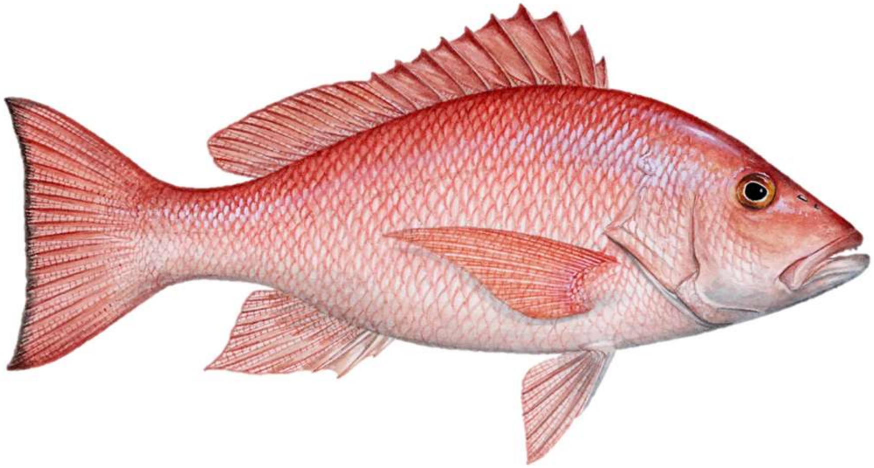
Estimation of US Atlantic Red Snapper Abundance



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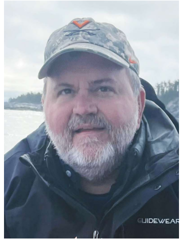
SOUTH CAROLINA DEPARTMENT OF NATURAL RESOURCES

Study Team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Alison Monroe


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Nick Weber


Andrew Fields


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Paul Ruderhausen


Nathan Hostetter


Krishna Pacifici


Viviane Zulian


Erin Schliep


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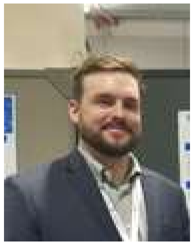
Chris Custer


Ben Goldstein


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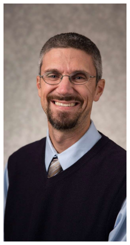
Kyle Shertzer


Nate Bacheler


Eric Anderson


Matt Vincent


Paul McLaughlin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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

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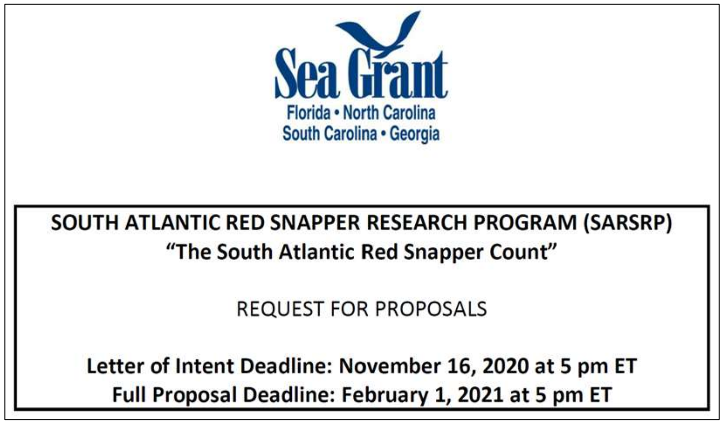
South Atlantic Red Snapper Research Program (SARSRP)



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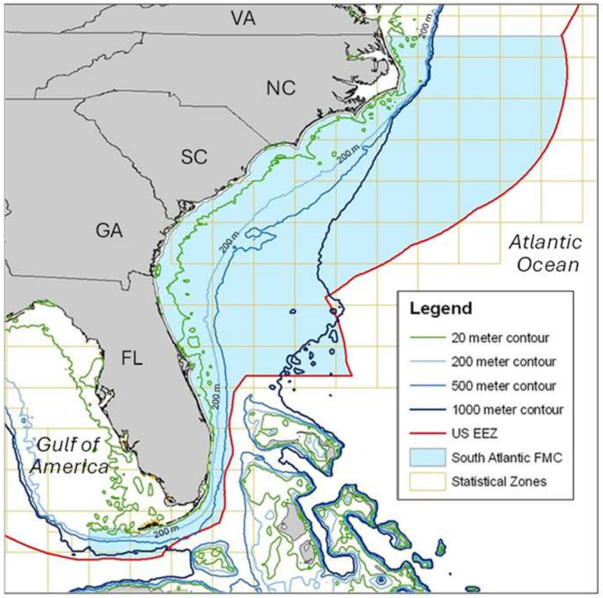
SOUTH ATLANTIC RED SNAPPER RESEARCH PROGRAM (SARSRP)
"The South Atlantic Red Snapper Count"

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."

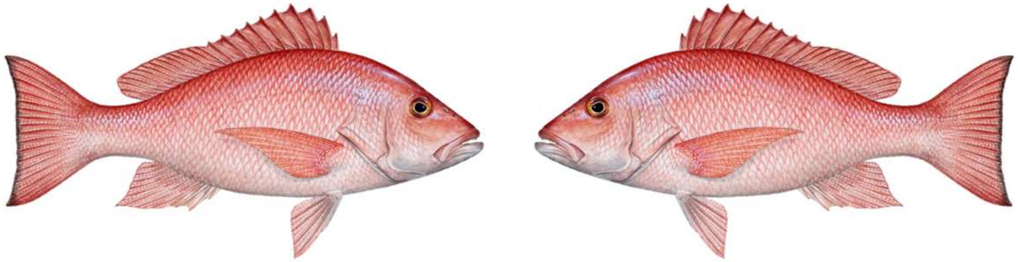
SARSRP Study Objectives

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

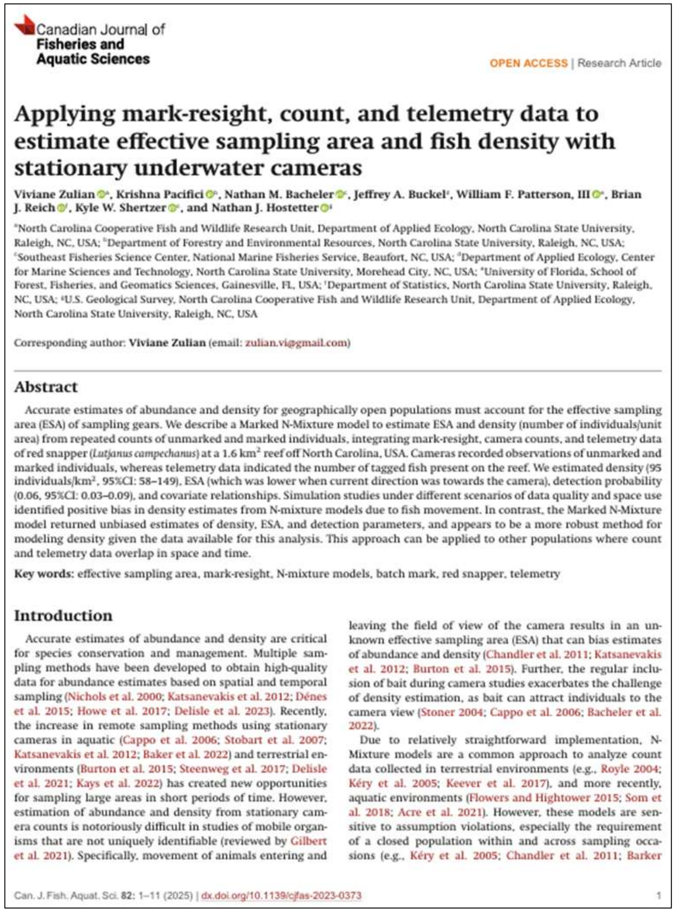
3) Conduct genetic close-kin mark recapture (CKMR) analysis to estimate age-2+ red snapper population size

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 Zulian[a], **Krishna Pacifici**[b], **Nathan M. Bacheler**[c], **Jeffrey A. Buckel**[d], **William F. Patterson, III**[e], **Brian J. Reich**[f], **Kyle W. Shertzer**[c], and **Nathan J. Hostetter**[g]

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Corresponding author: **Viviane Zulian** (email: zulian.vi@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 km^2 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/km^2, 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

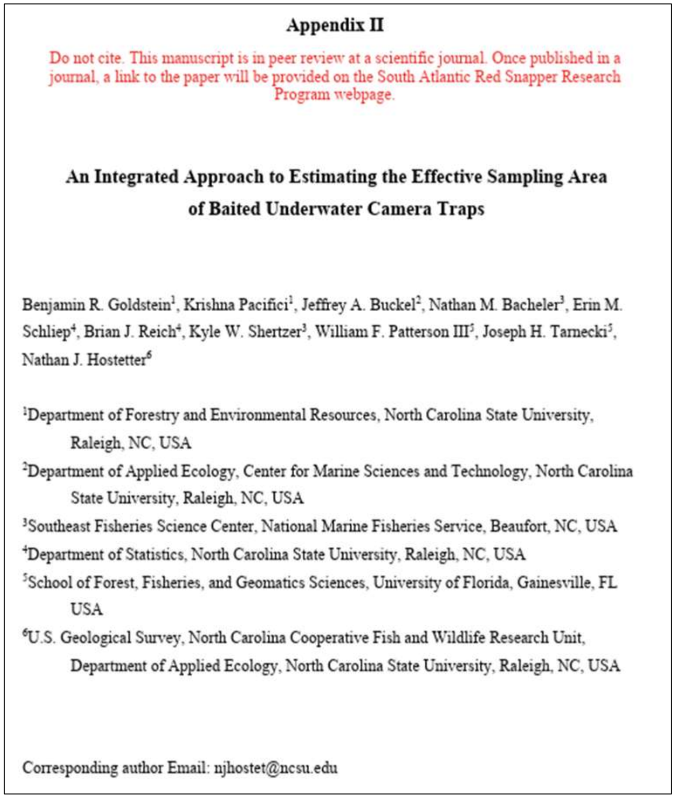
Introduction

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; Dénes 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; Bacheler 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

Can. J. Fish. Aquat. Sci. **82**: 1–11 (2025) | dx.doi.org/10.1139/cjfas-2023-0373

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. Goldstein[1], Krishna Pacifici[1], Jeffrey A. Buckel[2], Nathan M. Bacheler[3], Erin M. Schliep[4], Brian J. Reich[4], Kyle W. Shertzer[3], William F. Patterson III[5], Joseph H. Tarnecki[5], Nathan J. Hostetter[6]

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Appendix III

Contents lists available at ScienceDirect

Fisheries Research

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

ELSEVIER

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

Nathan M. Bacheler[a,*], William F. Patterson III[b], Joseph H. Tarnecki[b], Kyle W. Shertzer[a], Jeffrey A. Buckel[c], Nathan J. Hostetter[d], Krishna Pacifici[e], Viviane Zulian[f], Walter J. Bubley[g]

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ARTICLE INFO

Handled by Alejandra Vanina Volpedo

Keywords:
Reef 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 (2021–2023), 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 (Manooch and Potts, 1997; Hoese 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 (Gallaway et al., 1999; Mitchell et al., 2014; Bacheler et al., 2016). Benthic juveniles are mainly found over substrates consisting of shell hash and sand (Gallaway 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; Powles and Barans, 1980; Williams-Grove and Szedlmayer, 2016; Dance and Rooker, 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 (Manooch III et al., 1998). Recreational landings temporally lagged behind the commercial harvest, peaking at 280,800 kg in 1985, but also

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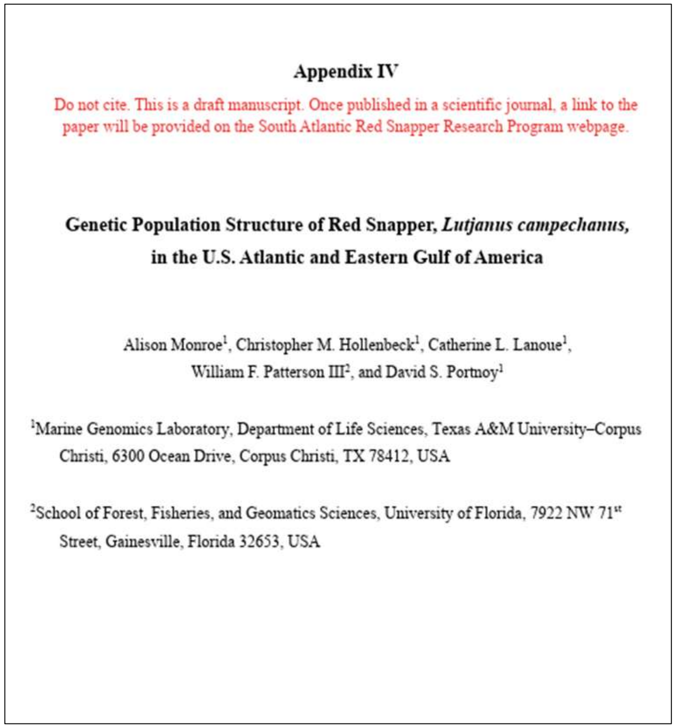
Received 20 February 2024; Received in revised form 10 September 2024; Accepted 3 October 2024

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 Monroe[1], Christopher M. Hollenbeck[1], Catherine L. Lanoue[1],
William F. Patterson III[2], and David S. Portnoy[1]

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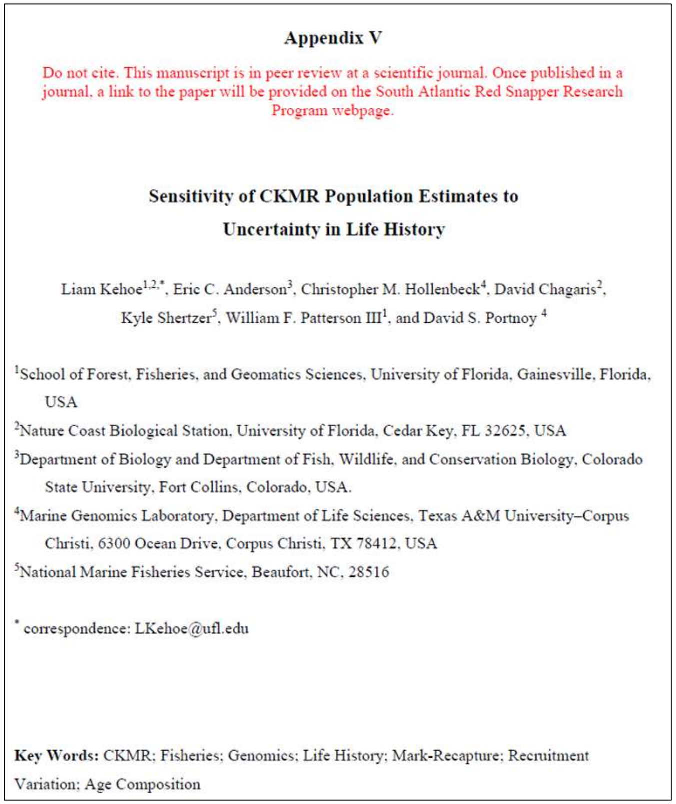
[2]School of Forest, Fisheries, and Geomatics Sciences, University of Florida, 7922 NW 71st Street, Gainesville, Florida 32653, USA

