SEDAR
Southeast Data, Assessment, and Review

SEDAR 57
Stock Assessment Report

U.S. Caribbean Spiny Lobster

August 2019

SEDAR
4055 Faber Place Drive, Suite 201
North Charleston, SC 29405

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SEDAR

Southeast Data, Assessment, and Review

SEDAR 57

U.S. Caribbean Spiny Lobster

SECTION I: Introduction

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Introduction

SEDAR 57 addressed the stock assessment for U.S. Caribbean spiny lobster. The assessment process consisted of two in-person workshops, as well as a series of webinars. The Data Workshop was held June 20-2, 2018 in San Juan, Puerto Rico. Assessment webinars were held between September and December 2018. The Review Workshop took place January 29-31, 2019 in Miami, Florida.

The Stock Assessment Report is organized into 6 sections. Section I – Introduction contains a brief description of the SEDAR Process, Assessment and Management Histories for the species of interest, and the management specifications requested by the Cooperator. The Data Workshop Report can be found in Section II. It documents the discussions and data recommendations from the Data Workshop Panel. Section III is the Assessment Process report. This section details the assessment model, as well as documents any changes to the data recommendations that may have occurred after the data workshop. Consolidated Research Recommendations from all three stages of the process (data, assessment, and review) can be found in Section IV for easy reference. Section V documents the discussions and findings of the Review Workshop (RW). Finally, Section VI – Addenda and Post-Review Workshop Documentation consists of any analyses conducted during or after the RW to address reviewer concerns or requests. It may also contain documentation of the final RW-recommended base model, should it differ from the model put forward in the Assessment Report for review.

The final Stock Assessment Report (SAR) for U.S. Caribbean was disseminated to the public in August 2019. The Council's Scientific and Statistical Committee (SSC) will review the SAR. The SSCs are tasked with recommending whether the assessments represent Best Available Science, whether the results presented in the SARs are useful for providing management advice and developing fishing level recommendations for the Council. An SSC may request additional analyses be conducted or may use the information provided in the SAR as the basis for their Fishing Level Recommendations (e.g., Overfishing Limit and Acceptable Biological Catch). The Caribbean Fishery Management Council's SSC will review the assessment at its Fall 2019 meeting, followed by the Council receiving that information at its December 2019. Documentation on SSC recommendations is not part of the SEDAR process and is handled through each Council.

1 SEDAR PROCESS DESCRIPTION

SouthEast Data, Assessment, and Review (**SEDAR**) is a cooperative Fishery Management Council process initiated in 2002 to improve the quality and reliability of fishery stock assessments in the South Atlantic, Gulf of Mexico, and US Caribbean. SEDAR seeks improvements in the scientific quality of stock assessments and the relevance of information available to address fishery management issues. SEDAR emphasizes constituent and stakeholder participation in assessment development, transparency in the assessment process, and a rigorous and independent scientific review of completed stock assessments.

SEDAR is managed by the Caribbean, Gulf of Mexico, and South Atlantic Regional Fishery Management Councils in coordination with NOAA Fisheries and the Atlantic and Gulf States Marine Fisheries Commissions. Oversight is provided by a Steering Committee composed of NOAA Fisheries representatives: Southeast Fisheries Science Center Director and the

Southeast Regional Administrator; Regional Council representatives: Executive Directors and Chairs of the South Atlantic, Gulf of Mexico, and Caribbean Fishery Management Councils; a representative from the Highly Migratory Species Division of NOAA Fisheries, and Interstate Commission representatives: Executive Directors of the Atlantic States and Gulf States Marine Fisheries Commissions.

SEDAR is normally organized around two workshops and a series of webinars. First is the Data Workshop, during which fisheries, monitoring, and life history data are reviewed and compiled. The second stage is the Assessment Process, which is conducted via a workshop and/or a series of webinars, during which assessment models are developed and population parameters are estimated using the information provided from the Data Workshop. The final step is the Review Workshop, during which independent experts review the input data, assessment methods, and assessment products. The completed assessment, including the reports of all 3 stages and all supporting documentation, is then forwarded to the Council SSC for certification as ‘appropriate for management’ and development of specific management recommendations.

SEDAR workshops are public meetings organized by SEDAR staff and the lead Cooperator. Workshop participants are drawn from state and federal agencies, non-government organizations, Council members, Council advisors, and the fishing industry with a goal of including a broad range of disciplines and perspectives. All participants are expected to contribute to the process by preparing working papers, contributing, providing assessment analyses, and completing the workshop report.

2 MANAGEMENT OVERVIEW

Tables 2.1. Pertinent Federal management information.

Harvest Restrictions: Trip Limits

First Yr In Effect	Effective Date	End Date	Fishery	Bag Limit Per Person/Day	Bag Limit Per Boat/Day	Region Affected	FR Reference
2012	1/30/12	Ongoing	Rec	3	10	Caribbean EEZ	76 FR 82414

Harvest Restrictions: Size Limits

First Yr In Effect	Effective Date	End Date	Fishery	Size Length	Length Type	Region Affected	FR Reference
1985	1/1/85	Ongoing	Commercial /Rec	3.5 inches[1]	Carapace Length	Caribbean EEZ	49 FR 50049
2009	2/11/09	Ongoing	Commercial	6oz tail weight	Carapace Length	Imports	74 FR 1148

[1]Non-egg-bearing spiny lobsters

Harvest Restrictions: Seasonal Closure

First Year In Effect	Last Year In Effect	Fishery	First Day Closed	Last Day Closed	Region Affected	Reference
2013	2013	Commercial/Rec	12/19	12/31	St. Croix EEZ	78FR 18247
2016	2016	Commercial/Rec	12/10	12/31	Puerto Rico EEZ	81FR 34283
2017	2017	Commercial/Rec	09/7	09/30	Puerto Rico EEZ	82FR 31489

Harvest Restrictions: Spatial Closures

Area	First Year In Effect	Last Year in Effect	First Day Closed	Last Day Closed	Restriction During Closure	Main Spawning Species Protected	Reference
Area closure for Red Hind spawning (later named Hind Bank Marine Conservation District in 1999)	1989	1989	12/6	12/31	All fishing prohibited	Red Hind	54 FR 50624
	1990	1999	1/1	2/28	All fishing prohibited	Red Hind	54 FR 50624
	1990	1999	12/1	12/31	All fishing prohibited	Red Hind	55 FR 46214
	2000	Ongoing	1/1	12/31	All fishing prohibited	Red Hind	64 FR 60132
Tourmaline[1] (PR) and Lang Bank (STX)	1993	Ongoing	12/1	12/31	All fishing prohibited	Red Hind	58 FR 53145
	1994	Ongoing	1/1	2/28	All fishing prohibited	Red Hind	58 FR 53145
Mutton Snapper Spawning Area (STX)	1994	Ongoing	3/1	6/30	All fishing prohibited	Mutton Snapper	58 FR 53145
Abrir La Sierra (PR)	1996	1996	12/7	12/31	All fishing prohibited	Red Hind	61 FR 64485
	1997	Ongoing	1/1	2/28	All fishing prohibited	Red Hind	61 FR 64485
	1997	Ongoing	12/1	12/31	All fishing prohibited	Red Hind	61 FR 64485
Bajo de Sico (PR)	1996	1996	12/7	12/31	All fishing prohibited	Red Hind	61 FR 64485
	1997	2010	1/1	2/28	All fishing prohibited	Red Hind	61 FR 64485
	1997	2009	12/1	12/31	All fishing prohibited	Red Hind	61 FR 64485
	2010	2010	12/2	12/31	Fishing for reef fish prohibited[2]	Red Hind	75 FR 67247
	2011	Ongoing	1/1	3/31	Fishing for reef fish prohibited[2]	Red Hind	75 FR 67247
	2011	Ongoing	10/1	12/31	Fishing for reef fish prohibited[2]	Red Hind	75 FR 67247
Grammanik Bank	2005	Ongoing	2/1	4/30	All fishing prohibited except HMS[3]	Yellowfin Grouper	70 FR 300, 70 FR 62073

[1]The size of the Tourmaline Bank was modified in January 1997 (61 FR 64485)

[2]Fishing for spiny lobster, HMS, and other pellagics allowed during closure

[3]HMS: Bluefin, bigeye, yellowfin, albacore, and skipjack tunas; swordfish; sharks; white marlin, blue marlin, sailfish, and longbill spearfish

Harvest Restrictions: Gear Restrictions

Gear Type	First Year In Effect	Effective Date	End Date	Gear/Harvesting Restrictions	Region Affected	Reference
Spear and Hooks	1985	1/1/85	Ongoing	Prohibited for spiny lobster	Caribbean EEZ	49 FR 50049
Poison and Drugs	1985	1/1/85	Ongoing	Prohibited for spiny lobster	Caribbean EEZ	49 FR 50049
	1985	9/22/85	Ongoing	Prohibited for reef fish	Caribbean EEZ	50 FR 34850
Explosives and Powerheads	1985	1/1/85	Ongoing	Prohibited for spiny lobster	Caribbean EEZ	49 FR 50049
	1985	9/22/85	Ongoing	Prohibited for reef fish	Caribbean EEZ	50 FR 34850
Pots and Traps	1985	1/1/85	9/19/91	Include one degradable panel and/or door	Caribbean EEZ	49 FR 50049
	1986	9/22/86	9/13/91	Minimum mesh size 1 1/4"	Caribbean EEZ	50 FR 34850
	1991	9/14/91	Ongoing	Minimum mesh size 2"	Caribbean EEZ	55 FR 46214
	1991	9/20/91	11/14/93	Include two degradable panels on opposite sides	Caribbean EEZ	56 FR 48755
	1993	11/15/93	11/27/05	Include two degradable panels (sides no longer specified)	Caribbean EEZ	58 FR 53145
	2005	11/28/05	Ongoing	Include one degradable panel	Caribbean EEZ	70 FR 62073
Slurp gun and Dip Nets	1993	11/15/93	11/28/2005[1]	Allow only slurp gun and hand-held dip nets for aquarium trade	Caribbean EEZ	58 FR 53145
Hookah	1997	1/13/97	Ongoing	Prohibited hookah gear for harvesting conch	Caribbean EEZ[2]	61 FR 65481
Gill Nets	2005	11/28/05	Ongoing	Prohibit gill and trammel net for reef species[3]	Caribbean EEZ	70 FR 62073
All	2005	11/28/05	Ongoing	Prohibited Fileting fish at sea	Caribbean EEZ	70 FR 62073
	2005	11/28/05	Ongoing	Reef fish vessels required to recover anchor by its crown	Caribbean EEZ	70 FR 62073
Bottom gears[4]	2005	11/28/05	Ongoing	Prohibited year-round	Closed areas[5]	70 FR 62073
Anchoring	2010	12/2/10	Ongoing	Anchoring by fishing vessels prohibited year-round	Bajo de Sico Bank	75 FR 67247
Spear	2010	12/2/10	Ongoing	Allow spear fishing for reef fish in the commercial sector[6]	Caribbean EEZ	75 FR 67247

[1]Aquarium trade species put in ‘data collection only’ category; eliminated existing federal harvest restrictions (70 FR 62073)

[2]Lang Bank (in St. Croix EEZ) only starting 11/28/2005 (see seasonal closures)

[3] Gill and trammel nets used to fish other species must be tended at all times

[4]Pots, traps, bottom longlines, gillnets, trammel nets

[5]Bajo de Sico, Abrir La Sierra, Tourmaline, Mutton Snapper Agg. Area, Lang Bank, Hind Bank Marine Conservation District, and Grammanik Bank

[6]This action was administrative in nature; spear has been historically used in the commercial reef fish fishery

3 ASSESSMENT HISTORY AND REVIEW

Previous stock assessments for Spiny Lobster in the US Caribbean have attempted to quantify stock status using both traditional as well as data-limited stock assessment procedures. Morris et al. (2004) and also SEDAR (2005A) provide assessment histories that summarize various traditional assessments (e.g. stock production analyses (ASPIC), CPUE examinations, yield per recruit, landings and length frequency). SEDAR (2016) was the most recent data-limited assessment (e.g. mean-length, indicator-based control rules) prior to the current assessment. To date, nearly all evaluations have resulted in unsatisfactory determination of stock status. The table below provides the references of past assessments.

Spiny Lobster Stock Units Assessed	**Assessment Method**	**Assessment Reference**
St. Thomas/St. John trap fishery St. Croix dive fishery	Comparison of multiple data-limited models	SEDAR 2016
US Caribbean	Stock production analyses (ASPIC)	SEDAR 2005A
US Caribbean	Yield per recruit analysis	Mateo 2004
Puerto Rico	Dynamic production model	Mateo and Die 2004
US Caribbean	Examining landings and length frequency	Bolden 2001
St. Croix	Production model (Schaefer and Fox)	Mateo and Tobias 2000
Puerto Rico	Examining CPUE and length frequency	Matos-Caraballo 1999
US Caribbean	Examining landings and CPUE	Bohnsack et al. 1990

References:

Bohnsack, J., S. Meyers, R. Appeldoorn, J. Beets, D. Matos, and Y. Sadovy. 1990. Stock Assessment of the Spiny Lobster, *Panulirus argus*, in the U.S. Caribbean. Final stock assessment and fishery evaluation (SAFE) report from the workshop on spiny lobster resources in the U.S. Caribbean. San Juan, Puerto Rico, September 11-13, 1990.

Bolden, S. 2001. Status of the U.S. Caribbean Spiny Lobster Fishery 1980-1999.

Mateo, I. and W.J. Tobais. 2000. Preliminary Estimations of Growth, Mortality and Yield Per Recruit for the Spiny Lobster Panulirus argus in St. Croix, USVI. Proceeding of the Gulf and Caribbean Fisheries Institute. 53:55-75

Mateo, I. and D. Die. 2004. The Status of Spiny Lobster Panulirus argus in Puerto Rico: Based on Commercial Landings Data. Rosenstiel School of Marine and Atmospheric Science, Cooperative Institute for Marine and Atmospheric Studies.

Mateo, I. 2004. Population dynamics for Spiny Lobster (*Panulirus argus*) in Puerto Rico: a progress report. Proceedings of the 55th Gulf and Caribbean Fisheries Institute 55:506–520.

Matos-Caraballo, D. 1999. Overview of the Spiny Lobster, Panulirus argus, Commercial Fishery in Puerto Rico During 1992-1998. Proceeding of the Gulf and Caribbean Fisheries Institute. 52:194-203

SEDAR. 2005A. SEDAR 8. Stock Assessment Report, Caribbean Spiny Lobster. SEDAR, North Charleston, SC. 195 99.

SEDAR. 2016. SEDAR46: U.S. Caribbean data-limited species. SEDAR, North Charleston, SC. 373 pp.

4 REGIONAL MAPS

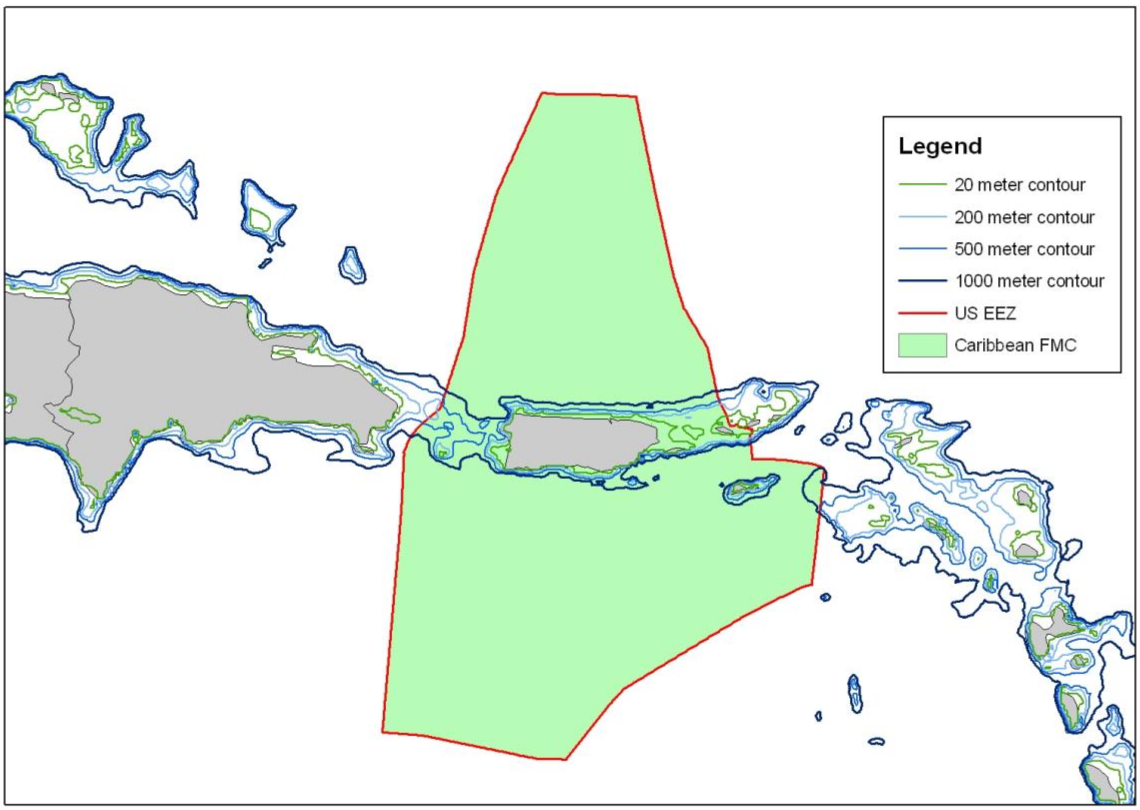

Figure 4.1 U.S. Caribbean Region including Council and EEZ Boundaries.

5 SEDAR ABBREVIATIONS

ABC	Acceptable Biological Catch
ACCSP	Atlantic Coastal Cooperative Statistics Program
ADMB	AD Model Builder software program
ALS	Accumulated Landings System; SEFSC fisheries data collection program
AMRD	Alabama Marine Resources Division
ASMFC	Atlantic States Marine Fisheries Commission
B	stock biomass level
BAM	Beaufort Assessment Model
BMSY	value of B capable of producing MSY on a continuing basis
CFMC	Caribbean Fishery Management Council
CIE	Center for Independent Experts
CPUE	catch per unit of effort
EEZ	exclusive economic zone
F	fishing mortality (instantaneous)
FMSY	fishing mortality to produce MSY under equilibrium conditions
FOY	fishing mortality rate to produce Optimum Yield under equilibrium
FXX% SPR	fishing mortality rate that will result in retaining XX% of the maximum spawning production under equilibrium conditions
FMAX	fishing mortality that maximizes the average weight yield per fish recruited to the fishery
F0	a fishing mortality close to, but slightly less than, Fmax
FL FWCC	Florida Fish and Wildlife Conservation Commission
FWRI	(State of) Florida Fish and Wildlife Research Institute
GA DNR	Georgia Department of Natural Resources
GLM	general linear model
GMFMC	Gulf of Mexico Fishery Management Council
GSMFC	Gulf States Marine Fisheries Commission
GULF FIN	GSMFC Fisheries Information Network
HMS	Highly Migratory Species
LDWF	Louisiana Department of Wildlife and Fisheries
M	natural mortality (instantaneous)
MARMAP	Marine Resources Monitoring, Assessment, and Prediction

MDMR	Mississippi Department of Marine Resources
MFMT	maximum fishing mortality threshold, a value of F above which overfishing is deemed to be occurring
MRFSS	Marine Recreational Fisheries Statistics Survey
MRIP	Marine Recreational Information Program
MSST	minimum stock size threshold, a value of B below which the stock is deemed to be overfished
MSY	maximum sustainable yield
NC DMF	North Carolina Division of Marine Fisheries
NMFS	National Marine Fisheries Service
NOAA	National Oceanographic and Atmospheric Administration
OY	optimum yield
SAFMC	South Atlantic Fishery Management Council
SAS	Statistical Analysis Software, SAS Corporation
SC DNR	South Carolina Department of Natural Resources
SEAMAP	Southeast Area Monitoring and Assessment Program
SEDAR	Southeast Data, Assessment and Review
SEFIS	Southeast Fishery-Independent Survey
SEFSC	Fisheries Southeast Fisheries Science Center, National Marine Fisheries Service
SERO	Fisheries Southeast Regional Office, National Marine Fisheries Service
SPR	spawning potential ratio, stock biomass relative to an unfished state of the stock
SSB	Spawning Stock Biomass
SS	Stock Synthesis
SSC	Science and Statistics Committee
TIP	Trip Incident Program; biological data collection program of the SEFSC and Southeast States.
TPWD	Texas Parks and Wildlife Department
Z	total mortality, the sum of M and F

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U.S. Caribbean Spiny Lobster

SECTION II: Data Workshop Report

September 2018

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1 INTRODUCTION

1.1 WORKSHOP TIME AND PLACE

The SEDAR 57 Data Workshop was held on June 20-22, 2018 in San Juan, Puerto Rico.

1.2 TERMS OF REFERENCE

1. Summarize and evaluate available life history information and describe uncertainty as applicable.
    a. Evaluate age, growth, natural mortality, and reproductive characteristics
    b. Provide appropriate models to describe growth, maturation, and fecundity by age, sex, or length as applicable.
    c. Evaluate the adequacy of available life-history information for conducting stock assessments and recommend life history information for use in population modeling.

2. Provide commercial catch statistics, including both landings and discards (if significant) in both pounds and numbers.
    a. Evaluate and discuss the adequacy of available data for accurately characterizing harvest and discard by species, spatial area, and fishery sector or gear.
    b. Provide and evaluate length and age distributions for both landings and discards if feasible.
    c. Provide and evaluate fishery catch per unit effort data for use as indices of abundance

3. Provide recreational catch statistics, including both landings and discards (if significant) in both pounds
and numbers.
    a. Evaluate and discuss the adequacy of available data for accurately characterizing harvest and discard by species, spatial area, and fishery sector or gear.
    b. Provide and evaluate length and age distributions for both landings and discards if feasible.
    c. Provide and evaluate fishery catch per unit effort data for use as indices of abundance if possible

4. Recommend discard mortality rate(s).
    a. Review available research and published literature and provide a rationale for recommended discard mortality rates.
    b. Provide justification for any recommendations that deviate from the range of discard mortality provided in the last benchmark or other prior assessment.

5. Review relevant fishery-independent and third-party information that may be of use for the assessment.

6. Provide recommendations and rate the relative quality of available data inputs associated with candidate assessment tools (e.g. length-based, index-based, catch-based methods).

7. Provide recommendations for future research in areas such as sampling, fishery monitoring, and stock assessment. Include specific guidance on sampling intensity (number of samples including age and length structures) and appropriate strata and coverage.

8. Prepare the Data Workshop report providing complete documentation of workshop actions and decisions in accordance with project schedule deadlines (Section II. of the SEDAR assessment report).

1.3 LIST OF PARTICIPANTS

Workshop Panel

Adyan Rios, Lead Analyst .... NMFS Miami
Bill Harford, Analyst .... RSMAS
J.J. Cruz- Motta .... Dept. Marine Science, UPR
Jesus Leon Fernández .... PR-DNER Fisheries Lab
Tommy Forte..
Jorge Garcia .... Reef Research/CFMC SSC
Joe Kimmel .... CFMC SSC
Winston Ledee .... Commercial Fisher STT
Julian Magras .... Commercial Fisher STT/STJ
Gerson N. Martinez .... Commercial Fisher STX
Daniel Matos Caraballo .... PR-DNER Fisheries Lab
Kevin McCarthy .... NMFS Miami
Luis. A. Rivera .... PR-DNER Fisheries Lab
Aida Rosario .... PR-DNER
Alexis Sabine .... USVI DPNR- Fish & Wildlife
Skyler Sagarese .... NMFS Miami
Veronica Seda .... PR-DNER Fisheries Lab
Robert Thomas .... USVI Fisher, STX
Orian Tzadik .... Pew Charitable Trusts
Carlos J. Velazques .... Commercial Fisherman, P.R.

Matthew Smith .... NMFS Miami

Attendees

Edgardo Ojeda.. PR SeaGrant

Alisha Gray .... NMFS St. Pete
Amanda Tyler-Jedlund .... FWRI St. Pete
Dominque Lazare .... FWC St. Pete
Mandy Taylor-Sedlord.. FWRI St.Pete

Mike Larkin..NOAA NMFA SERO

Staff
Julie Neer ....SEDAR
Graciela Garcia-Moliner ....CFMC

Additional Participants via Webinar
Bill Arnold .... NMFS SERO
Shannon Cass-Calay ....NMFS Miami
Nancie Cummings ....NMFS Miami
Kimberly Johnson... NOAA Miami
Beth Wrege ....NMFS Miami

1.4 LIST OF DATA WORKSHOP PAPERS AND REFERENCE DOCUMENTS

Document #	Title	Authors	Date Submitted
Documents Prepared for the Data Workshop			
SEDAR57-DW-01	Inventory of Fishery-Independent Programs and Survey Data Available for Stock Assessment of Caribbean Spiny Lobster in the US Caribbean	Skyler Sagarese, William Harford, Aida Rosario, Matt Johnson and Jay Grove	1 June 2018 Updated: 26 July 2018
SEDAR57-DW-02	Summary of Life History Information of Spiny Lobster for SEDAR 57	William Harford and Adyan Rios	6 June 2018 Updated: 18 Sept 2018
SEDAR57-DW-03	Building a Timeline of Major Socioeconomic Events Affecting Lobster Fisheries in Puerto Rico	Adyan Rios and Juan Agar	6 June 2018
SEDAR57-DW-04	Building a Timeline of Major Socioeconomic Events Affecting Lobster Fisheries in St. Croix USVI	Adyan Rios and Juan Agar	6 June 2018
SEDAR57-DW-05	Building a Timeline of Major Socioeconomic Events Affecting Lobster Fisheries in St. Thomas and St. John USVI	Adyan Rios and Juan Agar	6 June 2018

SEDAR57-DW-06	Summary of the Trip Interview Program data for Spiny Lobster from the US Caribbean	Adyan Rios, Skyler Sagarese, and William Harford	15 June 2018
Reference Documents			
SEDAR57-RD01	Line Point-Intercept (LPI) Survey Protocol for the U.S. Caribbean and Flower Garden Banks National Marine Sanctuary	National Coral Reef Monitoring Program (NCRMP), Coral Reef Conservation Program (CRCP), National Oceanic and Atmospheric Administration	
SEDAR57-RD02	Report of the US Caribbean Fishery-Independent Survey Workshop	Shannon L. Cass-Calay, William S. Arnold, Meaghan D. Bryan, Jennifer Schull	
SEDAR57-RD03	Working Towards a Framework for Stock Evaluations in Data-Limited Fisheries	Skyler R. Sagarese, Adyan B. Rios, Shannon L. Cass-Calay, Nancie J. Cummings, Meaghan D. Bryan, Molly H. Stevens, William J. Harford, Kevin J. McCarthy, and Vivian M. Matter	
SEDAR57-RD04	The United States Virgin Islands 2015 Comprehensive Economic Development Strategy		
SEDAR57-RD05	Report on the FAO/Danida/CFRAMP/WECAFC Regional Workshops on the assessment of the Caribbean Spiny Lobster (*Panulirus argus*)	Western Central Atlantic Fishery Commission	
SEDAR57-RD06	Population dynamics, ecology and behavior of spiny lobsters, *Panulirus argus*, of St. John, USVI: II Growth and Mortality	David A. Olsen and Ian G. Koblic	
SEDAR57-RD07	A review of the literature and life history study of Caribbean spiny lobster, *Panulirus argus*	Steven Saul	
SEDAR57-RD08	Maturity of spiny lobsters in the US Caribbean	David Die	
SEDAR57-RD09	A Collaborative Assessment of the Virgin Islands Spiny Lobster Fishery	David Olsen, Josh Nowlis, and Daryl Bryan	
SEDAR57-RD10	A study of the Virgin Islands Spiny Lobster Fishery: Growth, Population Size and Mortality	David Olsen, Josh Nowlis, and Daryl Bryan	

SEDAR57-RD11	Pilot Study of the Recreational Queen Conch (*Strombus gigas*) and Spiny Lobster (*Panulirus argus*) Fishery in Puerto Rico	Monica Valle-Esquivel and Robert J. Trumble
SEDAR57-RD12	Patterns of Spiny Lobster (*Panulirus argus*) Postlarval Recruitment in the Caribbean: A CRTR Project	MARK J. BUTLER, ANGELA M. MOJICA, ELOY SOSA-CORDERO, MARINES MILLET, PAUL SANCHEZ-NAVARRO, MIGUEL A. MALDONADO, JUAN POSADA, BLADIMIR RODRIGUEZ, CARLOS M. RIVAS, ADRIAN OVIEDO, MARCIO ARRONE, MARTHA PRADA, NICK BACH, NILDA JIMENEZ, MARIA DEL CARMEN GARCIA-RIVAS, KIRAH FORMAN, DONALD C. BEHRINGER, JR., THOMAS MATTHEWS, CLAIRE PARIS, and ROBERT COWEN
SEDAR57-RD13	Dependence of recruitment on parent stock of the spiny lobster, Panulirus argus, in Florida	NELSON M. EHRHARDT* AND MARK D. FITCHETT
SEDAR57-RD14	Larval Connectivity and the International Management of Fisheries	Andrew S. Kough, Claire B. Paris, Mark J. Butler IV
SEDAR57-RD15	Implications of the ecosystem approach to fisheries management in large ecosystems: The Caribbean spiny lobster, *Panulirus argus*, fisheries as a case	Nelson Ehrhardt, Rafael Puga and Mark Butler IV
SEDAR57-RD16	A pilot, cooperative fishery-independent trap survey of Saint Croix, United States Virgin Islands	Meaghan D. Bryan, Todd Gedamke, and John F. Walter
SEDAR57-RD17	USVI Caribbean Spiny Lobster Assessment	Shenell Gordon & Jason Vasques
SEDAR57-RD18	Activity and harvest patterns in the U.S. Virgin Islands recreational fisheries	Ivan Mateo, Ruth Gomez, K.Roger Uwate, Barbara Kojis, Dean C. Plaskett
SEDAR57-RD19	Recreational Fisheries Habitat Assessment for St.Thomas/St. John	Barry Volson, Shenell Gordon, Ginger Chapman, Gene Brin, George Green, Arthur Adams, and Joseph Barbel

2 LIFE HISTORY

2.1 STOCK DEFINITION AND DESCRIPTION

The Caribbean spiny lobster (hereafter referred to as spiny lobster), occurs in the Caribbean Sea, the Gulf of Mexico and the Western Central and South Atlantic Ocean. North Carolina marks its northernmost limit whereas Brazil marks its southernmost limit (Bliss 1982). The spiny lobster occurs from the extreme shallows of the littoral fringe to depths exceeding 100 meters (Kanciruk 1980; Munro 1974). CFMC (1981) reports that its distribution off Puerto Rico extends to the edge of the shelf, which is described as the 100−fathom contour (183 meters). Shallow areas with mangroves and seagrass (*Thalassia testudinum*) beds serve as nursery areas where available (Munro 1974). Generally, spiny lobsters move offshore when they reach reproductive size (Phillips et al. 1980). These animals are primarily carnivores, and serve as the major benthic carnivores in some ecosystems (Kanciruk 1980), feeding upon smaller crustaceans, mollusks and annelids (Cobb and Wang 1985).

RESEARCH RECOMMENDATIONS

- Research on stock structure is needed, particularly as it relates to connectivity caused by larval dispersal.
- Encountering the right habitat is important for survival of juvenile lobster recruits. Research should be conducted to explore effects of sargassum, water quality, coastal development, and mangrove root communities on the availability and quality of habitat for juvenile spiny lobsters.

2.2 LENGTH-WEIGHT CONVERSION

Length-weight conversions were estimated using the Trip Interview Program (TIP) database. TIP records were filtered according to island platform (Puerto Rico, St. Thomas and St. John, and St. Croix). Records were further filtered such that retained records consisted only of those with paired length-weight measurements that had reported units of measure (e.g., mm or kg) and corresponding measurement type (e.g., carapace length or whole weight). A subsequent evaluation of data entry and/or measurement errors led to the removal of 33, 55, and 1 records for Puerto Rico, St. Thomas/St. John, and St. Croix, respectively (Tables 2.1, 2.2, 2.3).

