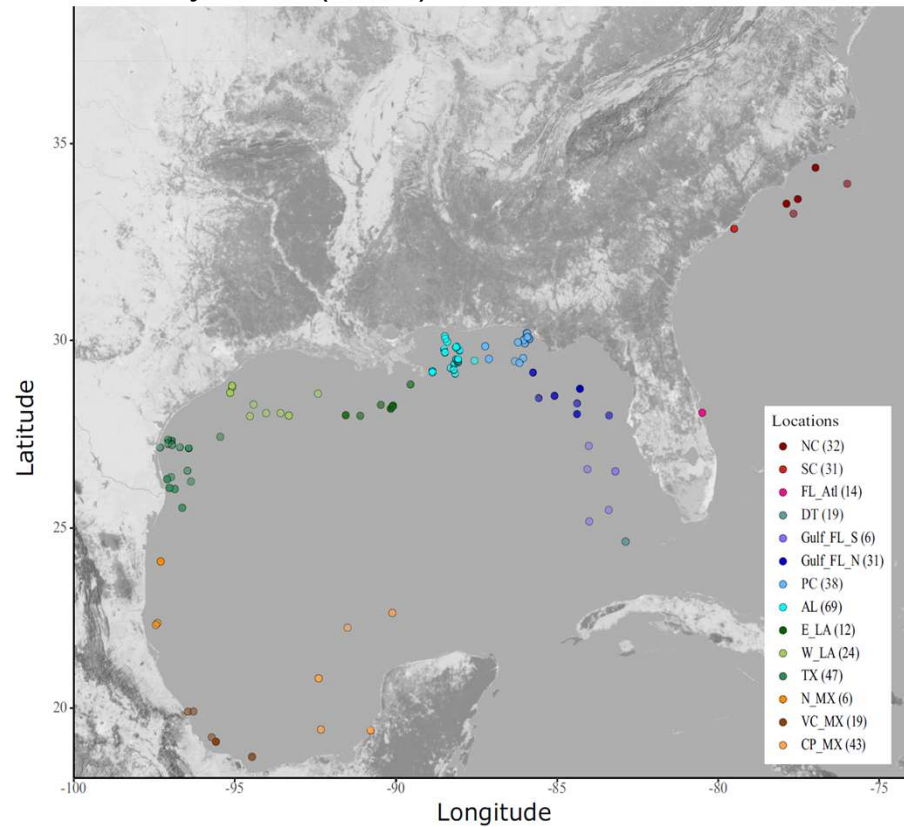
Received: 16 December 2021 | Revised: 27 July 2022 | Accepted: 31 July 2022
DOI: 10.1111/for.12607

ORIGINAL ARTICLE

FISHERIES RESEARCH WILEY

Source-sink recruitment of red snapper: Connectivity between the Gulf of Mexico and Atlantic Ocean

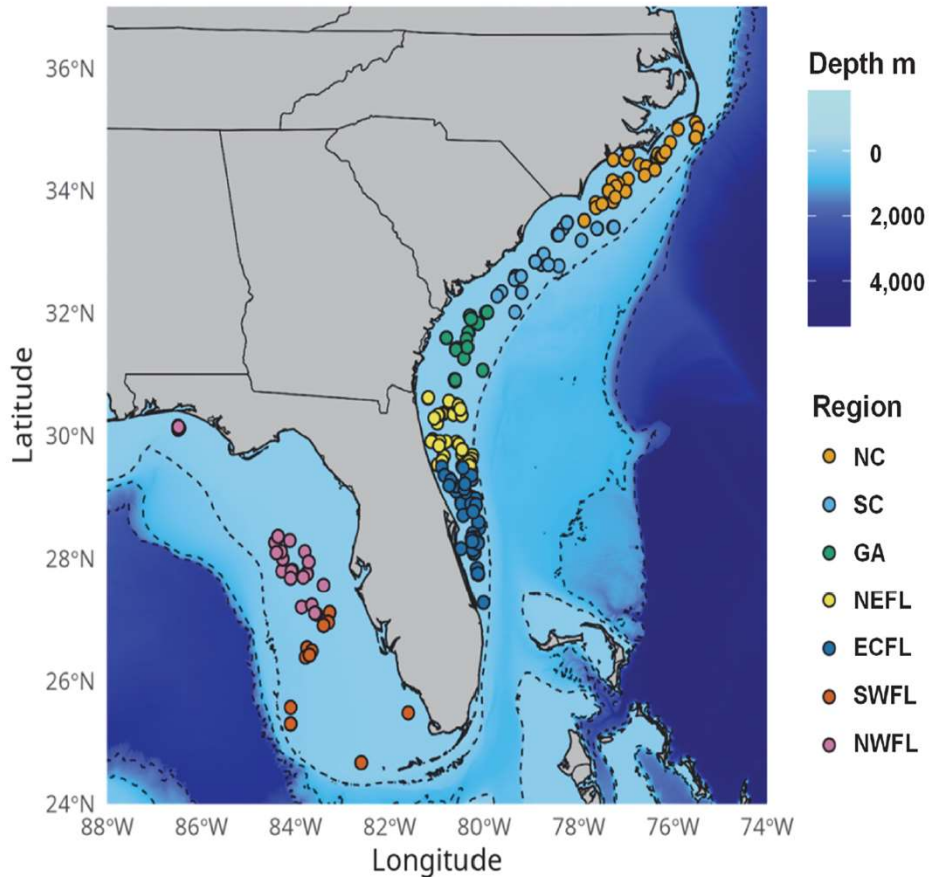
Mandy Karnauskas¹ | Kyle W. Shertzer² | Claire B. Paris³ |
Nicholas A. Farmer⁴ | Theodore S. Switzer⁵ | Susan K. Lowerre-Barbieri⁶ |
G. Todd Kellison² | Ruoying He⁷ | Ana C. Vaz^{1,3}



- Separate Atlantic and GOM stocks; weak heterogeneity within the GOM

- Estimate: 5-20% of Atlantic red snapper recruits spawned in the Gulf

Atlantic Red Snapper Population Structure



- Assessed genetic variation across 2,776 SNP-containing loci in 307 samples from Gulf and Atlantic
- Hierarchical AMOVA: genetic differences between the Gulf and Atlantic; no differences within Atlantic
- Results consistent with previous population genetic studies in the region
- Inference: any larval transport from Gulf to Atlantic does not equate to realized connectivity (larval transport followed by reproductive success)

Monroe et al. (2025); Appendix IV

CKMR Life History Simulations

Appendix XI

Do not cite. This is a draft manuscript. Once published in a journal, a link to the paper will be provided on the South Atlantic Red Snapper Research Program webpage.

Sensitivity of CKMR-Derived Atlantic Red Snapper Population Estimates to Uncertainty in Life History Parameters

Liam Kehoe,^{1,2,*} Eric C. Anderson,³ Christopher M. Hollenbeck,⁴ David Chagaris,² Kyle Shertzer^{5†}, William F. Patterson III¹, and David S. Portnoy⁴

¹School of Forest, Fisheries, and Geomatics Sciences, University of Florida, Gainesville, Florida, USA

²Nature Coast Biological Station, University of Florida, Cedar Key, FL 32625, USA

³Department of Biology and Department of Fish, Wildlife, and Conservation Biology, Colorado State University, Fort Collins, Colorado, USA.