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. Anderson[3], Christopher M. Hollenbeck[4], David Chagaris[2],
Kyle Shertzer[5], William F. Patterson III[1], and David S. Portnoy [4]

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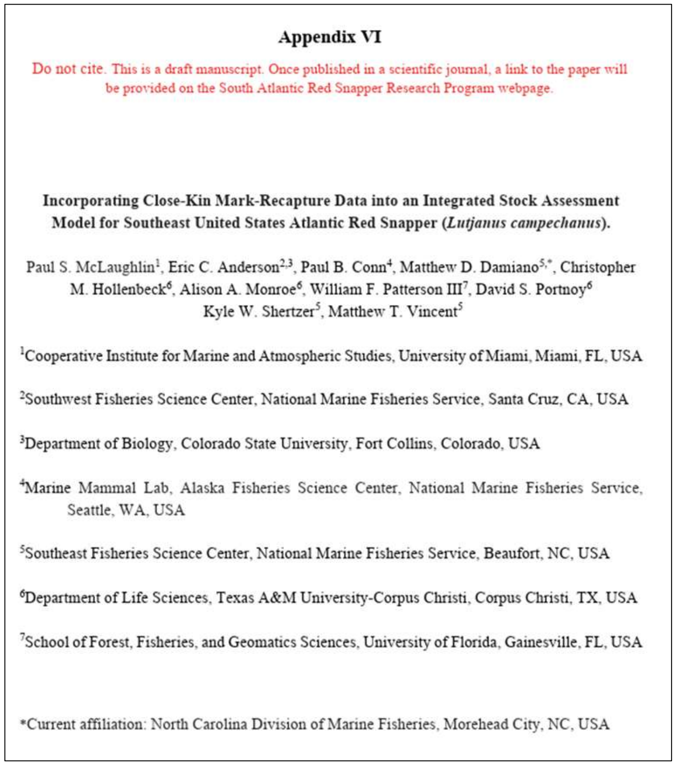
Key Words: CKMR; Fisheries; Genomics; Life History; Mark-Recapture; Recruitment Variation; Age Composition

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. McLaughlin[1], Eric C. Anderson[2,3], Paul B. Conn[4], Matthew D. Damiano[5,*], Christopher M. Hollenbeck[6], Alison A. Monroe[6], William F. Patterson III[7], David S. Portnoy[6]
Kyle W. Shertzer[5], Matthew T. Vincent[5]

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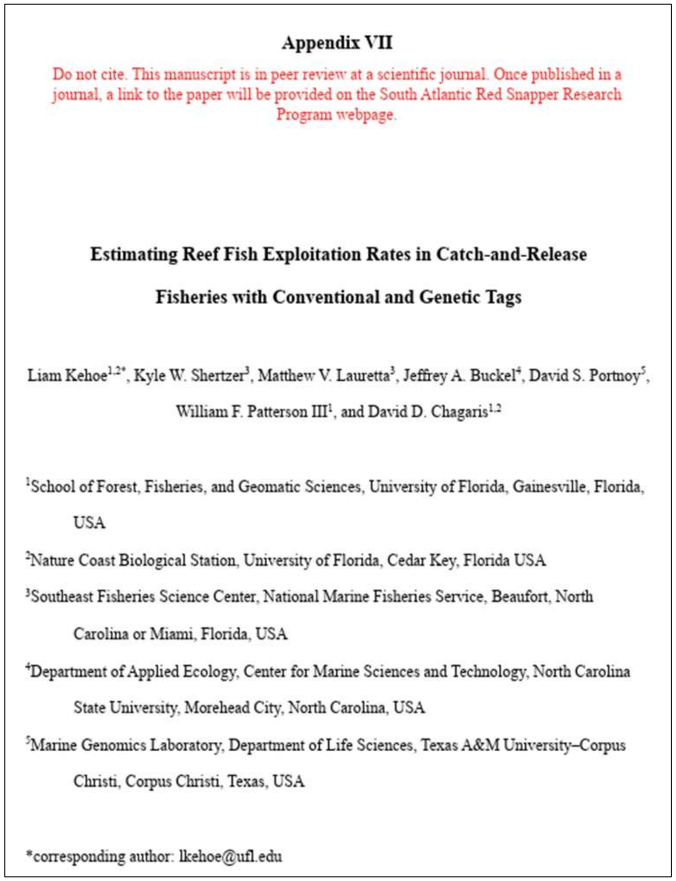
*Current affiliation: North Carolina Division of Marine Fisheries, Morehead City, NC, USA

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. Shertzer[3], Matthew V. Lauretta[3], Jeffrey A. Buckel[4], David S. Portnoy[5], William F. Patterson III[1], and David D. Chagaris[1,2]

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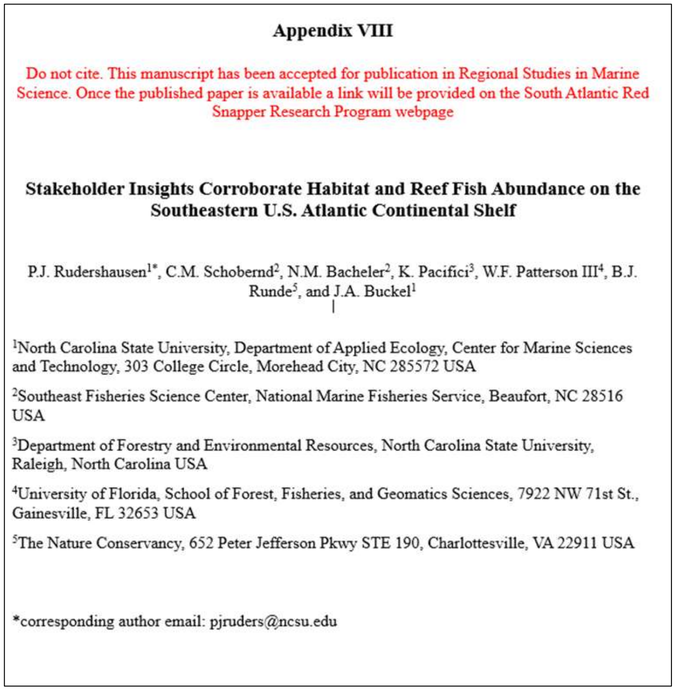
Appendix VIII



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. Schobernd[2], N.M. Bacheler[2], K. Pacifici[3], W.F. Patterson III[4], B.J. Runde[5], and J.A. Buckel[1]

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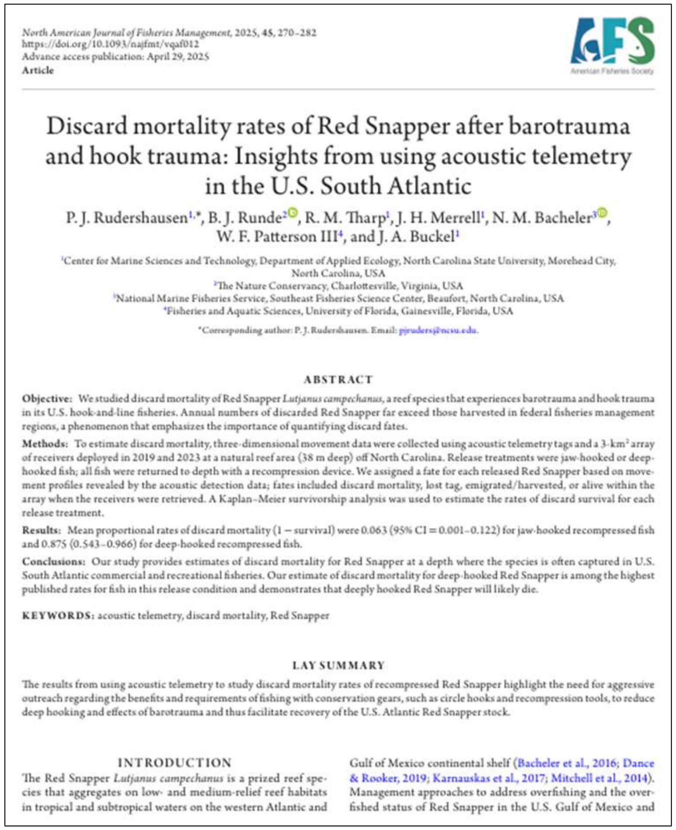
Appendix IX



North American Journal of Fisheries Management, 2025, 45, 270–282
https://doi.org/10.1093/najfmt/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. Runde[2], R. M. Tharp[1], J. H. Merrell[1], N. M. Bacheler[3], W. F. Patterson III[4], and J. A. Buckel[1]

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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-km^2 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 (Bacheler et al., 2016; Dance & Rooker, 2019; Karnauskas 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

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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 km^2 study site off Ponce Inlet, 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 descended fish, $D = 46.9\%$ for surface-released fish, and $D = 38.1\%$ 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 (Runde et al., 2019, 2021, Shertzer et al., 2024, Rudershausen 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

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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

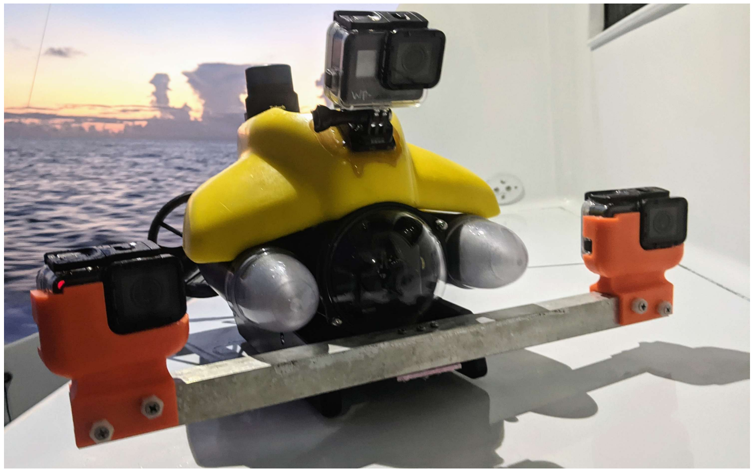
Liam Kehoe,[1,2,*] Eric C. Anderson,[3] Christopher M. Hollenbeck,[4] David Chagaris,[2] Kyle Shertzer[5†], William F. Patterson III[1], and David S. Portnoy [4]

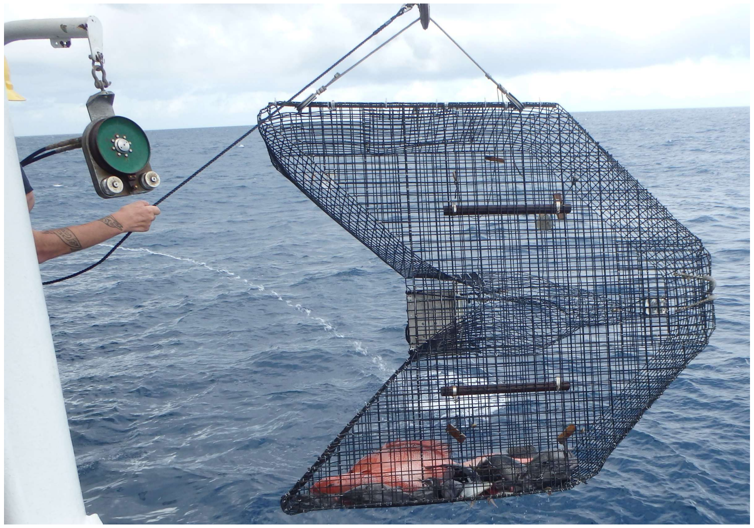
[1]School of Forest, Fisheries, and Geomatics Sciences, University of Florida, Gainesville, Florida, USA
[2]Nature Coast Biological Station, University of Florida, Cedar Key, FL 32625, USA
[3]Department of Biology and Department of Fish, Wildlife, and Conservation Biology, Colorado State University, Fort Collins, Colorado, USA.
[4]Marine Genomics Laboratory, Department of Life Sciences, Texas A&M University–Corpus Christi, 6300 Ocean Drive, Corpus Christi, TX 78412, USA
[5]National 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:

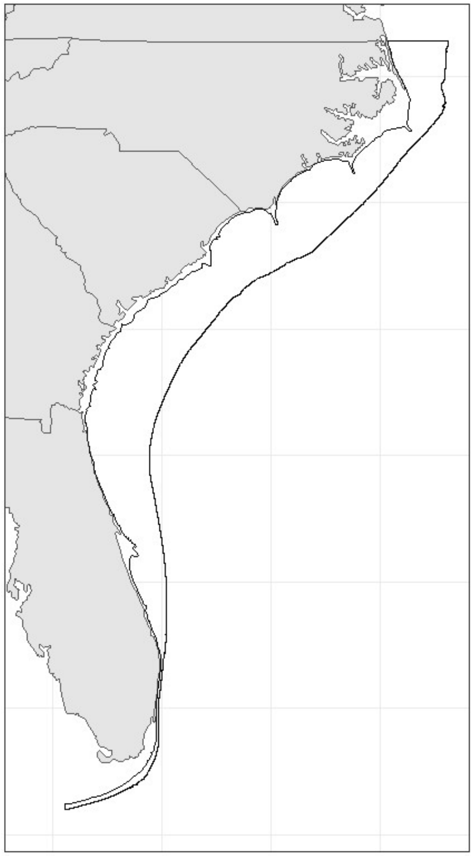
1) Integrate red snapper density estimates from multiple survey methods to jointly estimate red snapper abundance at three spatial scales: i) survey site (~10^3 $m^{2)}$, ii) grid cell (25 km^2), and iii) study area (~100 x 10^3 km^2)

2) Habitat suitability informed by study video data, fishery-dependent data, and informed priors from previous studies and mapping