Length-weight relationships were fit as log-linear functions in the R statistical computing software (Quinn and Deriso 1999, R Development Core Team 2012). The relationship for length (mm CL) to weight (kg whole weight) is:

$$W = aL^b$$

Model fitting was carried out using linear regression on the log transformed equation:

$$log(W) = log(a) + b * log(L)$$

Analyses were carried out separately for males, females, and for both sexes combined. For Puerto Rico, data workshop participants requested L-W relationships to be evaluated spatially according to four regions (Table 2.4). L-W curves for the spatial analysis were subjected to a statistical test of coincident curves (Chen et al. 1992). The coincident curve test evaluates whether two or more curves are statistically distinct, through the calculation of an F-statistic.

Resulting L-W relationships are found in Table 2.5. For St. Thomas/St. John, a total of *n*=11,723 L-W observations were available from TIP (*n* male=6,692; *n* female=5,031) from 1980 to 2017 (Fig. 2.1). The largest individual by length was 203.2 mm CL (3.175 kg), while the largest individual by weight was 4.7 kg (200 mm CL). For St. Croix, a total of *n*=20,046 L-W observations were available from TIP (*n* male=11,684; *n* female=8,362) from 1981 to 2017 (Fig. 2.1). The largest individual by length was 212.2 mm CL (1.5 kg), while the largest individual by weight was 4.5 kg (183.5 mm CL). For Puerto Rico, a total of *n*=22,980 L-W observations were available from TIP (*n* male=12,019; *n* female=10,961) from 1980 to 2016 (Fig. 2.1). The largest individual by length was 196 mm CL (4.536 kg), which was also the largest individual by weight.

Spatial analysis of Puerto Rico L-W data according to four spatial areas suggested that L-W curves were not significantly different (p-value = 1.0; Table 2.6)).

RESEARCH RECOMMENDATIONS

- Explore plausibility of cause and effect mechanisms that may lead to temporal growth variation.

2.2 AGE AND GROWTH

During SEDAR 8, von Bertalanffy growth curves for males and females were obtained from Leon et al. (1994) for Cuba (SEDAR 2005). Since SEDAR 8, several additional publications have become available for von Bertalanffy growth curves from regions such as Cuba, Puerto Rico, and Mexico (Table 2.7). Also, during SEDAR 46 (Spiny lobster St. Thomas & St. Croix), von Bertalanffy growth parameters from Leon et al. (1995) were reviewed, noting similar values used in other stock assessment (i.e., Gongora 2010; Babcock et al. 2014). These point estimates were also compared to a more recent study by Leon et al. (2005) and analyses in SEDAR 46 were based on a single growth curve for both sexes. During the SEDAR 57 data workshop, participants identified a mark-recapture dataset from a study undertaken by the St. Thomas Fishermen’s Association (Olsen et al. 2017). At time of reporting writing, analysts are examining the feasibility of obtaining a growth curves from this study.

2.3 NATURAL MORTALITY

During SEDAR 8, various sources are referenced with respect to natural mortality, including Olsen and Koblic 1975, Medley and Ninnes 1996, and FAO 2001. Natural mortality was specified at 0.36 for adult lobsters and used for all ages during SEDAR 8. During SEDAR 46 (Spiny lobster St. Thomas & St. Croix), consideration was given to natural mortality estimates from tagging studies, with estimates typically occurring between 0.26 and 0.44 year^{-1} for adult spiny lobster, with the most reliable estimates suggested to be in the range of 0.30 to 0.40 (FAO 2001). A point estimate of 0.34, calculated from a variant of Pauly's equation, is also widely reported (Cruz et al. 1981). Point estimates based on longevity were also considered, but require evidence of maximum age, which is difficult to obtain for lobsters (Kanciruk 1980). This issue is reinforced by additional statements made by Olsen and Koblic (1975). Further discussion about spiny lobster longevity can be found on pg 27, SEDAR 46, Data & Assessment Workshop report (SEDAR 2016). Several spiny lobster stock assessments in the Caribbean have used 0.34 to 0.36 year^{-1} in base model runs (Cruz 2001; Gongora 2010; SEDAR 2005; Babcock et al. 2014). During the SEDAR 57 data workshop, participants identified a mark-recapture dataset from a study undertaken by the St. Thomas Fishermen's Association (Olsen et al. 2017). At time of reporting writing, analysts are examining the feasibility of obtaining a natural mortality estimate from this study.

2.4 MATURITY & FECUNDITY

Die (2005) estimated a logistic maturity curve from TIP prior to 1990, prior to which landing of berried females was permitted. Data from Puerto Rico, St. Thomas, and St. John were aggregated for the purpose of model fitting. Two model parameterizations were considered, in both cases, length at 50% maturity were similar being either 91 mm or 92 mm CL.

For SEDAR 8 (2005), fecundity-at-length was obtained for Cuba spiny lobster (FAO 2001):

$$E = 0.5911L^{2.9866},$$

Where E is number of eggs and L is carapace length in mm.

2.5 DISCARD MORTALITY

For SEDAR 57, discard mortality was deemed negligible. SEDAR 8 dead discards of spiny lobster were also assumed negligible (SEDAR 2005). Fishing with traps and diving are the two predominant gears used to capture spiny lobster in the U.S. Caribbean. Diving is generally considered a highly selective fishing gear, as such, all lobster caught by divers are assumed to be retained. Spiny lobsters that are discarded by the trap fishery include sublegal and berried lobsters. Discard mortality in the trap fishery can be associated with handling, exposure to sun, and post-release predation. Little is known about post-release predation mortality (DiNardo et al. 2001). Given the small scale nature of the trap fishery in the US Caribbean, mortality due to limited handling and sun exposure are assumed to be negligible.

RESEARCH RECOMMENDATIONS

- Investigate potentially unaccounted for discards in the self-reported commercial logbook data to be able to quantify the number of lobster discarded dead, as well as the number of lobster discarded alive.
- Research aimed at quantifying post-release mortality (including post-release predation) of spiny lobster to better understand and propose mechanisms that could potentially mitigate mortality among lobsters that are discarded.

2.6 TABLES

Table 2.1. Records manually removed from Puerto Rico TIP prior to L-W model fitting.

L	W	Sex
267	0.42	F
325	0.582	F
340	0.846	F
342	0.7	F
899	0.564	F
162	30.6	F
94	7.681	F
100	9.481	F
90	6.116	F
20.574	0.467	F
10	0.531	F
10	0.849	F

L	W	Sex
209	0.907	M
340	0.67	M
340	0.498	M
300	0.38	M
310	0.552	M
514	0.83	M
275	0.364	M
290	0.442	M
262	0.33	M
202	1.03	M
814	0.814	M
952	0.64	M
123	11.4	M
101	8.871	M
1	1.142	M
20.574	0.56	M
20.32	0.506	M
20.574	0.59	M
20.574	0.682	M
60.7	4.075	M
192	0.68	M

Table 2.2. Records manually removed from St. Thomas/St. John TIP prior to L-W model fitting.

L	W	Sex	L	W	Sex
114.3	0.003	F	63.5	0.003	M
101.6	0.002	F	88.9	0.002	M
107.95	0.003	F	88.9	0.002	M
107.95	0.003	F	120.65	0.003	M
88.9	0.002	F	120.65	0.004	M
107.95	0.003	F	127	0.004	M
82.55	0.002	F	114.3	0.003	M
114.3	0.003	F	114.3	0.002	M
107.95	0.003	F	95.25	0.002	M
101.6	0.002	F	101.6	0.002	M
101.6	0.002	F	107.95	0.002	M
114.3	0.003	F	95.25	0.002	M
127	0.004	F	107.95	0.002	M
152.4	0.007	F	101.6	0.002	M
133.35	0.004	F	101.6	0.002	M
120.65	0.003	F	95.25	0.002	M
133.35	0.004	F	95.25	0.002	M
95.25	0.002	F	158.75	0.006	M
88.9	0.002	F	146.05	0.006	M
95.25	0.002	F	114.3	0.003	M
120.65	0.003	F	133.35	0.004	M
114.3	0.003	F	107.95	0.002	M
82.55	0.002	F	101.6	0.002	M
120.65	0.003	F	114.3	0.003	M
107.95	0.002	F	120.65	0.003	M
88.9	0.002	F	101.6	0.002	M
101.6	0.002	F	107.95	0.003	M
101.6	0.002	F			

Table 2.3. Records manually removed from St. Croix TIP prior to L-W model fitting.

L	W	Sex
1005	0.775	M

Table 2.4. Spatial areas for Puerto length-weight relationships. Areas were defined by aggregating municipalities into 4 areas: east, west, north, and south.

County	Spatial area
CEIBA	EAST
CULEBRA	EAST
FAJARDO	EAST
HUMACAO	EAST
JUNCOS	EAST
LAS PIEDRAS	EAST
MAUNABO	EAST
NAGUABO	EAST
SAN LORENZO	EAST
VIEQUES	EAST
YABUCOA	EAST
AGUAS BUENAS	NORTH
ARECIBO	NORTH
BARCELONETA	NORTH
BAYAMON	NORTH
CAGUAS	NORTH
CAMUY	NORTH
CANOVANAS	NORTH
CAROLINA	NORTH
CATANO	NORTH
CIALES	NORTH
COMERIO	NORTH
COROZAL	NORTH
DORADO	NORTH
FLORIDA	NORTH
GUAYNABO	NORTH
GURABO	NORTH
HATILLO	NORTH
ISABELA	NORTH
LARES	NORTH
LOIZA	NORTH
LUQUILLO	NORTH
MANATI	NORTH
MOROVIS	NORTH
NARANJITO	NORTH
QUEBRADILLAS	NORTH
RIO GRANDE	NORTH
SAN JUAN	NORTH
TOA ALTA	NORTH

Table 2.4 Continued. Spatial areas for Puerto length-weight relationships. Areas were defined by aggregating municipalities into 4 areas: east, west, north, and south.

County	Spatial area
TOA BAJA	NORTH
TRUJILLO ALTO	NORTH
UTUADO	NORTH
VEGA ALTA	NORTH
VEGA BAJA	NORTH
ADJUNTAS	SOUTH
AIBONITO	SOUTH
ARROYO	SOUTH
BARRANQUITAS	SOUTH
CAYEY	SOUTH
CIDRA	SOUTH
COAMO	SOUTH
GUANICA	SOUTH
GUAYAMA	SOUTH
GUAYANILLA	SOUTH
JAYUYA	SOUTH
JUANA DIAZ	SOUTH
LAJAS	SOUTH
OROCOVIS	SOUTH
PATILLAS	SOUTH
PENUELAS	SOUTH
PONCE	SOUTH
SABANA GRANDE	SOUTH
SALINAS	SOUTH
SANTA ISABEL	SOUTH
VILLALBA	SOUTH
YAUCO	SOUTH
AGUADA	WEST
AGUADILLA	WEST
ANASCO	WEST
CABO ROJO	WEST
HORMIGUEROS	WEST
LAS MARIAS	WEST
MARICAO	WEST
MAYAGUEZ	WEST
MOCA	WEST
RINCON	WEST
SAN GERMAN	WEST
SAN SEBASTIAN	WEST

Table 2.5. Fitted conversion functions from length (mm CL) to weight (kg whole weight) by island platform.

Island platform	Years	n	a	b
St. Thomas / St. John				
Males	1980-2017	6,692	3.548E-05	2.204
Females	1980-2017	5,031	4.889E-05	2.138
Males + Females	1980-2017	11,723	4.166E-05	2.171
Puerto Rico				
Males	1980-2016	12,019	6.836E-06	2.536
Females	1980-2016	10,961	7.612E-06	2.521
Males + Females	1980-2016	22,980	7.831E-06	2.511
St. Croix				
Males	1981-2017	11,684	1.271E-05	2.413
Females	1981-2017	8,362	2.323E-05	2.290
Males + Females	1981-2017	20,046	1.821E-05	2.339

Table 2.6. Fitted conversion functions from length (mm CL) to weight (kg whole weight) for four areas of Puerto Rico. Spatial analysis of Puerto Rico L-W data according to four spatial areas suggested that L-W curves were not significantly different (p-value = 1.0).

	Years	Area	n	a	b
Both sexes	1980-2016	East	4,955	4.215E-06	2.630
	1980-2016	North	445	2.866E-05	2.211
	1980-2016	South	10,408	7.155E-06	2.535
	1980-2016	West	7,172	7.625E-06	2.521

Table 2.7. von Bertalanffy growth parameters, noting values used in SEDARs 8 and 46 (i.e., Leon et al. (1995)) and with emphasis on studies that have been subsequently produced.

Study	Region/Country	Source	Sex	L_∞ (mm)	K
Leon et al. (1995)	Cuba	Length frequency	M	184	0.24
			F	155	0.22
Leon et al. (2005)	Cuba	Length frequency	Both	184	0.24
Mateo (2004)	Puerto Rico	Length frequency	M (1999)	197	0.24
			M (2000)	195	0.24
			F (1999)	191	0.25
			F (2000)	185	0.23
Velaquez-Abunader et al. (2015)	Mexico, Yucatan	Length frequency	M	203	0.28
			F	189	0.34

2.7 FIGURES

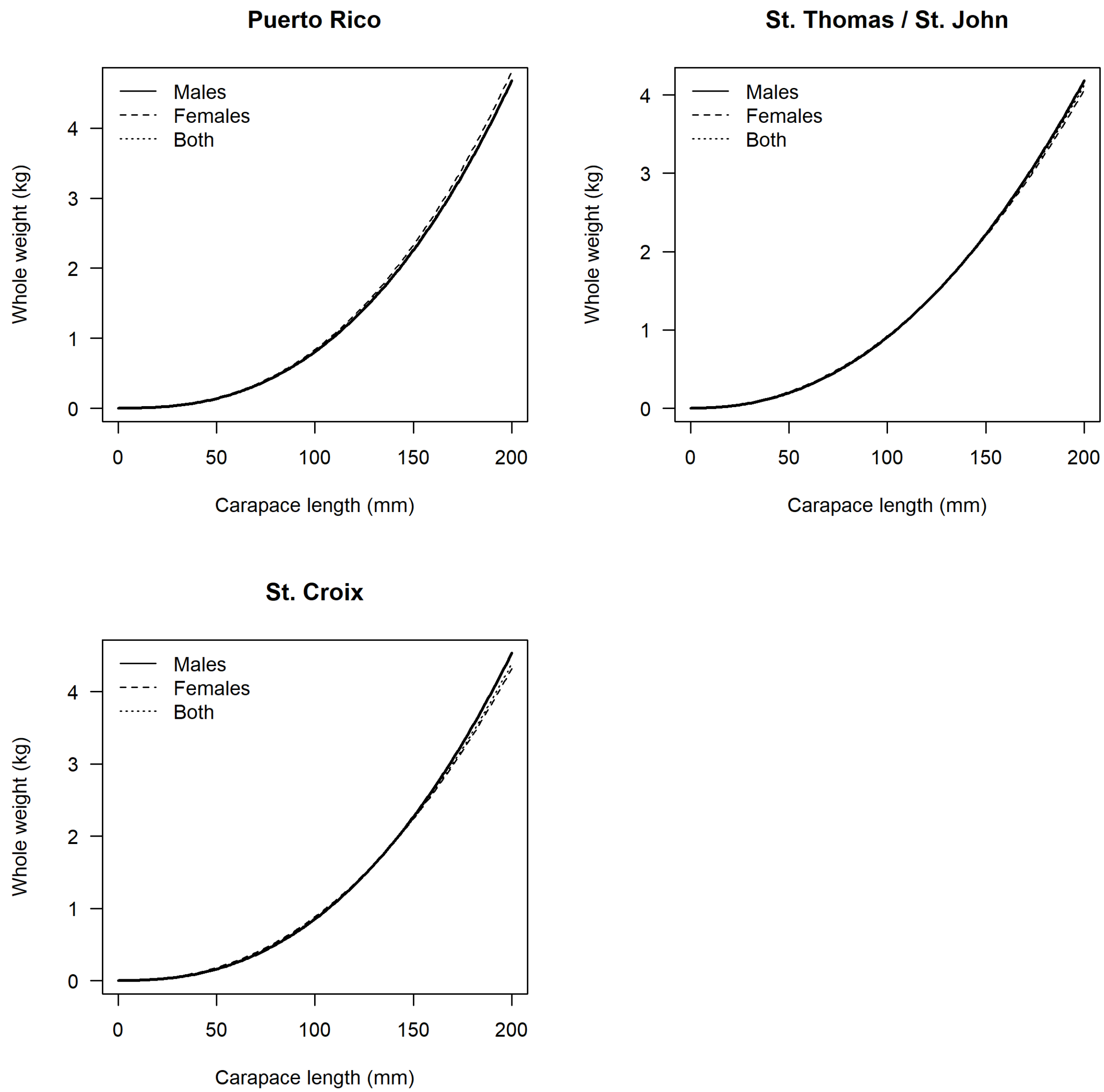

Figure 2.1. Length-weight curves for spiny lobster of Puerto Rico, St. Thomas/St. John, and St. Croix.

3 FISHERY-INDEPENDENT DATA SOURCES

3.1 OVERVIEW

Fishery independent monitoring surveys were examined for use in developing abundance indices and length compositions for spiny lobster. Data sources consulted included benthic transect surveys conducted by the National Centers for Coastal and Ocean Science (NCCOS), the National Coral Reef Monitoring Program (NCRMP), and the Puerto Rico Department of Natural and Environmental Resources (DNER), and larval/recruitment surveys conducted through SEAMAP-C. Other funded projects through academic grants were also explored for relevance to spiny lobster. At this time, none of the datasets were recommended for use in developing indices or length compositions for spiny lobster due to inconsistencies in methodology, limited temporal and spatial scales (i.e., not indexing the lobster population), and low overall sample sizes (see SEDAR57-DW-01 for details).

RESEARCH RECOMMENDATIONS

- Development of fishery-independent surveys that are specifically designed for spiny lobster, which would require considerable planning regarding data priorities (e.g., relative abundance versus length), the life stage to target (e.g., adult, juveniles, or larvae), type of gear, sampling design, temporal and spatial resolution, and the availability of funds. In addition to discussing field sampling, planning of how best to record and store data would be beneficial to future analyses and stock assessments.
- Research aimed at identifying correlations between larval and juvenile abundance from the SEAMAP-C surveys and lobster landings could assist in determining the relationship between juvenile abundance and adult abundance (e.g., Butler et al. 2010).

4 FISHERY-DEPENDENT DATA SOURCES

4.1 COMMERCIAL FISHERY STATISTICS

4.1.1 LANDINGS

PUERTO RICO

Commercial fishery landings data for Puerto Rico were available from self-reported fisher logbooks/sales receipts for the years 1983-2016. All landings reported as “spiny lobster” are assumed to be *Panulirus argus* and that reports of other species as “spiny lobster” (e.g., *P. guttatus*) were negligible. Commercial logbook reports also include information on fishing gear and fishing center where the catch was landed. Puerto Rico commercial landings have been incompletely reported (Caribbean Fisheries Data Evaluation Final Report, 2009) and required use of correction/expansion factors to estimate total landings. For the years 2003 to 2016, correction/expansion factors have been coast-specific (north, south, east, west). Estimation of commercial fishery landings of earlier years used a single, island-wide, expansion factor. Commercial landings are presented in this report by year and fishing gear used, but can be stratified by coast.

Puerto Rico expanded landings were estimated for each reported trip as:

trip-specific reported landings*year-specific expansion factor

Yearly total landings were estimated as the sum of all trip-specific expanded landings within each year. Estimation of landings for the most recent years (2003-2016) included year and coast-specific expansion factors. Reported landings were assigned to coast based upon the municipality of the fishing center reported for a trip and the appropriate correction/expansion factor used to estimate landings (Table 2.3).

Spiny lobster landings reported during the years 1983-2016 are provided in Table 4.1. Landings are provided by diving, fish traps, lobster traps, and other gear. Diving, fish traps, and lobster traps accounted for 95% of spiny lobster landings in Puerto Rico. Landings data in PR are also available by gear and coast (north, south, east, and west).

ST. THOMAS AND ST. JOHN

In the US Virgin Islands logbook landings data from the islands of St. Thomas and St. John were compiled separately from St. Croix. Logbook reporting began in July, 1974 with spiny lobster landings reported throughout the time series July, 1974-2016. Available data for summing commercial landings were the self-reported logbook records from commercial fishers. In the US Virgin Islands landings have been assumed to be fully reported and no correction/expansion factors have been used. All landings reported as "spiny lobster" are assumed to be *Panulirus argus*. Commercial spiny lobster landings data are provided, by year and gear, in Table 4.2 with landings totals beginning in 1975 (first full year of reported landings). Diving did not include trips reporting diving with nets. Pots and traps included trips reporting "pots and traps", "spiny lobster pots and traps", and "fish pots and traps". "Other gear" included all other gears. Diving and pots and traps accounted for 97% of spiny lobster landings in St. Thomas and St. John. Due to inconsistencies in area assignments over time, landings data by subregion are not available.

ST. CROIX

In St. Croix, logbook reporting began in July, 1975 with spiny lobster landings reported throughout the time series July, 1975-2016. Available data for summing commercial landings were the self-reported logbook records from commercial fishers. In the US Virgin Islands landings have been assumed to be fully reported and no correction/expansion factors have been used. All landings reported as "spiny lobster" are assumed to be *Panulirus argus*. Commercial spiny lobster landings data are provided, by year and gear, in Table 4.3 with landings totals beginning in 1976 (first full year of reported landings). Diving did not include trips reporting diving with nets. Pots and traps included trips reporting "pots and traps", "spiny lobster pots and traps", and "fish pots and traps". "Other gear" included all other gears. Diving and pots and traps accounted for 95% of spiny lobster landings in St. Croix. Landings data in St. Croix are also available by gear and coast (east and west).

RESEARCH RECOMMENDATIONS

- General data improvements are recommended, including continued reporting of specific gear categories (eg. different types of diving).
- Investigate the sensitivity of stock assessment results to landings data associated with high uncertainty.
- Investigate improvements or alternatives to past correction factors in Puerto Rico (2005 in particular).
- Continue SEFSC funded commercial landings validation studies in Puerto Rico and begin similar surveys in the US Virgin Islands.

4.1.2 DISCARDS

Commercial discard information includes the number of lobster discarded dead and the number of lobster discarded alive. For SEDAR 57, all legal spiny lobsters caught by commercial fisheries in the US Caribbean are assumed to be retained. Discards are assumed to include sublegal (less than 3.5-inch carapace length) and legal size berried female spiny lobsters. Consensus opinion during the data workshop was that discard mortality of spiny lobsters was negligible (See section 2.5), which is consistent with SEDAR 8. Due to the very small number of reported dead discards reported and the assumption that discard mortality was very low, dead discards were assumed to be insignificant relative to the landings.

- In Puerto Rico, discard information was reported during 2012-2013. Only 23 lobsters from 12 trips were reported as discarded dead.
- In St. Thomas and St. John. discard data were collected during the period July, 2011 to December, 2016. A total of 202 dead spiny lobster discards were reported during July, 2011 to December, 2015 from 51 trips. No dead discards of spiny lobster were reported during 2016.
- In St. Croix, Discard data were collected during the period July, 2011 to December, 2016. A total of 27 dead spiny lobster discards were reported during 2012 to 2014 from 5 trips. No dead discards of spiny lobster were reported during 2011, 2015, or 2016.

RESEARCH RECOMMENDATIONS

- General data improvements are recommended, including encouraging complete reporting of discards.

4.1.3 EFFORT

Puerto Rico

Commercial fishing trips reporting spiny lobster landings in Puerto Rico are summed by year and gear in Table 4.4. No correction factors for estimating total trips were available for Puerto Rico; correction factors were designed to more accurately estimate total landings. At time of report writing, analysts are examining the feasibility of obtaining detailed effort information (ex. hours fished, number of dives, number of traps) from the variables used to report effort on catch forms.

St. Thomas and St. John

Commercial fishing trips reporting spiny lobster landings in St. Thomas and St. John are summed by year and gear in Table 4.5. Available data for summing commercial trips were the self-reported logbook records from commercial fishers. In the US Virgin Islands, it was assumed that all trips had been reported and no correction/expansion factors have been used. At time of report writing, analysts are examining the feasibility of obtaining detailed effort information (ex. hours fished, number of dives, number of traps) from the variables used to report effort on catch forms.

St. Croix

Commercial fishing trips reporting spiny lobster landings in St. Croix are summed by year and gear in Table 4.6. Available data for summing commercial trips were the self-reported logbook records from commercial fishers. In the US Virgin Islands, it was assumed that all trips had been reported and no correction/expansion factors have been used. At time of report writing, analysts are examining the feasibility of obtaining detailed effort information (ex. hours fished, number of dives, number of traps) from the variables used to report effort on catch forms.

4.1.4 INDICES OF ABUNDANCE

At time of report writing, analysts are examining the feasibility of developing indices of abundance by standardizing catch per unit effort (CPUE) data associated with the main gear types for each island platform. In SEDAR 46, the CPUE data utilized in the assessment were calculated as pounds per trip, and nominal catch rates were developed across all trips associated with a given gear (SEDAR 46 data workshop report, 2016). For SEDAR 57, analysts are exploring the feasibility of using more detailed effort information (ex. hours fished, number of dives, number of traps) and attempting to standardize the CPUE data to remove the effect of factors that can bias the use of these data an index of stock abundance.

4.1.5 BIOLOGICAL SAMPLING

The NOAA Fisheries, Southeast Fisheries Science Center Trip Interview Program (TIP) is a port sampling program that collects data on individual size and weight, to complement information that is collected through the logbook reporting. Size frequency data, species composition information, and sometimes other biological information are collected. Information about fishing area, fishing gear, etc., is collected. Plots of the currently available length frequency data of spiny lobster sampled from the predominant gears in St. Croix, St. Thomas and Puerto Rico are included in SEDAR57-WP-07. Histograms of spiny lobster with carapace lengths greater than or equal to the 3.5-inch minimum size limit are summarized in Figures 4.1 to 4.4.

RESEARCH RECOMMENDATIONS

- Further explore TIP data for possible data entry and/or measurement errors, particularly regarding the number of individuals associated with a given length entry and associated with potentially miscoded species.

4.2 RECREATIONAL FISHERY STATISTICS

Fishery statistics of recreational spiny lobster removals are not available for any of the island-platforms in the US Caribbean. In Puerto Rico, recreational data (catch per unit effort, total effort, landings, and discards) were previously collected through the Marine Recreational Fisheries Statistical Survey (MRFSS). However, MRFSS sampling exclusively focused on finfish and the program permanently ended in mid-2017 (see SEDAR46-WP-07 for a summary of the MRFSS data in Puerto Rico from 2000 to 2014).

Two recent pilot studies have attempted to better characterize recreational fisheries in Puerto Rico (Valle-esquivel and Trumble 2016) and in St. Croix (Goedeke et al. 2016). Both studies documented difficulties associated with sampling non-commercial fisheries despite their recognized cultural importance in each region. In Puerto Rico, Valle-esquivel and Trumble reported that the non-commercial fishing consisted of a mixture of subsistence, recreational, and illegal (unlicensed) commercial fishing activities. They found that unlicensed commercial activity was more common than other types of non-commercial fishing, but they also reported that many anglers were reluctant to participate and they were only able to obtain limited interviews. In St. Croix, Goedeke et al. observed overall low numbers of shore-based fishing activity, but also concluded that other types of site-specific sampling (quantifying boat-based and charter activity in addition to shore-based fishing) or household surveys are needed in order to better characterize the fishery.

RESEARCH RECOMMENDATIONS

- Permanent programs that quantify the recreational effort and landings in the US Caribbean are needed. The results of recent pilot studies (Valle-esquivel and Trumble 2016 and Goedeke et al. 2016) should be used to develop future surveys.

4.3 STAKEHOLDER INPUT

Participation of constituents and stakeholders in the assessment process is encouraged at SEDAR workshops. Below is a list of topics that briefly summarize the large amount of participation and input provided by stakeholders and constituents during the SEDAR 57 data workshop

- Classification of gears
- Maximum observed size of spiny lobsters
- Socioeconomic and ecological major events (see SEDAR57-DW-03, SEDAR57-DW-04, and SEDAR57-DW-05 for details)
- Selectivity and retention
- Discards and discard mortality
- Willingness to assist in collaborative research

RESEARCH RECOMMENDATIONS

- Continue comprehensive bio-socio-economic database of events, compile references and time series of quantitative as available.
- Identify significant EBM quantitative socioeconomic indicators (ex. gravity of the market, network market analyses, population growth, tourism, poaching).

- A Caribbean-specific staff for data statistics and assessments was recommended to aid in establishing and maintaining high expertise of accessing and analyzing past, current, and future data collected in the region.

4.4 TABLES

Table 4.1. Puerto Rico commercial fishery spiny lobster landings in pounds whole weight by year and gear fished.

Year	Diving	Pots & Traps, Fish	Pots & Traps, Lobster	Other Gear	Total Landings
1983	411,152	6,967	29,723	533	448,375
1984	377,937	1,647	40,676	110	420,371
1985	135,045	205,441	24,295	11,862	376,643
1986	103,579	143,180	25,648	7,335	279,741
1987	63,907	117,139	19,624	3,937	204,607
1988	103,420	112,057	15,275	21,361	252,113
1989	130,163	187,920	29,647	15,849	363,578
1990	119,535	170,741	27,906	10,845	329,027
1991	157,369	196,280	28,976	31,910	414,535
1992	95,905	138,482	12,618	20,782	267,787
1993	122,438	129,230	7,598	22,095	281,362
1994	123,189	142,294	17,634	17,013	300,130
1995	165,879	159,783	34,320	32,776	392,758
1996	174,186	152,544	41,625	24,761	393,115
1997	151,788	131,171	53,253	26,722	362,933
1998	176,565	132,119	48,406	24,304	381,395
1999	169,829	173,735	40,505	33,768	417,837
2000	228,675	170,112	31,335	18,977	449,100
2001	200,381	152,037	47,776	11,381	411,575
2002	175,469	127,095	39,906	7,029	349,499
2003	162,243	160,839	45,057	27,757	395,896
2004	211,960	142,469	100,309	21,665	476,404
2005	275,463	321,458	166,061	11,564	774,546
2006	136,341	89,927	40,541	10,110	276,919
2007	153,751	76,168	27,673	8,193	265,784
2008	209,811	72,062	36,219	11,722	329,814
2009	199,333	84,398	33,097	6,286	323,113
2010	168,234	62,875	31,607	26,766	289,481
2011	172,881	29,907	66,506	3,942	273,235
2012	223,749	35,177	114,685	10,825	384,435
2013	177,282	7,222	75,042	15,772	275,319
2014	220,391	39,767	92,053	23,873	376,084
2015	236,250	76,764	81,726	22,856	417,596
2016	237,335	120,407	62,509	25,819	446,070

Table 4.2. St. Thomas and St. John commercial fishery lobster landings in pounds whole weight by year and gear fished.

Year	Diving	Pots and Traps	Other Gear	Total Landings
1975	1,812	4,460	524	6,796
1976	612	4,897	1,233	6,742
1977	4,497	14,806	159	19,462
1978	7,738	48,873	1,821	58,432
1979	3,330	24,045	2,010	29,385
1980	1,555	28,078	6,455	36,088
1981	2,660	33,112	2,296	38,068
1982	2,632	32,801	1,228	36,661
1983	3,374	32,026	741	36,141
1984	4,612	30,680	688	35,979
1985	3,652	24,413	1,293	29,358
1986	3,710	16,987	2,940	23,637
1987	4,320	35,299	1,049	40,667
1988	5,116	48,066	1,501	54,682
1989	3,104	53,859	1,895	58,858
1990	4,733	54,762	18,343	77,837
1991	6,920	46,031	1,849	54,800
1992	3,631	80,696	2,125	86,451
1993	5,172	77,258	832	83,261
1994	3,038	57,887	849	61,773
1995	2,954	63,234	1,202	67,390
1996	5,202	81,821	1,014	88,037
1997	4,689	89,772	637	95,097
1998	3,185	69,615	916	73,715
1999	5,208	70,271	345	75,823
2000	4,547	71,427	179	76,153
2001	7,573	80,815	1,323	89,711
2002	11,901	103,840	231	115,972
2003	9,650	125,486	156	135,292
2004	3,223	130,574	185	133,982
2005	2,884	114,544	7,216	124,643
2006	3,516	111,826	20,686	136,027
2007	2,786	101,199	15,656	119,641
2008	2,423	107,795	247	110,465
2009	4,163	111,014	586	115,762
2010	1,740	110,370	2,468	114,577
2011	1,758	79,185	3,359	84,302
2012	987	81,767	403	83,157
2013	431	83,068	734	84,233
2014	494	91,338	429	92,261
2015	1,079	108,171	205	109,455
2016	1,388	119,817	490	121,695

Table 4.3. St. Croix commercial fishery spiny lobster landings in pounds whole weight by year and gear fished.