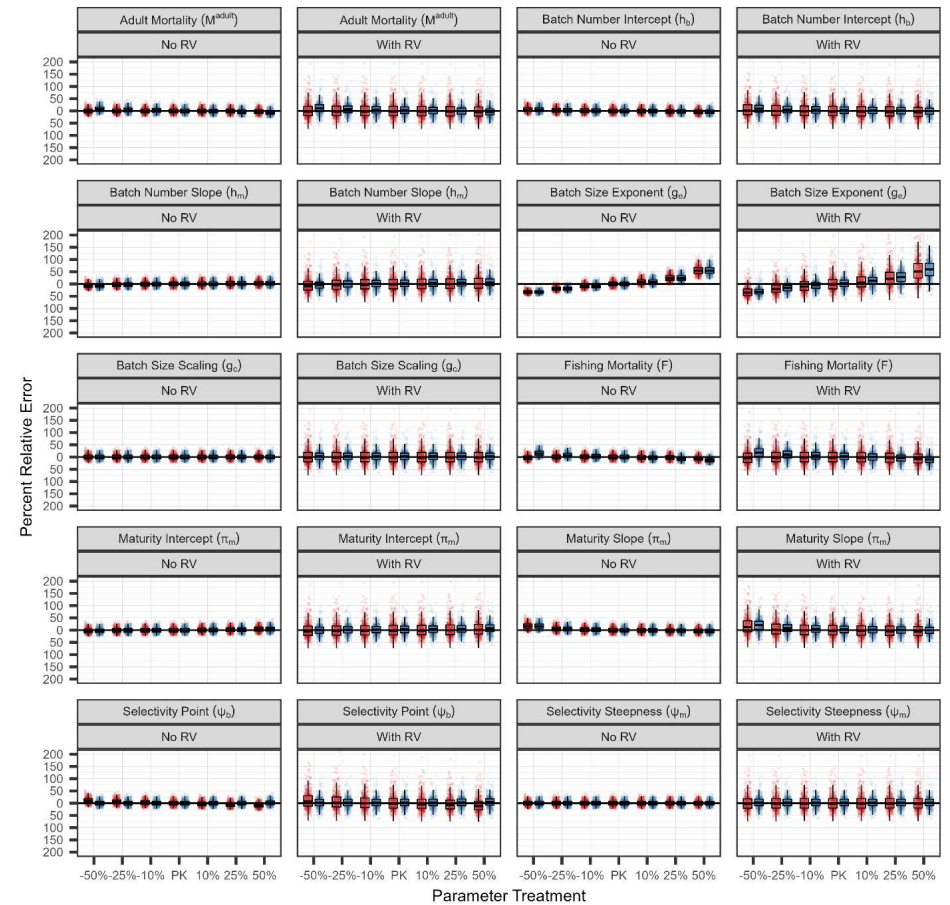
⁴Marine Genomics Laboratory, Department of Life Sciences, Texas A&M University–Corpus Christi, 6300 Ocean Drive, Corpus Christi, TX 78412, USA

⁵National Oceanic and Atmospheric Administration, Southeast Fisheries Science Center, Beaufort Laboratory, Beaufort, NC, 28516

[†]deceased

* correspondence: LKehoe@ufl.edu

Key Words: CKMR; Fisheries; Genomics; Life History; Mark-Recapture; Recruitment Variation; Age Composition



Model type EQAC EXAC

CKMR Life History Simulations

Appendix XI

Do not cite. This is a draft manuscript. Once published in a journal, a link to the paper will be provided on the South Atlantic Red Snapper Research Program webpage.

Sensitivity of CKMR-Derived Atlantic Red Snapper Population Estimates to Uncertainty in Life History Parameters

Liam Kehoe,^{1,2,*} Eric C. Anderson,³ Christopher M. Hollenbeck,⁴ David Chagaris,² Kyle Shertzer^{5†}, William F. Patterson III¹, and David S. Portnoy⁴

¹School of Forest, Fisheries, and Geomatics Sciences, University of Florida, Gainesville, Florida, USA

²Nature Coast Biological Station, University of Florida, Cedar Key, FL 32625, USA

³Department of Biology and Department of Fish, Wildlife, and Conservation Biology, Colorado State University, Fort Collins, Colorado, USA.

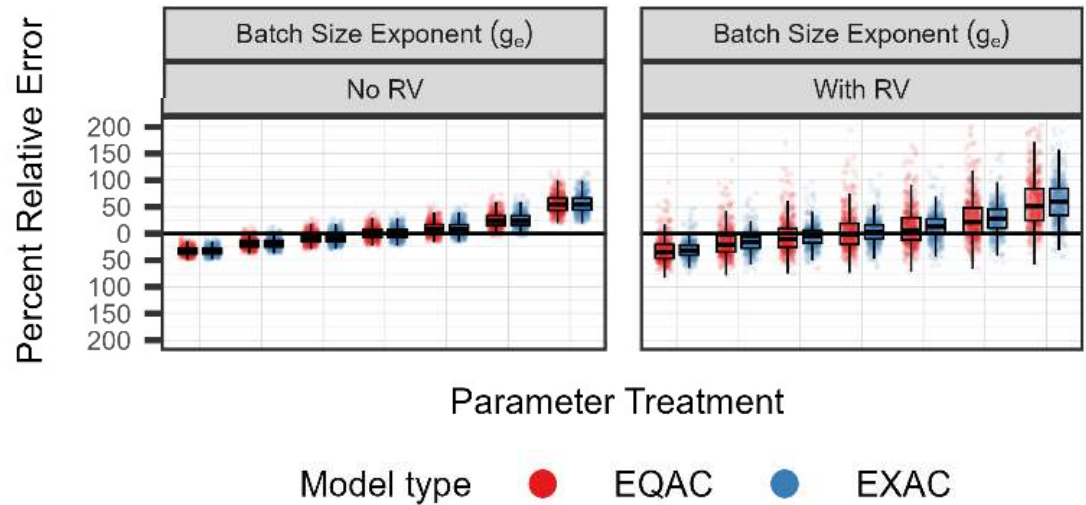
⁴Marine Genomics Laboratory, Department of Life Sciences, Texas A&M University–Corpus Christi, 6300 Ocean Drive, Corpus Christi, TX 78412, USA

⁵National Oceanic and Atmospheric Administration, Southeast Fisheries Science Center, Beaufort Laboratory, Beaufort, NC, 28516

[†]deceased

* correspondence: LKehoe@ufl.edu

Key Words: CKMR; Fisheries; Genomics; Life History; Mark-Recapture; Recruitment Variation; Age Composition