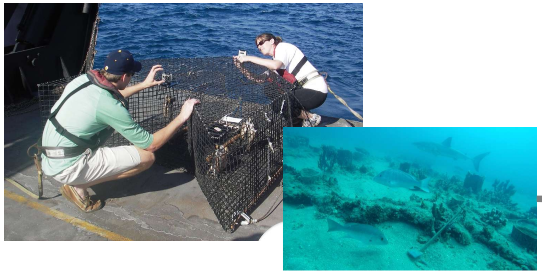
3) Separate observation models to account for different detection probabilities and effective sampling area of ROV, traps, and cameras mounted to traps

Bayesian Hierarchical Integrated Modeling

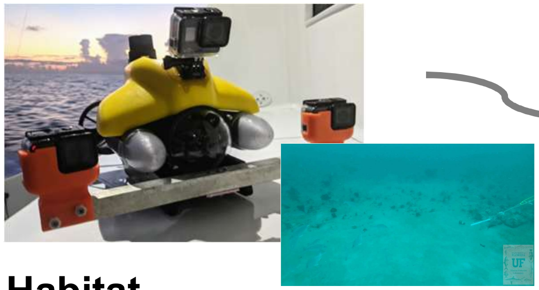
Study area



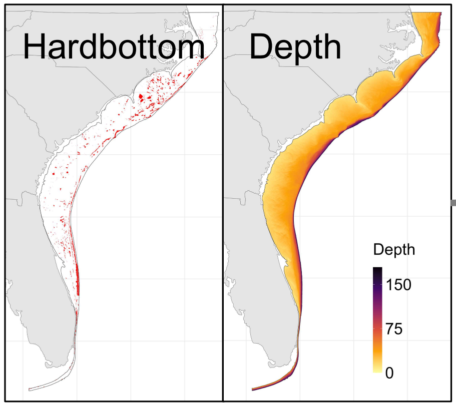
Camera counts



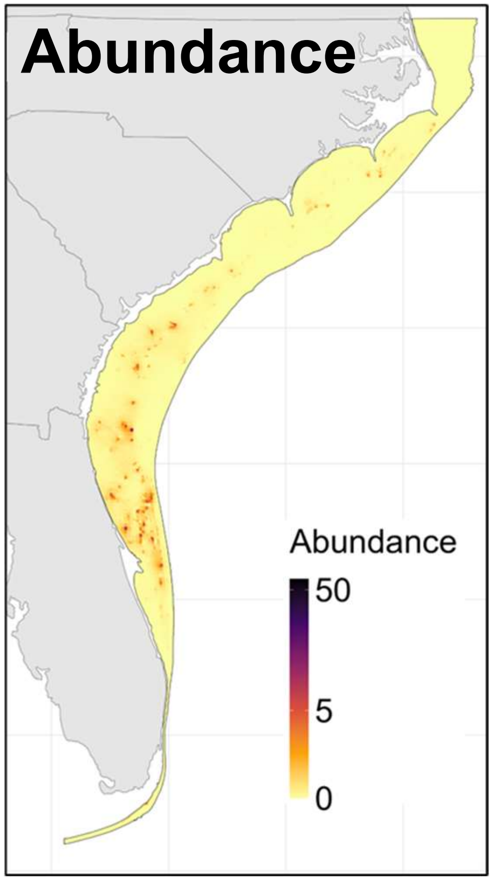
ROV counts



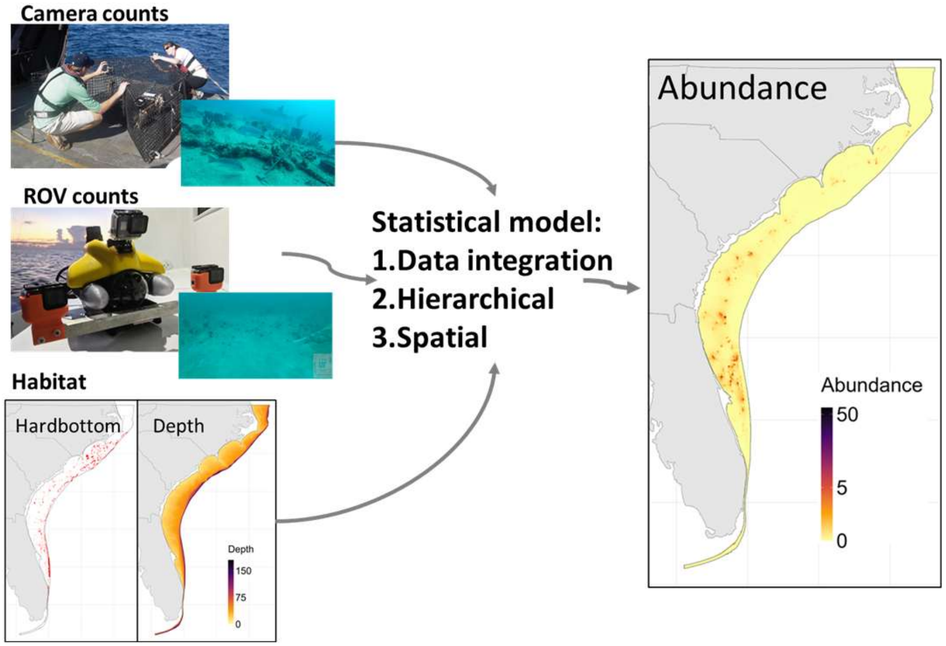
Habitat



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



Bayesian Hierarchical Integrated Modeling



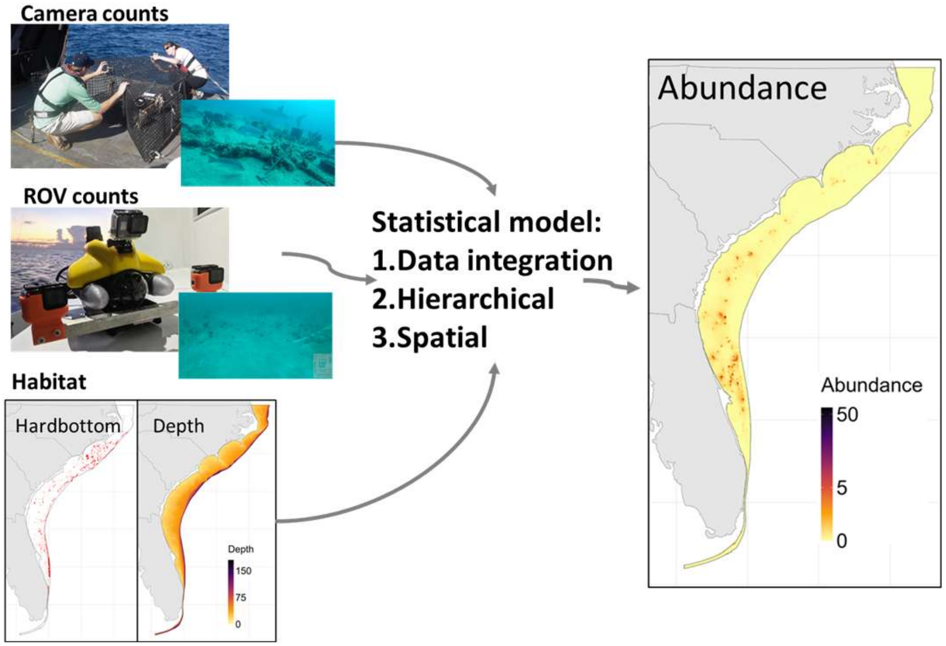
Statistical model:
1.Data integration
2.Hierarchical
3.Spatial

- 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



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

+ Integrate results from separate studies via informative priors

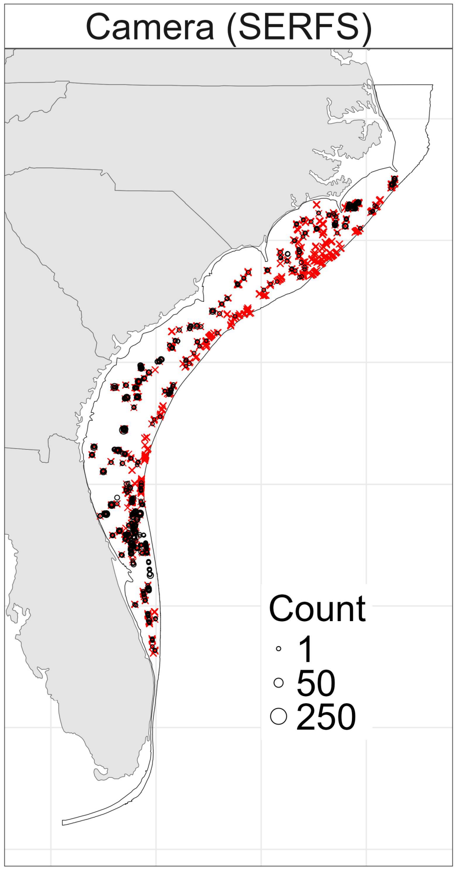
+ Vague priors when information is unavailable

- Markov chain Monte Carlo can be slow

Bayesian Hierarchical Integrated Modeling: Data

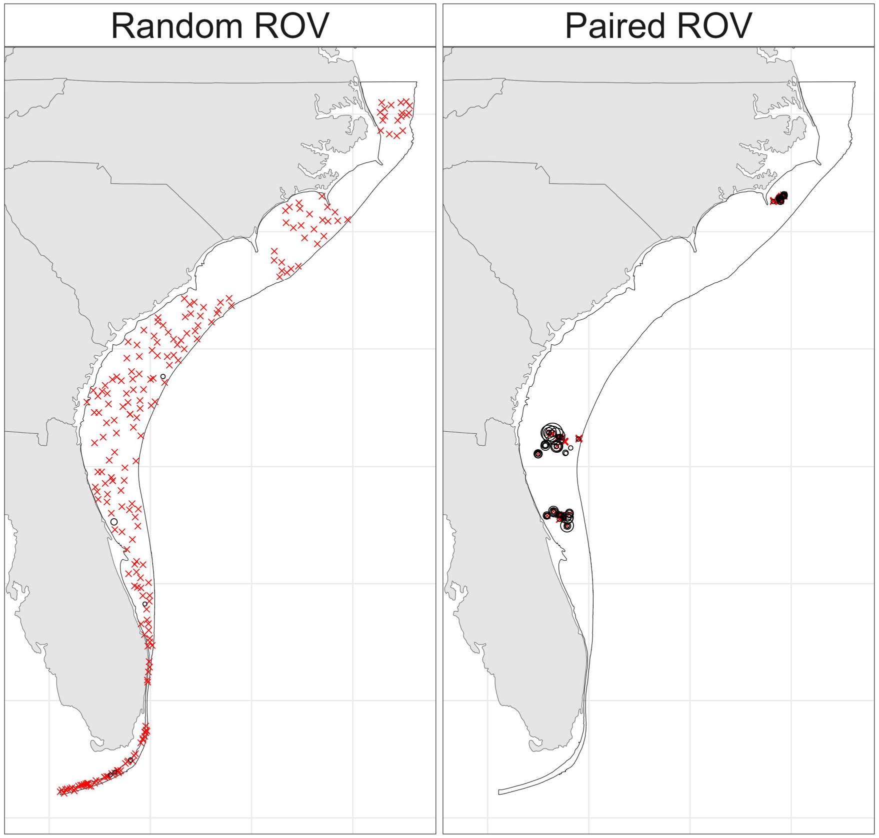
SERFS

- 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

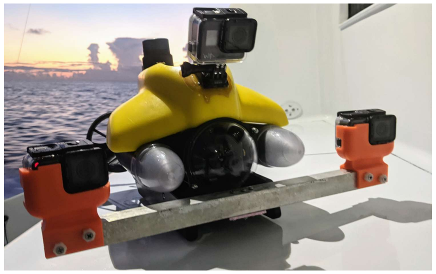
- SRS: n = 231 sites; paired with SERFS: n = 205

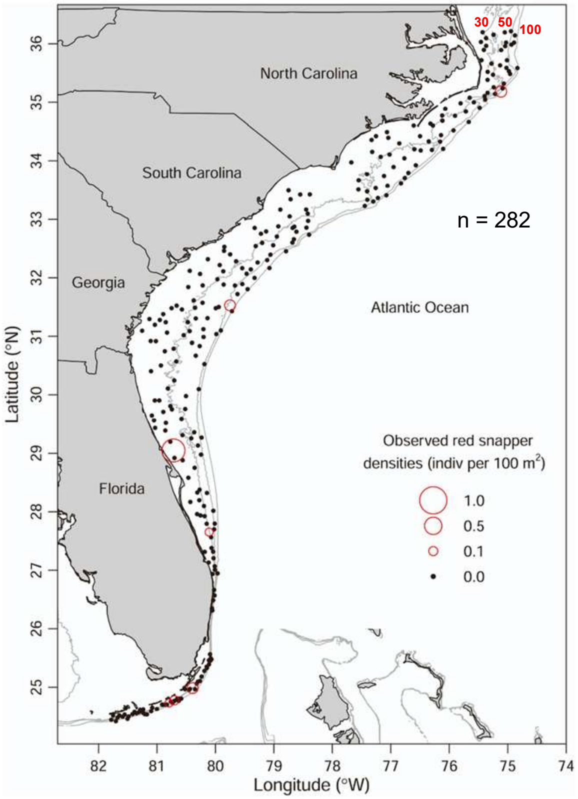


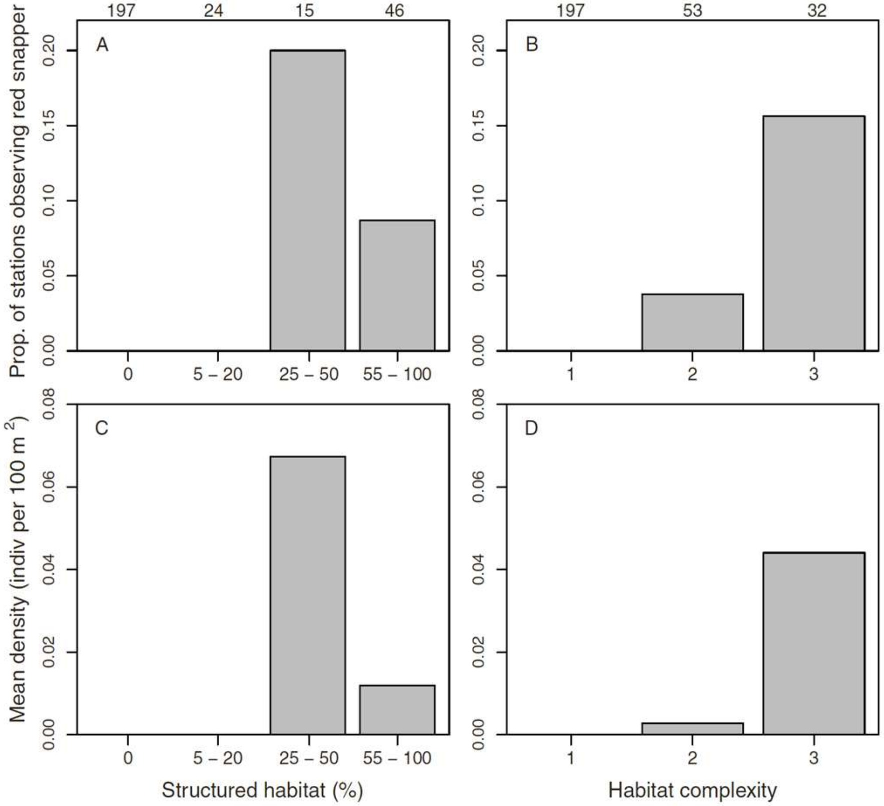
Bayesian Hierarchical Integrated Modeling: ROV Sampling