Year	Diving	Pots and Trips	Other Gear	Total Landings
1976	Confidential data	1,925	250	2,175
1977	Confidential data	2,350	4,051	6,401
1978	3,440	1,066	475	4,981
1979	354	1,754	Confidential data	2,108
1980	469	307	512	1,288
1981	874	604	626	2,104
1982	1,321	1,141	230	2,692
1983	1,231	2,770	479	4,480
1984	5,696	1,466	403	7,564
1985	3,421	753	252	4,426
1986	1,696	3,465	809	5,970
1987	6,683	5,025	1,324	13,032
1988	4,252	2,842	918	8,012
1989	1,339	851	Confidential data	2,190
1990	15,777	2,493	1,202	19,472
1991	28,015	5,230	4,002	37,246
1992	13,604	4,021	3,507	21,132
1993	25,279	6,988	4,909	37,176
1994	22,993	4,266	2,531	29,790
1995	18,192	4,431	2,406	25,029
1996	25,021	2,084	1,739	28,843
1997	30,304	4,175	1,470	35,949
1998	36,128	3,457	3,206	42,790
1999	45,373	6,501	1,455	53,329
2000	81,706	4,258	3,056	89,020
2001	108,462	3,516	4,641	116,619
2002	109,018	3,885	3,370	116,273
2003	100,541	3,231	2,268	106,039
2004	118,588	3,901	2,926	125,415
2005	115,703	2,564	2,663	120,929
2006	140,597	3,993	2,002	146,592
2007	148,271	5,478	14,256	168,005
2008	140,552	4,226	3,225	148,003
2009	141,161	3,927	4,820	149,908
2010	123,867	8,575	7,243	139,685
2011	84,963	15,708	9,080	109,751
2012	66,094	15,454	5,450	86,997
2013	49,563	6,010	3,825	59,398
2014	30,524	2,564	6,636	39,724
2015	35,956	5,655	3,352	44,963
2016	27,383	951	3,248	31,582

Table 4.4. Puerto Rico commercial trips reporting spiny lobster landings by year and gear fished.

Year	Diving	Pots and traps, fish	Pots and traps, lobster	Other Gear	Total Trips
1983	23,256	352	776	48	24,432
1984	22,788	829	822	36	24,475
1985	6,588	11,248	472	879	19,187
1986	4,842	5,286	552	704	11,384
1987	2,831	4,394	413	305	7,943
1988	3,327	4,030	421	794	8,572
1989	3,434	5,722	560	386	10,102
1990	2,942	6,314	533	907	10,696
1991	5,010	8,093	740	1,138	14,981
1992	3,373	4,373	325	872	8,943
1993	4,879	4,948	445	1,224	11,496
1994	5,942	6,085	647	1,114	13,788
1995	8,752	9,786	1,220	1,613	21,371
1996	9,632	11,132	1,200	1,900	23,864
1997	8,773	8,345	1,199	1,651	19,968
1998	9,784	8,104	1,282	1,054	20,224
1999	10,235	10,347	1,378	1,671	23,631
2000	8,516	7,797	1,136	1,182	18,631
2001	9,169	6,924	1,753	1,042	18,888
2002	9,148	6,633	1,978	677	18,436
2003	5,481	3,788	1,094	625	10,988
2004	5,784	2,732	1,079	593	10,188
2005	5,198	1,950	1,135	424	8,707
2006	5,702	1,831	912	753	9,198
2007	5,620	1,442	571	523	8,156
2008	5,510	1,108	618	488	7,724
2009	5,932	1,400	830	293	8,455
2010	4,768	1,075	971	432	7,246
2011	6,933	1,008	1,123	236	9,300
2012	7,417	840	1,707	495	10,459
2013	8,190	235	2,044	716	11,185
2014	8,375	671	1,859	975	11,880
2015	8,247	1,450	1,542	928	12,167
2016	7,412	1,856	1,157	904	11,329

Table 4.5. St. Thomas and St. John commercial trips reporting spiny lobster landings by year and gear fished.

Year	Diving	Pots and Trips	Other Gear	Total Trips
1975	20	62	3	85
1976	53	195	20	268
1977	15	163	13	191
1978	70	400	7	477
1979	131	586	29	746
1980	90	525	28	643
1981	54	436	37	527
1982	80	493	64	637
1983	68	461	65	594
1984	120	443	64	627
1985	187	385	48	620
1986	154	499	36	689
1987	121	404	83	608
1988	137	516	59	712
1989	152	661	39	852
1990	127	617	34	778
1991	108	761	71	940
1992	138	768	63	969
1993	124	1,184	71	1,379
1994	200	1,056	28	1,284
1995	162	939	28	1,129
1996	115	905	28	1,048
1997	160	1,002	26	1,188
1998	190	1,121	26	1,337
1999	98	1,004	32	1,134
2000	153	1,059	8	1,220
2001	165	1,046	7	1,218
2002	232	1,157	23	1,412
2003	295	1,276	12	1,583
2004	253	1,439	12	1,704
2005	102	1,609	6	1,717
2006	81	1,468	56	1,605
2007	100	1,249	146	1,495
2008	76	1,219	133	1,428
2009	100	1,347	6	1,453
2010	120	1,269	8	1,397
2011	76	1,157	23	1,256
2012	89	971	29	1,089
2013	64	1,002	13	1,079
2014	31	965	23	1,019
2015	27	902	12	941
2016	60	965	8	1,033

Table 4.6. St. Croix commercial trips reporting spiny lobster landings by year and gear fished.

Year	Diving	Pots and Trips	Other Gear	Total Trips
1976	Confidential data	108	7	115
1977	Confidential data	85	19	104
1978	101	41	15	157
1979	16	67	Confidential data	83
1980	27	24	15	66
1981	43	33	14	90
1982	45	71	9	125
1983	41	180	24	245
1984	185	132	28	345
1985	121	59	13	193
1986	67	131	37	235
1987	268	191	69	528
1988	173	88	41	302
1989	50	46	Confidential data	96
1990	390	128	48	566
1991	814	192	60	1,066
1992	409	176	116	701
1993	761	296	140	1,197
1994	696	137	101	934
1995	707	177	103	987
1996	905	136	111	1,152
1997	1,064	175	146	1,385
1998	1,153	154	212	1,519
1999	1,326	225	105	1,656
2000	2,186	190	190	2,566
2001	2,913	112	261	3,286
2002	3,115	113	206	3,434
2003	3,093	101	125	3,319
2004	3,341	94	155	3,590
2005	3,298	137	132	3,567
2006	3,837	141	116	4,094
2007	3,864	215	396	4,475
2008	3,417	135	143	3,695
2009	3,599	93	154	3,846
2010	3,148	170	221	3,539
2011	2,021	200	298	2,519
2012	1,658	188	198	2,044
2013	1,329	113	142	1,584
2014	761	68	240	1,069
2015	822	97	89	1,008
2016	707	40	87	834

4.5 FIGURES

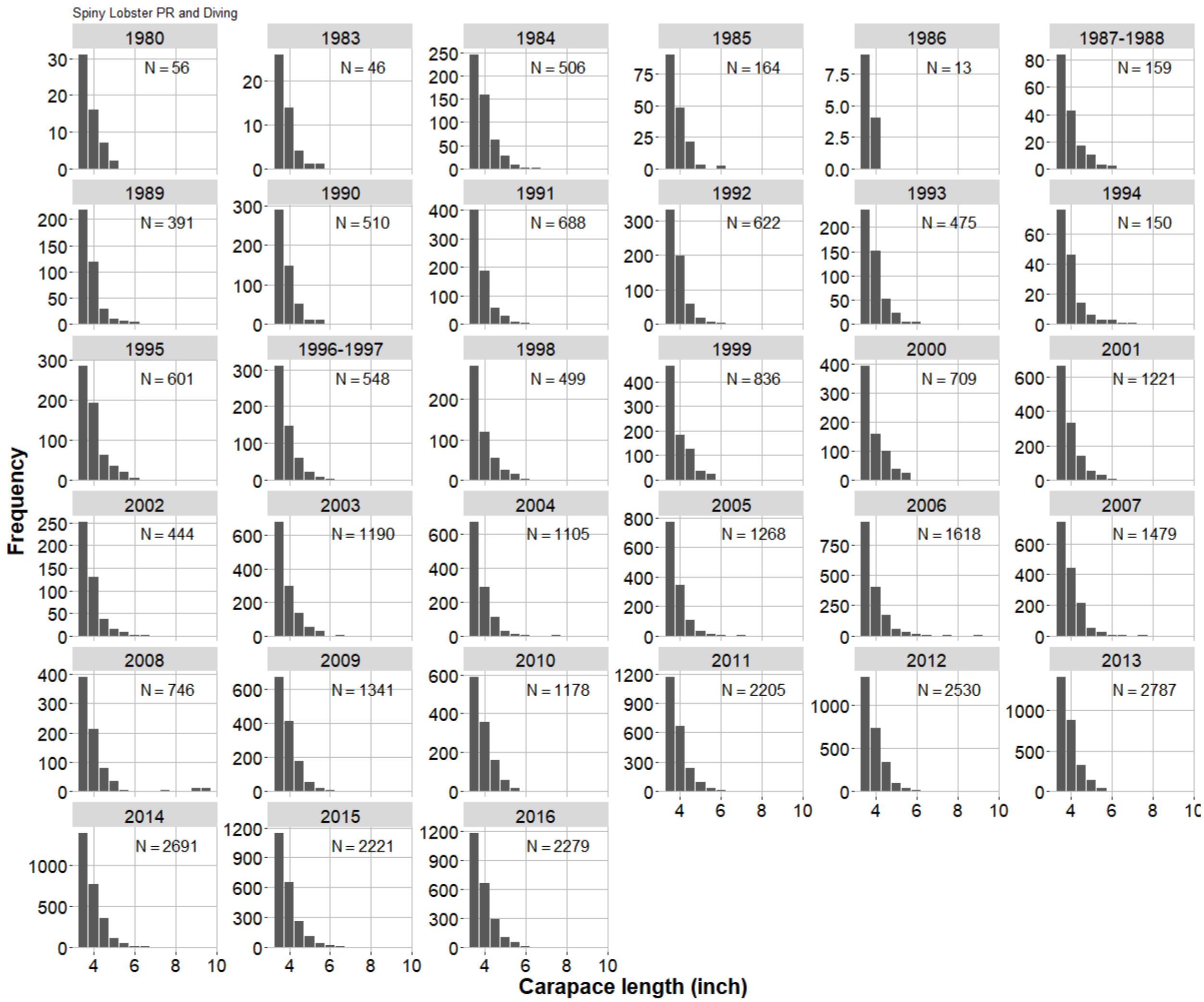

Figure 4.1. Spiny lobster length frequency associated with diving in Puerto Rico. N indicates the number of lengths per year (or years). Years are aggregated as necessary to meet confidentiality requirements. Each bar represents a 0.5-inch length bin. Partial years of data (2017) are excluded.

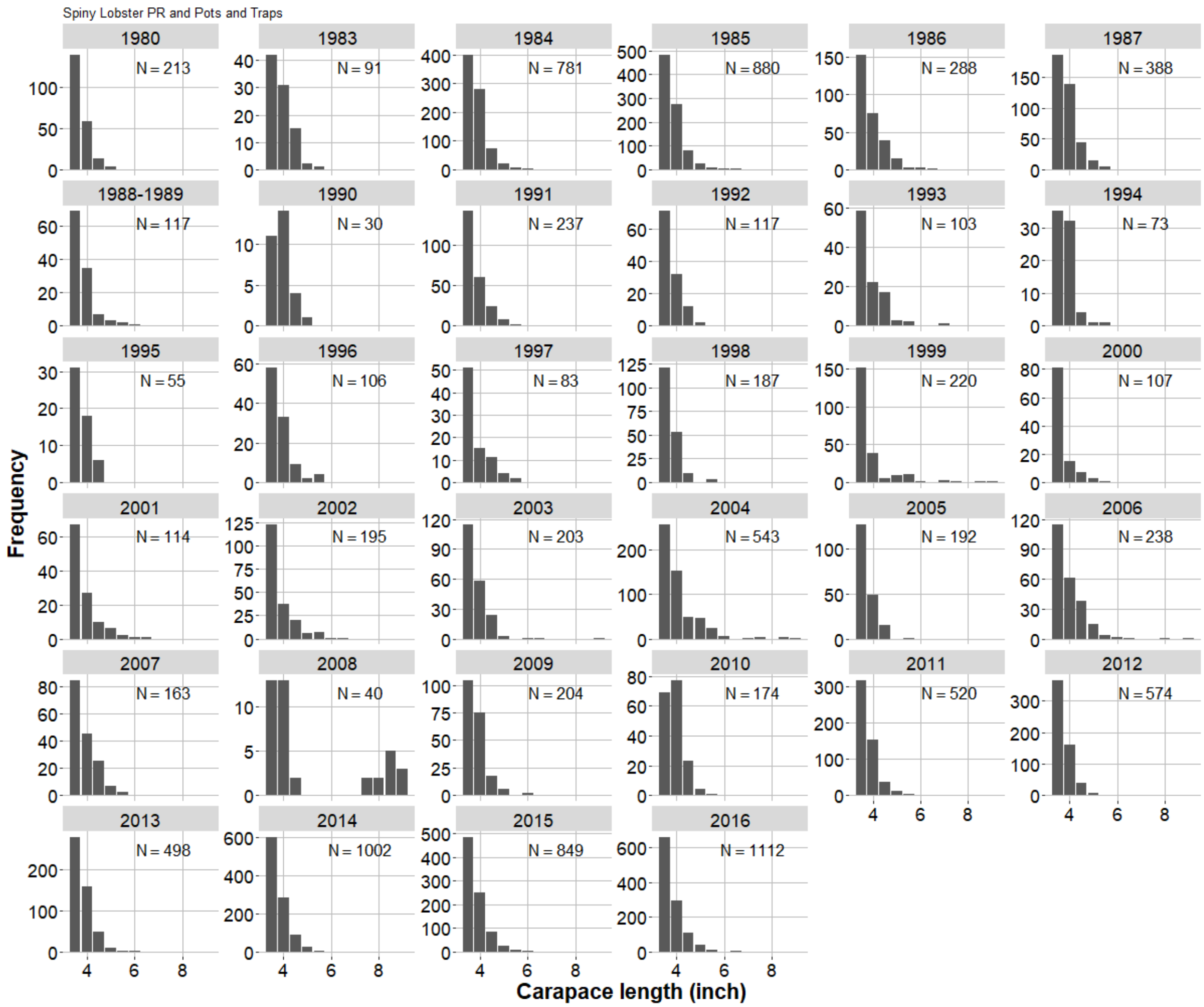

Figure 4.2. Spiny lobster length frequency associated with pots and traps in Puerto Rico. N indicates the number of lengths per year (or years). Years are aggregated as necessary to meet confidentiality requirements. Each bar represents a 0.5-inch length bin. Partial years of data (2017) are excluded.

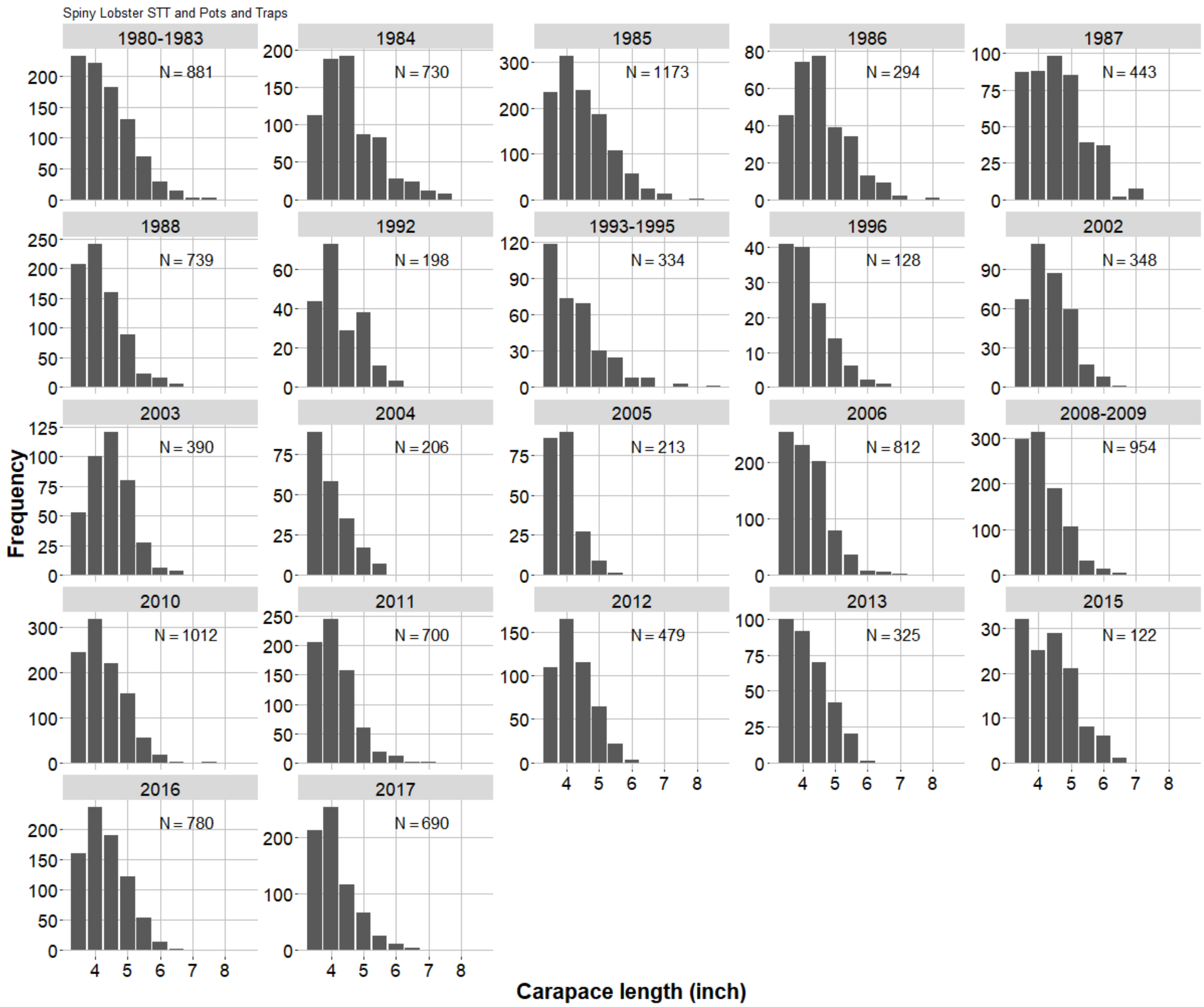

Figure 4.2. Spiny lobster length frequency associated with pots and traps in St. Thomas/St. John. N indicates the number of lengths per year (or years). Years are aggregated as necessary to meet confidentiality requirements. Each bar represents a 0.5-inch length bin.

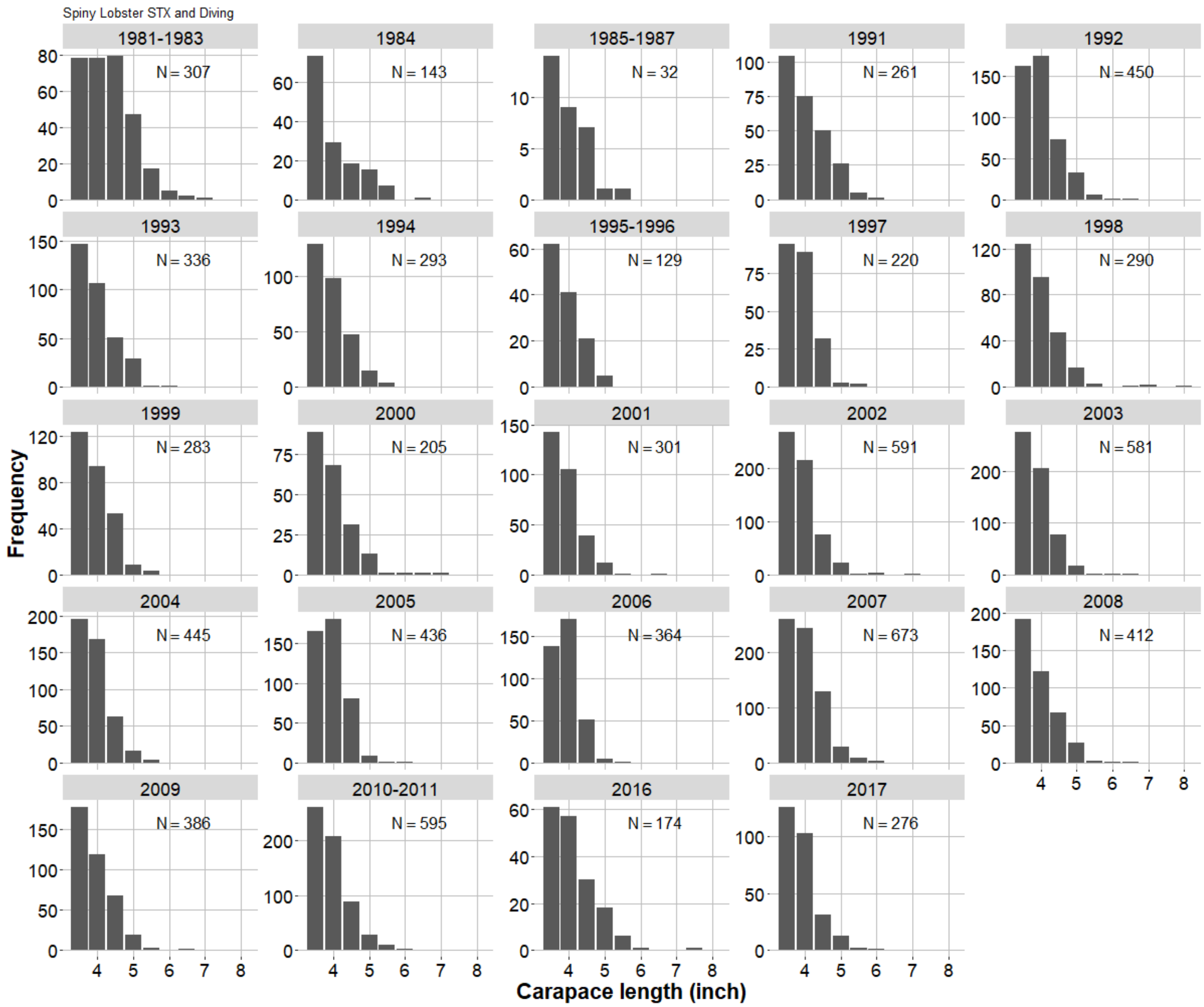

Figure 4.3. Spiny lobster length frequency associated with diving in St. Croix. N indicates the number of lengths per year (or years). Years are aggregated as necessary to meet confidentiality requirements. Each bar represents a 0.5-inch length bin.

5 RESEARCH RECOMMENDATIONS

LIFE HISTORY

- Research on stock structure is needed, particularly as it relates to connectivity caused by larval dispersal.

- Encountering the right habitat is important for survival of juvenile lobster recruits. Research should be conducted to explore effects of sargassum, water quality, coastal development, and mangrove root communities on the availability and quality of habitat for juvenile spiny lobsters.

- Explore plausibility of cause and effect mechanisms that may lead to temporal growth variation.

- Investigate potentially unaccounted for discards in the self-reported commercial logbook data to be able to quantify the number of lobster discarded dead, as well as the number of lobster discarded alive.

- Research aimed at quantifying post-release mortality (including post-release predation) of spiny lobster to better understand and propose mechanisms that could potentially mitigate mortality among lobsters that are discarded.

FISHERY-INDEPENDENT

- Development of fishery-independent surveys that are specifically designed for spiny lobster, which would require considerable planning regarding data priorities (e.g., relative abundance versus length), the life stage to target (e.g., adult, juveniles, or larvae), type of gear, sampling design, temporal and spatial resolution, and the availability of funds. In addition to discussing field sampling, planning of how best to record and store data would be beneficial to future analyses and stock assessments.

- Research aimed at identifying correlations between larval and juvenile abundance from the SEAMAP-C surveys and lobster landings could assist in determining the relationship between juvenile abundance and adult abundance (e.g., Butler et al. 2010)

FISHERY-DEPENDENT

- General data improvements are recommended, including continued reporting of specific gear categories (eg. different types of diving).

- Investigate the sensitivity of stock assessment results to landings data associated with high uncertainty.

- Investigate improvements or alternatives to past correction factors in Puerto Rico (2005 in particular).

- Continue SEFSC funded commercial landings validation studies in Puerto Rico and begin similar surveys in the US Virgin Islands.

- General data improvements are recommended, including encouraging complete reporting of discards.

- Further explore TIP data for possible data entry and/or measurement errors, particularly regarding the number of individuals associated with a given length entry and associated with potentially miscoded species.

- Permanent programs that quantify the recreational effort and landings in the US Caribbean are needed. The results of recent pilot studies (Valle-esquivel and Trumble 2016 and Goedeke et al. 2016) should be used to develop future surveys.

- Continue comprehensive bio-socio-economic database of events, compile references and time series of quantitative as available.

- Identify significant EBM quantitative socioeconomic indicators (ex. gravity of the market, network market analyses, population growth, tourism, poaching).

- A Caribbean-specific staff for data statistics and assessments was recommended to aid in establishing and maintaining high expertise of accessing and analyzing past, current, and future data collected in the region.

OVERALL

- Where possible, the research recommended above should consider ecosystem linkages toward developing capacity in the region for ecosystem based fisheries management.

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SEDAR

Southeast Data, Assessment, and Review

SEDAR 57

U.S. Caribbean Spiny Lobster

SECTION III: Assessment Process Report

April 2019

SEDAR
4055 Faber Place Drive, Suite 201
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NOTE: Additional analyses were conducted during the Review Workshop. Please see that report section (Section V) and the Addendum documenting those analyses (Section VI) for Final results.

1. EXECUTIVE SUMMARY

This report documents three stock assessments for Caribbean spiny lobsters in St Croix, St Thomas/St John and Puerto Rico using an integrated length and age-based stock assessment (Stock Synthesis) method. The assessment takes a structured approach to evaluating whether the data allows for advice utilizing data-moderate levels of assessment complexity (resulting in quantitative overfishing limits and absolute stock status derived from estimation of key parameters) or a more data-limited level of assessment complexity (providing relative status advice based on equilibrium metrics).

The approach uses sex and gear-specific carapace length data collected over 35-40 years coupled with fishery landings that can be traced back to almost the start of the commercial fishery for St Thomas and St Croix. The Puerto Rico fishery was established prior to the availability of landings reports. Fishery selectivity is estimated for St Thomas. Then these selectivity estimates are used as informative priors in assessments of St. Croix and Puerto Rico. This island-based approach facilitates borrowing information from one island's fishery to help guide modeling of the other island's fisheries, including selectivity and life history information. The assessments do not rely on indices abundance because of concerns regarding the reliability of fishery-dependent indices and the paucity of reliable surveys. Further, the approach made the following assumptions: that recreational removals are either negligible (or constant) over time (for each island); that, for Puerto Rico, initial fishing mortality in 1983, which was the start of the data time series, is greater than zero, requiring estimation; and, that there is little uncertainty in total commercial removals. Far stronger assumptions regarding commercial and recreational removals are made in the Annual Catch Limit (ACL) advice that uses simply average recent catches.

The models all generally pass diagnostic criteria necessary for consideration for providing advice on stock status and overfishing limits. As proxies for maximum sustainable yield have not yet been determined, placeholder proxies of SPR (ratio of biomass per recruit compared to virgin conditions) of 30% are herein entertained. Final selection of the proxy should be made by the Caribbean Council Scientific and Statistical Committee. Stock status estimates relative to the Minimum Sustainable Stock Size (MSST) of 75% of SPR30% indicate that neither island stock is overfished and that neither stock is undergoing overfishing.

Given the data inputs (landings, size composition information) these models likely qualify for providing advice utilizing the data-moderate level of assessment complexity.

2. INTRODUCTION

This document summarizes the SEDAR 57 assessment of U.S. Caribbean Spiny Lobster *Panulirus argus* using data inputs through 2016 as implemented in the Stock Synthesis 3.3 modeling framework (Methot and Wetzel 2013).

2.1 Workshop Time and Place

The SEDAR 57 assessment of U.S. Caribbean Spiny Lobster was conducted via a series of webinars held between March 2018 and November 2018.

2.2 Terms of Reference

Assessment Process Terms of Reference:

1. Develop and apply assessment tools that are compatible with available data and document input data, model assumptions and configuration, and equations for each approach considered.

    a. Evaluate candidate assessment tools considering the relative reliability of the data inputs.

    b. Provide recommendations for status determination criteria consistent with the available data, applicable FMPs and National Standards (if possible considering the data limited nature of this assessment).

    c. Provide declarations of stock status relative to status determination criteria and the overfishing limit (OFL) to the extent possible given the available data.

    d. Characterize assessment uncertainty including (as possible) input data, modeling approach and estimated parameters to guide subsequent determinations of allowable biological catch (ABC).

2. Provide recommendations for future research and data collection.

3. Provide an Assessment Workshop Report in accordance with project schedule deadlines.

2.3 List of Participants

Assessment Panel

Adyan Rios, Lead Analyst ....NMFS Miami
Bill Harford, Analyst ....RSMAS
J.J. Cruz- Motta...Dept. Marine Science, UPR/CFMC SSC
Nancie Cummings...NMFS Miami
Jorge Garcia ....Reef Research/CFMC SSC
Walter Keithly..LSU/CFMC SSC
Daniel Matos Caraballo ....PR-DNER Fisheries Lab
Kevin McCarthy...NMFS Miami
Aida Rosario .... PR-DNER
Skyler Sagarese...NMFS Miami
Orian Tzadik ....Pew Charitable Trusts

Appointed Observers

Julian Magras .... Commercial Fisher STT/STJ

Staff

Julie Neer .... SEDAR
Graciela Garcia-Moliner .... CFMC

Additional Participants via Webinar

Bill Arnold .... NMFS SERO
Shannon Cass-Calay ....NMFS Miami
Doug Gregory .... CFMC SSC
Kimberly Johnson ....NMFS Miami
Maria Lopez-Mercer .... NMFS SERO
Beth Wrege ....NMFS Miami

2.4 List of Assessment Workshop Working Papers and Reference Documents

Document #	Title	Authors	Date Submitted
Documents Prepared for the Assessment Process			
SEDAR57-AP-01	Efficacy of TIP length composition for use in length-based mortality estimation	William Harford and Adyan Rios	24 September 2018 Updated: 16 April 2019
SEDAR57-AP-02	Reliability testing of non-equilibrium mean length mortality estimation routines	Victoria P. Simmons, Quang C. Huynh, Elizabeth A. Babcock, and William J. Harford	3 November 2018
Reference Documents			
SEDAR57-RD20	Environmental Impact Statement/Fishery Management Plan and Regulatory Impact Review for the Spiny Lobster Fishery of Puerto Rico and the U.S. Virgin Islands	CFMC/NMFS	

2.5 Assessment History

Previous stock assessments for Spiny Lobster in the US Caribbean have attempted to quantify stock status using both traditional as well as data-limited stock assessment procedures. Morris et al. (2004) and SEDAR (2005A) provide assessment histories that summarize various traditional assessments (e.g. stock production analyses (ASPIC), CPUE examinations, yield per recruit, landings and length frequency). SEDAR (2016) explored the use of multiple data-limited models and management procedures (e.g. abundance-, index-, depletion-based methods) and was the most recent data-limited assessment prior to the current assessment. To date, nearly all evaluations have resulted in unsatisfactory determination of stock status. The table below provides the references of past assessments.