Kehoe et al. (2025c) Appendix XI, Figure 5

CKMR Population Estimation

Sample Size Estimation

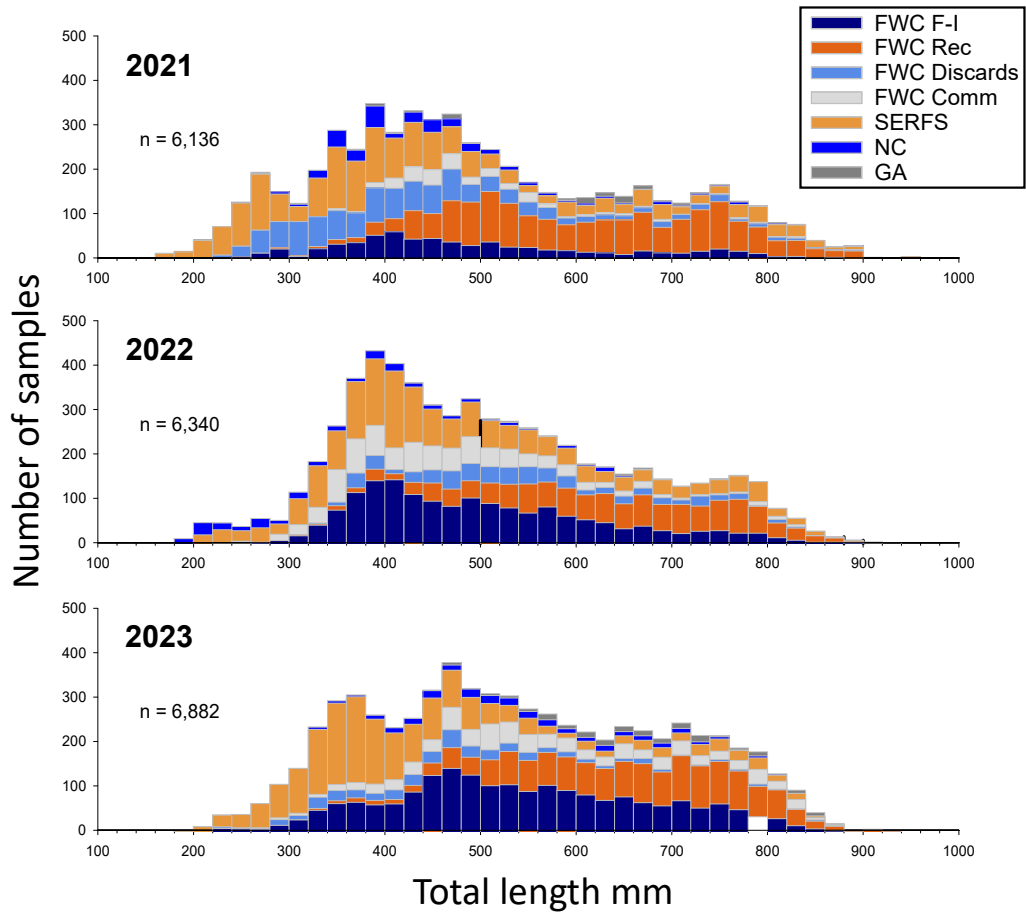
- Forward simulation is run in *CKMRpop*
 - Run 20x for each of three population sizes
 5×10^5 , 1×10^6 , and 1.5×10^6
 - Parametrized using life history data from SEDAR (2017)
- N_{adult} estimated using pseudolikelihood
 - Sample size 2,500 and 5,000 per year for two years
 - Only cross-cohort half siblings
- For each pair

$$PHS(b_1, b_2, N, \Theta)$$
- Likelihood of observing number of pairs for given N_{adult}

$$LLNHS = -\sum_{HS\ pairs} \log PHS(b_1, b_2, N, \Theta)$$
- Posterior distribution used to estimate N_{adult} and corresponding CV

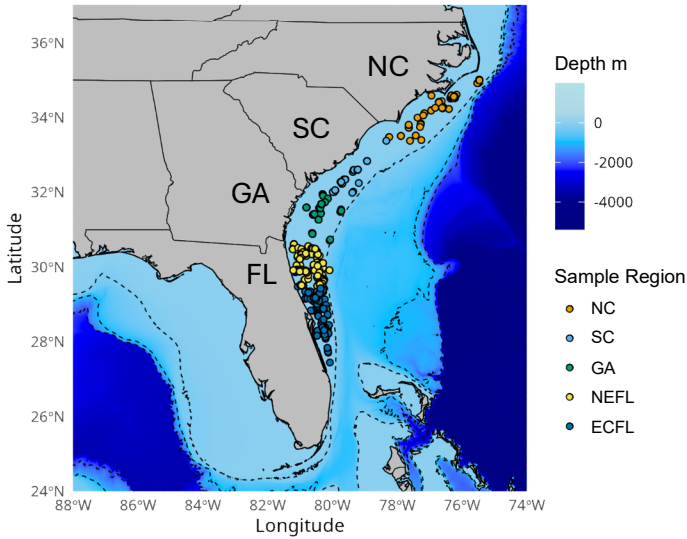
Census	S	\hat{N}_{adult}	CV
500,000	2,500	496,054	16.0%
	5,000	500,428	7.7%
1,000,000	2,500	998,591	23.2%
	5,000	1,023,518	11.1%
1,500,000	2,500	1,568,213	30.0%
	5,000	1,566,668	13.8%