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

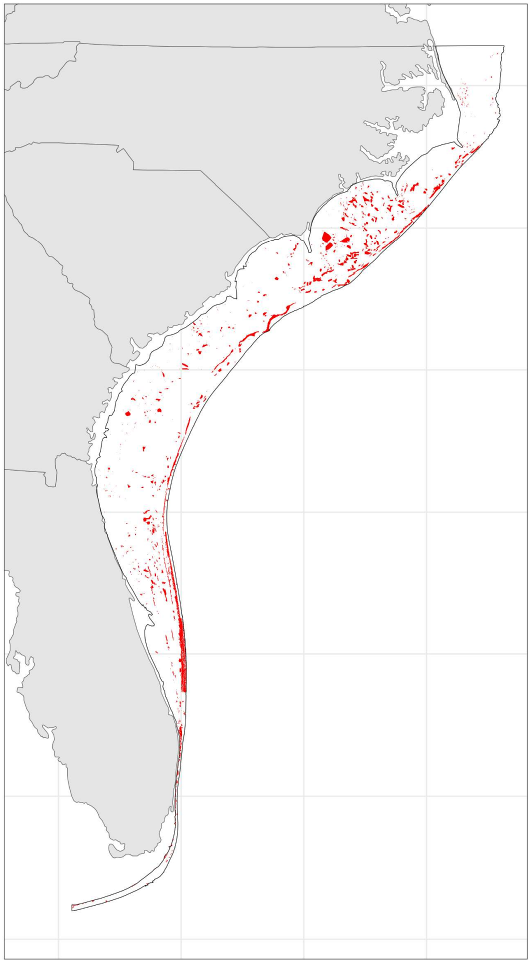
Bayesian Hierarchical Integrated Modeling: Hardbottom Distribution

Working group evaluated:

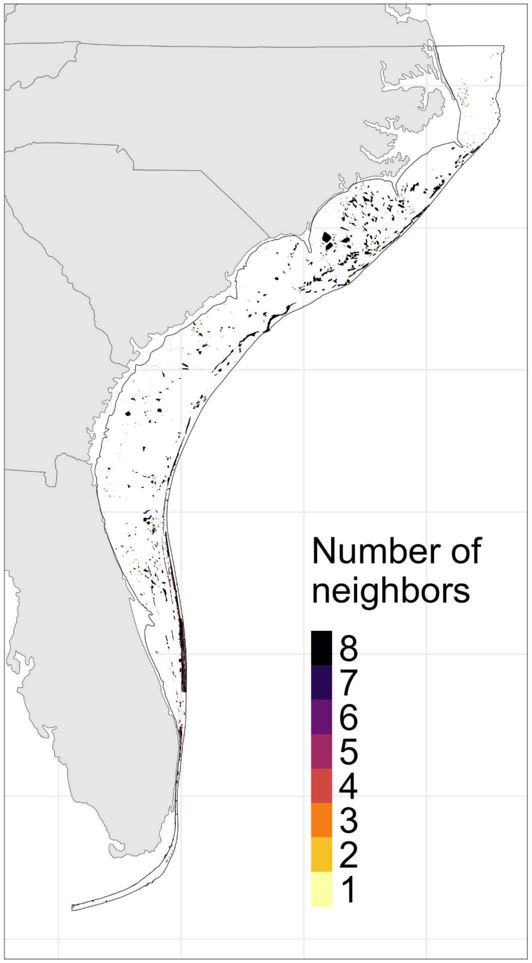
1) Expert Opinion map [EO]
(Steward et al. 2022)

2) TNC SAB map [TNC]
(Conley et al. 2017)

Hardbottom



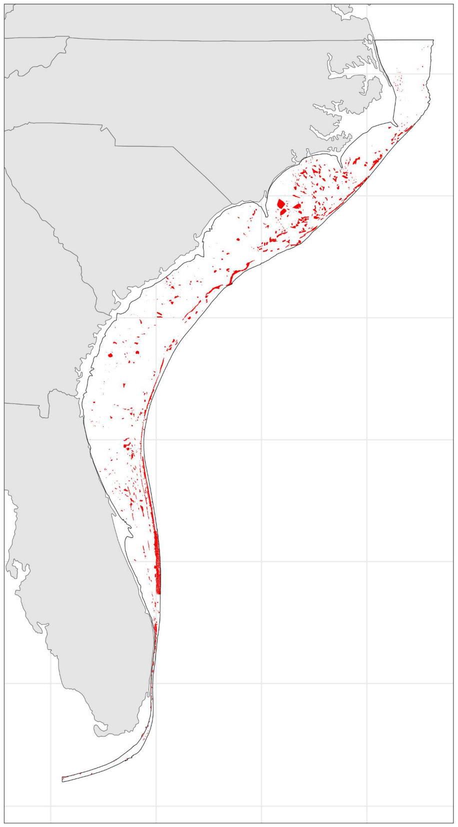
Hardbottom neighbors



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 ≈ increased estimated abundance

Bayesian Hierarchical Integrated Modeling: CIE Review

Positives:

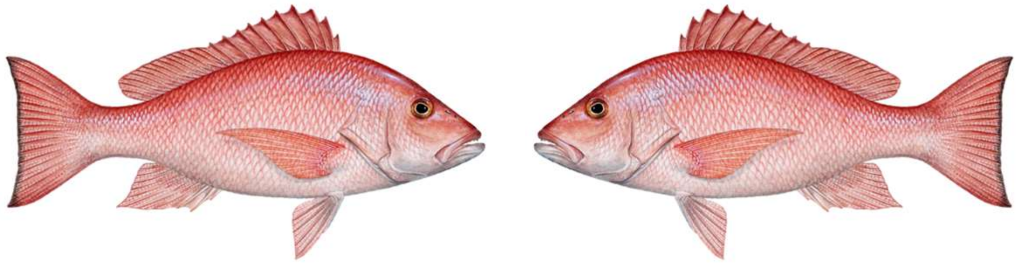
-methods applied appropriately, with several innovative approaches within BHIM

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.



Close-Kin Mark-Recapture

MarineGenomics Laboratory
Texas A&M University - Corpus Christi

Objectives:

1) To estimate red snapper population size in US Atlantic

2) To estimate red snapper genetic population structure

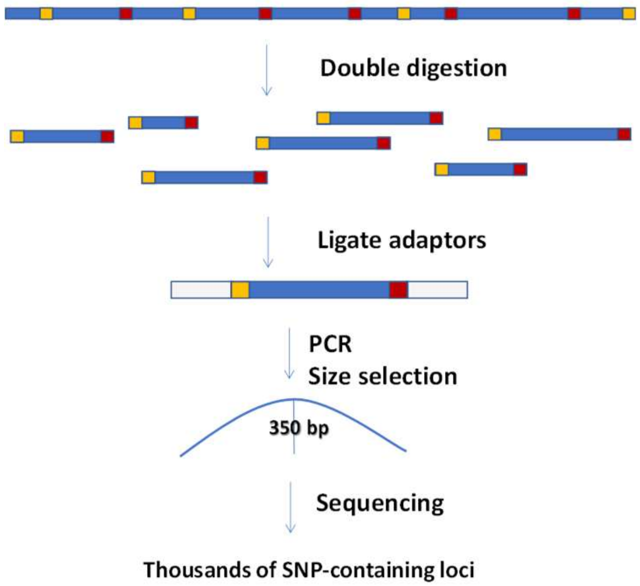
Approach:

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

Reduced representation genomics



Double digestion

Ligate adaptors

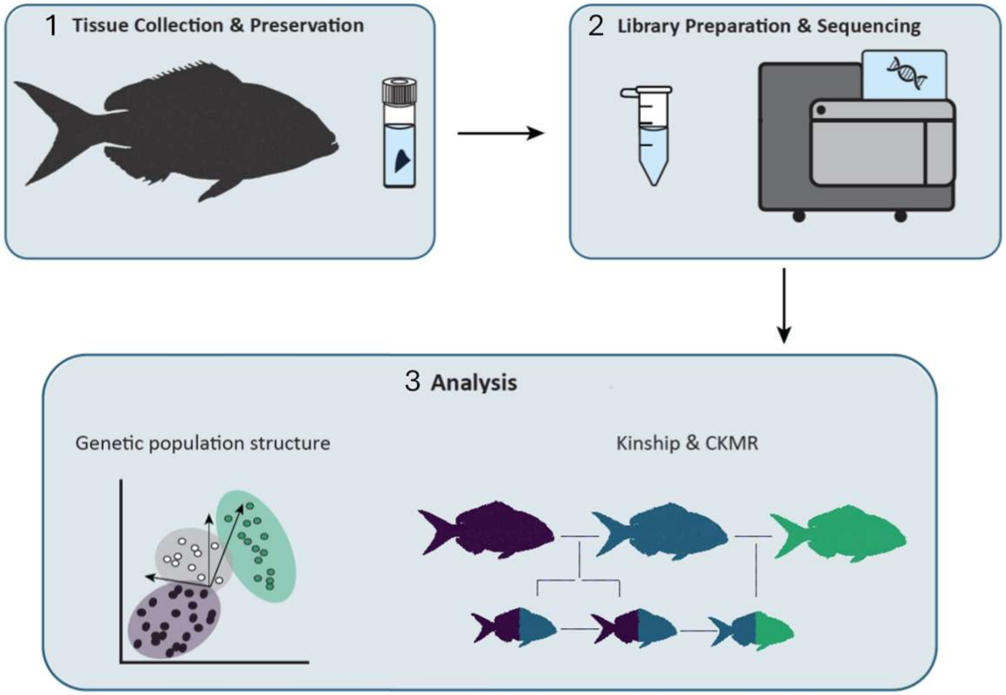
PCR
Size selection

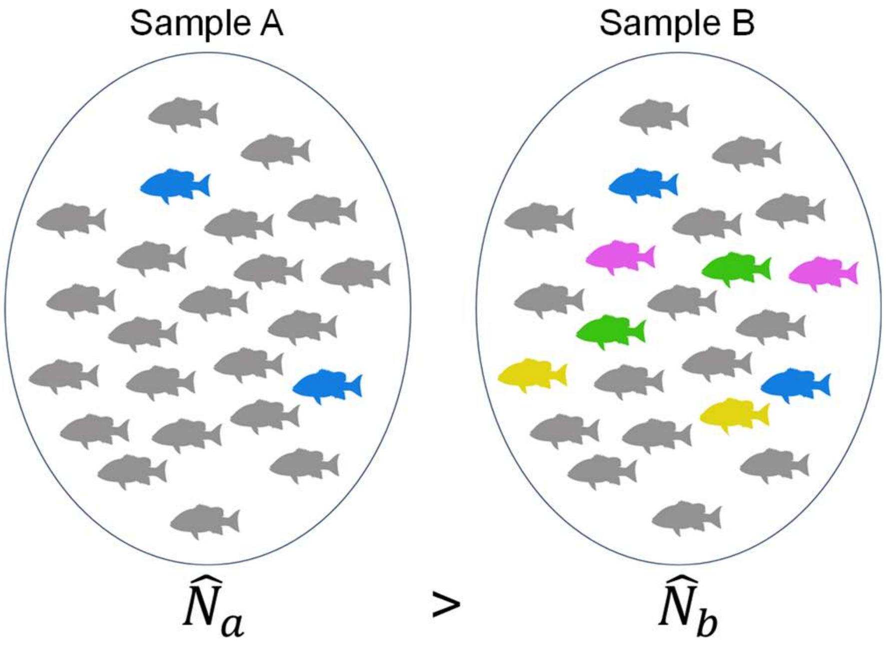
350 bp

Sequencing

Thousands of SNP-containing loci

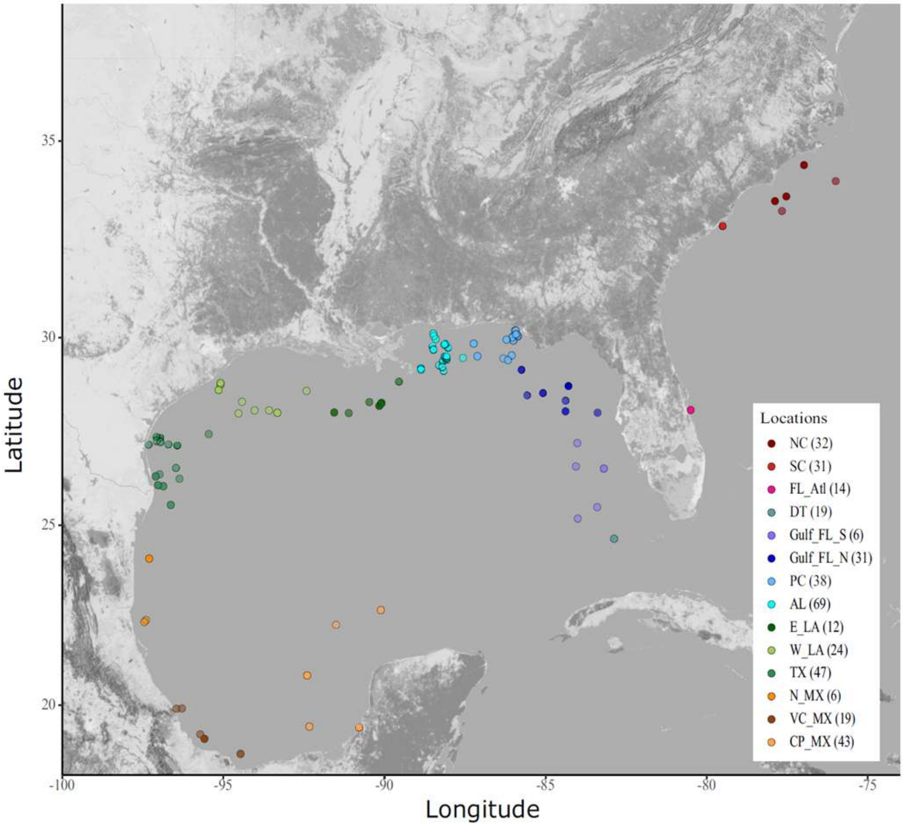
Close-Kin Mark-Recapture: Conceptual Approach