Spiny Lobster Stock Units Assessed	**Assessment Method**	**Assessment Reference**
St. Thomas/St. John trap fishery St. Croix dive fishery	Comparison of multiple data-limited models	SEDAR 2016
US Caribbean	Surplus production model (ASPIC)	SEDAR 2005A
US Caribbean	Yield per recruit analysis	Mateo 2004
Puerto Rico	Dynamic production model	Mateo and Die 2004
US Caribbean	Examining landings and length frequency	Bolden 2001
St. Croix	Surplus production model (Schaefer & Fox)	Mateo and Tobias 2000
Puerto Rico	Examining CPUE and length frequency	Matos-Caraballo 1999
US Caribbean	Examining landings and CPUE	Bohnsack et al. 1990

3. INPUT DATA

3.1 Stock structure and Management Unit

Stock assessments were conducted separately for three island platforms: St. Croix USVI, St. Thomas and St. John USVI, and Puerto Rico. The Fishery Management Plan for the Spiny Lobster Fishery of Puerto Rico and U.S. Virgin Islands and territorial regulations in each of Puerto Rico and the U.S. Virgin Islands allocate catch limits according to three island management areas also referred to as island platforms: Puerto Rico, St. Croix, and St. Thomas/St. John.

3.2 Life History Parameters

3.2.1 Natural Mortality

A point estimate of 0.34 $year^{-1}$ was used for all age classes, for each island platform. The SEDAR 57 Data Workshop Report outlines a variety of sources of natural mortality information, which have been obtained mainly from mark-recapture studies. Longevity-based estimates of natural mortality require evidence of maximum age, which is difficult to obtain for lobsters. During SEDAR 46 (Spiny lobster St. Thomas & St. Croix; SEDAR 2016), consideration was given to natural mortality estimates from tagging studies, with estimates typically occurring between 0.26 and 0.44 $year^{-1}$ for adult spiny lobster, with the most reliable estimates suggested to be in the range of 0.30 to 0.40 (FAO 2001). A point estimate of 0.34, calculated from a variant of Pauly's equation, is also widely reported (Cruz et al. 1981), and several spiny lobster stock assessments in the Caribbean have used 0.34 to 0.36 year^{-1} in base model runs (SEDAR 2005A, SEDAR 2005B, González-Yáñez et al. 2006, Gongora 2010, Babcock et al. 2014).

3.2.2 Release Mortality

During the SEDAR 57 Data Workshop, panelists agreed that discard mortality was deemed negligible. SEDAR 8 dead discards of spiny lobster were also assumed negligible. Fishing with traps and diving are the two predominant gears used to capture spiny lobster in the U.S. Caribbean. Diving is generally considered a highly selective fishing gear, as such, all lobster caught by divers are assumed to be retained. Spiny lobsters that are discarded by the trap fishery include sublegal and berried lobsters. Discard mortality in the trap fishery can be associated with handling, exposure to sun, and post-release predation. Little is known about post-release predation mortality (DiNardo and DeMartini 2002). Given the small scale nature of the trap fishery in the US Caribbean, mortality due to limited handling and sun exposure are assumed to be negligible.

3.2.3 Reproduction

For each island platform, fecundity-at-length was:

$$E = 0.5911 L_{CL}^{\ 2.9866},$$

where E is eggs per female and L_{CL} is carapace length. This relationship was obtained for SW Cuba spiny lobster (FAO 2001), and was also used in SEDAR 8.

Die (2005) evaluated maturity from TIP prior to 1990; a period during which landing of berried females was permitted. Data from Puerto Rico, St. Thomas, and St. John were aggregated in producing a logistic maturity curve. Parameter estimates were derived by Die (2005) in relation to growth in inches. These parameters were re-calculated in mm for SEDAR 57. Logistic growth was modeled as:

$$mat = \frac{1}{\left(1 + exp\left(\alpha(L_{CL} - L_{50})\right)\right)},$$

where α is the slope and L_{50} is the length at 50% maturity, with values of -0.102 and 92 mm, respectively.

3.2.4 Growth

Discussions during the SEDAR 57 assessment webinars highlighted the availability of von Bertalanffy growth parameters for Puerto Rico (Mateo 2004); however, these discussions also highlighted a lack of availability of growth parameters for St. Croix and for St. Thomas/St. John. The panel considered the use of a variety of growth curves, including those from spiny lobster stocks of Puerto Rico, Cuba, and/or Mexico (Leon et al. 1995, Velazquez-Abunader et al. 2015).

The panel adopted the use of Puerto Rico growth parameters for St. Croix and for St. Thomas/St. John. This decision is supported by a comparison between the growth trajectory represented by Puerto Rico growth parameters and the trajectories of individual lobsters observed during the St. Thomas Fishermen's association mark-recapture study (Figure 1). The mark-recapture study led by the St. Thomas Fishermen's association provided useful information for selecting an appropriate growth function for St. Thomas/St. John and for St. Croix (Olsen et al. 2017). An attempt was also made to directly obtain von Bertalanffy growth parameters from the mark-recapture study; however, an absence of the largest size classes from this dataset prevented biologically realistic estimates of the asymptotic size from being obtained during model fitting (Figure 1).

Growth parameters used in assessment:

Female Linf = 191 mm CL

Female K = 0.25 $year^{-1}$

Male Linf = 195 mm CL

Male K = 0.24 $year^{-1}$

3.2.5 Conversion factors

Length-to-weight conversion factors were calculated for each Island platform using the Trip Interview Program (TIP) database (Table 1). Length-to-weight conversion was of the form $W = aL^b$, where W is kg whole weight and L is carapace length in mm.

3.3 Commercial Fishery-Dependent Data

3.3.1 Commercial Landings

Commercial fishery landings data for each island were available from self-reported logbook records. All landings reported as "spiny lobster" are assumed to be *Panulirus argus* and that reports of other species as "spiny lobster" (e.g., *P. guttatus*) are assumed to be negligible.

For each island platform, annual landings were summed by gear (Table 2, 0, and Table 4). The gear types were diving, pots and traps, and all other gears. Pots and traps included gears reported as "pots and traps", "spiny lobster pots and traps", and "fish pots and traps". The two main gear types (diving and pots and traps) accounted for 95%, 97%, and 95% of spiny lobster landings in Puerto Rico, St. Thomas and St. John, and St. Croix, respectively. Diving did not include trips reporting diving with nets. Diving with nets was aggregated into all other gears. Puerto Rico commercial landings have been incompletely reported (Caribbean Fisheries Data Evaluation Final Report, 2009) and required use of correction/expansion factors to estimate total landings. For the years 2003 to 2016, correction/expansion factors have been coast-specific (north, south, east, west). Estimation of commercial fishery landings of earlier years used a single, island-wide, expansion factor. Commercial landings are presented in this report by year and fishing gear used, but can be stratified by coast. In the US Virgin Islands landings have been assumed to be fully reported and no correction/expansion factors have been used. All landings reported as "spiny lobster" are assumed to be *Panulirus argus*.

Subsequent review of the landings by the Assessment panel indicated that the estimated landings in Puerto Rico in 2005 were 351.3 mt which was vastly higher than in other years probably due low reporting and large expansion factors (Table 4). The consensus decision of the assessment panel was to replace the 2005 landings with the means of 2004 and 2006.

3.3.2 Commercial Indices

No indices of abundance were utilized in this assessment. Currently, additional efforts are required to update and improve on past efforts of utilizing catch per unit effort (CPUE) data with standardization procedures that attempt to remove the effects of factors that can bias the use of these data in developing an index of stock abundance. Explorations of the feasibility of developing indices of abundance by standardizing CPUE data in the current assessment resulted in three research recommendations: (1) Develop best practices for compiling and interpreting Caribbean logbook trip level information. (2) Explore the tradeoff between length of time series and information/variables available for use. (3) Investigate consistency of reporting and consistency in catch, effort and gear configuration definitions.

3.3.3 Commercial Length Data

Length samples were obtained from the NOAA Fisheries, Southeast Fisheries Science Center Trip Interview Program (TIP). TIP is a port sampling program that collects data on individual size and weight, to complement information that is collected through the logbook reporting. Size frequency data, species composition information, and sometimes other biological information are collected. Length frequency data of spiny lobster sampled from the predominant gears in St. Croix, St. Thomas and Puerto Rico are included in SEDAR57-DW-06. Due to a proclivity of the TIP spiny lobster carapace measurements to be reported in quarter inches, the data were binned to reflect 0.25 inch increments in mm.

Outlier removal and data exclusion decisions were finalized during the assessment webinars. Data were removed that were above 250 mm CL (9.8 in. CL) and less than 51 mm CL (2 in. CL). Furthermore, concerns with the length data from Puerto Rico in 2008 and from St. Thomas and St. John led the assessment panel to recommend excluding an entire year of data for each of these island platforms. The TIP data from Puerto Rico in 2008 revealed what seemed to be errors in species code (Figure 2). The concern in St. Thomas and St. John was related to the quantity of lobsters reflected in a single length measurement. Length measurements recorded in the TIP database can be associated with more than one individual length measurement (i.e. a quantity of 2 reflects that there were 2 observed individuals of the specified size and this is noted in a single record). In all years of the TIP data for St. Thomas and St. John the quantity of each length record is only as high as 2, except in 1988 which has unusually large quantities and includes values that range from 19 to 43. The decision to remove the entire year in each instance was preferred to selectively excluding data within years.

3.4 Fishery-Independent Data

Fishery-independent data sources reviewed during the Data Workshop included benthic transect surveys conducted by the National Centers for Coastal and Ocean Science (NCCOS), the National Coral Reef Monitoring Program (NCRMP), and the Puerto Rico Department of Natural and Environmental Resources (DNER), and larval/recruitment surveys conducted through SEAMAP-C. Other funded projects through academic grants were also explored for relevance to spiny lobster. Consensus opinion during the Data Workshop was that none of the datasets were recommended for use in developing indices or length compositions for spiny lobster due to inconsistencies in methodology, limited temporal and spatial scales (i.e., not indexing the lobster population), and low overall sample sizes (see SEDAR57-DW-01 for details).

3.4.1 St. Thomas Fishermen's association mark-recapture study

A recent collaborative mark-recapture study led by the St. Thomas Fishermen's association provided a potentially valuable source of information on spiny lobster growth and/or natural mortality (Olsen et al. 2017). The study's Principal Investigator provided the raw data to SEFSC to support the SEDAR 57 assessment and provided estimates of von Bertalanffy growth parameters (Olsen et al. 2017). SEFSC staff estimates of von Bertalanffy growth using Fabens length increment resulted in very low L_{inf} values which did not appear to be consistent with observed sizes of lobster in the fishery. While Olsen et al. (2017) report more reasonable parameter estimates for von Bertalanffy growth parameters, a re-analysis of their fitting routine appears to indicate a computational error in model fitting. Nonetheless, the mark-recapture data were of substantial value for the assessment as it allowed for verification that the growth curve estimated in Puerto Rico was not inconsistent with growth observed in St Thomas (Figure 1). The growth trajectories for each recaptured lobster were plotted over top of the growth curve assuming age based on size and then plotting the growth transition as a vector in time and size. Most of the vectors fall well within the expected range of the size at age, indicating that the growth curve from Puerto Rico is not inconsistent with growth in St Thomas, at least for the sizes of lobster recaptured. Unfortunately, the lack of larger, older recaptures limited the ability to estimate the full growth curve and likely led to some of the previously mentioned problems with obtaining reasonable estimates. Future work should continue to monitor for recaptures, particularly for some of the older and larger lobsters that may still be alive.

Exploratory modeling to estimate natural mortality (M) conducted by SEFSC also resulted in values that were much higher ($M > 2.0$ year^{-1}) than assumed values and were viewed as biologically implausible. SEFSC modeling efforts accounted for individual variability in lobster growth, a latent molting process connected to probability of tag loss, gear selectivity of recaptures, and reporting rate and initial tag loss. It is possible that reporting practices stated by Olsen et al. (2017) were underestimated (and hence M overestimated), but it is also possible that an inability to estimate growth trajectories (and therefore molting frequency) prevented reasonable estimates of M from being obtained.

4. STOCK ASSESSMENT METHODS

4.1 Overview

The assessment model selected for SEDAR 57 was Stock Synthesis (SS) version 3.30. Descriptions of SS algorithms and options are available in the SS user's manual, the SS website (https://vlab.ncep.noaa.gov/web/stock-synthesis), and Methot and Wetzel (2013). Stock Synthesis is an integrated statistical catch-at-age (SCAA) model, which projects forward from initial conditions using age-structured population dynamics equations. SCAA models are comprised of three modeling modules: the population dynamics module, an observation module, and a likelihood function. Each of the modules is closely linked. Stock synthesis uses biological parameters (e.g., growth, fecundity, and natural mortality) to propagate abundance and biomass forward from initial conditions (population dynamics model) and develops predicted data sets based on estimates of fishing mortality, selectivity, and catchability (the observation model). Finally, the observed and predicted data are compared (the likelihood module) to determine best fit parameter estimates using a statistical maximum likelihood framework (see Methot and Wetzel, 2013 for a description of equations and complete modeling framework). The integrated approach to natural resource modeling aims to utilize available data in the least processed form possible in order to maintain consistency in error structure across data analysis and modeling assumptions, while more reliably propagating uncertainty estimates, especially in critical population parameters such as stock status and projected yield (Maunder and Punt 2013).

Because of its extreme flexibility, there is not a single prototypical Stock Synthesis model. Depending on the life history and data availability of the modeled species, SS models can range from highly complex and data rich individual-based models to relatively simple age-structured production models. The flexibility allows the user to input all data sources that are available, but can also lead to overparametrization if careful attention is not paid to model configuration and diagnostics. Although SS makes it relatively easy to implement highly complex models, models of moderate complexity are often best given the data limitations in most fisheries. Many of the modeling assumptions in Stock Synthesis have been thoroughly simulation tested. The framework is used for fisheries management of a wide variety of marine species worldwide, most notably for United States federally managed fish stocks in the northwest Pacific and Gulf of Mexico.

For spiny lobster, low complexity models were examined. Models were separately developed and subjected to diagnostic testing for each of the three island platforms. The resulting models all predicted data for one or two fleets (pots and traps; diving), with a principle focus on fits to length compositions. Estimated parameters include selectivity of each fleet, and virgin recruitment. Models account for regulatory changes in minimum harvest length through time-varying retention parameters, each fixed in accordance with regulatory requirements. In the cases of St. Croix and St. Thomas/St. John, unfished stock size was assumed at the beginning of the available catch time series in years 1976 and 1975, respectively. This assumption reflects information about fishery expansion only following the expansion of the tourism industry (Olsen et al. 2017). This assumption about initial unfished stock size was also tested during the model development process. For Puerto Rico, a non-zero fishing mortality rate for the initial equilibrium year was explored, as records indicate fishing activity prior to modern landings time series which starts in 1983 (Figure 3; Bohnsack et al. 1990).

Figure 4 provides a conceptual overview of the model development process that was used to determine stock status and the overfishing limit (OFL). The model development process reflects constraints on model structure and interpretation of model outputs that are consistent with limitations of the available data. Four levels of candidate assessment methods were attempted, including three data moderate methods and one data limited method.

The data limited method involves utilizing recent mean length data along with estimates of equilibrium yield per recruit (YPR) and spawning per recruit (SPR) derived from the life history relationship for various levels of mean lengths associated with equilibrium. This level of assessment complexity would only provide stock status relative to maximizing YPR, and not relative to maximum sustainable yield or MSY proxies. This strategy is similar to traditional data-limited mean length assessment methods, with the added flexibility of being able to explicitly assume both logistic and non-logistic selectivity patterns.

For the three data moderate levels that utilized a length-based statistical catch-at-age model, a variety of derived quantities are produced including full time series of recruitment, abundance, biomass, spawning stock biomass, and harvest rate. Projections are implemented within SS starting from the year succeeding the terminal year of the assessment model utilizing the same population dynamics equations and modeling assumptions. The r4ss software (www.cran.r-project.org/web/packages/r4ss/index.html) was utilized extensively to develop various graphics for the SS outputs and was also used to summarize various SS output files and to perform diagnostic runs.

4.2 Model configuration

Model development proceeded stepwise from the simplest configuration to those of moderate complexity, with some diagnostics (namely likelihood profiling) being carried out at each step to examine the stability of parameter estimation as each additional parameter is added to the model (Table 5 and Table 6). Of interest was the question of whether selectivity was asymptotic or dome-shaped, as the assessment panel suggested that both fleets may have lower selectivity at larger lobster sizes due to market demands or gear limitations (i.e., trap size). Additionally, model development addressed questions of (i) whether fleet-specific selectivity could be estimated, (ii) whether sex-specific retention could be estimated, noting that berried females cannot be legally retained, and (iii) whether the assumption of unfished initial equilibrium was supported by fits to the data, and/or whether initial equilibrium fishing mortality required estimation.

<u>General structure</u>

- Age structure model: ages 0 to 15+
- One area model; single spawning population and associated stock-recruit function
- Time-varying retention to account for implementation of 3.5” minimum CL (89 mm)

- Length-based selectivity estimated for primary fleets
- Complete catch history for two fishing fleets (Diving, Pots and Traps); fleet relative contribution to catch varies considerably between island platforms

4.2.1 Spatiotemporal Structure

The base model for the SEDAR 57 assessment included spiny lobster age classes from age zero through age 15, where age 15 was a plus group (i.e., aggregate of ages 15 to max age). The model was specified as a single spawning population and associated stock-recruit function. For St. Croix and St. Thomas/St. John, the time series in the model started in 1976 and 1975, respectively, when the stock was assumed to be in a virgin, unfished state. This is consistent with reports that the fishery only began in earnest in the 1970s with the expansion of the tourism industry (Olsen et al 2017). Tourism coincided with human population growth, which increased steeply through the 1960s and 1970s, but has since plateaued (Figure 5; (Anon. 2018)). For Puerto Rico, initial equilibrium fishing mortality was examined as part of model development, as the stock was not assumed to be in an unfished state at the beginning of the time series in 1983 (Figure 3; Bohnsack et al. 1990).

4.2.2 Life History

The weight-length relationship, the maturity schedule, fecundity estimates, natural mortality, and growth (Section 2.2) were incorporated as fixed parameters and these processes were neither estimated nor updated. The Stock Synthesis (SS) framework is capable of estimating many of these parameters internally if given the appropriate data. However, the ability to estimate growth parameters has not been widely tested for SEFSC assessed stocks and little is known about potential overparametrization in regards to SS life history parameter estimation.

Stock Synthesis uses these parameters to move fish among age classes and length bins on January 1st of each modeled year starting from birth at age-0. The average spawning date for spiny lobster is assumed to occur half way through the year on July 1. But because spiny lobster may spawn throughout the year, or at least during multiple times of the year (FAO 2001), growth variation of the youngest age was specified with a CV=0.1, while growth for older ages was specified with a CV=0.043, which was obtained from estimation of inter-annual variation in the asymptotic size parameter (L_∞) from the Cuban spiny lobster fishery (de León et al. 2005).

4.2.3 Recruitment Dynamics

A Beverton-Holt stock-recruit function was used to parametrize the relationship between spawning output and resulting age-0 spiny lobster. The stock-recruit function (representing the arithmetic mean spawner-recruit levels) requires three parameters: (1) steepness (h) characterizes the initial slope of the ascending limb (i.e., the fraction of virgin recruits produced at 20% of the equilibrium spawning biomass); (2) the virgin recruitment (R0; estimated in log space) represents the asymptote or unfished recruitment levels; and (3) a variance term (sigmaR) that reflects the standard deviation of the log of recruitment (it both penalizes deviations from the spawner-recruit curve and defines the offset between the arithmetic mean spawner-recruit curve and the expected geometric mean from which the deviations are calculated). Although these parameters are often highly correlated, they can sometimes be simultaneously estimated in SS if data quality is high.

In contrast to more data rich assessments, each of these island-based applications has some substantial data limitations including the lack of indices and potential uncertainties in total removals. Hence it is unlikely that the model would be able to estimate the stock recruitment relationships, which are often not well determined even in data rich situations. In addition, the high connectivity of the spiny lobster population in the Pan-Caribbean basin indicates that much of the recruitment could be produced by other geographic locations. Indeed, physical oceanographic modeling indicates that much of the larval supply to Puerto Rico, St. Thomas and St. Croix is a result of larval subsidies from other areas (Kough et al. 2013), making detection of a stock-recruitment relationship based on self-recruitment unlikely.

In similar situations where steepness is inestimable, SEFSC convention has been to fix this parameter at a high value and then employ proxies for Fmsy. This provides some protection from recruitment overfishing. Hence, for modeling purposes, steepness fixed at a value of 0.95 and hence any benchmarks should also employ a proxy for Fmsy such as an SPR%. Similarly, sigmaR was fixed at 0.6, a common value of recruitment variability. The only estimated parameter of the stock recruitment relationship was R0 to enable estimation of the scale of stock biomass in relation to the landings.

4.2.4 Fleet Structure

For each island platform, two commercial fleets were specified: (i) pots and traps and (ii) diving. Pots and traps are the dominant gear for St. Thomas, while diving is the dominant gear for St. Croix and Puerto Rico.

Recreational catches were not represented in the assessment as very limited data exist for them. Recreational catches may or may not make up a substantial fraction of the total landings.

St. Croix

In St. Croix, logbook reporting began in July, 1975 with spiny lobster landings reported throughout the time series July, 1975-2016. Available data for summing commercial landings were the self-reported logbook records from commercial fishers (Figure 6). For assessment, landings under the category named “Other gear” were added to landings from diving, as “Other gear” typically reflects an inability to categorize reported landings to diving or pots and traps, and does not typically indicate landings by some alternative gear type.

St. Thomas/St. John

In the US Virgin Islands logbook landings data from the islands of St. Thomas and St. John were compiled separately from St. Croix. Logbook reporting began in July, 1974 with spiny lobster landings reported throughout the time series July, 1974-2016 (Figure 7). For assessment, landings under the category named “Other gear” were added to landings from pots and traps, as “Other gear” typically reflects an inability to categorize reported landings to diving or pots and traps, and does not typically indicate landings by some alternative gear type.

Puerto Rico

Commercial fishery landings data for Puerto Rico were available from self-reported fisher logbooks/sales receipts for the years 1983-2016 (Figure 8). Commercial logbook reports also include information on fishing gear and fishing center where the catch was landed. For assessment, landings under the category named "Other gear" were added to landings from diving, as "Other gear" typically reflects an inability to categorize reported landings to diving or pots and traps, and does not typically indicate landings by some alternative gear type.

4.2.5 Selectivity and retention

Selectivity represents the probability of capture by age or length for a given fishery and subsumes a number of interrelated dynamics (e.g., gear type, targeting, and availability of fish due to spatial structure). For SEDAR 57, two selectivity types were considered in model development: a two parameter logistic function, and a three parameter logistic-exponential function. The logistic-exponential enables a descending limb to vary between a near-asymptotic position to a strongly dome-shaped position, which was useful in evaluating the support in the data for the presence of a descending limb. Both of these selectivity functions were length-based and fits to the data were explored for each fleet type.

Retention was specified as a logistic function with fixed parameter values, and was time-varying to reflect regulatory changes to minimum harvest size. For St. Croix, full retention was fixed at 89 mm, with a very steep ascending slope (i.e., knife-edge retention) beginning in 1985. This retention pattern reflects a minimum harvest length regulation of 3.5" (89 mm) CL that was introduced on January 1, 1985. Analysis of length composition data suggests compliance with the regulation, with undersized lobster representing 1.3% of total landing in St. Croix from 1985 through 1989 (Bohnsack et al. 1990). More recent time periods in the length composition data continue to reflect this compliance (Figure 9 and Figure 10). Prior to 1985, retention was fixed such that it equaled 1 for all sizes.

For St. Thomas/St. John, the same fixed retention pattern was specified, as 2.9% of total landing were undersized from 1985 through 1989 (Bohnsack et al. 1990). However, during 2004 to 2006 undersized reporting was evident (Figure 11 and Figure 12). Thus, retention was fixed such that it equaled 1 for all sizes during two time periods: 1975-1984 (prior to the 3.5" regulation) and 2004-2006.

For Puerto Rico, full retention was initially fixed at 89 mm, with a very steep ascending slope (i.e., knife-edge retention) beginning in 1999. Although a minimum harvest length regulation of 3.5" (89 mm) CL was introduced on January 1, 1985, the regulation was not meaningfully enforced until 1999 (Figure 13 and Figure 14). Model development explored estimating the slope of the logistic function reflecting moderate compliance with the size limit that is evident in the length composition data.

4.2.6 Length Composition

Length samples obtained from TIP were reasonably sampled in each decade and therefore included in the assessment for each island platform (Figure 15, Figure 16, and Figure 17), with the exception of an absence of length samples during 2012 to 2015 for St. Croix (Figure 15).

4.2.7 Discards

Discard mortality was fixed at zero in all model configurations. Consensus opinion during the Data Workshop was that discard mortality of spiny lobsters was negligible, which is consistent with SEDAR 8 and SEDAR 46. Thus, the data and assessment panels agreed that dead discards can be assumed to be insignificant relative to the landings. Discards are assumed to include sublegal (less than 3.5-inch carapace length) and legal size berried female spiny lobsters.

4.3 Maximum Likelihood and Uncertainty

A maximum likelihood approach was used to assess goodness of fit to each of the data sources. Each data set had an assumed error distribution and an associated likelihood component, the value of which was determined by the difference in observed and predicted values along with the assumed variance of the error distribution. The total likelihood was the sum of each individual component. A nonlinear iterative search algorithm was used to minimize the total negative loglikelihood across the multidimensional parameter space in order to determine the parameter values that provided the global best fit to all the data.

With this type of integrated modeling approach data weighting (i.e., the variance associated with each data set) can greatly impact model results, particularly if the various data sets indicate differing population trends. Ideally, the model would allow the data to 'self-weight' in order to determine the relative variance among data sets. However, it is seldom possible to freely estimate all the variance terms in addition to the set of model parameters, and variance terms must be input based on calculated variance from the observed data. The latter approach suffers from a lack of information regarding relative variance among different data sets. Ultimately, expert judgement usually must be used to input relative variance components, and this is the approach used in SS.

4.3.1 Error Structure

Landing were assumed to have a lognormal error structure. Landings were assumed to have a low error variance (i.e., log(SE)=0.01), which was constant through time. The length composition data for the various fisheries followed a multinomial error structure where the variance was determined by the input effective sample size (Neff). For the multinomial likelihood a smaller sample size represents higher variance and vice versa, because Neff is meant to represent the number of fish sampled each year to determine the composition. Observed sample sizes are often overestimated for fisheries data, because samples are rarely truly random or independent (Hulson et al. 2012). To prevent overestimated sample sizes in some years from dominating model fits, input effective sample sizes were specified as the square root of the observed sample size which reduced the initial input sample size while avoiding the imposition of an artificial cap.

4.3.2 Uncertainty Estimation

Uncertainty estimates for estimated and derived quantities were calculated based on the asymptotic standard error determined from the inversion of the Hessian matrix (i.e., the matrix of second derivatives was used to determine the level of curvature in the parameter phase space and to calculate parameter correlation; Methot and Wetzel, 2013). Asymptotic standard errors provided a minimum estimate of uncertainty in parameter values.

4.3.3 Estimated Parameters

St. Croix and St. Thomas/St. John each had a total of four parameters estimated for their base model (Table 7). These include the three parameters of the exponential-logistic selectivity as well as virgin recruitment (R0).

Puerto Rico had a total of 16 parameters for its base model (Table 8). These include the initial F, virgin recruitment (R0), the three parameters of the exponential-logistic selectivity for each of the two fleet and two time blocks (a total of 12 selectivity parameters), and one retention parameter for each of the two fleets during the second time block (a total of two retention parameters).

4.4 Model Diagnostics

4.4.1 Correlation Analysis

High correlation among parameters can lead to flat likelihood response surfaces and poor model stability. By performing a correlation analysis, modeling assumptions that lead to inadequate model parametrizations can be highlighted. Because of the highly parametrized nature of stock assessment models, it is expected that some parameters will always be correlated (e.g., stock-recruit parameters). However, a large number of extremely correlated parameters warrant reconsideration of modeling assumptions and parametrization. A correlation analysis was carried out on the base models and correlations with an absolute value greater than 0.7 were examined and those greater than 0.95 are reported here.

4.4.2 Profile Likelihood

Profile likelihoods are used to examine the change in log-likelihood for each data source in order to address the stability of a given parameter estimate, and to visualize the effect of various data components on parameter estimation. Given the limited data sources used in this assessment, we present likelihood profiles for the total log-likelihood. The analysis is performed by holding the given parameter at a constant value and rerunning the model. This is done for a range of reasonable parameter values. Ideally, the graph of likelihood value against parameter value will give a well-defined minimum indicating that each data source is in agreement. When a given parameter is not well estimated, the resulting total likelihood surface will often be flat, indicating that multiple parameter values are equally likely given the data. In such instances, the model assumptions need to be reconsidered as the model is unstable and generally unreliable. Typically, profiling is carried out for a handful of problematic (and often correlated) parameters, particularly those defining the stock-recruit relationship (e.g., R0). Profiles were carried out for virgin recruitment, and parameters of the selectivity function(s).

4.4.3 Jitter Analysis

Jitter analysis is a relatively simple method that can be used to assess model stability and to determine whether a global as opposed to local minima has been found by the search algorithm. The premise is that all of the starting values are randomly altered (or 'jittered') by an input constant value and the model is rerun from the new starting values. If the resulting population trajectories across a number of runs converge to the same final solution, it can be reasonably assured that the global minimum has been obtained. Of course, this process is not fault-proof and no guarantee can ever be made that the 'true' solution has been found or that the model does not contain misspecification. However, if the jitter analysis results are consistent, it provides additional support that the model is performing well and has come to a stable solution. For this assessment, a jitter value of 10% was applied to the starting values and 50 runs were completed.

4.4.4 Retrospective Analysis

A retrospective analysis is a useful approach for addressing the consistency of terminal year model estimates. The analysis sequentially removes a year of data at a time and reruns the model. If the resulting estimates of derived quantities such as SSB or recruitment differ significantly, particularly if there is serial over- or underestimation of any important quantities, it can indicate that the model has some unidentified process error, and requires reassessing model assumptions. It is expected that removing data will lead to slight differences between the new terminal year estimates and the updated estimates for that year in the model with the full data. Oftentimes additional data, especially compositional data, will improve estimates in years prior to the new terminal year, because the information on cohort strength becomes more reliable. Therefore, slight differences are expected between model runs as more years of data are peeled away. Ideally, the difference in estimates will be slight and more or less randomly distributed above and below the estimates from the model with the complete data sets. Typically, 5-10 year retrospective analyses are completed. Care must be taken when time blocks exist for selectivity parameters or when there are any short data time series that span only the last few years of the model, because removing a few years of data may cause the model to become unstable when not enough data are available to estimate parameters for these short data sets. The instability is not a reflection of poor model performance, but simply an issue of overparametrization caused by a short time series. A five-year retrospective was carried out.

5. MODEL RESULTS

5.1 Landings

USVI (St. Croix and St. Thomas/St. John)

Landings were assigned comparatively small standard error and were reproduced by the model according to the hybrid approximation method in SS. Landings in St. Croix are predominantly obtained through diving, with a peak in landings in the mid-2000s, followed by a decline (Figure 6). Landings in St. Thomas/St. John are predominantly obtained through pots and traps, with a positive trend of increasing landings throughout the time series (Figure 7).

Puerto Rico

In the first two years of the time series and after the mid-2000s, the landings in Puerto Rico are predominately from diving (Table 4 and Figure 8). Between 1985 and 2005, the landings from the second predominant gear, pots and traps, were similar in magnitude to the landings associated with diving. Although we have some knowledge prior to 1983 that traps made up a larger component of landings prior to 1993 (Bohnsack et al. 1990), only one parameter for initial F was utilized to represent the initial equilibrium fishing mortality associated with both fleets.