CKMR Population Estimation

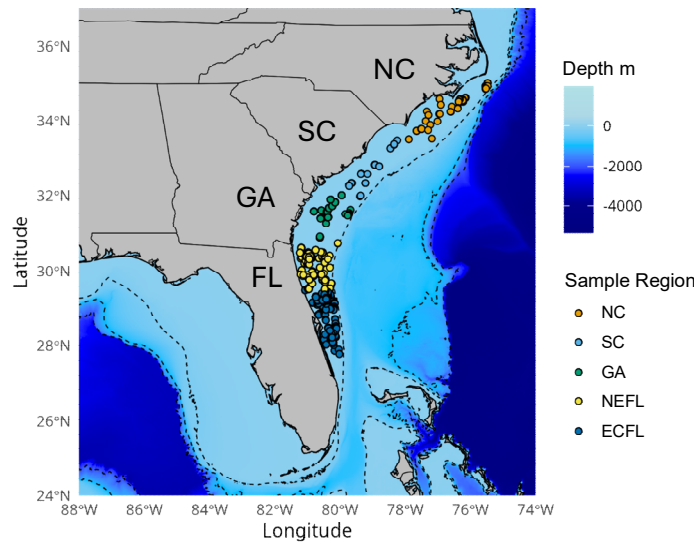


CKMR Population Estimation

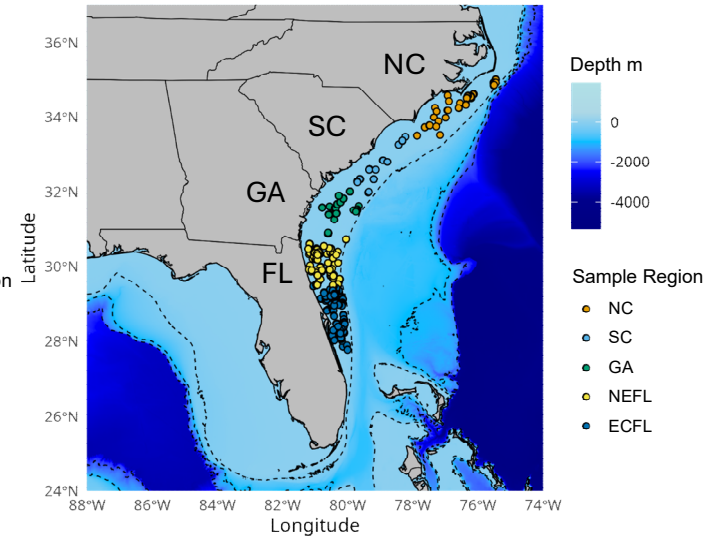
2021



2022



2023

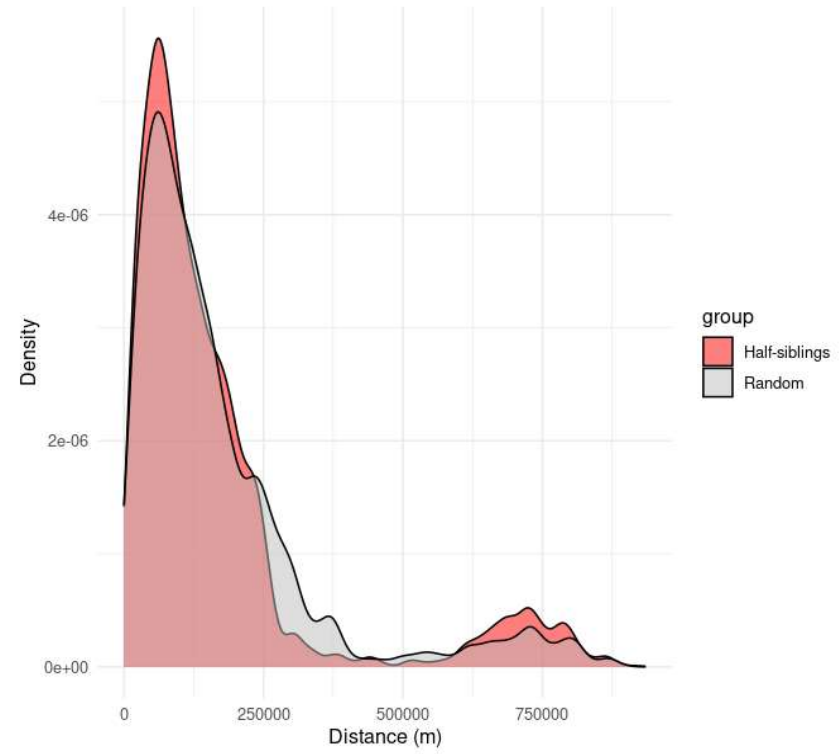
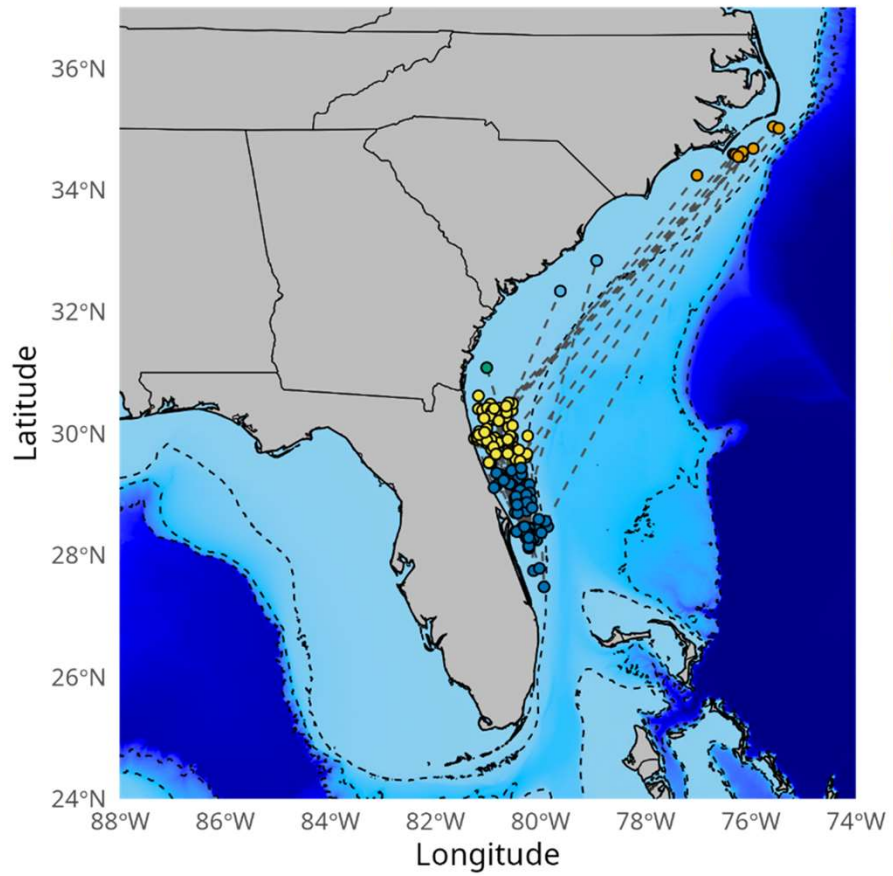


Source	NC	SC	GA	FL
Rec land	165	0	37	1244
Rec disc	0	0	0	841
Comm	43	0	0	134
Fish-ind	0	0	0	522
SERFS	203	93	255	801

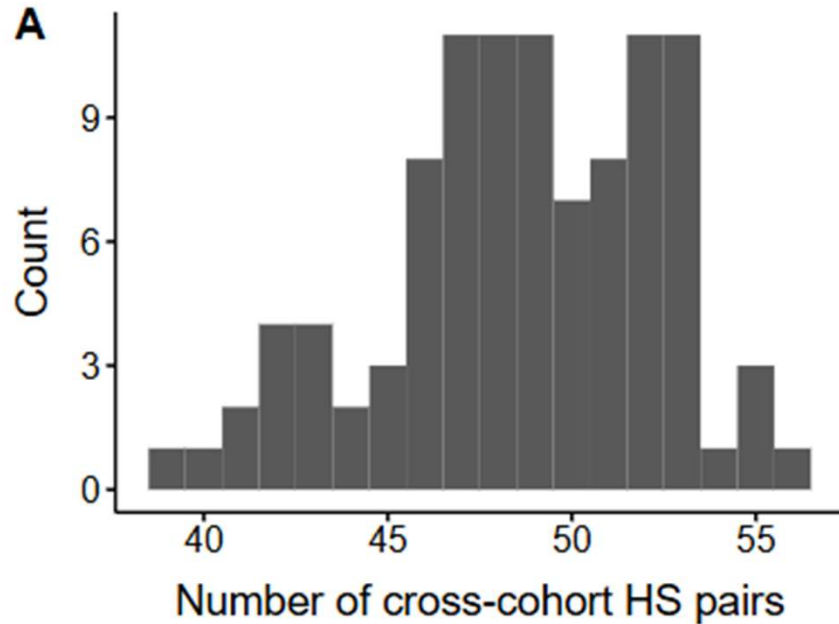
Source	NC	SC	GA	FL
Rec land	54	0	10	876
Rec disc	0	0	0	743
Comm	9	0	6	500
Fish-ind	0	0	0	1041
SERFS	115	83	272	648

Source	NC	SC	GA	FL
Rec land	151	0	112	1201
Rec disc	0	0	0	353
Comm	33	0	0	567
Fish-ind	0	0	0	1439
SERFS	67	132	180	1137