Atlantic Red Snapper Population Structure

Portnoy et al. (2022)



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


Received: 16 December 2021 | Revised: 27 July 2022 | Accepted: 31 July 2022

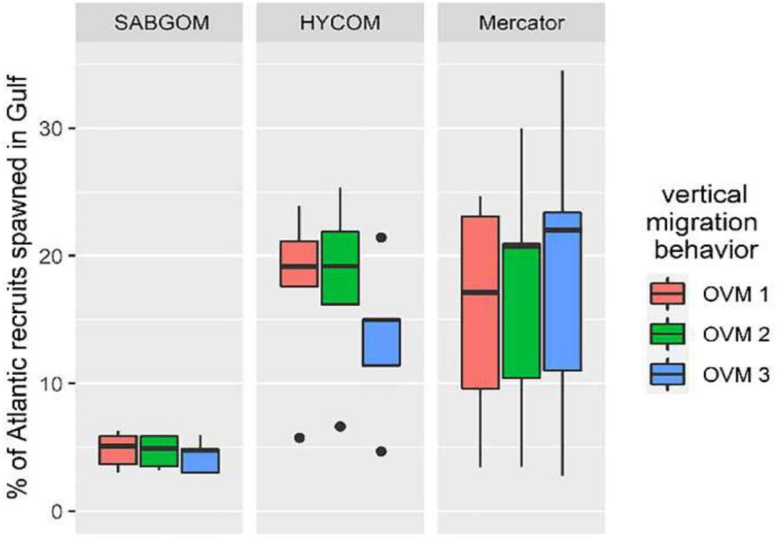
DOI: 10.1111/fog.12607

ORIGINAL ARTICLE

WILEY

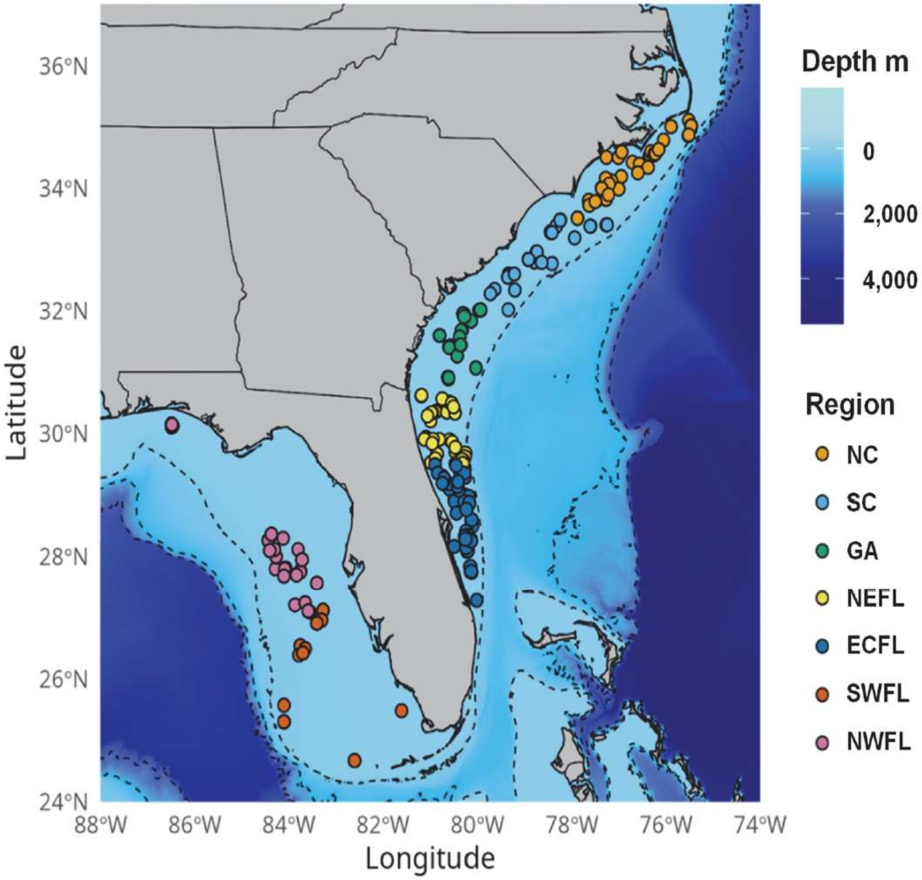
Source–sink recruitment of red snapper: Connectivity between the Gulf of Mexico and Atlantic Ocean

Mandy Karnauskas[1] | Kyle W. Shertzer[2] | Claire B. Paris[3] | Nicholas A. Farmer[4] | Theodore S. Switzer[5] | Susan K. Lowerre-Barbieri[6] | G. Todd Kellison[2] | Ruoying He[7] | Ana C. Vaz[1,3]



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

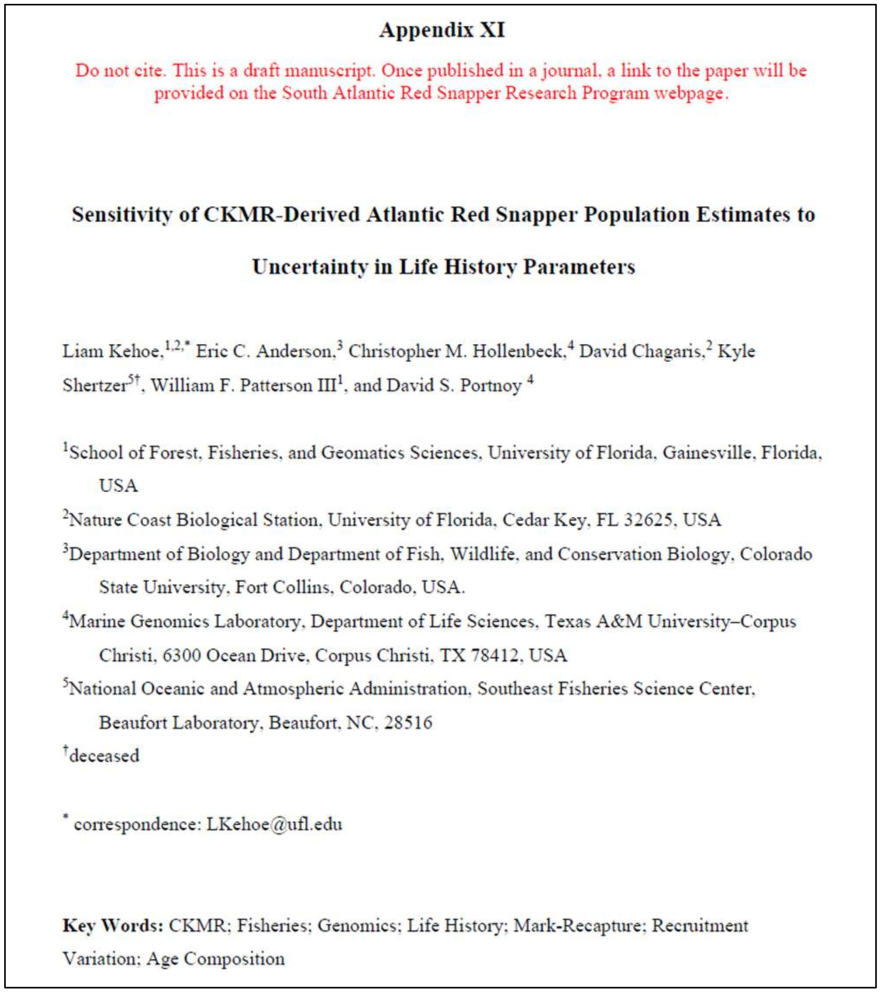
Atlantic Red Snapper Population Structure



Monroe et al. (2025); Appendix IV

- 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)

CKMR Life History Simulations



Appendix XI

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

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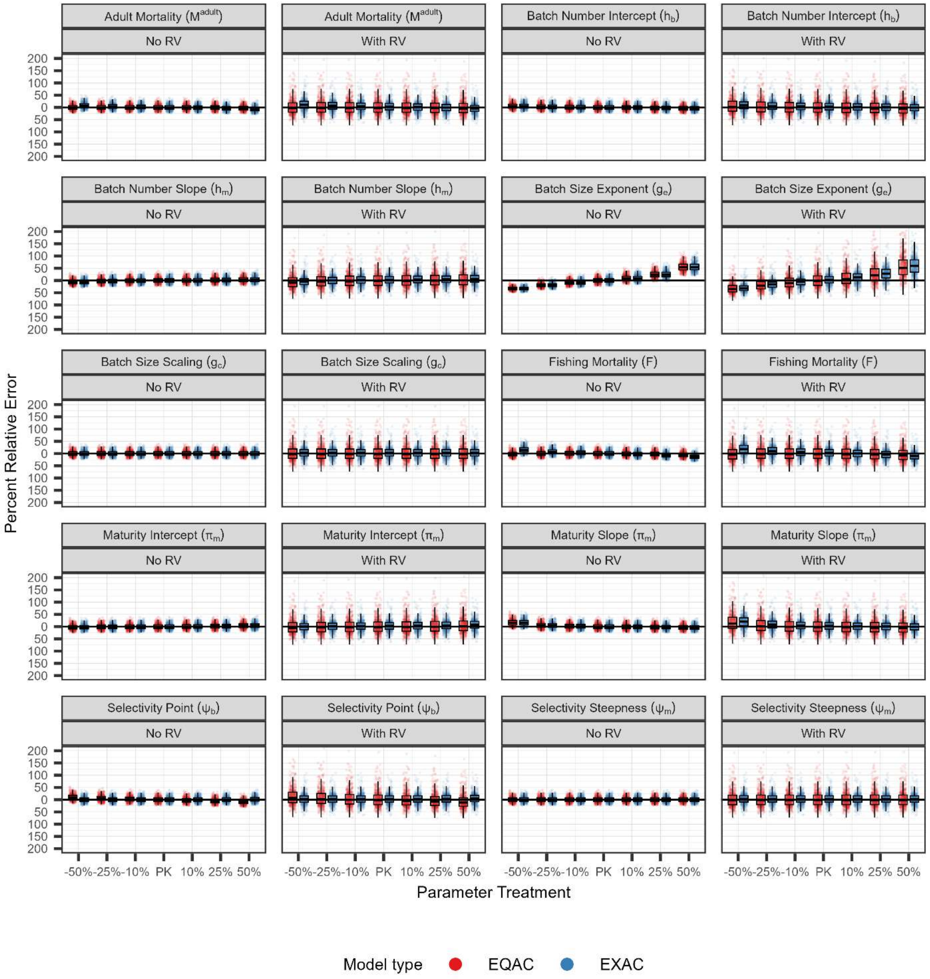
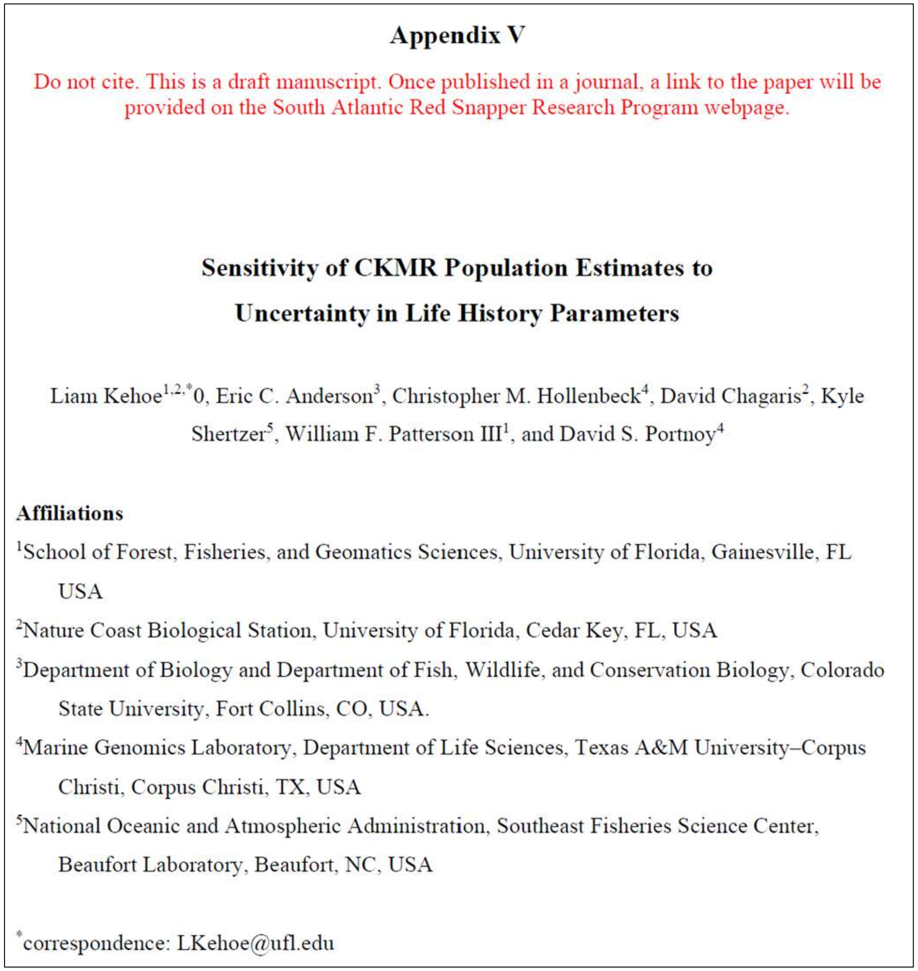
Key Words: CKMR; Fisheries; Genomics; Life History; Mark-Recapture; Recruitment Variation; Age Composition