Furthermore, in all other years the annual landings in Puerto Rico were between a minimum of 92.8 mt (204,607 lbs) and a maximum of 216.1 mt (476,404 lbs). However, in 2005, the expanded landings were 351.3 mt (774,546 lbs). As this year is associated with low reporting and large expansion factors, the assessment panel replaced 2005 landings with the mean of 2004 and 2006 (170.9mt; 376,661 lbs). This assumption was also tested in the modeling framework.

5.2 Length Composition

Model fits to length composition were based on effective sample sizes that were approximated by taking the square root of the observed sample size. Across island platforms, for years with sufficient sample size (e.g. sample size > 50, or $\sqrt{50} = 7.1$), the model fit to the length composition data quite well.

USVI (St. Croix and St. Thomas/St. John)

For St. Croix and St. Thomas/St. John, length compositions were reasonably reproduced by the base models (Figure 9, Figure 10, Figure 11, and Figure 12). Residuals tended to be small, and temporal patterns in residuals were not evident (Figure 18 and Figure 19). When length compositions are viewed in aggregate across years, selectivity shows a reasonable fit, with two exceptions (Figure 20 and Figure 21). First, there is some evidence of selectivity differences between males and females, which is not accounted for in the model structure. This result likely reflects a lower retention of egg-bearing females. However, model structures that included male and female differences in retention demonstrated poor stability during likelihood profiling. Second, larger Pearson residuals were evident for the diving fleet for St. Thomas/St. John because (i) the selectivity of this fishery was mirrored to that of pots and traps, and/or (ii) the sparse sampling of this gear type that comprises only a small fraction of the landings.

Puerto Rico

For Puerto Rico, length compositions were reasonably reproduced by the base models (Figure 13 and Figure 14). Residuals tended to be small, and temporal patterns in residuals were not evident (Figure 22). When length compositions are viewed in aggregate across years, selectivity shows a reasonable fit, with the exception of evidence for differences in the proportions retained at size between males and females (Figure 23).

5.3 Fishery Selectivity and Retention

USVI (St. Croix and St. Thomas/St. John)

In model development, support for the shape of the descending limb was examined in a stepwise manner, first fitting logistic selectivity, and then examining the relative support for dome-shaped selectivity (Table 5). Model fits (i.e., log likelihoods) and model diagnostics for base models for St. Thomas/St. John supported model structure with logistic exponential (dome-shaped) selectivity, estimated for the pots and traps fishery and mirrored for the diving fishery. Other model configurations either had poorer fits (higher negative log-likelihoods) or had poor stability characteristics (i.e., poor R0 likelihood profile). Estimation of selectivity for St. Croix was not feasible, as all model configurations that entertained logistic exponential (dome-shaped) selectivity had poor stability. Consequently, selectivity for St. Croix diving was specified using an informative prior based on the selectivity parameters estimates and their respective standard errors. These prior probability distributions were specified as Gaussian distributions. The base model for St. Croix demonstrated reasonable stability under this specification of priors, with the pots and traps fishery mirrored to that of diving.

Estimated selectivity for St. Croix suggested that full selectivity (the peak of the selectivity function) occurred at 102 mm CL and had a strongly descending limb with <10% selectivity occurring at approximately 141 mm CL (Figure 24).

Estimated selectivity for St. Thomas/St. John suggested that full selectivity (the peak of the selectivity function) occurred at 108 mm CL and had a strongly descending limb with <10% selectivity occurring at approximately 178 mm CL (Figure 25).

Puerto Rico

Model development and diagnostics for Puerto Rico were explored in a similar stepwise manner, first fitting logistic selectivity, and then investigating both asymptotic selectivity and dome-shaped selectivity using the exponential-logistic selectivity pattern (Table 6). Model fits (i.e., log likelihoods) and model diagnostics for the initial dome-shaped models for Puerto Rico had poor stability characteristics. As such, estimation of selectivity for Puerto Rico was not feasible. Consequently, selectivity for Puerto Rico was specified using an informative prior based on the selectivity parameter estimates from St. Thomas along with their respective standard errors. These prior probability distributions were specified as Gaussian distributions. Additionally, time varying selectivity was explored and it was observed to improve model fit to the length data. All three parameters of the selectivity function were estimated utilizing the priors for the later time period, and only utilized a prior on the third parameter of the exponential-logistic selectivity pattern during the earlier time period. The improved fit with the time varying selectivity suggests that starting in 1999 there was both a change in retention to exclude smaller individuals and also an adaptation of fishery dynamics in both fleets towards generally targeting larger individuals

(Figure 26-Figure 31). As there is likely size-based habitat segregation in lobsters this might provide a plausible mechanism for such a change.

For the 1983 to 1998 period, the estimated selectivity for both diving and pots and traps suggested both a stronger ascending limb and lower peak than during the later period when the size limit was exercised. During the earlier period, the estimated selectivity differed between the two fleets. The peak (full selectivity) for pots and traps was at a smaller size (82.5 mm CL) than for diving (87.5 mm). In the later time block, the selectivity patterns for the two fleets were estimated to be similar to one another, both with their estimated peaks at approximately 97.5 mm CL.

5.4 Recruitment

Stock-recruitment steepness was fixed at 0.95. The estimated value of the virgin recruitment in log-space was:

St. Croix: log(R0) = 5.47; equivalent to 237,000 spiny lobster

St. Thomas/St. John: log(R0) = 5. 23; equivalent to 187,000 spiny lobster

Puerto Rico: log(R0) = 6.55; equivalent to 699,000 spiny lobster

In keeping with the “data-limited to moderate” nature of this assessment we did not estimate recruitment deviations in initial model fitting. Given the sparse nature of the length compositions in many years coupled with a clear tendency for the data to be in quarter inch increments it was unlikely that estimating recruitment deviations would be informative. Initial explorations into estimating deviations for St. Thomas indicated that there was very little recruitment signal in the data. As such, the annual recruitment estimates for each island are nearly constant through the time, but differ in magnitude between islands. The estimates and their standard errors are summarized in Table 9.

5.5 Population Trajectories

USVI (St. Croix and St. Thomas/St. John)

Beginning in an unfished state, St. Croix total biomass and spawning biomass did not appreciably begin to decline until the 1990s, reflecting steady increases in landings around this time (Figure 32; Table 10 – Table 11). Spawning biomass reached its lowest point to date in 2011, followed by an upward trend that is consistent with a steep decline in landings. Relative spawning biomass, represented in terms of depletion, is highly uncertain during the two decades following 2000. This uncertainty could reflect an absence of length samples between 2012 and 2015; an issue that is also reflected in the high degree of uncertainty in fishing mortality rates during this same time period. Population trajectory is consistent with the relatively stable trend in mean length, with a slight decline during 2000 to 2010, and a slight rebound during the most recent decade (Figure 33). However, wide confidence intervals of mean length observations may also be contributing to uncertainty in spawning depletion during the two most recent decades.

For St. Thomas/St. John a more pronounced decline in total biomass and spawning biomass occurs throughout the time series, without an appreciable rebounding of biomass except during the most recent decade (Figure 34; Table 10 – Table 11). This trend is consistent with a continually increasing trend in landings, save for a decrease between 2005 and 2013. Uncertainty in spawning depletion increases appreciably towards the end of the time series, reflecting cohorts that are only partially resolved in the length composition. Like St. Croix, wide confidence intervals may also be contributing to uncertainty in spawning depletion (Figure 35).

Puerto Rico

After starting at its most depleted state, Puerto Rico total biomass increases throughout the time series (Figure 36; Table 10 - Table 11). Similarly, spawning biomass begins low and increases initially through 1987, it then fluctuates with a general decline through 2004 and then remains high between 2006 and 2012. The most recent three years of the time series show an appreciable decline in the trend of the spawning biomass and subtle declining trend in the total biomass. The trend in the predicted mean length for both the diving and the pots and traps fleets reveal relatively steady mean lengths prior to 1999 and after 1999, with a higher mean length observed in the more recent time period (Figure 37).

5.6 Fishing Mortality

The proportion of the stock killed by fishing (i.e., harvest or exploitation rate in biomass landed / total biomass) was used as the proxy for annual fishing mortality rate. Predicted annual harvest rates were less than 0.25 (25% of biomass removed by fishing), and 95% CIs typically ranged between 0.0 and 0.4 throughout the time series for St. Croix (Figure 38; Table 12). Similarly, predicted annual harvest rates were less than 0.3 (95% CIs typically between 0.0 and 0.45) throughout the time series for St. Thomas/St. John (Figure 39; Table 12). For USVI fisheries, an increasing trend in harvest rate across decades is predicted, with harvest rate stabilizing or decreasing after 2010. Predicted annual harvest rates in Puerto Rico declined at the start of the time series in the mid-80s from around 0.3 to less than 0.2, and remained below 0.2 for the remainder of the time series, dropping to 0.1 starting in the late 2000s (Figure 40; Table 12). The most recent four years predict a slightly increasing trend in the harvest rate.

5.7 Measures of Uncertainty

The estimated parameters and derived quantities as well as the SS estimated asymptotic standard errors are summarized in Table 7 and Table 8. Most parameter estimates appear reasonable and coefficients of variation (CV; standard error divided by [mean] parameter estimate) were low indicating relatively well estimated parameters.

5.8 Diagnostic Runs

5.8.1 Correlation analysis

USVI (St. Croix and St. Thomas/St. John)

Given the nature of this model structure, particularly the structure of the selectivity functions, some parameters may be expected to be correlated. No parameter correlations had an absolute correlation greater than 0.70.

Puerto Rico

All of the three parameters used to estimate selectivity during the starting block of the model were correlated. For diving, the correlations between P1 & P2, P1 & P3, and P2 & P3 were: -0.94, -0.83, and 0.75, and for pots and traps they were: -0.95, -0.87, and 0.86, respectively. These six correlations were the only correlations in the base model that were greater than 0.70.

5.8.2 Profile Likelihoods

USVI (St. Croix and St. Thomas/St. John)

Profile likelihoods were carried out for R0 and for each of 3 parameters of the logistic exponential selectivity functions, for each island platform. Given that the approach for profile likelihoods is to fix important model parameters across a range of potential values, most of which are not supported by the data, this approach was useful in examining the tension between estimating scaling parameters (i.e, R0) and the descending limb of the selectivity function that influences vulnerability to the fishery.

The base models for St. Croix and St. Thomas/St. John demonstrated relatively smooth profile surfaces with global minima well defined (Figure 41 and Figure 42). As noted, the base models did not include male/female offset in retention, despite visual evidence for this process in the length composition data, as profiles became agnostic about scale (R0) vs. selectivity parameters under this configuration (Table 5). In addition to the model configurations for St. Thomas/St. John described in Table 5, the cause of the inability to estimate sex-specific retention was investigated by doing the following: (i) removing diving length composition, in an attempt to limit sparse data inputs, and mirror trap fishery selectivity, (ii) repeat step (i), but with all but the largest sample sizes removed from the trap fishery (i.e., only sample sizes > 235 were retained), and (iii) removing years 2004 to 2006 from the dataset, as these length compositions were notably different from surrounding years. These tests were intended for diagnostics only; such arbitrary data filtering was not part of selecting a base model. In doing these tests we did not obtain a model with sex-specific retention that achieved a reasonable profile for R0.

Puerto Rico

A profile of likelihood was carried out for a range of fixed values of initial F. Although the profile of the total likelihood is relatively smooth with a global minimum, the likelihoods of the individual components reveal tension between fitting the priors and fitting the length composition data (Figure 43). Next, a bivariate profile was carried out for R0 and initial F

(Figure 44 and Figure 45). Although there is also a global minimum identified, the profile revealed somewhat of a flat surface. That said, the changes in the log-likelihood observed across multiple values of F revealed that the minimum log-likelihood occurred at similar values of R0. This suggests that OFL advice could be averaged across an assumed range of fixed values of initial F in order to address uncertainty.

5.8.3 Jitter Analysis

A jitter value of 10% was randomly added to each of the starting parameter values, which is a diagnostic to evaluate model stability. In the jitter analysis the starting parameter values were set to the maximum likelihood point estimates obtained in initial model fits. The jitter analysis did not reveal any model solution with a lower negative log-likelihood. The jitter analysis, along with the likelihood profile suggest that the global minimum has been obtained in model fitting for each island platform.

5.8.4 Retrospective Analysis

USVI (St. Croix and St. Thomas/St. John)

Results of the retrospective analysis illustrate a strong level of consistency within the model. As up to 5 years of data are sequentially removed, consistent trends in spawning biomass remain (Figure 46 and Figure 47).

Puerto Rico

Results of the retrospective analysis illustrate a strong level of consistency within the model (Figure 48), except with the removal of the fifth year of data which caused a change in the plotted trend of the spawning output. Upon further exploring the length composition, it became evident that the sensitivity to removal of the five most recent years of data may be due to how the length composition data in years with low sample sizes (less than 64 samples) earlier in the time series yield a stronger influence on the model results as the recent years of data are removed. To test this, a model was developed excluding years with low sample sizes. The model resulted in nearly identical parameter estimates and the retrospective analysis revealed consistent trends (Table 13; Figure 49).

6. REFERENCE POINTS

6.1 Projections

6.1.1 Projection Specifications

Projections were implemented within Stock Synthesis. The projections were conducted by assuming fishing mortality allocations by fleet and selectivity to be the average of the most recent three years. Benchmarks were also estimated to be derived from the average allocation of fishing mortality and selectivity for the terminal year. These specifications imply that the selection and F allocation patterns will persist into the near future. The projections also utilized provisional catch estimates of commercial removals through the current year (2018) with estimates for 2017 carried over for 2018. One projection was made that applied a constant fishing mortality of $F_{SPR30\%}$ after 2018. Given that recruitment was assumed to be unrelated to spawning stock biomass, $F_{SPR30\%}$ is the fishing mortality rate that would produce (in equilibrium) the same spawning output as the stock at 30% of unfished stock size.

6.1.2 Stock Status

Due to the lack of an estimable spawner-recruit relationship, MSY could not be reliably estimated for the Caribbean Spiny Lobster stocks. Currently, the FMPs for these stocks do not specify an MSY proxy. To facilitate the discussion, the stock status, OFL and projected landings were presented relative to a provisional MSY-proxy of F30% SPR (see Appendix A). However, the selection of the proxy must be further evaluated by the Caribbean Council and its Scientific and Statistical Committee.

Estimated spawning output and fishing mortality relative to various reference levels (i.e. unfished, SPR30) and management thresholds (i.e. MSST and MFMT) are summarized in Table 14 and Figure 50 (St. Croix), Table 15 and Figure 51 (St. Thomas/St. John) and Table 16 and Figure 52 (Puerto Rico). For the purpose of this report, the provisional minimum stock size threshold (MSST) was assumed to be 75% of S_{SPR30} and the provisional maximum fishing mortality threshold (MFMT) was assumed to be equal to $F_{SPR30\%}$.

Base Stock Synthesis runs, assume Spiny Lobster in the USVI to be unfished in 1975 (Table 14 and Table 15). The stocks in both St. Croix and St. Thomas/St. John approached the levels corresponding to $F_{SPR30\%}$ and $S_{SPR30\%}$ during the mid to late 2000s. Since that time, a reduction in fishing mortality has allowed the stock spawning output to increase. In Puerto Rico the stocks were already exploited when the time series began (Table 16). Fishing mortality was initially above $F_{SPR30\%}$, but declined and remained below that threshold after 1986, with some exceptions, particularly during the period 1999-2005. Spawning output remained below $S_{SPR30\%}$ from the initial year through 1992, but has since remained above $S_{SPR30\%}$, except between 2000 and 2007.

If the provisional management thresholds (i.e. MSST and MFMT) are accepted for use for management, the stocks in the USVI and Puerto Rico are not considered overfished (i.e. current Spawning Output is above MSST) and are not undergoing overfishing (i.e. current Fishing Mortality is below MFMT), although the stock in St. Thomas/St. John and in Puerto Rico are close to the overfishing as F/MFMT is near 1.0. Stock Synthesis derived estimates of quantities relevant to the Magnuson-Stevens Reauthorization Act (MSRA), including provisional stock status determination criteria and maximum sustainable yield, are summarized in Table 17.

6.2 Overfishing Limits

Provisional estimates of the catches corresponding to the overfishing limit (OFL) were calculated using the median of the projection at $F_{SPR30\%}$ and are summarized in Table 18.

6.3 Other Projection Runs

For Puerto Rico, it is feasible to provide projections at various assumed levels of Initial F and utilize model averaging to account for uncertainty in the poorly estimated initial F parameter. This would only require pre-specifying what MSY proxy and a range of initial F values to utilize.

7. DISCUSSION

SEDAR 57 was able to explore data moderate length-based statistical catch at age models for each island platform in the US Caribbean. The flexibility of these methods, along with the use of explicit and documented assumptions, is an improvement to traditional data limited methods that are often associated with inflexible implicit assumptions, particularly related to the shape of selectivity.

The proposed base models that resulted from the development process (Figure 4) resulted in three models of moderate assessment complexity. For St. Thomas, the data were informative enough to estimate four main parameters: R0 and three parameters to define the exponential-logistic selectivity. While the diagnostics support the use of the length based statistical catch at age model for provision of management advice, it is important to note the model's explicit assumptions including assuming commercial landings are known, negligible recreational removals, growth and no variation in growth over time, steepness (assumed to be 0.95), natural mortality, sex ratio, and non-sex specific retention. Currently, given the data limited to data moderate nature of this assessment, these assumptions were necessary. The assumptions could be further explored or even their parameters estimated as more data become available.

The models in St. Croix and Puerto Rico were unable to independently estimate selectivity parameters, but they were able to utilize the selectivity information generated from St. Thomas. In St. Croix, the diagnostics resulting from the models that utilized the selectivity information from St. Thomas/St. John supported use of the moderate assessment complexity (the second highest level of assessment complexity identified in Figure 4). The explicit assumptions for St. Croix are similar to those noted above for the data moderate assessment conducted for St. Thomas.

In Puerto Rico, there was an added difficulty of needing to estimate initial F. The diagnostics resulting from the models that utilized the selectivity information from St. Thomas/St. John marginally supports using the moderate assessment complexity. Thus management advice from Puerto Rico could be utilized with larger scientific uncertainty than the advice derived from the models in the USVI.

Provisional projection advice generated from these models indicate substantial increases from 2017/2018 values. We note that these projections are preliminary and that the MSST has not yet been determined nor are these projections the resulting ABC advice as they would be decremented by scientific uncertainty. Furthermore, a large part of the increases is a function of the very low reported catches in recent years in both STX and Puerto Rico, much of which is related to disruptions from recent hurricanes. The assessment models assume that lobsters were unaffected by these events and that the only impact on the population was a reduction in catch, leaving the uncaught population in the water.

The projections also note a steady decrease in the OFL, which is a function of the stock being above the MSST and the projections fishing the stock down in size. Similar patterns have occurred in other management regions and councils have often implemented relatively constant ABC advice to maintain fishery continuity.

7.1 Research Recommendations

- *Independently estimate availability/selectivity.* There are three main parameters currently estimated in the SEDAR 57 stock assessment for Caribbean spiny lobster in Puerto Rico. They are R0, selectivity, and initial F. Selectivity, as it is used in the model, is both a combination of contact selectivity e.g. selection created by contact with the gear itself such as trap opening diameter and availability which might be a function of depth and habitat. In the base model, selectivity is assumed to be dome-shaped based on information from STT. This is an important assumption since it affects the estimates of both initial F and R0. Knowing more about gear selectivity or having a survey that can provide the underlying size distribution of all lobster in the population, across all habitat and depths, and not just those targeted by the commercial fishery, could greatly improve the stock assessment in Puerto Rico and help determine the appropriateness of the assumed selectivity pattern.
- *Collect data on recreational landings.* The magnitude of recreational removals of spiny lobster on each island platform is unknown.
- *More basic biological studies* to improve understanding of key life history processes such as growth, length/age at maturity, fecundity, and their spatial variability.
- *Improve data on commercial landings and catch and effort***.** Concerns of misreporting should be investigated and corrected where practicable. Commercial catch and effort may provide CPUE indices in the future.

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9. TABLES

Table 1. Fitted conversion functions from length (mm CL) to weight (kg whole weight) by island platform.

Island platform	Years	n	a	b
St. Thomas / St. John				
Males	1980-2017	6,692	3.55E-05	2.204
Females	1980-2017	5,031	4.89E-05	2.138
Males + Females	1980-2017	11,723	4.17E-05	2.171
Puerto Rico				
Males	1980-2016	12,019	6.84E-06	2.536
Females	1980-2016	10,961	7.61E-06	2.521
Males + Females	1980-2016	22,980	7.83E-06	2.511
St. Croix				
Males	1981-2017	11,684	1.27E-05	2.413
Females	1981-2017	8,362	2.32E-05	2.29
Males + Females	1981-2017	20,046	1.82E-05	2.339

Table 2. St. Thomas and St. John commercial fishery spiny lobster landings in metric tons by year and gear group.

Year	Diving	Pots and Traps	Other Gear	Total Landings
1975	0.8	2.0	0.2	3.1
1976	0.3	2.2	0.6	3.1
1977	2.0	6.7	0.1	8.8
1978	3.5	22.2	0.8	26.5
1979	1.5	10.9	0.9	13.3
1980	0.7	12.7	2.9	16.4
1981	1.2	15.0	1.0	17.3
1982	1.2	14.9	0.6	16.6
1983	1.5	14.5	0.3	16.4
1984	2.1	13.9	0.3	16.3
1985	1.7	11.1	0.6	13.3
1986	1.7	7.7	1.3	10.7
1987	2.0	16.0	0.5	18.4
1988	2.3	21.8	0.7	24.8
1989	1.4	24.4	0.9	26.7
1990	2.1	24.8	8.3	35.3
1991	3.1	20.9	0.8	24.9
1992	1.6	36.6	1.0	39.2
1993	2.3	35.0	0.4	37.8
1994	1.4	26.3	0.4	28.0
1995	1.3	28.7	0.5	30.6
1996	2.4	37.1	0.5	39.9
1997	2.1	40.7	0.3	43.1
1998	1.4	31.6	0.4	33.4
1999	2.4	31.9	0.2	34.4
2000	2.1	32.4	0.1	34.5
2001	3.4	36.7	0.6	40.7
2002	5.4	47.1	0.1	52.6
2003	4.4	56.9	0.1	61.4
2004	1.5	59.2	0.1	60.8
2005	1.3	52.0	3.3	56.5
2006	1.6	50.7	9.4	61.7
2007	1.3	45.9	7.1	54.3
2008	1.1	48.9	0.1	50.1
2009	1.9	50.4	0.3	52.5
2010	0.8	50.1	1.1	52.0
2011	0.8	35.9	1.5	38.2
2012	0.4	37.1	0.2	37.7
2013	0.2	37.7	0.3	38.2
2014	0.2	41.4	0.2	41.8
2015	0.5	49.1	0.1	49.6
2016	0.6	54.3	0.2	55.2

Table 3. St. Croix commercial fishery spiny lobster landings in metric tons by year and gear group. Confidential means that values apply to 2 or fewer individual fishing entities and are masked in this report to preserve data confidentiality.

Year	Diving	Pots and Trips	Other Gear	Total Landings
1976	Confidential	0.9	0.1	1.0
1977	Confidential	1.1	1.8	2.9
1978	1.6	0.5	0.2	2.3
1979	0.2	0.8	Confidential	1.0
1980	0.2	0.1	0.2	0.6
1981	0.4	0.3	0.3	1.0
1982	0.6	0.5	0.1	1.2
1983	0.6	1.3	0.2	2.0
1984	2.6	0.7	0.2	3.4
1985	1.6	0.3	0.1	2.0
1986	0.8	1.6	0.4	2.7
1987	3.0	2.3	0.6	5.9
1988	1.9	1.3	0.4	3.6
1989	0.6	0.4	Confidential	1.0
1990	7.2	1.1	0.5	8.8
1991	12.7	2.4	1.8	16.9
1992	6.2	1.8	1.6	9.6
1993	11.5	3.2	2.2	16.9
1994	10.4	1.9	1.1	13.5
1995	8.3	2.0	1.1	11.4
1996	11.3	0.9	0.8	13.1
1997	13.7	1.9	0.7	16.3
1998	16.4	1.6	1.5	19.4
1999	20.6	2.9	0.7	24.2
2000	37.1	1.9	1.4	40.4
2001	49.2	1.6	2.1	52.9
2002	49.4	1.8	1.5	52.7
2003	45.6	1.5	1.0	48.1
2004	53.8	1.8	1.3	56.9
2005	52.5	1.2	1.2	54.9
2006	63.8	1.8	0.9	66.5
2007	67.3	2.5	6.5	76.2
2008	63.8	1.9	1.5	67.1
2009	64.0	1.8	2.2	68.0
2010	56.2	3.9	3.3	63.4
2011	38.5	7.1	4.1	49.8
2012	30.0	7.0	2.5	39.5
2013	22.5	2.7	1.7	26.9
2014	13.8	1.2	3.0	18.0
2015	16.3	2.6	1.5	20.4
2016	12.4	0.4	1.5	14.3

Table 4. Puerto Rico commercial fishery spiny lobster landings in metric tons by year and gear group. The asterisk highlights the year 2005, which was associated with low reporting and large expansion factors. The original expanded landings are included in this table, but in the SEDAR 57 stock assessment these values in 2005 were replaced with the mean of the values from 2004 and 2006.

Year	Diving	Pots and Traps	Other Gear	Total Landings
1983	186.5	16.6	0.2	203.4
1984	171.4	19.2	0.0	190.7
1985	61.3	104.2	5.4	170.8
1986	47.0	76.6	3.3	126.9
1987	29.0	62.0	1.8	92.8
1988	46.9	57.8	9.7	114.4
1989	59.0	98.7	7.2	164.9
1990	54.2	90.1	4.9	149.2
1991	71.4	102.2	14.5	188.0
1992	43.5	68.5	9.4	121.5
1993	55.5	62.1	10.0	127.6
1994	55.9	72.5	7.7	136.1
1995	75.2	88.0	14.9	178.2
1996	79.0	88.1	11.2	178.3
1997	68.8	83.7	12.1	164.6
1998	80.1	81.9	11.0	173.0
1999	77.0	97.2	15.3	189.5
2000	103.7	91.4	8.6	203.7
2001	90.9	90.6	5.2	186.7
2002	79.6	75.8	3.2	158.5
2003	73.6	93.4	12.6	179.6
2004	96.1	110.1	9.8	216.1
2005*	124.9	221.1	5.2	351.3
2006	61.8	59.2	4.6	125.6
2007	69.7	47.1	3.7	120.6
2008	95.2	49.1	5.3	149.6
2009	90.4	53.3	2.9	146.6
2010	76.3	42.9	12.1	131.3
2011	78.4	43.7	1.8	123.9
2012	101.5	68.0	4.9	174.4
2013	80.4	37.3	7.2	124.9
2014	100.0	59.8	10.8	170.6
2015	107.2	71.9	10.4	189.4
2016	107.7	83.0	11.7	202.3

Table 5. Summary of model development approach for USVI (St. Croix (STX) and St. Thomas/St. John (STT)).

Config.	Description	NLL	Notes
STT			
1A	Logistic selectivity on diving, traps mirrored selectivity, no female offset, no retention parameters, initial unfished equilibrium	181.7	Simplest configuration
1B	Config #1, but selectivity changed exponential-logistic	151.9	Simplest configuration, plus evaluate support for logistic exponential selectivity
2	Exponential-logistic selectivity on diving, traps mirrored selectivity, no female offset, retention blocks 1985-2003 and 2007 to 2016, initial unfished equilibrium	126.1	**Base model**
3	Config 2 + female retention offset	-	Poor profile on R0
4	Config 2 + estimate initial equilibrium fishing mortality	-	Initial fishing mortality parameters hit bound at 0.
5	Config 2 + exponential-logistic selectivity separately estimated for each fishery	-	Poor profile on R0
6	Config 5 + female retention offset	-	Poor profile on R0
STX			
1A	Logistic selectivity on diving, traps mirrored selectivity, no female offset, no retention parameters, initial unfished equilibrium	456.4	Simplest configuration
1B	Config #1, plus selectivity changed exponential-logistic	-	Poor profile on R0
2	Exponential-logistic selectivity on diving, traps mirrored selectivity, no female offset, retention blocks 1985 to 2016, initial unfished equilibrium	-	Poor profile on R0
3	Config 2 + female retention offset	-	Poor profile on R0
4	Config 2 + estimate initial equilibrium fishing mortality	-	Initial fishing mortality parameters hit bound at 0.
5	Config 2 + exponential-logistic selectivity separately estimated for each fishery	-	Poor profile on R0
6	Config 5 + female retention offset	-	Poor profile on R0
7	Config 2, except informative prior of selectivity parameters	162.9	**Base model**

Table 6. Summary of model development approach for Puerto Rico (PR).

Config.	Description	NLL	Notes
PR			
1A	Logistic selectivity on diving, traps mirrored selectivity, no female offset, no retention parameters	415.22	Simplest configuration
1B	Config #1A, but selectivity changed to exponential-logistic	-	Initial fishing mortality parameters hit bound at 0.
1C	Config #1B, but selectivity changed to exponential-logistic fixed to be asymptotic (P3 = 0.001)	414.9	
2	Config #1C, but with 1999-2016 time block and estimated width of logistic retention	340.84	
3	Config 2 + 2005 removals replaced with mean of 2004 and 2006	308.39	
4	Config 3 + but with forced asymptotic logistic exponential selectivity estimated for each fishery	265.75	Correlation of 0.77 between Initial F & R0
1D	Config #1C, but with informative prior of selectivity parameters from STT	379.12	Correlation of 0.99 between Initial F & R0
5	Config #1D, but with 1999-2016 time block and estimated width of logistic retention	303.58	Correlation of 0.99 between Initial F & R0
6	Config 5 + 2005 removals replaced with mean of 2004 and 2006	295.79	Correlation of 0.83 between Initial F & R0
7	Config 6 + informative prior of selectivity parameters from STT for each fishery	271.44	Correlation of 0.84 between Initial F & R0
8	Config 7 + selectivity time block	249.41	**Base model**
9	Config 8 + filtered to remove length composition data with small sample size ($\sqrt{n} < 8$)	-	Improved retrospective diagnostic compared to Config 8

Table 7. Parameter estimates for base models, St. Croix and St. Thomas/St. John. Est. is the maximum likelihood estimate; SE is standard error of the estimator.

Parameter	St. Croix		St. Thomas/St. John	
	Est.	SE	Est.	SE
Log(R0)	5.47	0.17	5.23	0.13
Sel. P1	0.19	0.01	0.13	0.01
Sel. P2	0.38	0.01	0.4	0.01
Sel. P3	0.39	0.02	0.29	0.05

Table 8. Parameter estimates for base model, Puerto Rico. Est. is the maximum likelihood estimate; SE is standard error of the estimator.

Parameter	Puerto Rico		Puerto Rico Diving 1983-1998		Puerto Rico Diving 1999-2016		Puerto Rico Trap 1983-1998		Puerto Rico Trap 1999-2016	
	Est.	SE	Est.	SE	Est.	SE	Est.	SE	Est.	SE
Log(R0)	6.55	0.05	-	-	-	-	-	-	-	-
Initial F	1.35	0.21	-	-	-	-	-	-	-	-
Sel. P1	-	-	0.32	0.05	0.15	0.01	0.20	0.04	0.15	0.01
Sel. P2	-	-	0.31	0.01	0.38	< 0.01	0.34	0.02	0.38	< 0.01
Sel. P3			0.10	0.03	0.43	0.03	0.20	0.06	0.43	0.04
Ret. P2	-	-	-	-	3.00	0.52	-	-	4.45	0.98

Table 9. Recruitment estimates (1000s of Age-0 lobster) and standard error from Stock Synthesis base models.