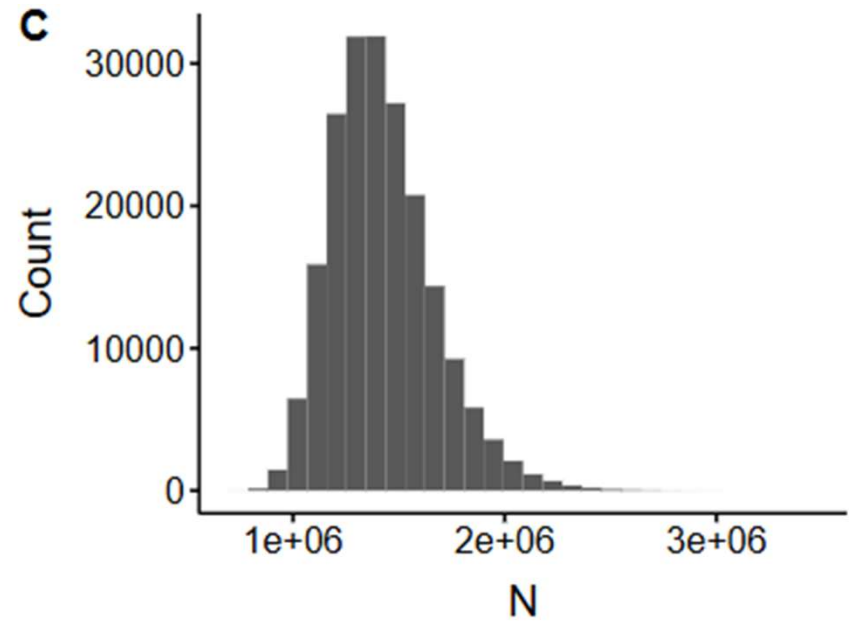
Spatial Distribution of Kin



CKMR Population Estimation: Base Model Results



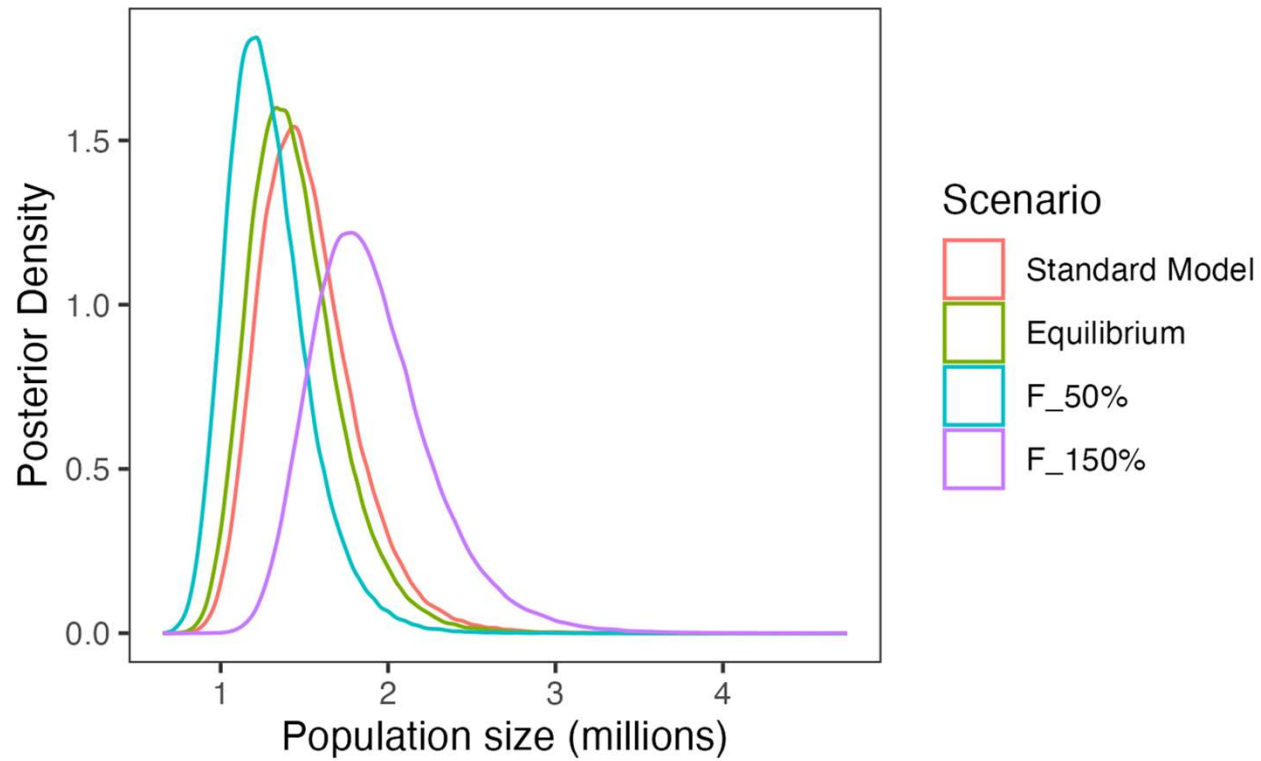
100 age realizations
39 - 56 cross-cohort pairs



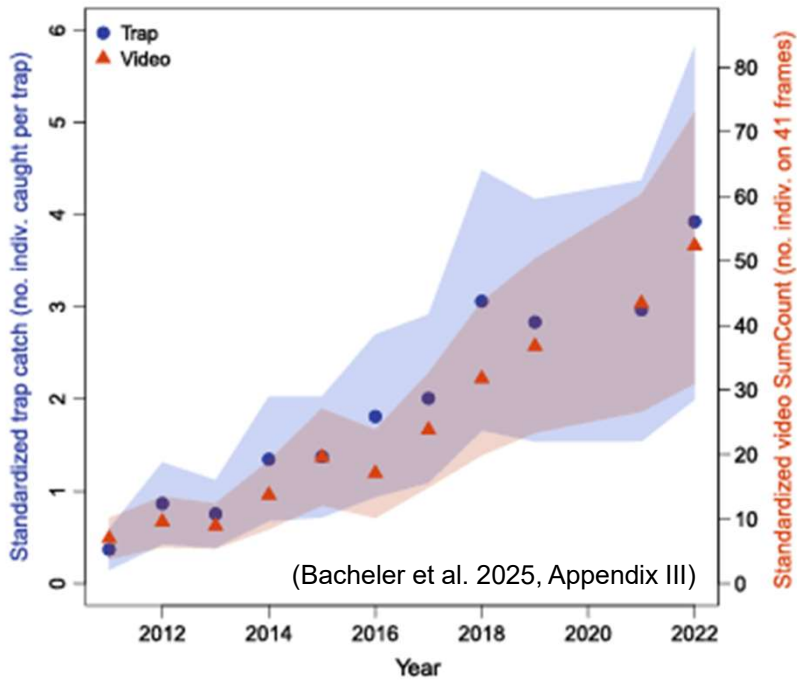
Point estimates 1.18 -1.69 M
Merged estimate 1.42 M
CV 17%, 90% CI 1.08 -1.87

Impacts of Relative Age Composition and F from SEDAR (2024)

- Base estimate: 1.52 M
90% CI 1.12 – 2.06
- Equilibrium estimate: 1.45 M
90% CI 1.07 – 1.95
- $F_{50\%}$ estimate: 1.29 M
90% CI 0.95 – 1.73
- $F_{150\%}$ estimate: 1.91 M
90% CI 1.41 – 2.57