CKMR Life History Simulations



Appendix V

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Affiliations

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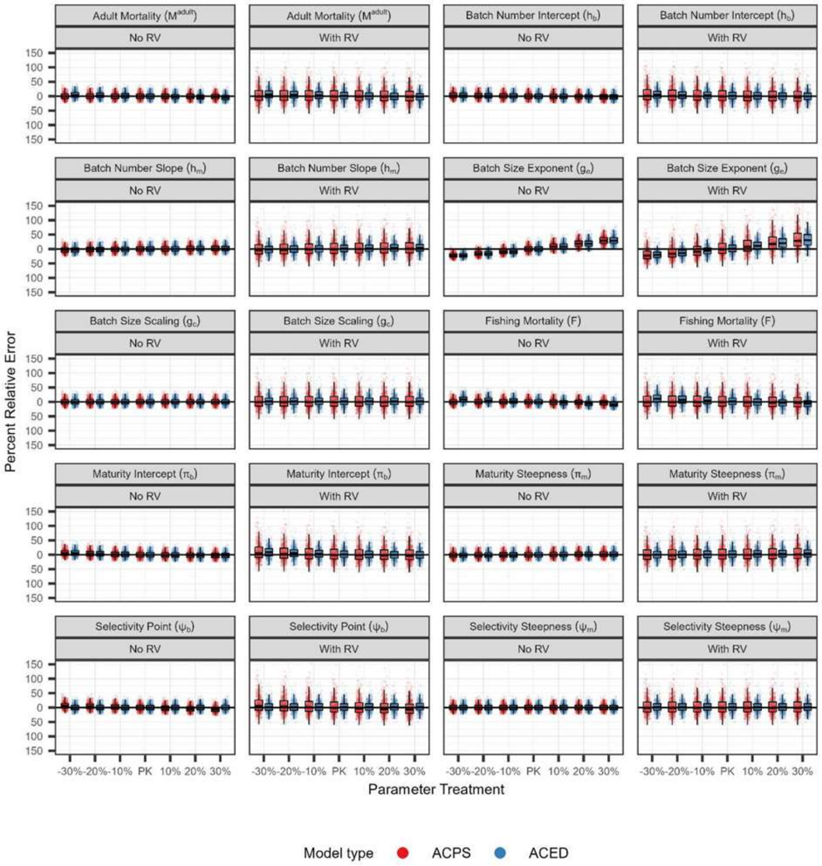
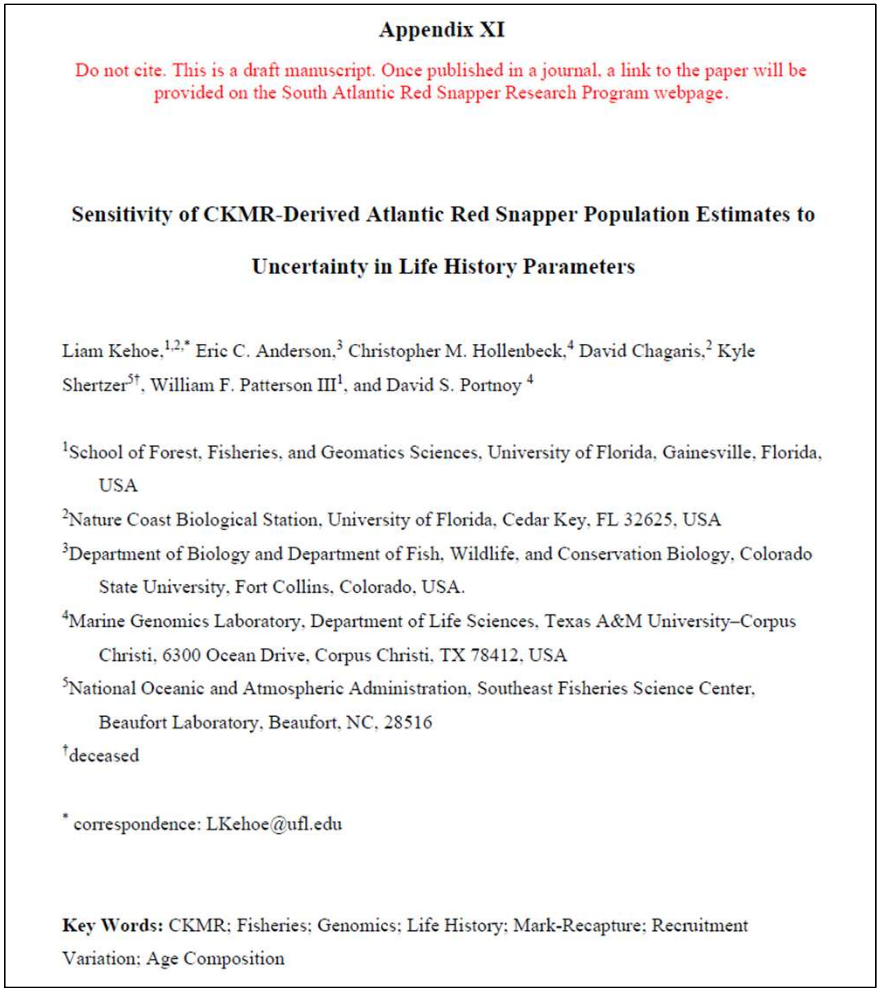


Kehoe et al. (2025c) Appendix V, Figure 8

CKMR Life History Simulations



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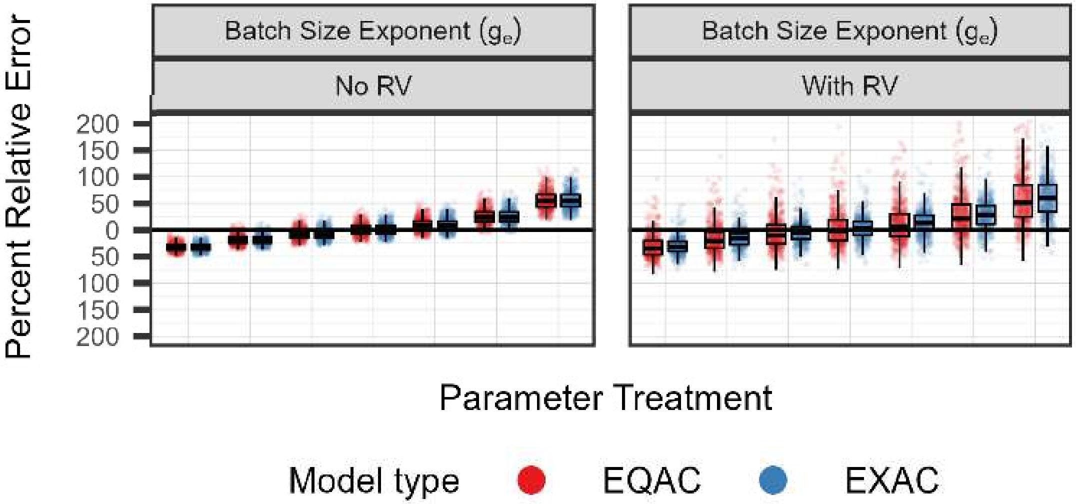


Kehoe et al. (2025c) Appendix V, Figure 8

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

  $$PHS(b_1, b_2, N, \Theta)$$

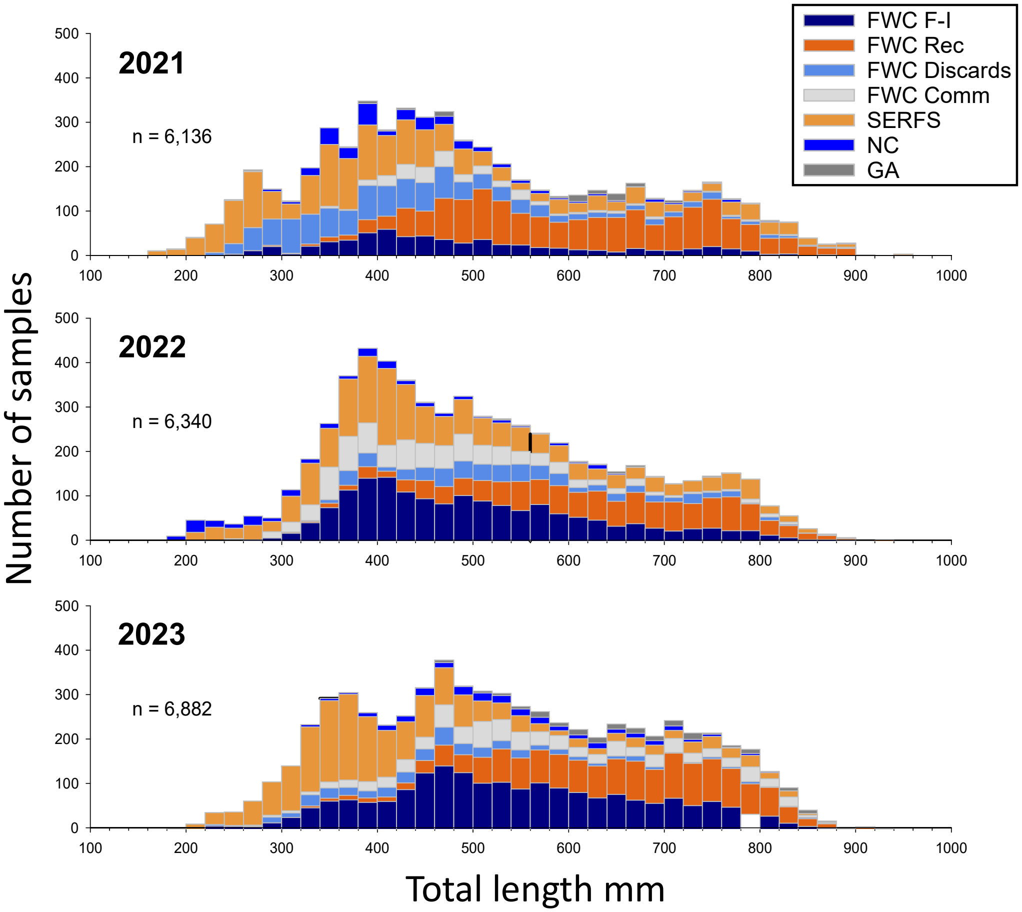
- Likelihood of observing number of pairs for given N_{adult}

  $$LLNHS = -\sum_{HS\,pairs} log\, PHS(b_1, b_2, N, \Theta)$$

- Posterior distribution used to estimate N_{adult} and corresponding CV

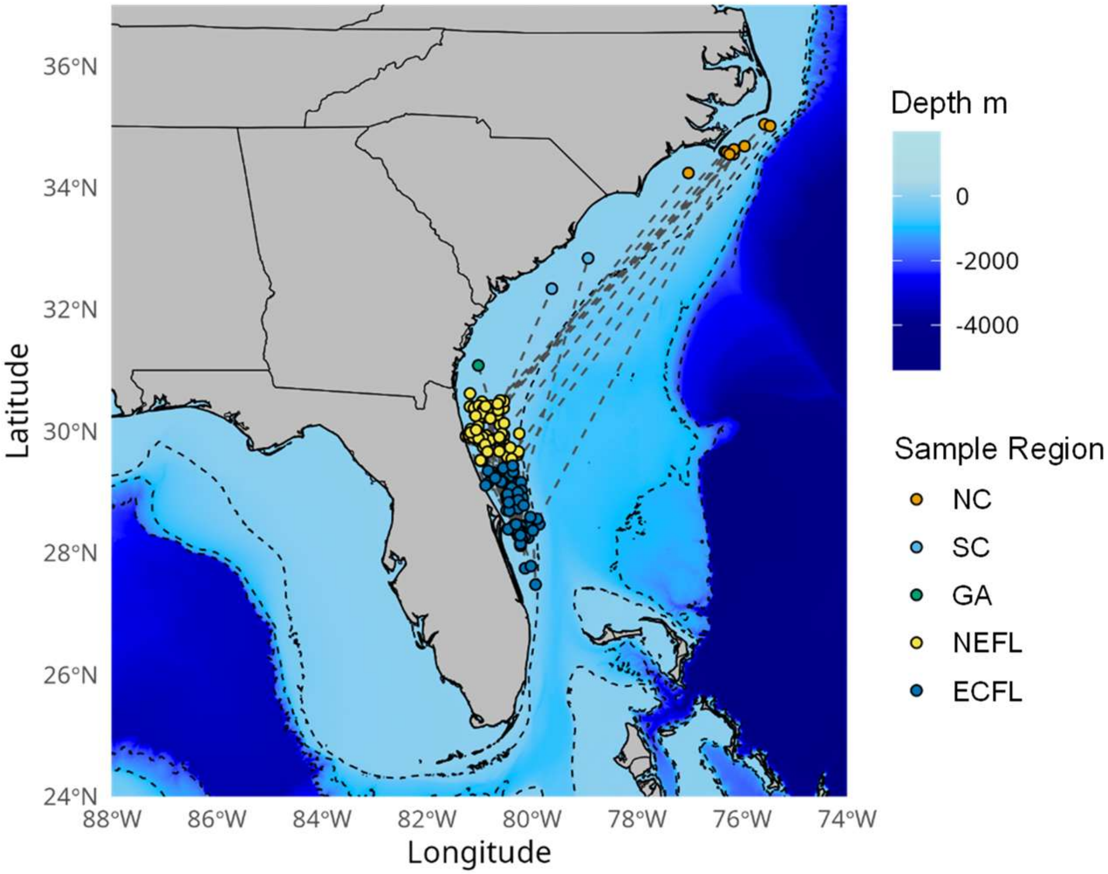
Census	S	$\hat{N}_{adult}$	CV
500,000	2,500	496,054	16.0%
	5,000	500,428	7.7%
1,000,000	2,500	998,591	23.2%
	5,000	1,023,518	11.1%
1,500,000	2,500	1,568,213	30.0%
	5,000	1,566,668	13.8%