	St. Croix		St. Thomas/St. John		Puerto Rico	
YEAR	Recruits (1000s)	Std. Err.	Recruits (1000s)	Std. Err.	Recruits (1000s)	Std. Err.
1975	-	-	186.43	25.04	-	-
1976	238.37	41.08	186.41	25.04	-	-
1977	238.36	41.08	186.40	25.04	-	-
1978	238.34	41.08	186.35	25.05	-	-
1979	238.33	41.08	186.21	25.05	-	-
1980	238.32	41.08	186.14	25.05	-	-
1981	238.33	41.08	186.06	25.05	-	-
1982	238.33	41.08	186.00	25.05	-	-
1983	238.33	41.08	185.94	25.05	641.49	49.34
1984	238.32	41.08	185.90	25.05	640.58	49.96
1985	238.31	41.08	185.87	25.06	641.22	50.05
1986	238.31	41.08	185.87	25.05	643.95	49.71
1987	238.30	41.08	185.89	25.05	653.82	45.52
1988	238.28	41.08	185.87	25.06	665.91	40.63
1989	238.27	41.08	185.78	25.06	673.16	38.23
1990	238.27	41.08	185.69	25.07	675.33	37.68
1991	238.24	41.08	185.52	25.08	677.14	37.07
1992	238.16	41.08	185.45	25.09	676.51	37.17
1993	238.12	41.08	185.26	25.11	678.66	36.31
1994	238.05	41.08	185.08	25.13	680.73	35.56
1995	238.00	41.08	185.04	25.13	682.21	35.05
1996	237.97	41.08	185.00	25.14	681.80	35.02
1997	237.95	41.08	184.85	25.16	680.84	35.08
1998	237.91	41.09	184.65	25.20	680.23	35.05
1999	237.85	41.09	184.60	25.20	679.33	35.10
2000	237.76	41.09	184.57	25.21	677.28	35.37
2001	237.56	41.11	184.55	25.22	675.05	35.78
2002	237.23	41.14	184.44	25.24	674.00	36.00
2003	236.87	41.19	184.13	25.31	675.10	35.76
2004	236.55	41.24	183.60	25.45	675.39	35.77
2005	236.15	41.32	183.05	25.62	673.38	36.36
2006	235.78	41.42	182.54	25.81	673.93	36.29
2007	235.25	41.57	181.85	26.11	677.39	35.49
2008	234.47	41.85	181.36	26.36	680.82	34.79
2009	233.82	42.13	181.23	26.45	682.50	34.50
2010	233.19	42.45	181.12	26.54	683.78	34.26
2011	232.76	42.72	181.07	26.61	685.24	34.00
2012	232.88	42.69	181.65	26.34	686.65	33.76
2013	233.44	42.43	182.19	26.11	686.46	33.77
2014	234.30	42.04	182.61	25.94	687.30	33.62
2015	235.18	41.70	182.84	25.85	686.98	33.64
2016	235.82	41.50	182.80	25.87	685.89	33.77

Table 10. Spawning Output (1000s of eggs) and standard error from Stock Synthesis base models. Note: Unlike other Stock Synthesis estimates which are typically computed midyear, Stock Synthesis estimates of spawning output are "beginning of the year". Therefore, the 2017 estimate is provided in this table.

	St. Croix		St. Thomas/St. John		Puerto Rico	
YEAR	Spawning Output (1000s eggs)	Std. err.	Spawning Output (1000s eggs)	Std. err.	Spawning Output (1000s eggs)	Std. err.
1975	-	-	1.72E+08	2.31E+07	-	-
1976	2.20E+08	3.79E+07	1.71E+08	2.31E+07	-	-
1977	2.20E+08	3.79E+07	1.70E+08	2.31E+07	-	-
1978	2.18E+08	3.79E+07	1.67E+08	2.31E+07	-	-
1979	2.18E+08	3.79E+07	1.58E+08	2.31E+07	-	-
1980	2.17E+08	3.79E+07	1.54E+08	2.31E+07	-	-
1981	2.17E+08	3.79E+07	1.50E+08	2.30E+07	-	-
1982	2.17E+08	3.79E+07	1.46E+08	2.29E+07	-	-
1983	2.17E+08	3.79E+07	1.44E+08	2.29E+07	8.13E+07	3.05E+07
1984	2.17E+08	3.79E+07	1.42E+08	2.29E+07	8.01E+07	3.05E+07
1985	2.16E+08	3.79E+07	1.40E+08	2.28E+07	8.09E+07	3.11E+07
1986	2.16E+08	3.79E+07	1.40E+08	2.28E+07	8.46E+07	3.29E+07
1987	2.15E+08	3.79E+07	1.41E+08	2.28E+07	1.01E+08	3.54E+07
1988	2.14E+08	3.79E+07	1.40E+08	2.28E+07	1.32E+08	3.81E+07
1989	2.13E+08	3.79E+07	1.36E+08	2.28E+07	1.60E+08	4.03E+07
1990	2.14E+08	3.79E+07	1.32E+08	2.28E+07	1.70E+08	4.14E+07
1991	2.12E+08	3.79E+07	1.25E+08	2.28E+07	1.80E+08	4.14E+07
1992	2.07E+08	3.79E+07	1.23E+08	2.28E+07	1.77E+08	4.07E+07
1993	2.04E+08	3.79E+07	1.16E+08	2.27E+07	1.89E+08	3.96E+07
1994	2.00E+08	3.79E+07	1.11E+08	2.27E+07	2.04E+08	3.84E+07
1995	1.97E+08	3.79E+07	1.10E+08	2.27E+07	2.15E+08	3.73E+07
1996	1.96E+08	3.79E+07	1.08E+08	2.27E+07	2.12E+08	3.61E+07
1997	1.94E+08	3.79E+07	1.04E+08	2.27E+07	2.05E+08	3.49E+07
1998	1.92E+08	3.79E+07	9.93E+07	2.27E+07	2.00E+08	3.36E+07
1999	1.89E+08	3.79E+07	9.82E+07	2.27E+07	1.94E+08	3.25E+07
2000	1.84E+08	3.78E+07	9.75E+07	2.27E+07	1.81E+08	3.13E+07
2001	1.75E+08	3.78E+07	9.70E+07	2.27E+07	1.69E+08	3.05E+07
2002	1.61E+08	3.77E+07	9.46E+07	2.27E+07	1.63E+08	3.02E+07
2003	1.49E+08	3.76E+07	8.83E+07	2.27E+07	1.69E+08	3.03E+07
2004	1.39E+08	3.76E+07	7.92E+07	2.27E+07	1.70E+08	3.07E+07
2005	1.29E+08	3.75E+07	7.16E+07	2.26E+07	1.61E+08	3.10E+07
2006	1.20E+08	3.75E+07	6.57E+07	2.25E+07	1.63E+08	3.13E+07
2007	1.10E+08	3.74E+07	5.91E+07	2.25E+07	1.82E+08	3.18E+07
2008	9.73E+07	3.72E+07	5.51E+07	2.26E+07	2.04E+08	3.24E+07
2009	8.89E+07	3.71E+07	5.41E+07	2.27E+07	2.18E+08	3.28E+07
2010	8.19E+07	3.72E+07	5.33E+07	2.30E+07	2.29E+08	3.29E+07
2011	7.77E+07	3.73E+07	5.30E+07	2.32E+07	2.43E+08	3.29E+07
2012	7.89E+07	3.77E+07	5.73E+07	2.36E+07	2.59E+08	3.27E+07
2013	8.45E+07	3.83E+07	6.21E+07	2.40E+07	2.56E+08	3.25E+07
2014	9.49E+07	3.88E+07	6.65E+07	2.43E+07	2.66E+08	3.22E+07
2015	1.08E+08	3.92E+07	6.91E+07	2.44E+07	2.62E+08	3.18E+07
2016	1.21E+08	3.94E+07	6.86E+07	2.44E+07	2.50E+08	3.15E+07
2017	1.34E+08	3.95E+07	6.57E+07	2.43E+07	2.32E+08	3.11E+07

Table 11. Total biomass (mt) from Stock Synthesis base models.

	St. Croix	St. Thomas/St. John	Puerto Rico
YEAR	Total Biomass (mt)	Total Biomass (mt)	Total Biomass (mt)
1975	-	501.049	-
1976	640.633	498.029	-
1977	639.606	495.35	-
1978	635.893	487.445	-
1979	633.952	463.298	-
1980	633.288	454.988	-
1981	633.749	445.884	-
1982	633.961	437.846	-
1983	633.922	432.141	430.493
1984	633.054	428.029	420.184
1985	630.812	425.027	414.229
1986	630.24	425.904	425.963
1987	629.173	429.713	483.918
1988	625.063	425.84	581.126
1989	623.659	416.191	656.233
1990	625.328	405.928	672.537
1991	619.231	388.985	697.235
1992	605.473	384.584	677.091
1993	600.4	367.859	722.584
1994	589.376	354.971	762.441
1995	583.273	353.825	790.688
1996	580.787	351.355	770.878
1997	577.589	340.625	746.764
1998	571.903	328.258	736.338
1999	563.927	327.074	718.577
2000	552.239	325.859	695.304
2001	525.966	325.02	665.705
2002	490.206	318.565	657.18
2003	459.112	301.434	680.158
2004	437.66	277.976	684.032
2005	412.128	257.095	651.597
2006	392.954	242.579	664.459
2007	366.284	225.29	723.847
2008	334.166	218.697	787.656
2009	315.295	218.606	817.703
2010	299.47	217.266	844.87
2011	291.253	217.012	882.456
2012	298.504	230.217	922.814
2013	316.868	243.071	907.166
2014	347.074	254.011	937.609
2015	383.769	259.887	920.069
2016	413.841	257.08	881.888

Table 12. Fishing mortality (% of the total stock biomass removed by fishing) and standard error from Stock Synthesis base models.

	St. Croix		St. Thomas/St. John		Puerto Rico	
YEAR	F	Std. Err.	F	Std. Err.	F	Std. Err.
1975	-	-	0.01	0.00	-	-
1976	0.00	0.00	0.01	0.00	-	-
1977	0.01	0.00	0.02	0.00	-	-
1978	0.00	0.00	0.05	0.01	-	-
1979	0.00	0.00	0.03	0.00	-	-
1980	0.00	0.00	0.04	0.01	-	-
1981	0.00	0.00	0.04	0.01	-	-
1982	0.00	0.00	0.04	0.01	-	-
1983	0.00	0.00	0.04	0.01	0.47	0.10
1984	0.01	0.00	0.04	0.01	0.46	0.10
1985	0.00	0.00	0.03	0.00	0.41	0.10
1986	0.00	0.00	0.03	0.00	0.30	0.07
1987	0.01	0.00	0.04	0.01	0.19	0.04
1988	0.01	0.00	0.06	0.01	0.20	0.04
1989	0.00	0.00	0.06	0.01	0.25	0.05
1990	0.01	0.00	0.09	0.01	0.22	0.04
1991	0.03	0.00	0.06	0.01	0.27	0.05
1992	0.02	0.00	0.10	0.02	0.18	0.03
1993	0.03	0.01	0.10	0.02	0.18	0.03
1994	0.02	0.00	0.08	0.01	0.18	0.03
1995	0.02	0.00	0.09	0.02	0.23	0.03
1996	0.02	0.00	0.11	0.02	0.23	0.03
1997	0.03	0.01	0.13	0.02	0.22	0.03
1998	0.03	0.01	0.10	0.02	0.24	0.03
1999	0.04	0.01	0.11	0.02	0.26	0.03
2000	0.07	0.01	0.11	0.02	0.29	0.04
2001	0.10	0.02	0.13	0.03	0.28	0.04
2002	0.11	0.02	0.17	0.03	0.24	0.03
2003	0.10	0.03	0.20	0.05	0.26	0.04
2004	0.13	0.03	0.22	0.05	0.32	0.04
2005	0.13	0.04	0.22	0.06	0.26	0.04
2006	0.17	0.05	0.25	0.07	0.19	0.03
2007	0.21	0.06	0.24	0.07	0.17	0.02
2008	0.20	0.07	0.23	0.07	0.19	0.02
2009	0.22	0.08	0.24	0.08	0.18	0.02
2010	0.21	0.08	0.24	0.08	0.16	0.02
2011	0.17	0.07	0.18	0.06	0.14	0.02
2012	0.13	0.05	0.16	0.05	0.19	0.02
2013	0.09	0.03	0.16	0.05	0.14	0.01
2014	0.05	0.02	0.17	0.05	0.18	0.02
2015	0.05	0.02	0.19	0.05	0.21	0.02
2016	0.03	0.01	0.22	0.06	0.23	0.02

Table 13. Parameter estimates for Puerto Rico model with length composition data filtered to remove years with small sample size ($\sqrt{n} < 8$). Est. is the maximum likelihood estimate; SE is standard error of the estimator.

Parameter	Puerto Rico		Puerto Rico Diving 1983-1998		Puerto Rico Diving 1999-2016		Puerto Rico Trap 1983-1998		Puerto Rico Trap 1999-2016	
	Est.	SE	Est.	SE	Est.	SE	Est.	SE	Est.	SE
Log(R0)	6.55	0.05	-	-	-	-	-	-	-	-
Initial F	1.36	0.22	-	-	-	-	-	-	-	-
Sel. P1	-	-	0.32	0.06	0.15	0.01	0.21	0.04	0.15	0.01
Sel. P2	-	-	0.31	0.01	0.38	< 0.01	0.33	0.02	0.38	< 0.01
Sel. P3			0.10	0.03	0.43	0.03	0.20	0.06	0.43	0.04
Ret. P2	-	-	-	-	3.00	0.52	-	-	4.45	0.98

Table 14. St. Croix: Estimated spawning output and fishing mortality relative to various reference levels (i.e. unfished, SPR30%) and management thresholds. The provisional minimum stock size threshold (MSST) was assumed to be 75% of $SSB_{SPR30\%}$. The provisional maximum fishing mortality threshold was assumed to be equal to $F_{SPR30\%}$.

YEAR	SSB	S/S0	S/S_SPR30	S/MSST	F	F/FSPR30	F/MFMT
1975	-	-	-	-	-	-	-
1976	2.20E+08	1.00	3.30	4.59	0.00	0.01	0.01
1977	2.20E+08	1.00	3.20	4.58	0.01	0.02	0.02
1978	2.18E+08	0.99	3.25	4.55	0.00	0.01	0.01
1979	2.18E+08	0.99	3.28	4.54	0.00	0.01	0.01
1980	2.17E+08	0.99	3.31	4.53	0.00	0.00	0.00
1981	2.17E+08	0.99	3.30	4.53	0.00	0.01	0.01
1982	2.17E+08	0.99	3.29	4.53	0.00	0.01	0.01
1983	2.17E+08	0.99	3.26	4.53	0.00	0.01	0.01
1984	2.17E+08	0.99	3.21	4.52	0.01	0.02	0.02
1985	2.16E+08	0.98	3.26	4.51	0.00	0.01	0.01
1986	2.16E+08	0.98	3.24	4.50	0.00	0.02	0.02
1987	2.15E+08	0.98	3.13	4.49	0.01	0.04	0.04
1988	2.14E+08	0.97	3.20	4.46	0.01	0.02	0.02
1989	2.13E+08	0.97	3.30	4.44	0.00	0.01	0.01
1990	2.14E+08	0.97	3.03	4.45	0.01	0.06	0.06
1991	2.12E+08	0.96	2.77	4.41	0.03	0.11	0.11
1992	2.07E+08	0.94	2.99	4.31	0.02	0.06	0.06
1993	2.04E+08	0.93	2.76	4.26	0.03	0.11	0.11
1994	2.00E+08	0.91	2.86	4.17	0.02	0.09	0.09
1995	1.97E+08	0.90	2.93	4.11	0.02	0.08	0.08
1996	1.96E+08	0.89	2.88	4.08	0.02	0.09	0.09
1997	1.94E+08	0.88	2.77	4.05	0.03	0.11	0.11
1998	1.92E+08	0.87	2.67	4.00	0.03	0.14	0.14
1999	1.89E+08	0.86	2.51	3.93	0.04	0.17	0.17
2000	1.84E+08	0.84	2.03	3.84	0.07	0.30	0.30
2001	1.75E+08	0.79	1.65	3.64	0.10	0.41	0.41
2002	1.61E+08	0.73	1.57	3.36	0.11	0.44	0.44
2003	1.49E+08	0.68	1.65	3.10	0.10	0.43	0.43
2004	1.39E+08	0.63	1.43	2.90	0.13	0.53	0.53
2005	1.29E+08	0.58	1.43	2.68	0.13	0.54	0.54
2006	1.20E+08	0.55	1.15	2.50	0.17	0.69	0.69
2007	1.10E+08	0.50	0.89	2.29	0.21	0.85	0.85
2008	9.73E+07	0.44	0.96	2.03	0.20	0.82	0.82
2009	8.89E+07	0.40	0.94	1.85	0.22	0.88	0.88
2010	8.19E+07	0.37	1.02	1.71	0.21	0.86	0.86
2011	7.77E+07	0.35	1.38	1.62	0.17	0.70	0.70
2012	7.89E+07	0.36	1.76	1.64	0.13	0.54	0.54
2013	8.45E+07	0.38	2.25	1.76	0.09	0.35	0.35
2014	9.49E+07	0.43	2.62	1.98	0.05	0.21	0.21
2015	1.08E+08	0.49	2.58	2.26	0.05	0.22	0.22
2016	1.21E+08	0.55	2.80	2.52	0.03	0.14	0.14
2017	1.34E+08	0.61	2.94	2.78	-	-	-

Table 15. St. Thomas/St. John: Estimated spawning output and fishing mortality relative to various reference levels (i.e. unfished, SPR30%) and management thresholds. The provisional minimum stock size threshold (MSST) was assumed to be 75% of $SSB_{SPR30\%}$. The provisional maximum fishing mortality threshold was assumed to be equal to $F_{SPR30\%}$.

YEAR	SSB	S/S0	S/S_SPR30	S/MSST	F	F/FSPR30	F/MFMT
1975	1.72E+08	1.00	3.44	4.59	0.01	0.02	0.02
1976	1.71E+08	0.99	3.42	4.56	0.01	0.02	0.02
1977	1.70E+08	0.99	3.40	4.53	0.02	0.07	0.07
1978	1.67E+08	0.97	3.34	4.45	0.05	0.21	0.21
1979	1.58E+08	0.92	3.16	4.21	0.03	0.11	0.11
1980	1.54E+08	0.89	3.07	4.10	0.04	0.14	0.14
1981	1.50E+08	0.87	2.99	3.99	0.04	0.15	0.15
1982	1.46E+08	0.85	2.92	3.90	0.04	0.15	0.15
1983	1.44E+08	0.83	2.87	3.82	0.04	0.15	0.15
1984	1.42E+08	0.82	2.83	3.77	0.04	0.15	0.15
1985	1.40E+08	0.81	2.80	3.73	0.03	0.12	0.12
1986	1.40E+08	0.81	2.80	3.73	0.03	0.10	0.10
1987	1.41E+08	0.82	2.82	3.76	0.04	0.17	0.17
1988	1.40E+08	0.81	2.79	3.73	0.06	0.23	0.23
1989	1.36E+08	0.79	2.72	3.63	0.06	0.25	0.25
1990	1.32E+08	0.77	2.64	3.52	0.09	0.34	0.34
1991	1.25E+08	0.73	2.50	3.34	0.06	0.25	0.25
1992	1.23E+08	0.71	2.46	3.28	0.10	0.40	0.40
1993	1.16E+08	0.68	2.33	3.10	0.10	0.40	0.40
1994	1.11E+08	0.64	2.22	2.95	0.08	0.31	0.31
1995	1.10E+08	0.64	2.19	2.92	0.09	0.34	0.34
1996	1.08E+08	0.63	2.17	2.89	0.11	0.45	0.45
1997	1.04E+08	0.61	2.08	2.78	0.13	0.50	0.50
1998	9.93E+07	0.58	1.98	2.65	0.10	0.40	0.40
1999	9.82E+07	0.57	1.96	2.62	0.11	0.41	0.41
2000	9.75E+07	0.57	1.95	2.60	0.11	0.42	0.42
2001	9.70E+07	0.56	1.94	2.58	0.13	0.49	0.49
2002	9.46E+07	0.55	1.89	2.52	0.17	0.65	0.65
2003	8.83E+07	0.51	1.76	2.35	0.20	0.80	0.80
2004	7.92E+07	0.46	1.58	2.11	0.22	0.86	0.86
2005	7.16E+07	0.42	1.43	1.91	0.22	0.86	0.86
2006	6.57E+07	0.38	1.31	1.75	0.25	1.00	1.00
2007	5.91E+07	0.34	1.18	1.57	0.24	0.95	0.95
2008	5.51E+07	0.32	1.10	1.47	0.23	0.90	0.90
2009	5.41E+07	0.31	1.08	1.44	0.24	0.94	0.94
2010	5.33E+07	0.31	1.07	1.42	0.24	0.94	0.94
2011	5.30E+07	0.31	1.06	1.41	0.18	0.69	0.69
2012	5.73E+07	0.33	1.15	1.53	0.16	0.64	0.64
2013	6.21E+07	0.36	1.24	1.66	0.16	0.62	0.62
2014	6.65E+07	0.39	1.33	1.77	0.17	0.65	0.65
2015	6.91E+07	0.40	1.38	1.84	0.19	0.75	0.75
2016	6.86E+07	0.40	1.37	1.83	0.22	0.84	0.84
2017	6.57E+07	0.38	1.31	1.75	-	-	-

Table 16. Puerto Rico: Estimated spawning output and fishing mortality relative to various reference levels (i.e. unfished, SPR30%) and management thresholds. The provisional minimum stock size threshold (MSST) was assumed to be 75% of $SSB_{SPR30\%}$. The provisional maximum fishing mortality threshold was assumed to be equal to $F_{SPR30\%}$.

YEAR	SSB	S/S0	S/S_SPR30	S/MSST	F	F/FSPR30	F/MFMT
1983	8.13E+07	0.13	0.43	0.58	0.47	1.95	1.95
1984	8.01E+07	0.12	0.43	0.57	0.46	1.87	1.87
1985	8.09E+07	0.13	0.43	0.57	0.41	1.70	1.70
1986	8.46E+07	0.13	0.45	0.60	0.30	1.23	1.23
1987	1.01E+08	0.16	0.54	0.72	0.19	0.79	0.79
1988	1.32E+08	0.20	0.70	0.93	0.20	0.81	0.81
1989	1.60E+08	0.25	0.85	1.13	0.25	1.03	1.03
1990	1.70E+08	0.26	0.91	1.21	0.22	0.91	0.91
1991	1.80E+08	0.28	0.96	1.28	0.27	1.11	1.11
1992	1.77E+08	0.27	0.94	1.25	0.18	0.74	0.74
1993	1.89E+08	0.29	1.01	1.34	0.18	0.73	0.73
1994	2.04E+08	0.32	1.08	1.45	0.18	0.73	0.73
1995	2.15E+08	0.33	1.14	1.53	0.23	0.93	0.93
1996	2.12E+08	0.33	1.13	1.50	0.23	0.95	0.95
1997	2.05E+08	0.32	1.09	1.45	0.22	0.91	0.91
1998	2.00E+08	0.31	1.06	1.42	0.24	0.97	0.97
1999	1.94E+08	0.30	1.03	1.38	0.26	1.09	1.09
2000	1.81E+08	0.28	0.96	1.28	0.29	1.21	1.21
2001	1.69E+08	0.26	0.90	1.20	0.28	1.15	1.15
2002	1.63E+08	0.25	0.87	1.16	0.24	0.99	0.99
2003	1.69E+08	0.26	0.90	1.20	0.26	1.09	1.09
2004	1.70E+08	0.26	0.91	1.21	0.32	1.30	1.30
2005	1.61E+08	0.25	0.85	1.14	0.26	1.08	1.08
2006	1.63E+08	0.25	0.87	1.16	0.19	0.78	0.78
2007	1.82E+08	0.28	0.97	1.29	0.17	0.69	0.69
2008	2.04E+08	0.32	1.09	1.45	0.19	0.78	0.78
2009	2.18E+08	0.34	1.16	1.54	0.18	0.74	0.74
2010	2.29E+08	0.35	1.22	1.62	0.16	0.64	0.64
2011	2.43E+08	0.38	1.29	1.72	0.14	0.58	0.58
2012	2.59E+08	0.40	1.38	1.83	0.19	0.78	0.78
2013	2.56E+08	0.40	1.36	1.82	0.14	0.57	0.57
2014	2.66E+08	0.41	1.42	1.89	0.18	0.75	0.75
2015	2.62E+08	0.41	1.40	1.86	0.21	0.85	0.85
2016	2.50E+08	0.39	1.33	1.77	0.23	0.94	0.94
2017	2.32E+08	0.36	1.24	1.65	-	-	-

Table 17. MSRA Table: Provisional status indicators (standard error), benchmarks, and related quantities from the Stock Synthesis base runs for each island platform.

Value	Definition	Units	STX	STT	PR
S_{MSY}	Spawning Output using proxy of SSPR30	1000s eggs	6.40E+07 (1.10E+07)	5.00E+07 (6.72E+06)	1.88E+08 (8.76E+06)
F_{MSY}	Fishing Mortality that produces MSY in equilibrium using proxy of S_{SPR30}	Proportion of Stock removed by fishing	0.246 (0.001)	0.255 (0.001)	0.243 (0.001)
MSST	Min. Stock Size Threshold (75% of SSPR30)	1000s eggs	4.80E+07	3.75E+07	1.41E+08
MFMT	Max. Fishing Mortality Threshold (F_{SPR30})	Proportion of Stock biomass removed by fishing	0.246 (0.001)	0.255 (0.001)	0.243 (0.001)
MSY	Equilibrium Retained Yield at proxy of S_{SPR30}	lbs	1.41E+05 (2.40E+04)	1.18E+05 (1.50E+04)	3.91E+05 (1.70E+04)
S_0	Unfished Stock Output	1000s eggs	2.20E+08 (3.79E+07)	1.72E+08 (2.31E+07)	6.47E+08 (3.01E+07)
$S_{Current}$	Spawning Output at Beginning of 2017	1000s eggs	1.34E+08 (3.95E+07)	6.57E+07 (2.43E+07)	2.32E+08 (3.11E+07)
$S_{Current}/S_0$	Calculated from definitions above	proportion	0.609	0.382	0.359
$S_{Current}/S_{MSY}$	Calculated from definitions above	proportion	2.094	1.314	1.234
$S_{Current}$/MSST	Calculated from definitions above	proportion	2.792	1.752	1.645
$F_{Current}$	Fishing Mortality in 2016, (exploitation rate in biomass)	Proportion of Stock biomass removed by fishing	0.035 (0.010)	0.215 (0.060)	0.230 (0.024)
$F_{Current}/F_{MSY}$	Calculated from definitions above	proportion	0.142	0.843	0.947
$F_{Current}$/MFMT	Calculated from definitions above	proportion	0.142	0.843	0.947

Table 18. Provisional base model OFL projections (and standard error). Provisional landings for 2017 and 2018, highlighted by the asterisk, were set to the estimates of landings for 2017 that were available as of August 2018.

a) in metric tons.

	St. Croix	St. Thomas	Puerto Rico
	Base Model	Base Model	Base Model
2017*	11.64	41.64	129.76
2018*	11.64	41.64	129.76
2019	93.52 (17.53)	62.65 (13.93)	201.92 (17.29)
2020	73.49 (14.07)	57.78 (10.72)	185.80 (17.77)
2021	68.55 (13.39)	55.81 (9.52)	181.64 (18.18)
2022	66.92 (13.21)	54.93 (9.00)	180.14 (18.36)

b) in pounds.

	St. Croix	St. Thomas	Puerto Rico
	Base Model	Base Model	Base Model
2017*	25,671	91,801	286,081
2018*	25,671	91,801	286,081
2019	206,176 (38,647)	138,120 (30,710)	445,162 (38,118)
2020	162,018 (31,019)	127,383 (23,634)	409,608 (39,176)
2021	151,127 (29,520)	123,040 (20,988)	400,445 (40,080)
2022	147,533 (29,123)	121,100 (19,842)	397,134 (40,477)

10. FIGURES

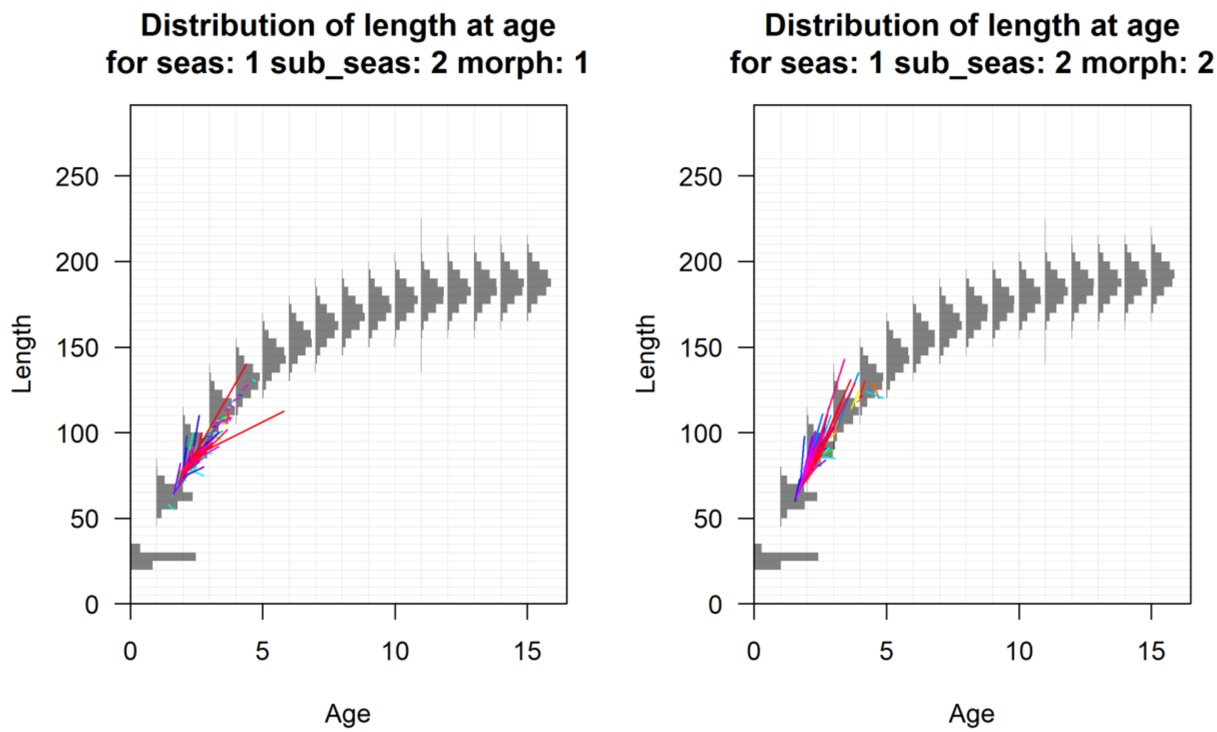

Figure 1. Individual growth trajectories of spiny lobster observed during a mark-recapture study led by the St. Thomas Fishermen's Association (Olsen et al. 2017). Individual growth trajectories (colored lines) are plotted against Von Bertalanffy growth trend for Puerto Rico (Mateo 2004), which is represented according to variation in size for each age class (grey histograms). Morph 1 is female; Morph 2 is male.

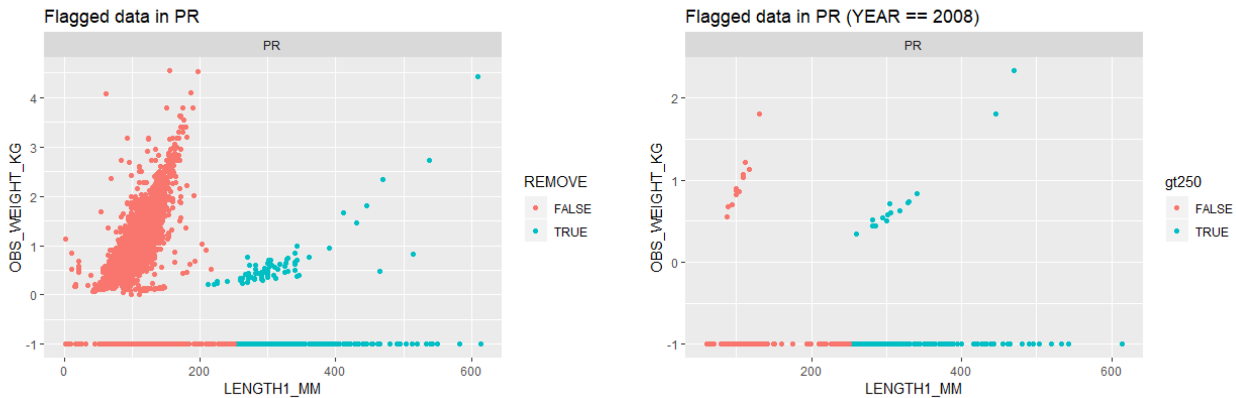

Figure 2. Summary of lengths and weights for flagged length data from Puerto Rico. A negative value for weight reflects a missing weight associated with a given length record. An unusual bimodal distribution associated with 2008 appears to be caused by lengths at and above 200 mm CL that likely have an error such as a misidentified species code.