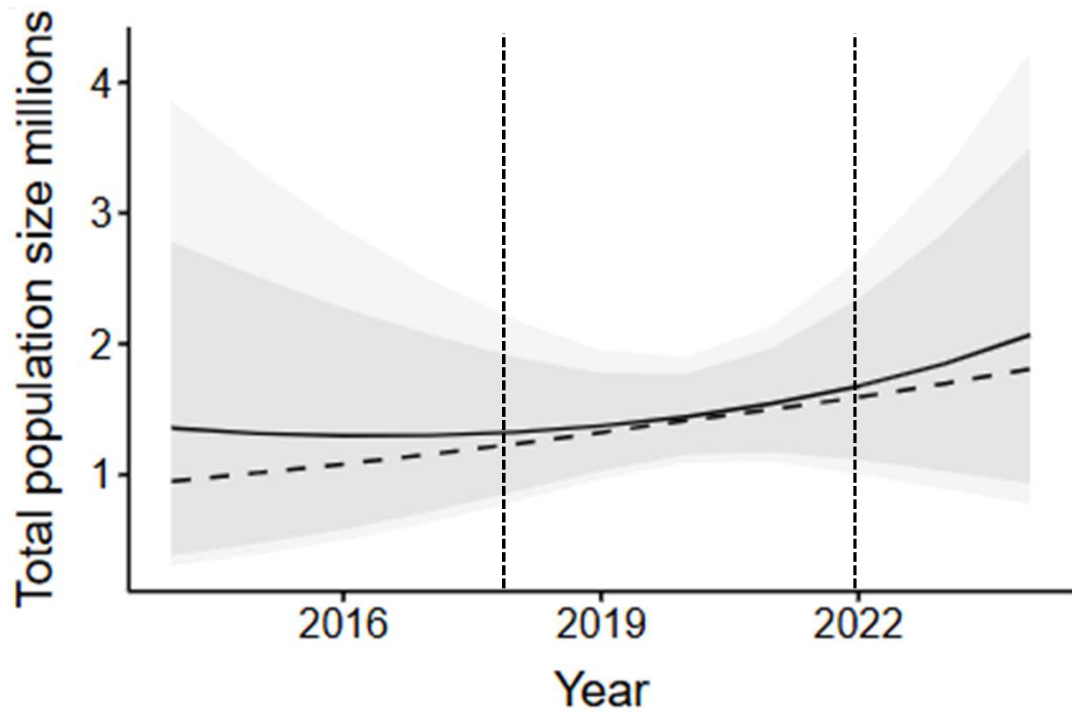


CKMR Population Estimation: Equilibrium Population Size Assumption



Assumption of equilibrium population size likely violated

Population Growth/Decline



Mean from 2018 to 2022 1.47M

CKMR Population Estimation: CIE Review

Positives:

-CKMR methodology and study design robust and the sampling effort sufficient for an initial estimate of population abundance, although the uncertainty likely to have been underestimated

Concerns:

-CKMR estimate not independent of the RS stock assessment

-estimated CV on the population estimate may be too low

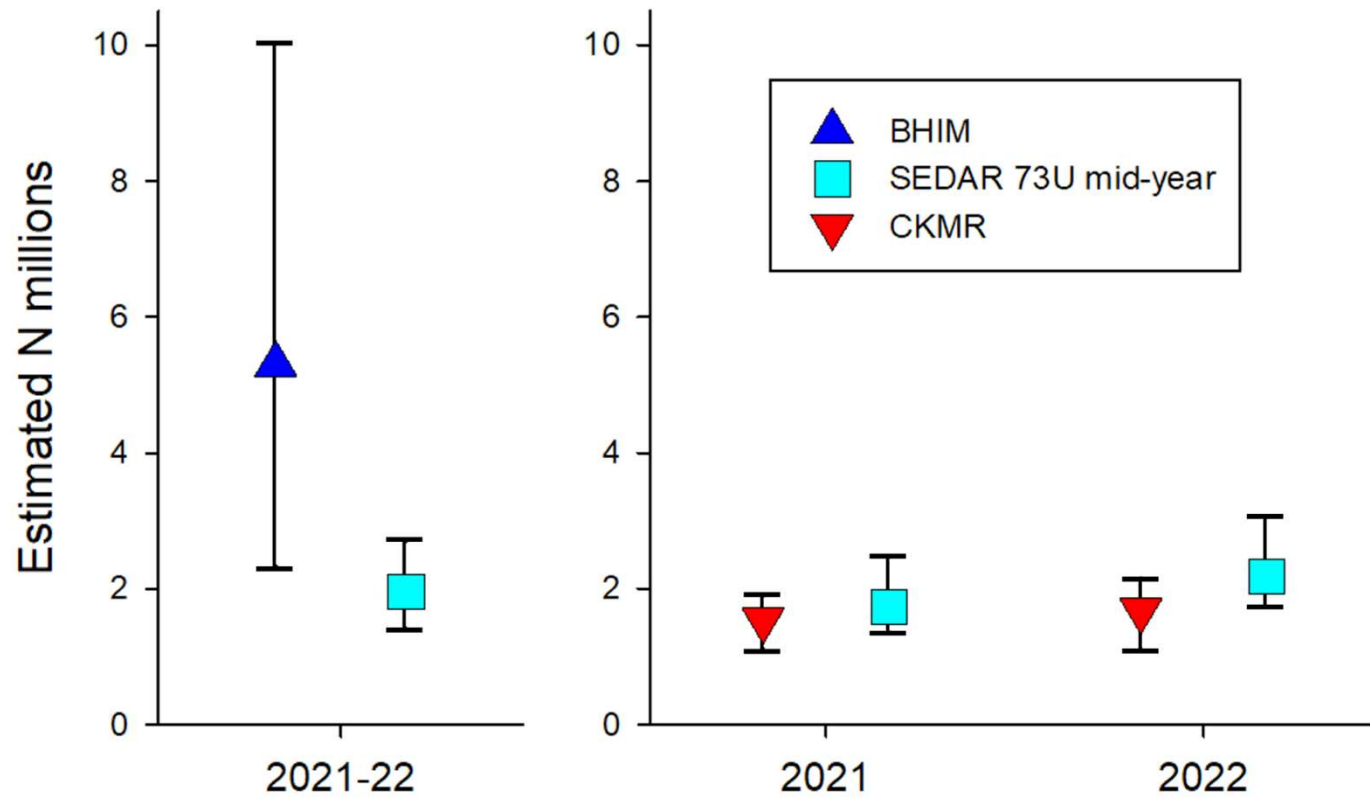
-assumption of equal sex-specific fecundity-at-age or fecundity-at-size not tested

-simplify sensitivity (simulation) analyses by focusing only on red snapper CKMR model