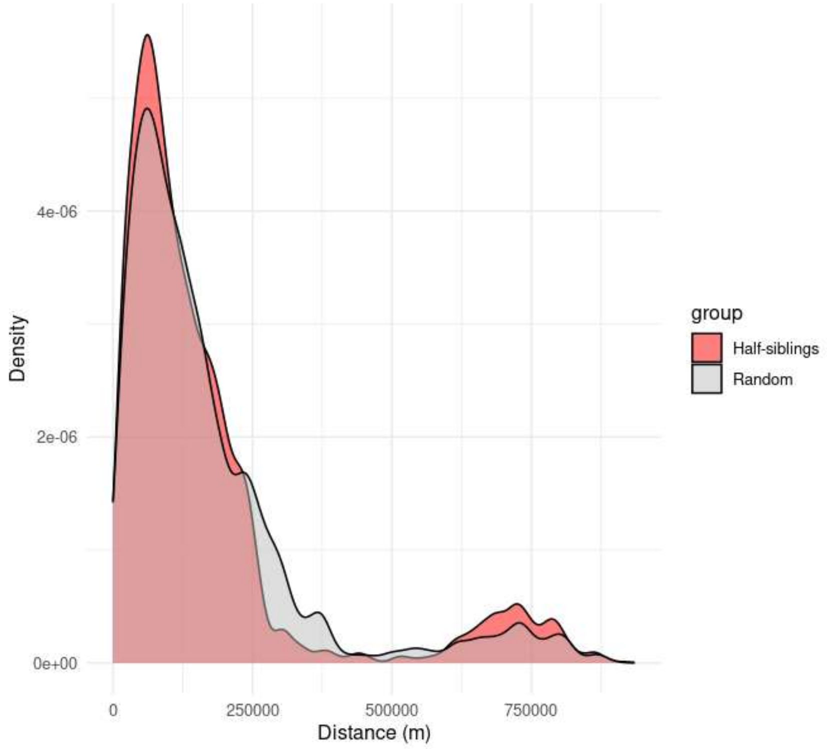
CKMR Population Estimation



CKMR Population Estimation

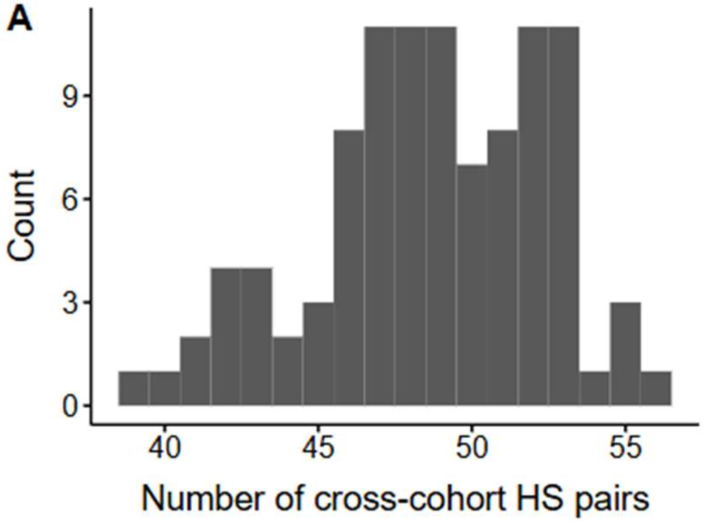
Spatial Distribution of Kin

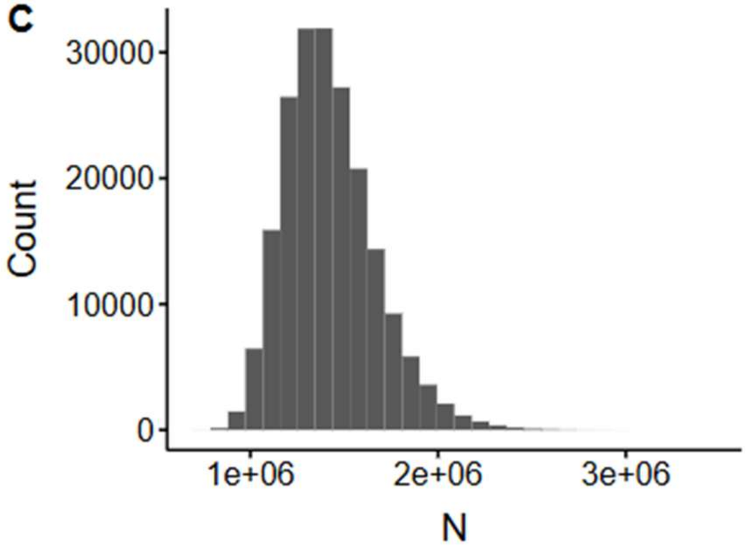




CKMR Population Estimation

Base Model Results





100 age realizations

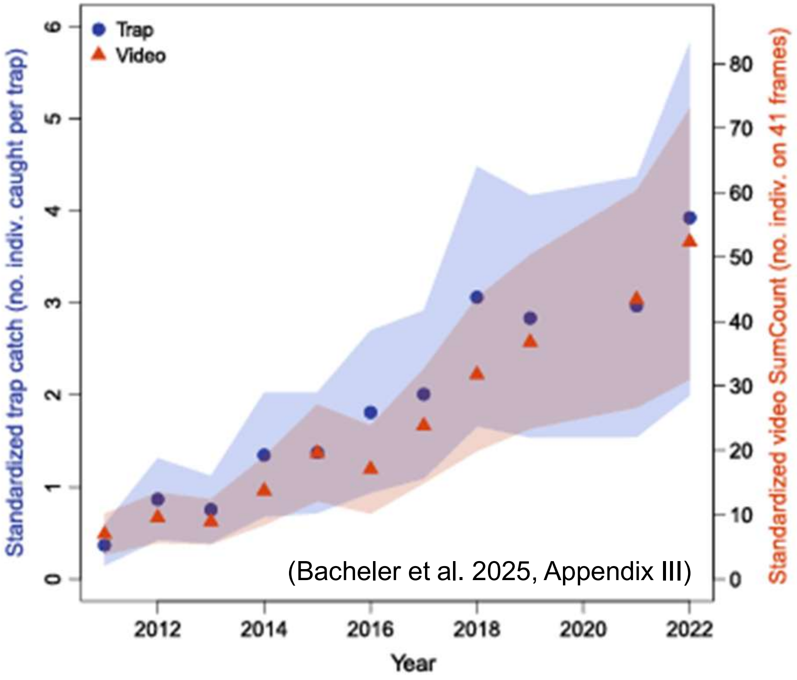
39 - 56 cross-cohort pairs

Point estimates 1.18 -1.69 M

Merged estimate 1.42 M

CV 17%, 90% CI 1.08 -1.87

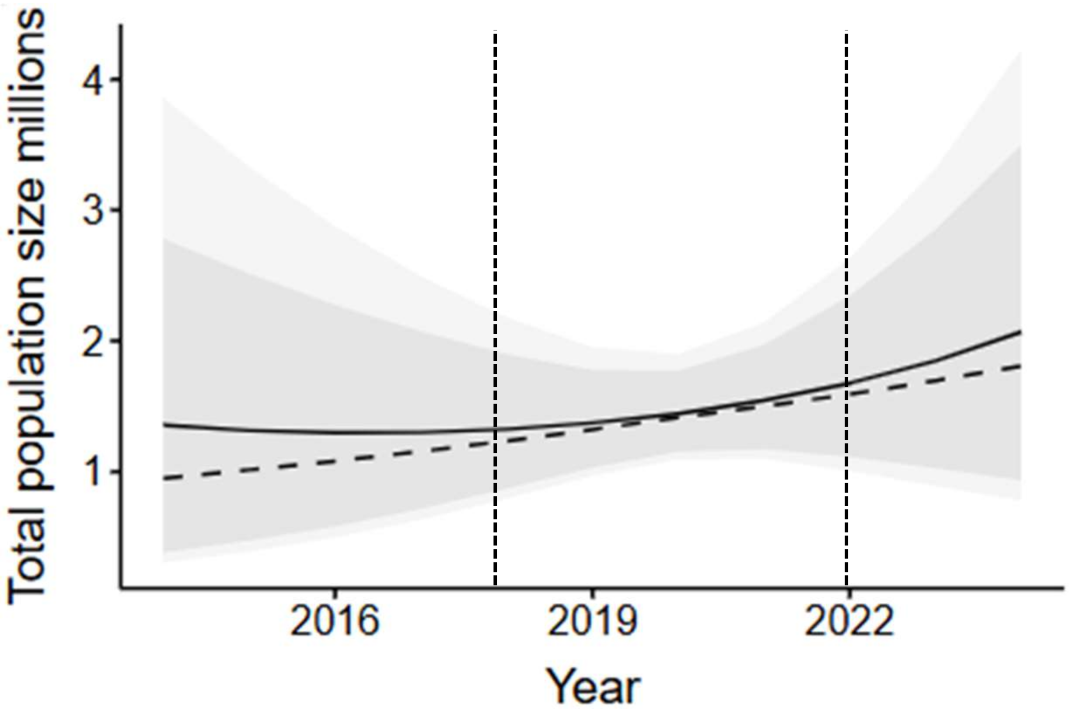
CKMR Population Estimation



(Bacheler et al. 2025, Appendix III)

Assumption of equilibrium population size likely violated

Population Growth/Decline

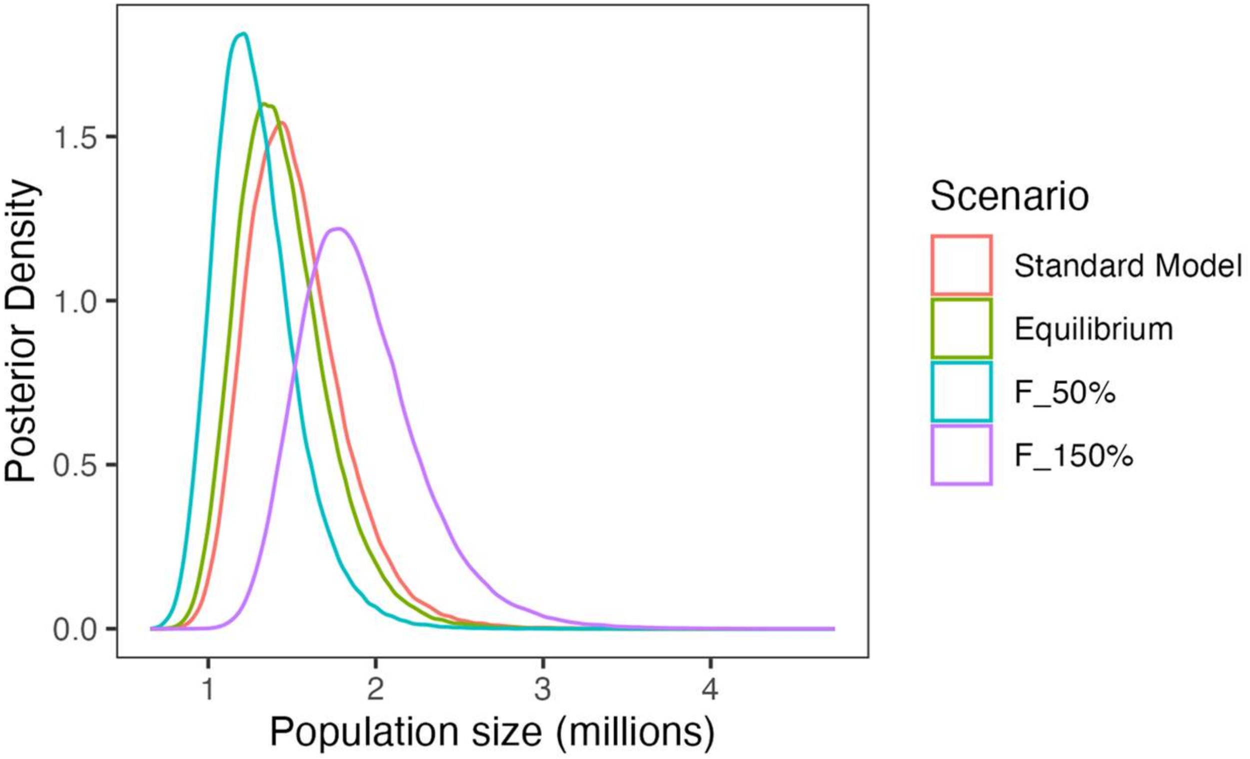


Mean from 2018 to 2022 1.47M

CKMR Population Estimation

Impacts of Including 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: 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

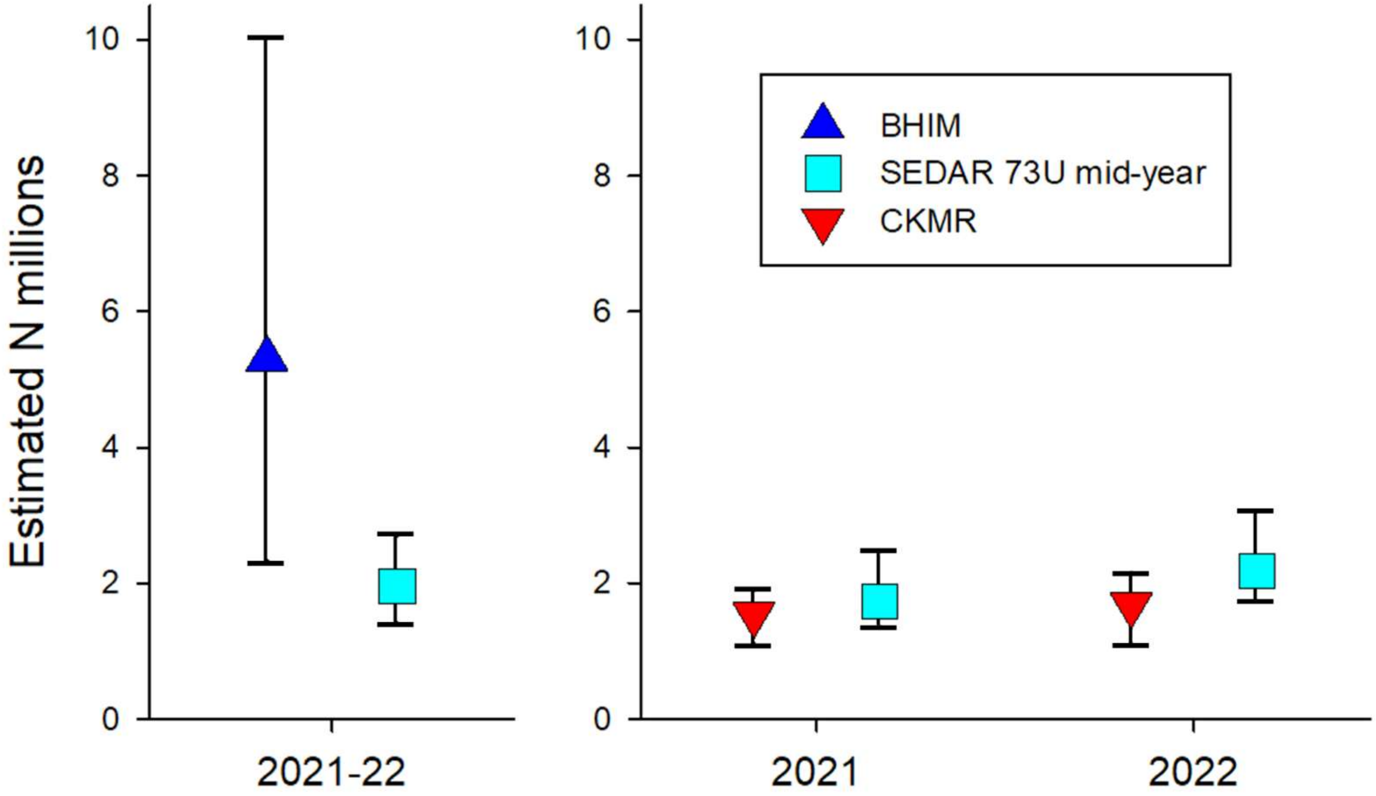
-assumption of equal sex-specific fecundity-at-age or fecundity-at-size not tested