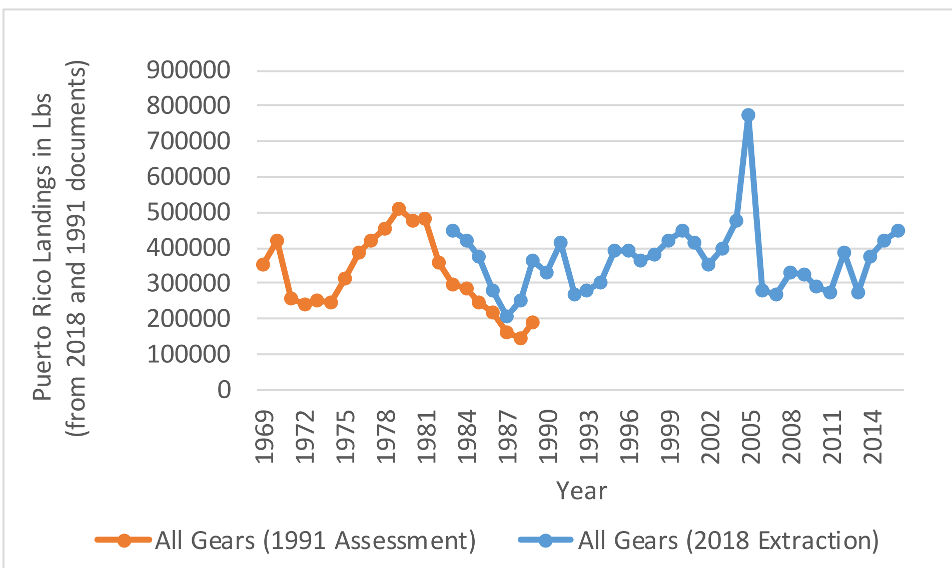

Figure 3. Historical landings for Puerto Rico before the use of expansion factors (orange lines Bohnsack et al. 1990) plotted with landings history (blue lines) utilized in the current assessment. The expanded landings in Puerto Rico from the 2018 extraction are included in this figure, but for the SEDAR 57 stock assessment the values for 2005 were replaced with the mean of the values from 2004 and 2006.

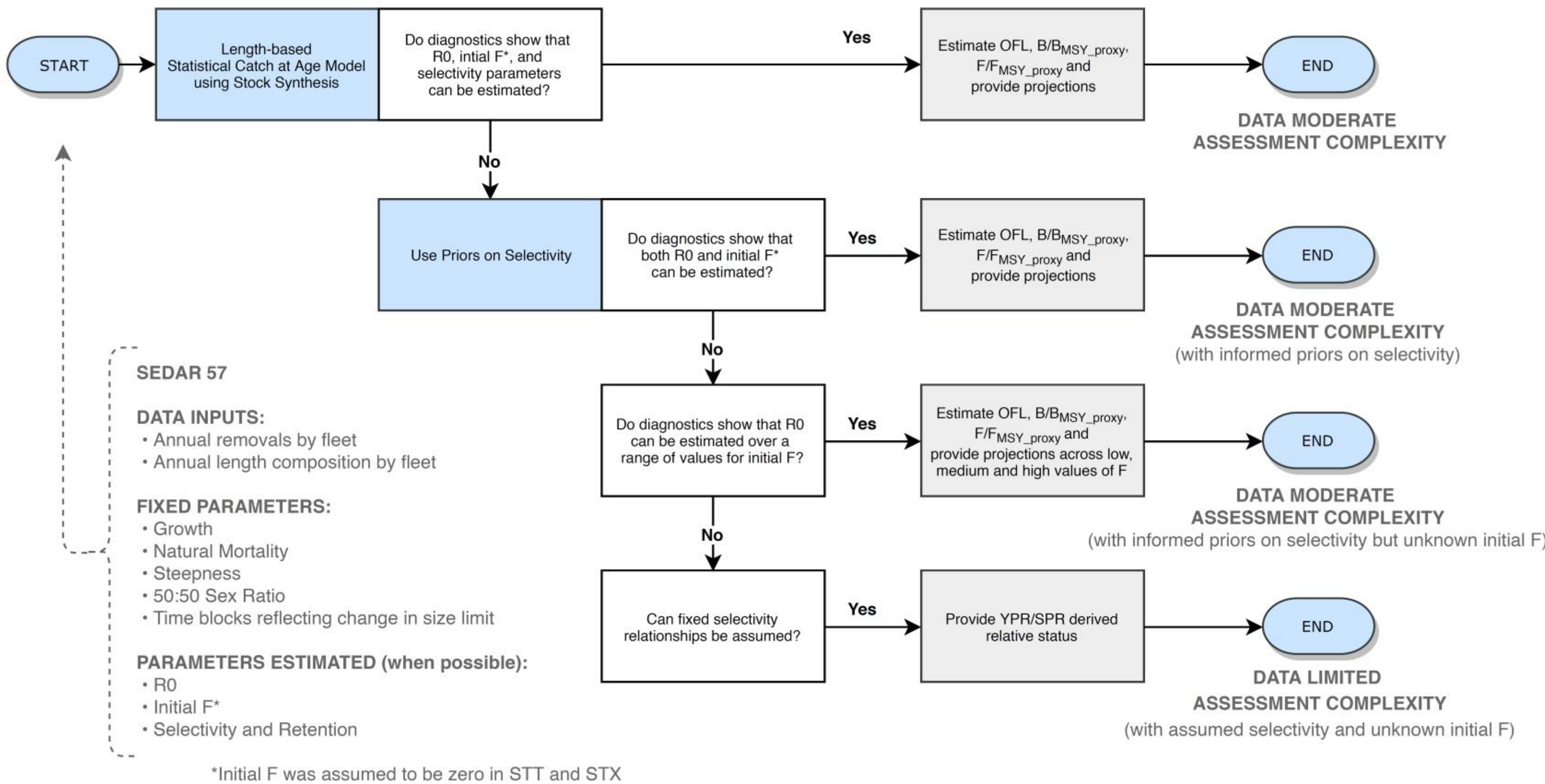

Figure 4. Conceptual overview of the model development process that was used in SEDAR 57. The model development process reflects constraints on model structure and interpretation of model outputs that are consistent with limitations of the available data.

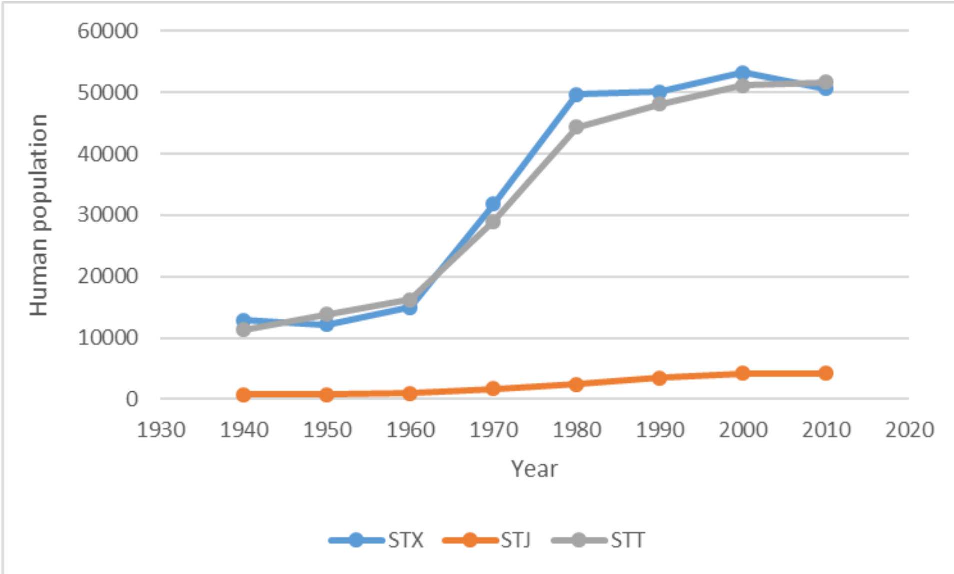

Figure 5. Human population growth USVI. Obtained from United States Census Bureau. [https://www.census.gov/newsroom/releases/archives/2010_census/press-kits/island-areas.html.Accessed 30 November 2018](https://www.census.gov/newsroom/releases/archives/2010_census/press-kits/island-areas.html).

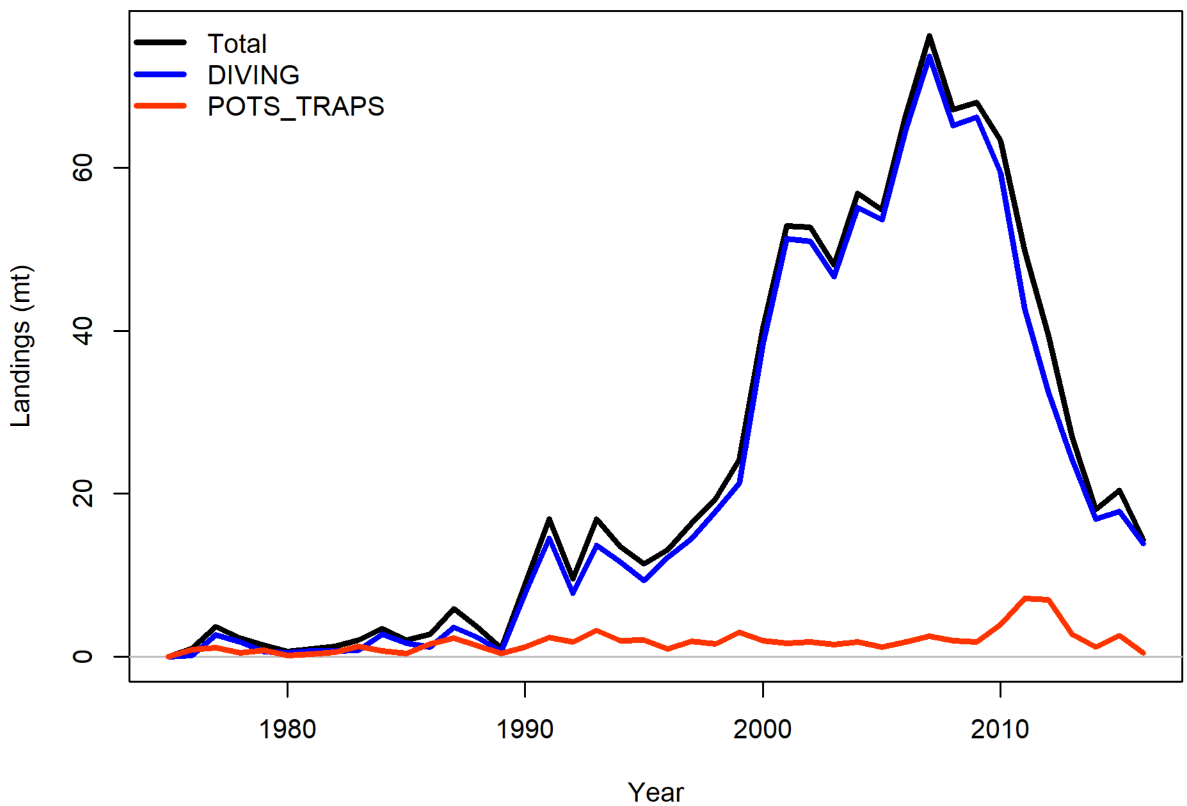

Figure 6. Landings history for St. Croix

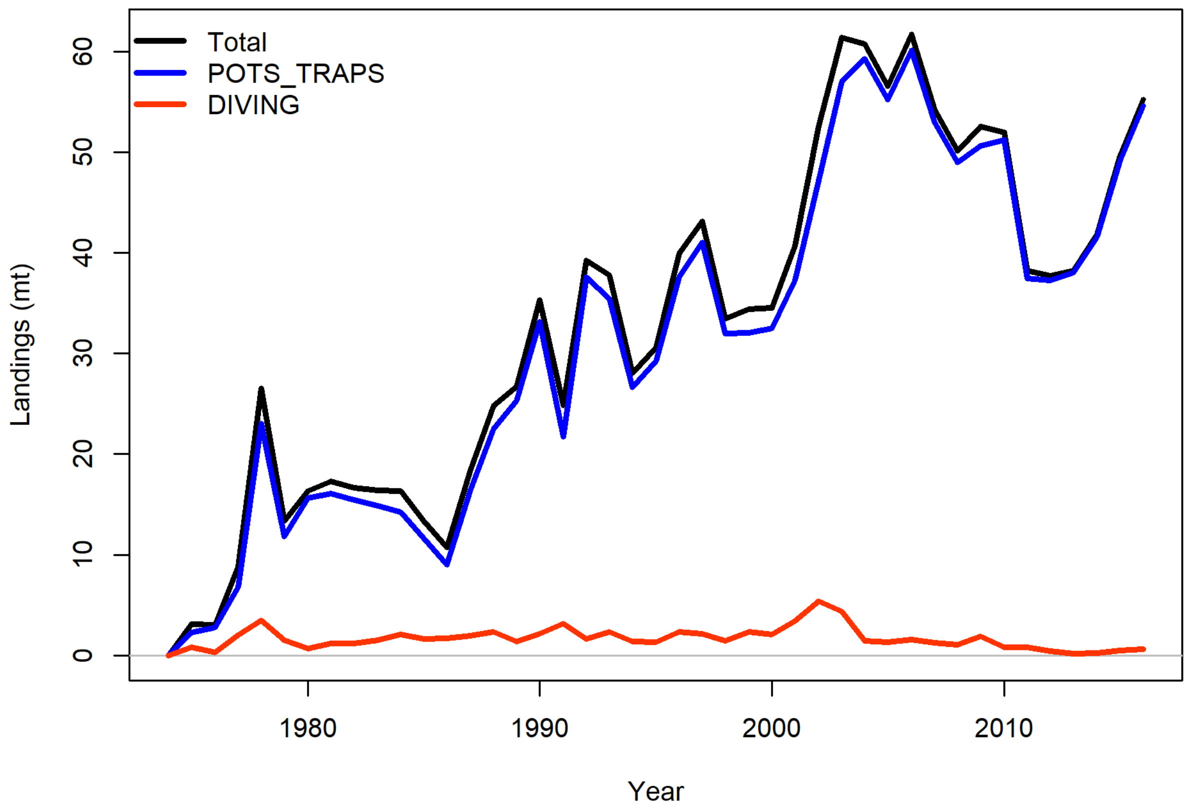

Figure 7. Landings history for St. Thomas/St. John.

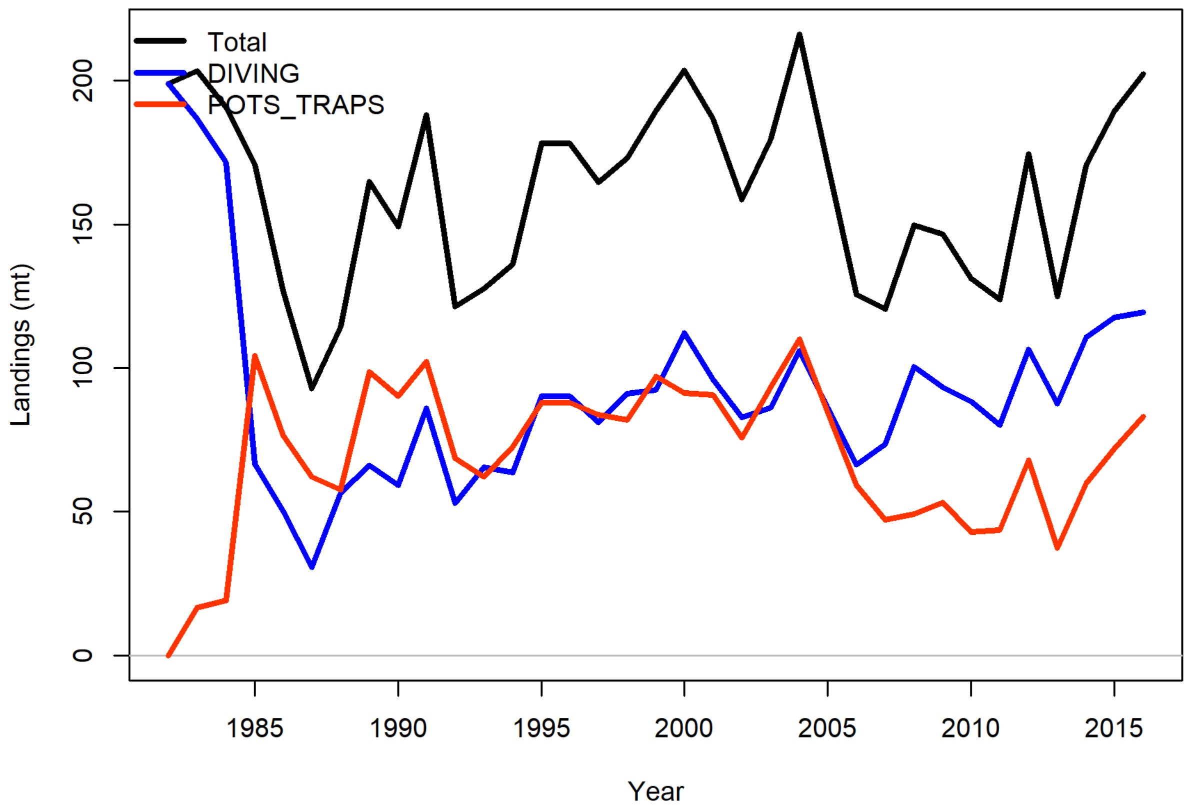

Figure 8. Landings history for Puerto Rico. The original expanded landings values in 2005 were associated with low reporting and large expansion factors (Table 4) are not plotted here. The values in 2005 year were replaced with the mean of values from 2004 and 2006.

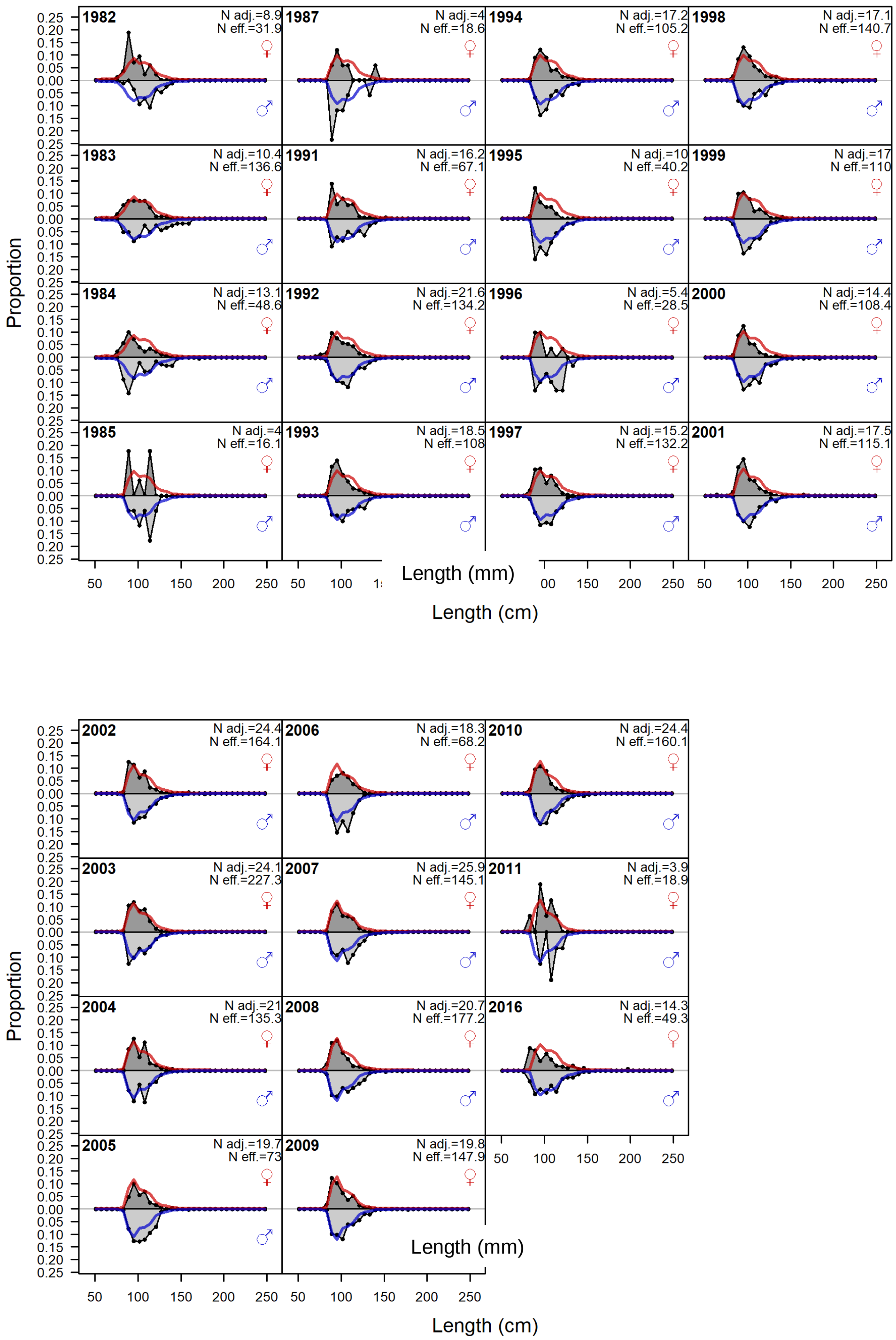

Figure 9. St. Croix, diving fleet. Observed (grey histograms) and expected (lines) length frequency distributions.

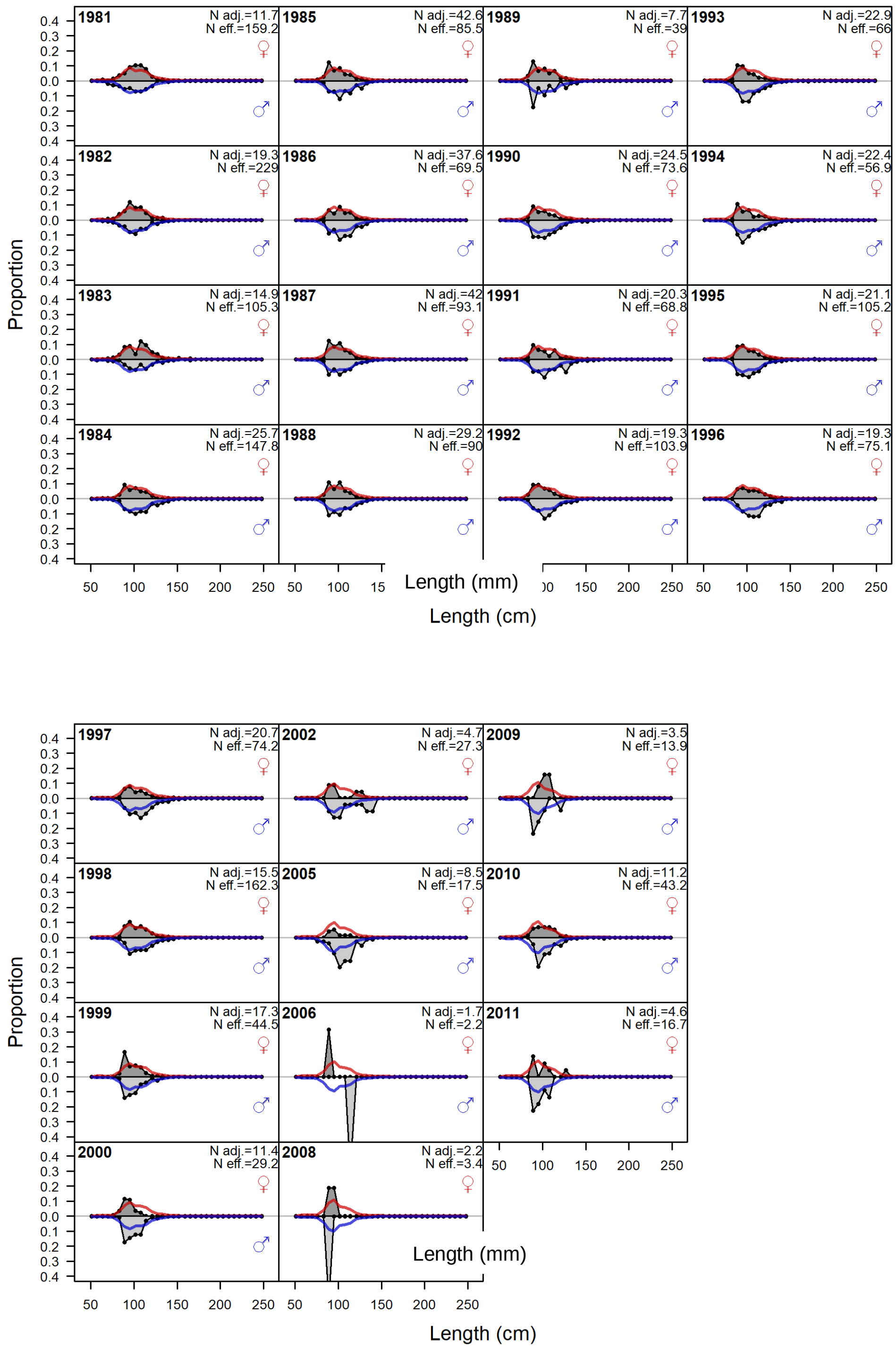

Figure 10. St. Croix, pots and traps fleet. Observed (grey histograms) and expected (lines) length frequency distributions.

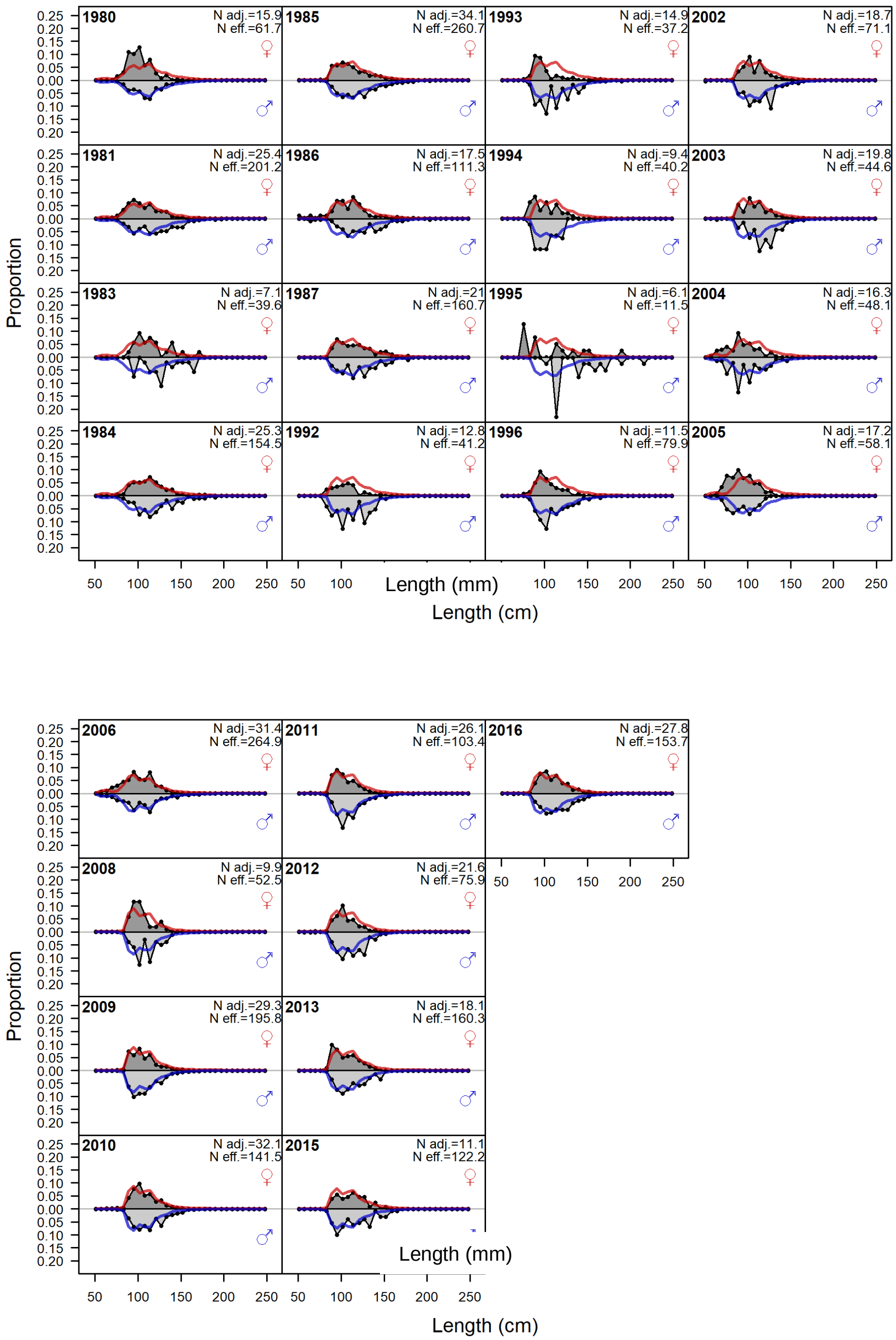

Figure 11. St. Thomas/St. John, pots and traps fleet. Observed (grey histograms) and expected (lines) length frequency distributions.

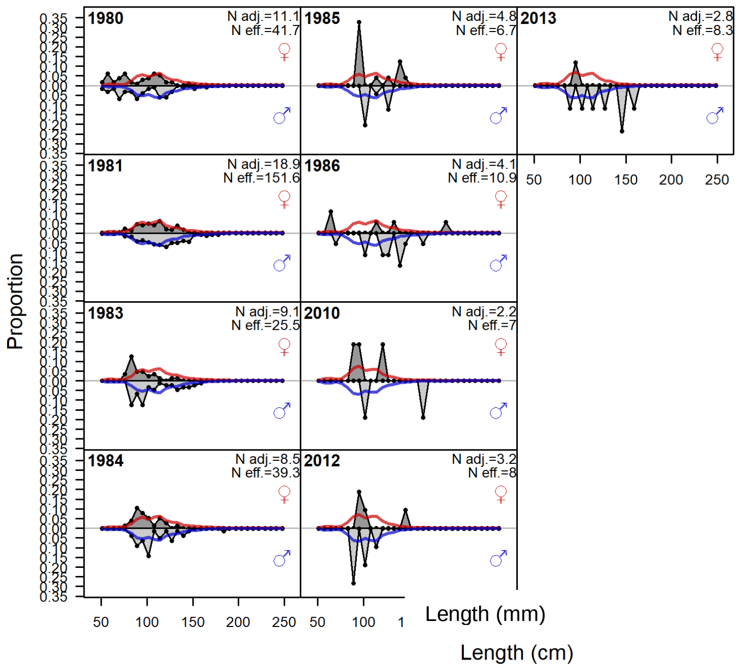

Figure 12. St. Thomas/St. John, diving fleet. Observed (grey histograms) and expected (lines) length frequency distributions.