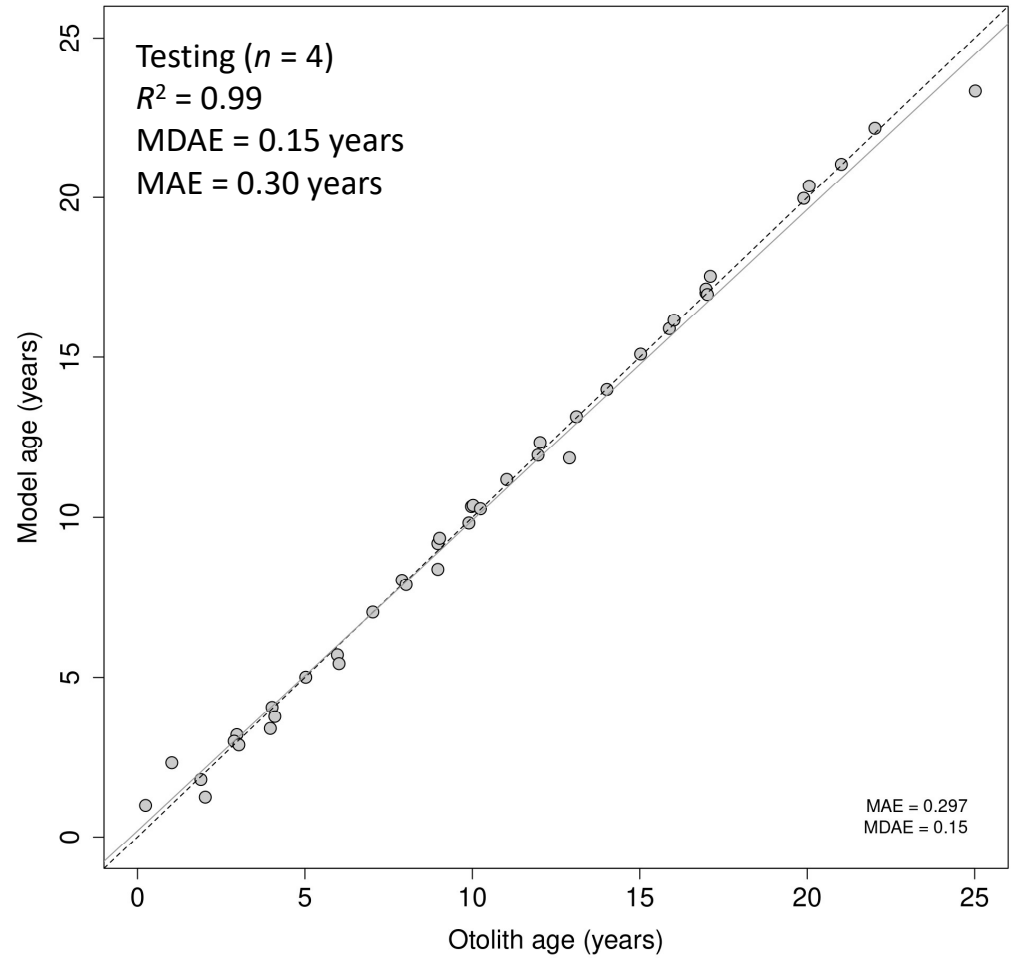
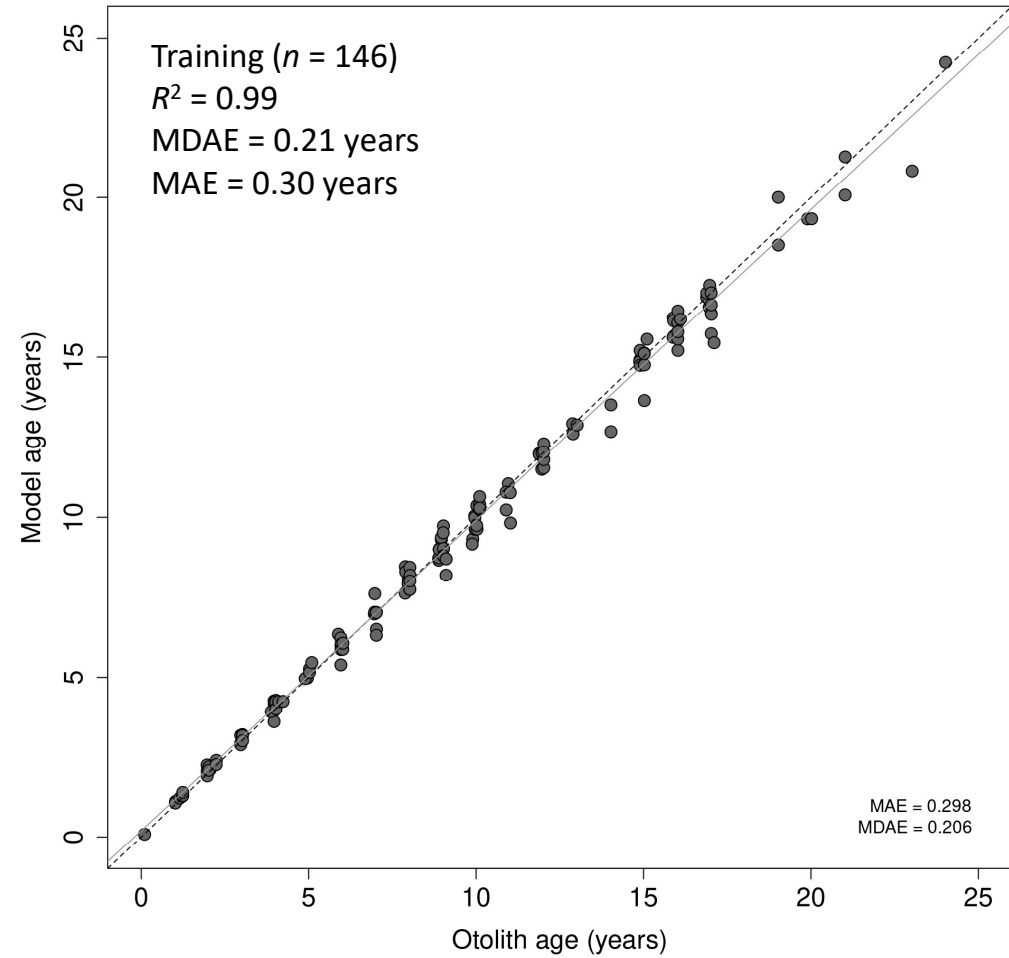
-apply epigenetic clock for age estimation

-provide chromosome-level genome sequence to assess the degree of linkage among ~1755 haplotypic loci