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

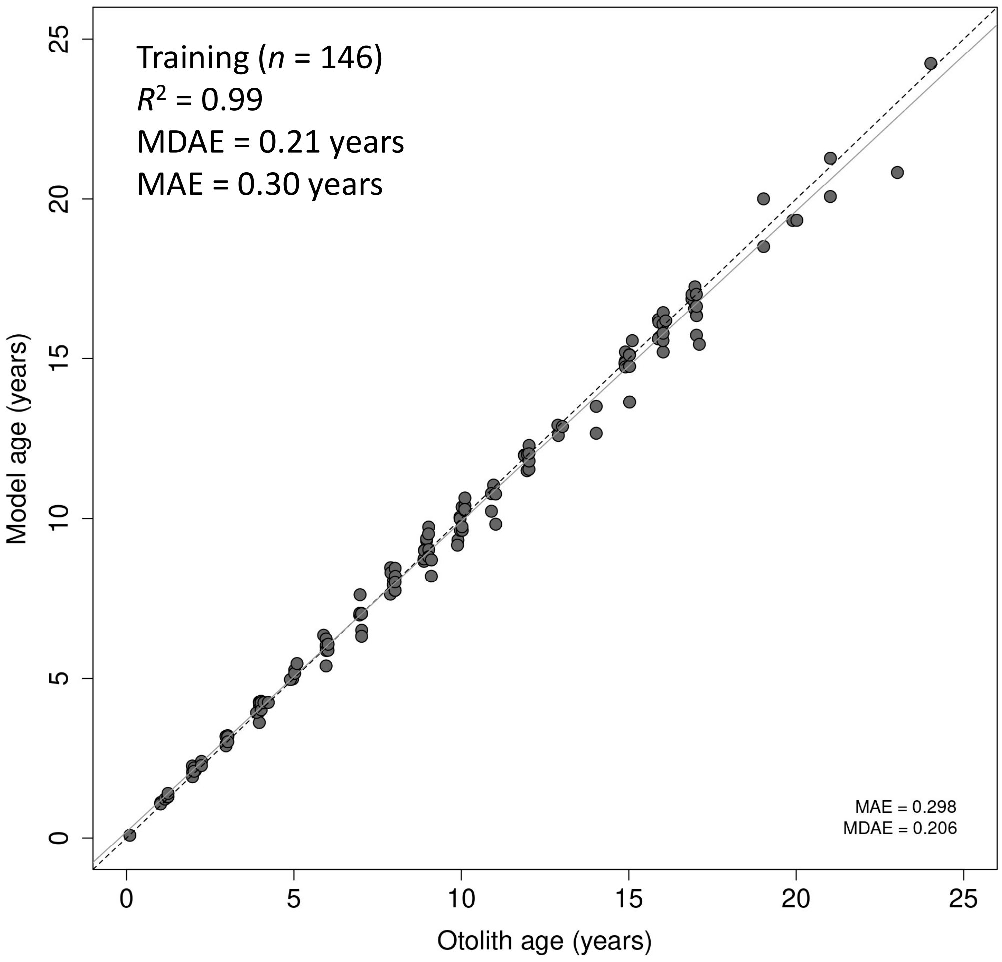
-apply epigenetic clock for age estimation

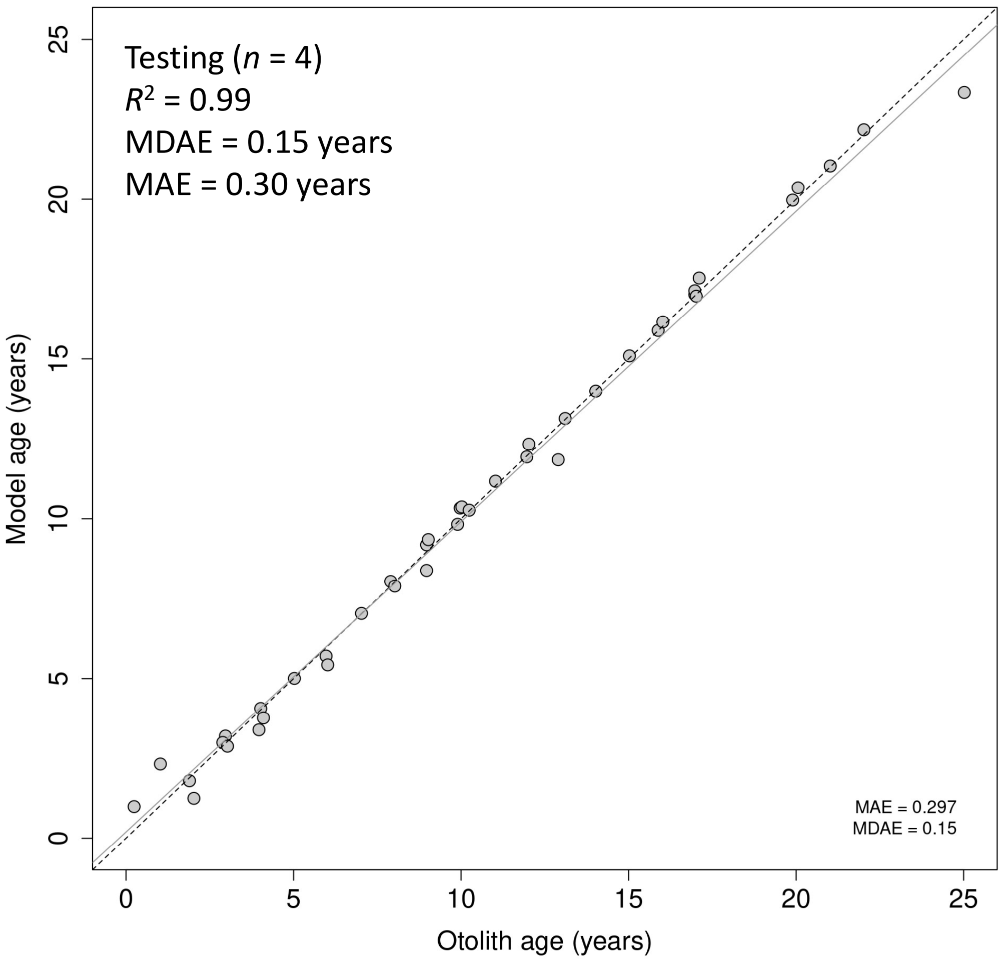
-provide chromosome-level genome sequence to assess the degree of linkage among ~1755 haplotypic loci

Summary Population Size Estimation

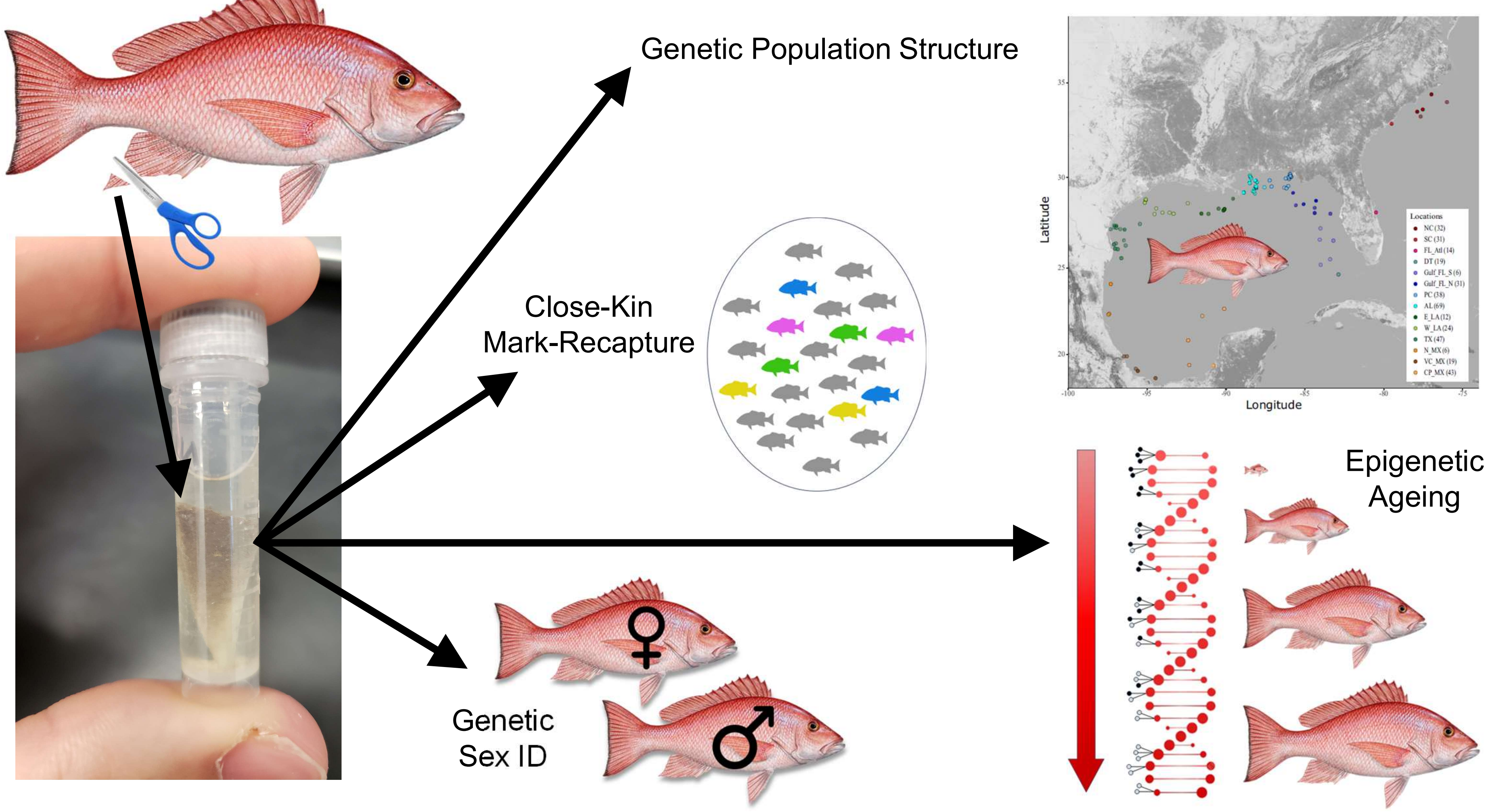


Future Work: Epigenetic Clock Implementation





Genomic Fisheries Analyses



Genetic Population Structure

Close-Kin Mark-Recapture

Genetic Sex ID

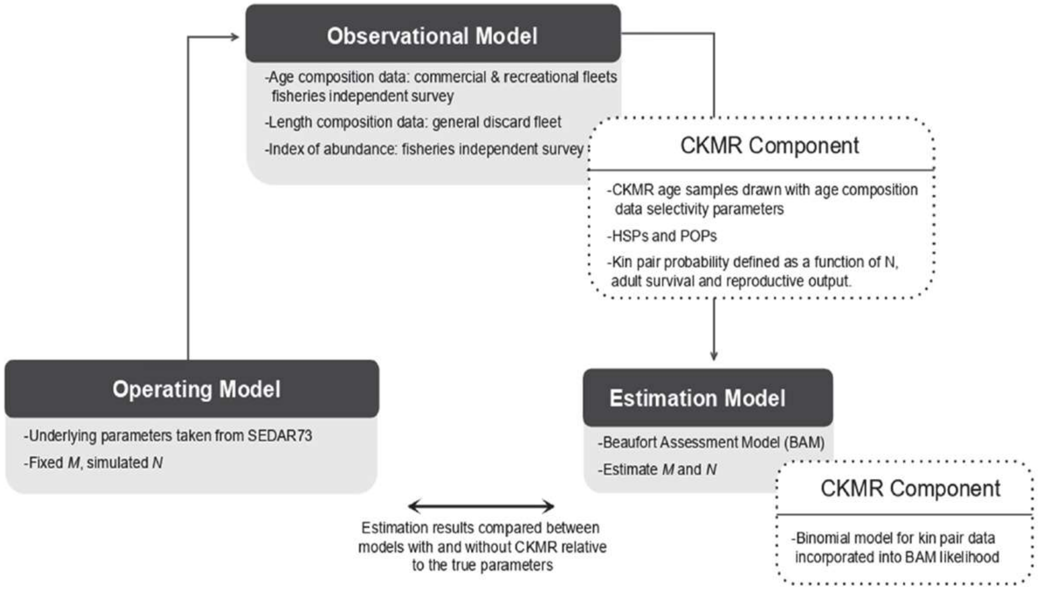
Epigenetic Ageing

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



Observational Model

-Age composition data: commercial & recreational fleets fisheries independent survey

-Length composition data: general discard fleet

-Index of abundance: fisheries independent survey

CKMR Component

-CKMR age samples drawn with age composition data selectivity parameters

-HSPs and POPs

-Kin pair probability defined as a function of N, adult survival and reproductive output.

Operating Model

-Underlying parameters taken from SEDAR73

-Fixed *M*, simulated *N*

Estimation Model

-Beaufort Assessment Model (BAM)

-Estimate *M* and *N*

CKMR Component

-Binomial model for kin pair data incorporated into BAM likelihood

Estimation results compared between models with and without CKMR relative to the true parameters

McLaughlin et al. (2025); Appendix VI


Kyle Shertzer


Matt Damiano


Matt Vincent


Paul McLaughlin

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