Summary Population Size Estimation



Future Work: Epigenetic Clock Implementation



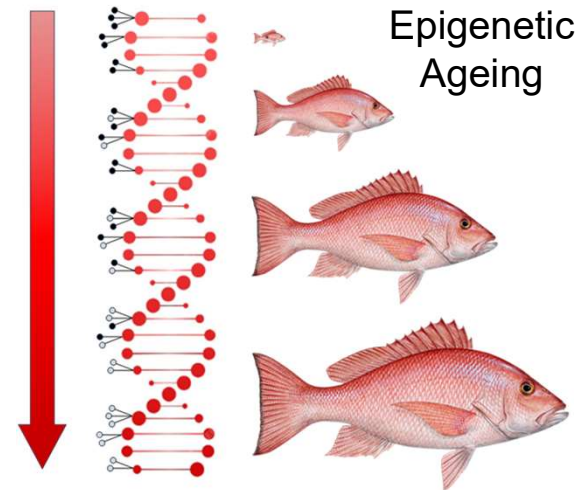
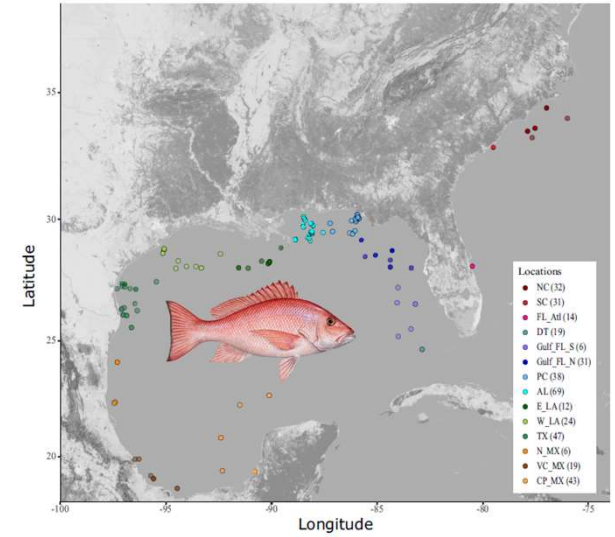
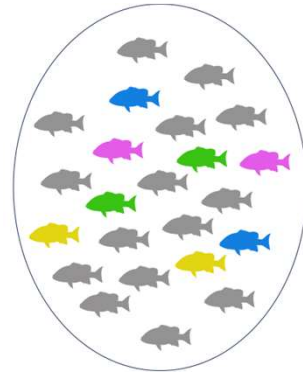
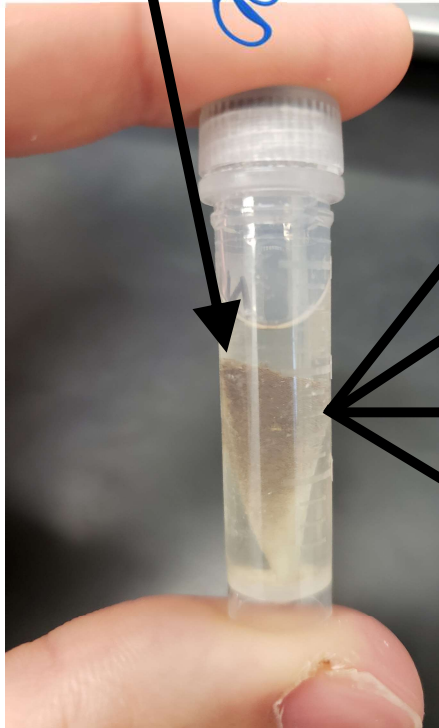
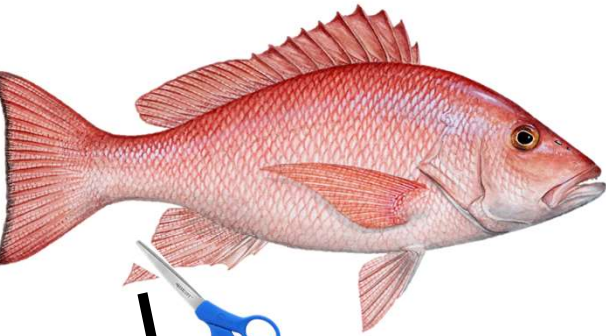
Genomic Fisheries Analyses

Genetic Population Structure

Close-Kin
Mark-Recapture

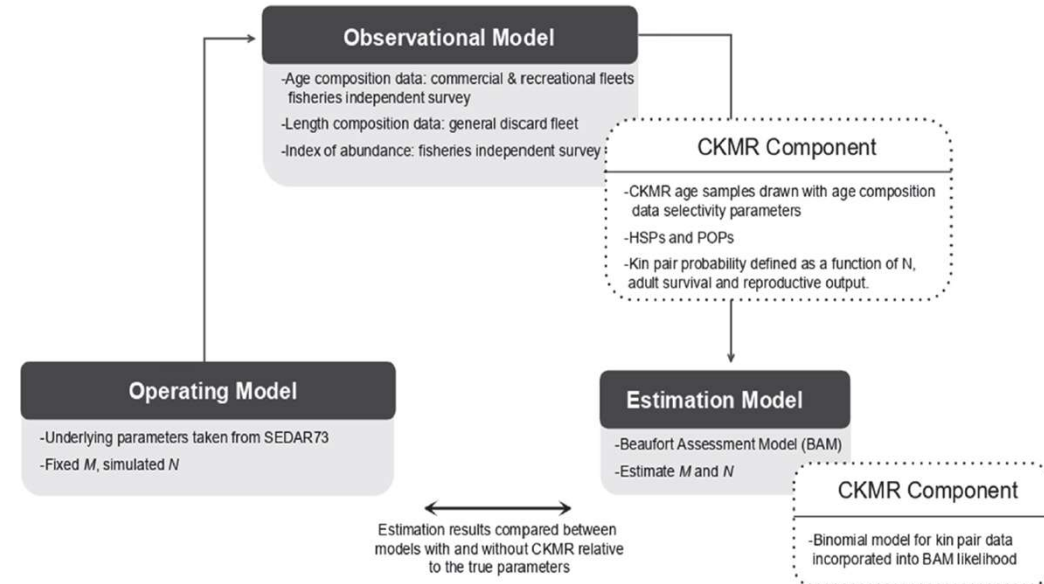
Genetic
Sex ID

Epigenetic
Ageing



Integrating Red Snapper Pop Estimates into Assessment and Management

- 1) Evaluate two assessment approaches:
 - A. Scale the current assessment model to the externally derived abundance estimates
 - B. Integrate new data and pop estimation into the assessment model
- 2) Matt Damiano, Matt Vincent, and Paul McLaughlin have worked on integration of CKMR into BAM assessment model
- 3) Plan has been to integrate into ongoing SEDAR 90 Atlantic red snapper stock assessment in 2026/27



McLaughlin et al. (2025); Appendix VI



Kyle Shertzer

Matt Damiano

Matt Vincent

Paul McLaughlin

Acknowledgements

South Carolina Sea Grant
Technical Review Committee
SARSRP Steering Committee
Susan Lovelace
Emily Osborne
Jocelyn Juliano
Crystal Narayana
Matt Gorstein
Ryan Bradley
Susannah Sheldon
Graham Gaines
Sherry Larkin
Sarah Mathias
Tracey Smart
Jessica Carroll
Chris Bradshaw
Agency Scientists

Fishery Observers
Selia Zimmermann
Paul Conn
Port Agents
Zach Siders
Jordan Bajema
Derek Chamberlin
Shay Husband
Adam Searlus
Megan Siemann
Kaitlyn Tucker
Olavi Poyhonen
Jeffrey Merrell
Tom Baer
Derek Brown
Chris Daniels
Drew Demaree

Wade Fickling
Chris Gaffney
Robbie Hall
Keith Green
Paul Johnson
Robert Johnson
Hans Kraaz
Josh Livingston
Tim Mullray
Joey Rivenbark
Greg Sosnow
Jayme Stephenson
Robert Taylor
Robert Williams
Dylan Barley
Jordan Doucette
Destyn Dreading

Michael Korn
Dalton Hegedus
Brad Mismas
Trey Sadler
Dalton Shank
Dylan Scott
John Smith
Greg Sosnow
Brighton Templeton
Gunner Tootle
Dalton Vuncannon
Tripp Weathersbee
Fishermen Interviewees
UF, TAMU, NCSU, SCDNR
and FWC accounts personnel