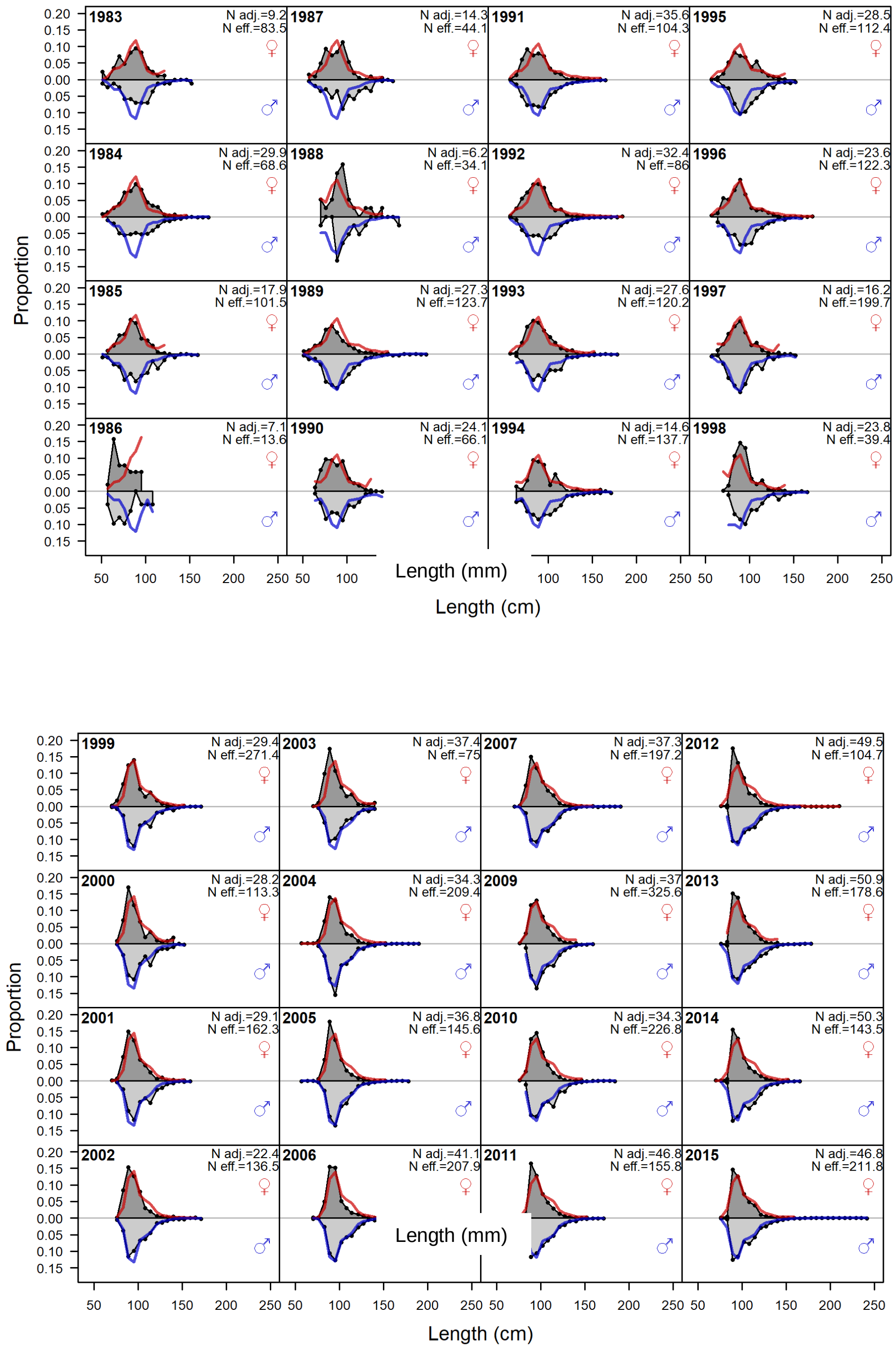

Figure 13. Puerto Rico, diving. Observed (grey histograms) and expected (lines) length frequency distributions.

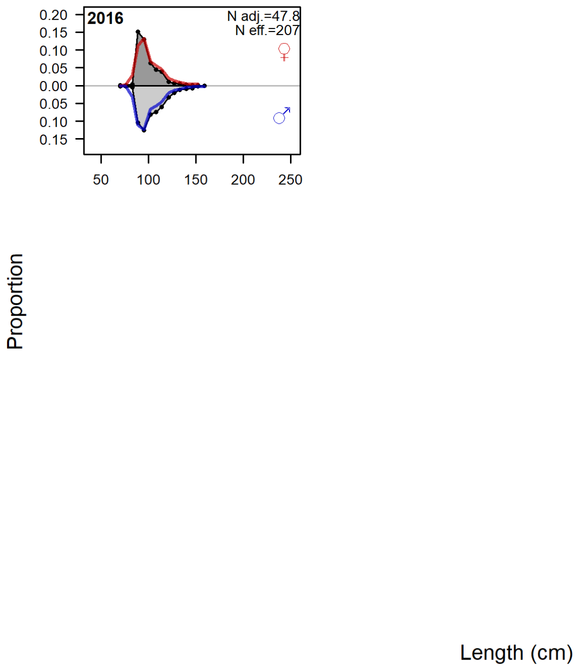

Figure 13. (Continued) Puerto Rico, diving. Observed (grey histograms) and expected (lines) length frequency distributions.

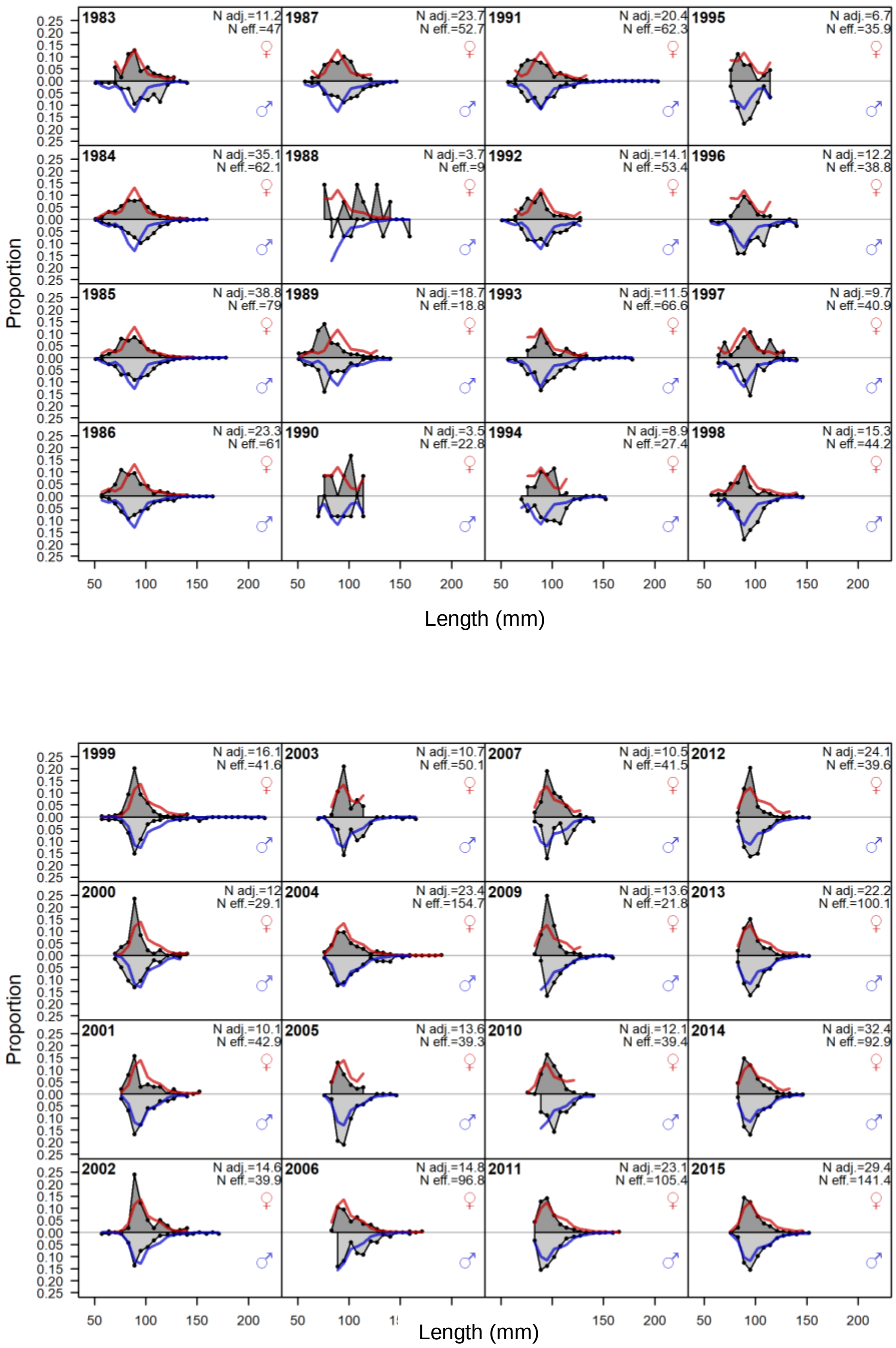

Figure 14. Puerto Rico, pots and traps. Observed (grey histograms) and expected (lines) length frequency distributions.

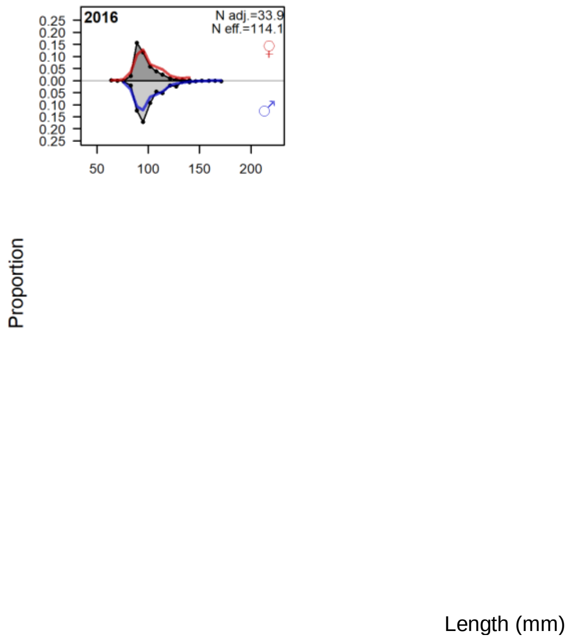

Figure 14. (Continued) Puerto Rico, pots and traps. Observed (grey histograms) and expected (lines) length frequency distributions.

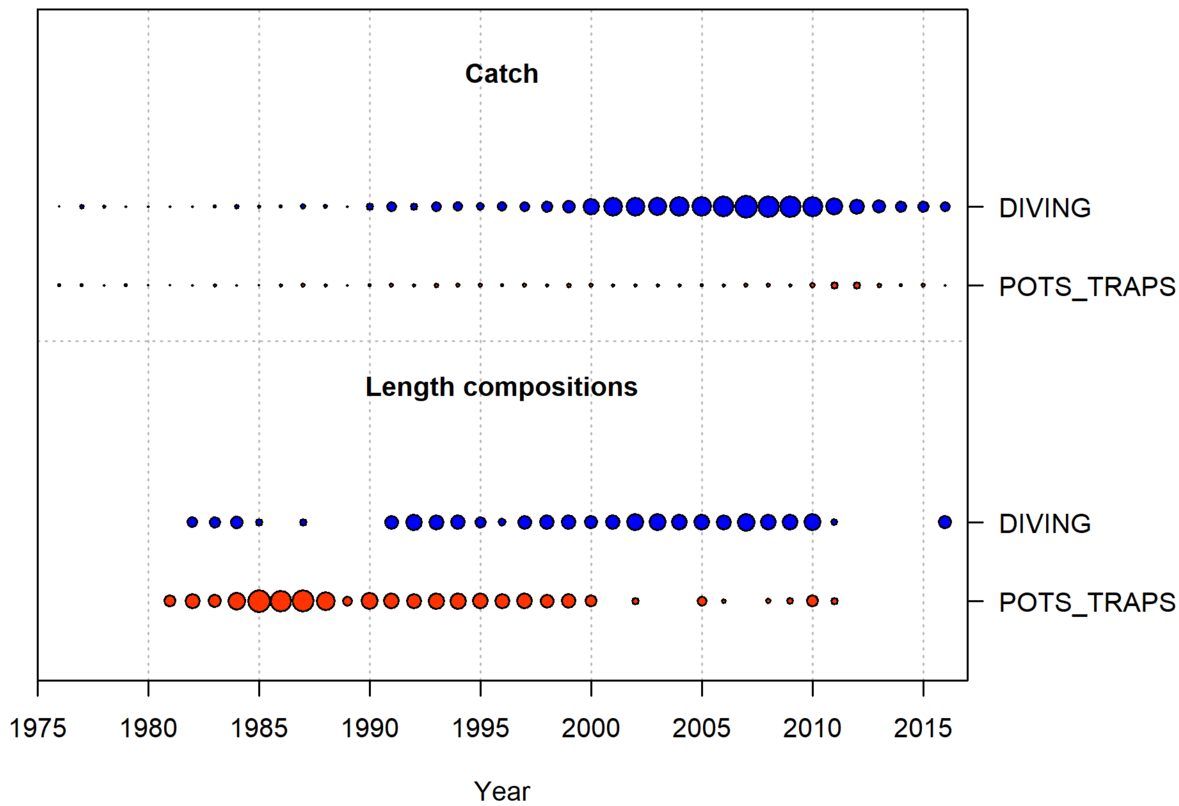

Figure 15. Relative sampling intensity and frequency for St. Croix.

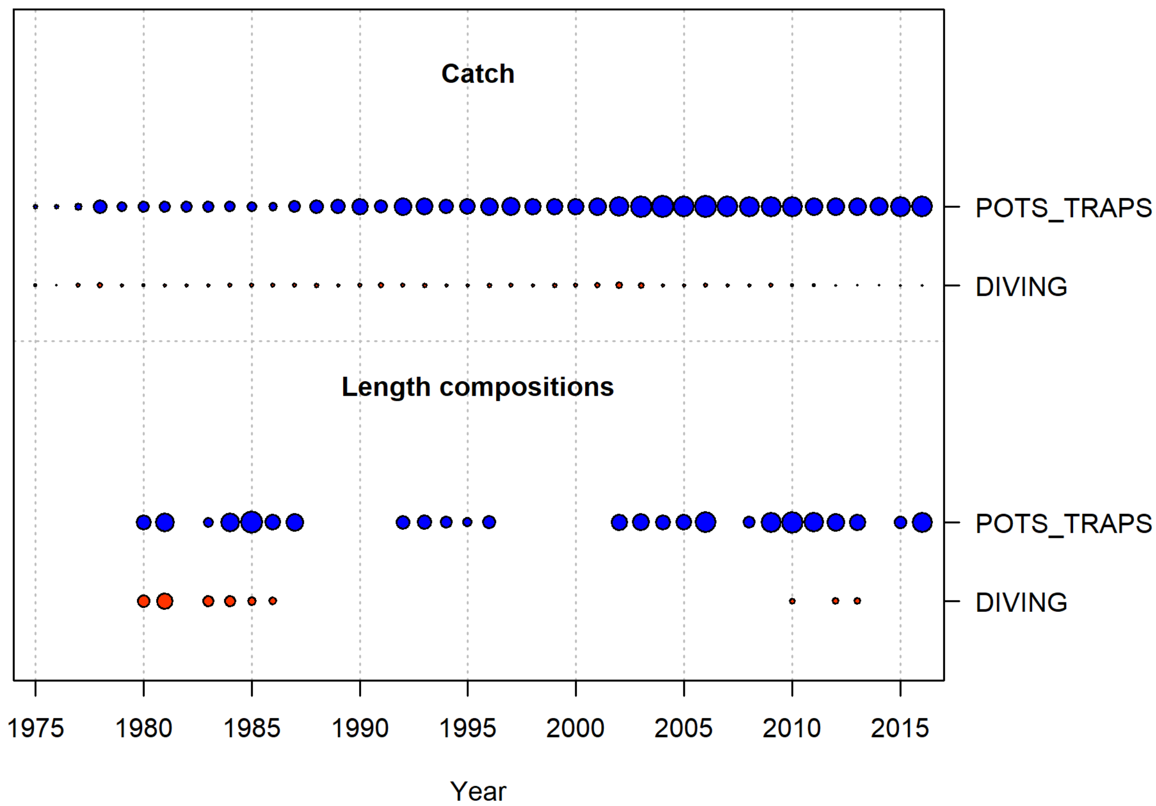

Figure 16. Relative sampling intensity and frequency for St. Thomas/St. John

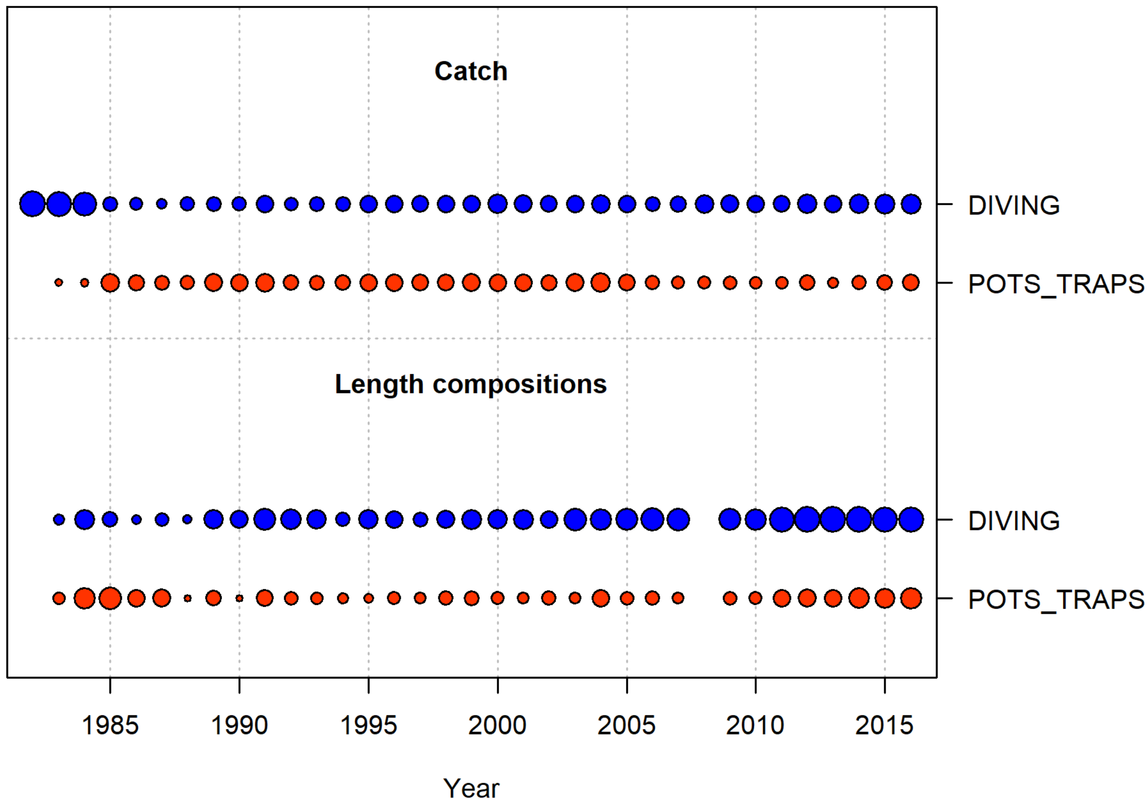

Figure 17. Relative sampling intensity and frequency for Puerto Rico

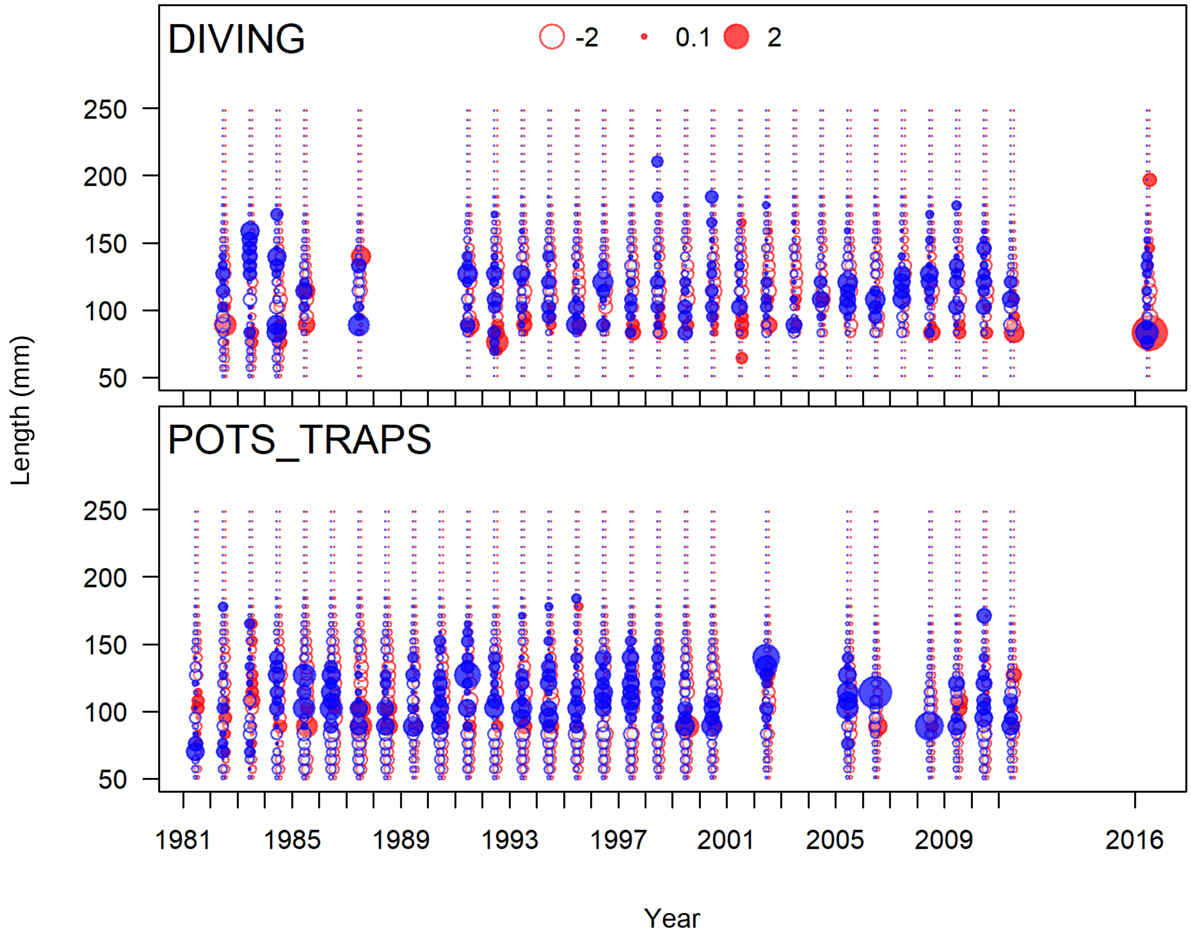

Figure 18. St. Croix, residual diagnostic for fits to length composition data. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

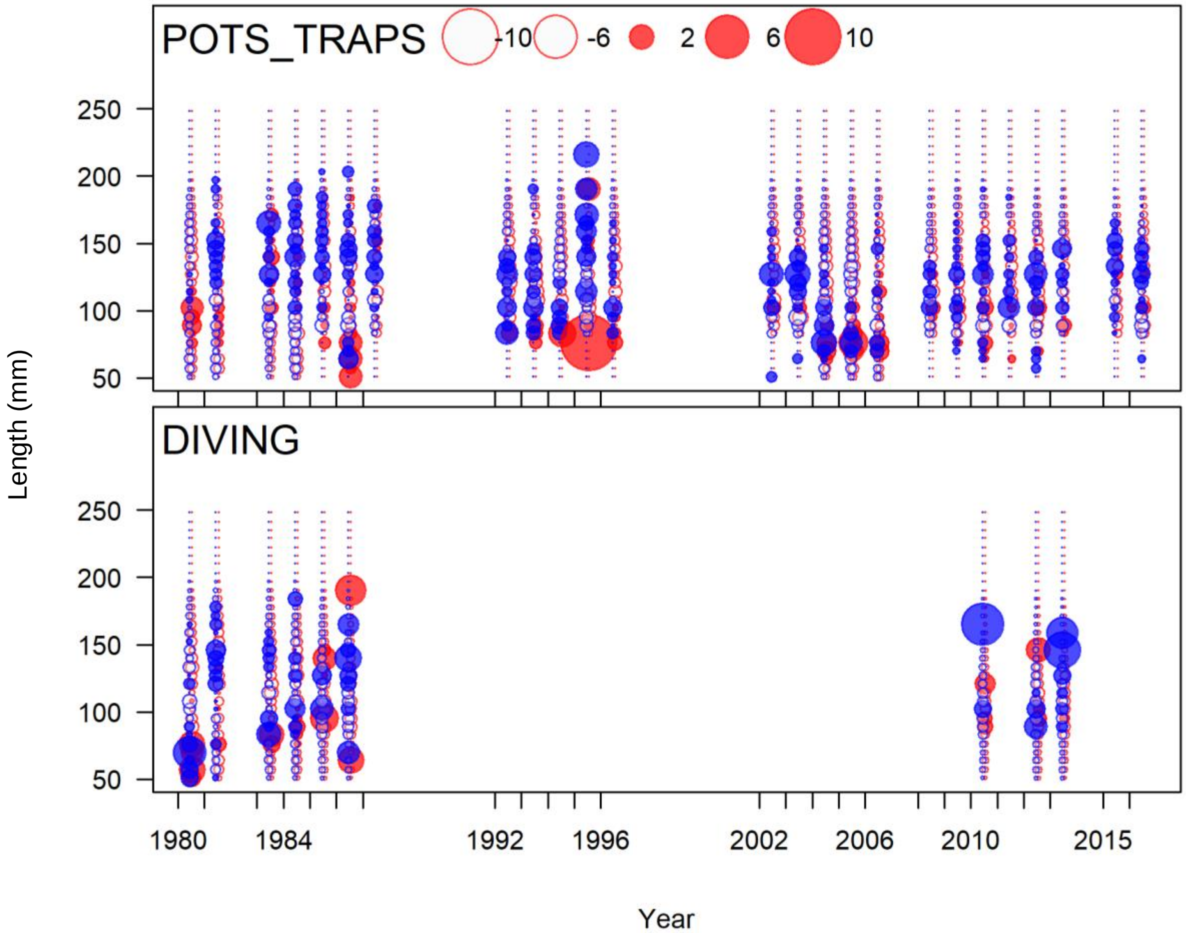

Figure 19. St. Thomas/St. John, residual diagnostic for fits to length composition data. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

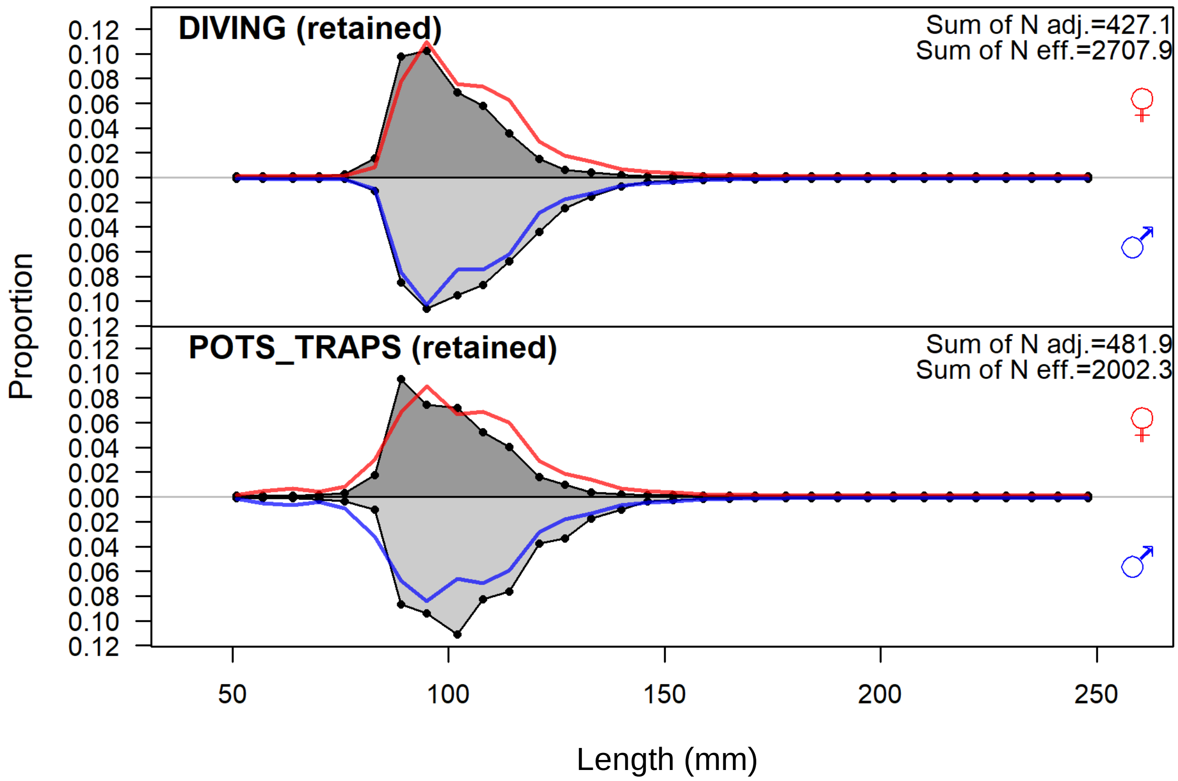

Figure 20. St. Croix, aggregate fit to length composition data. Observed (grey histograms) and expected (lines) length frequency distributions.

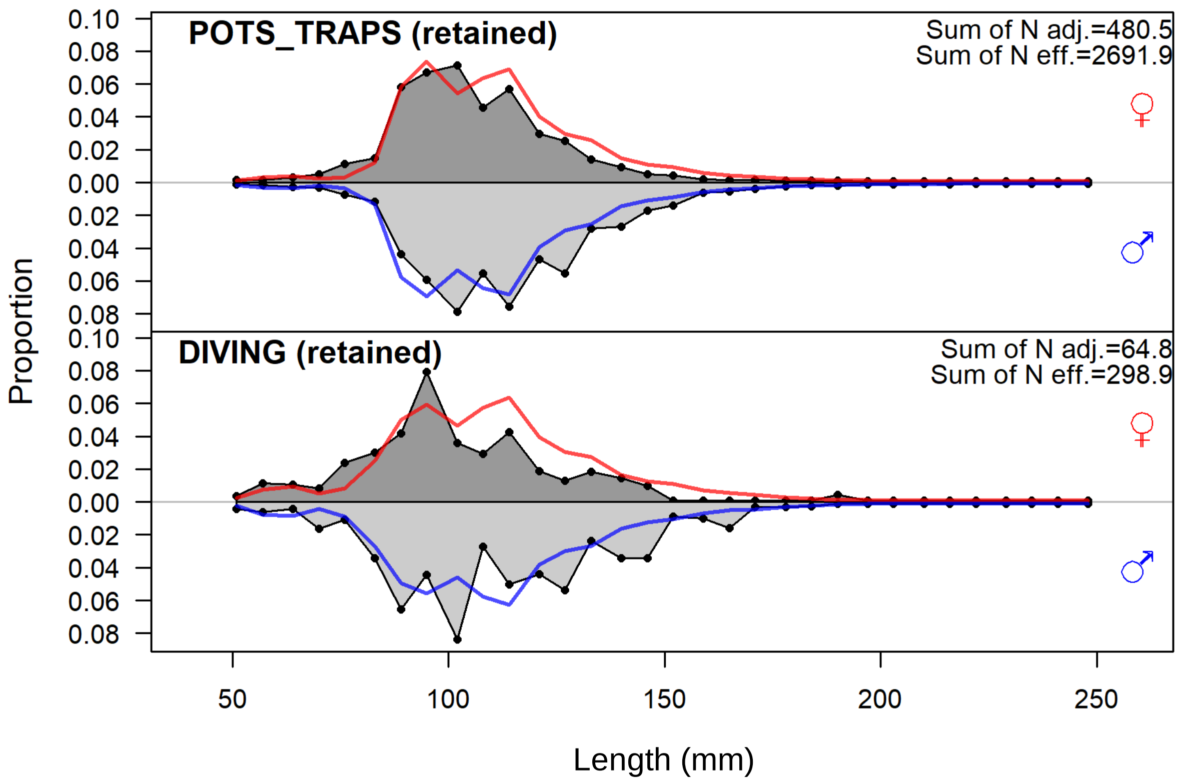

Figure 21. St. Thomas/St. John, aggregate fit to length composition data. Observed (grey histograms) and expected (lines) length frequency distributions.

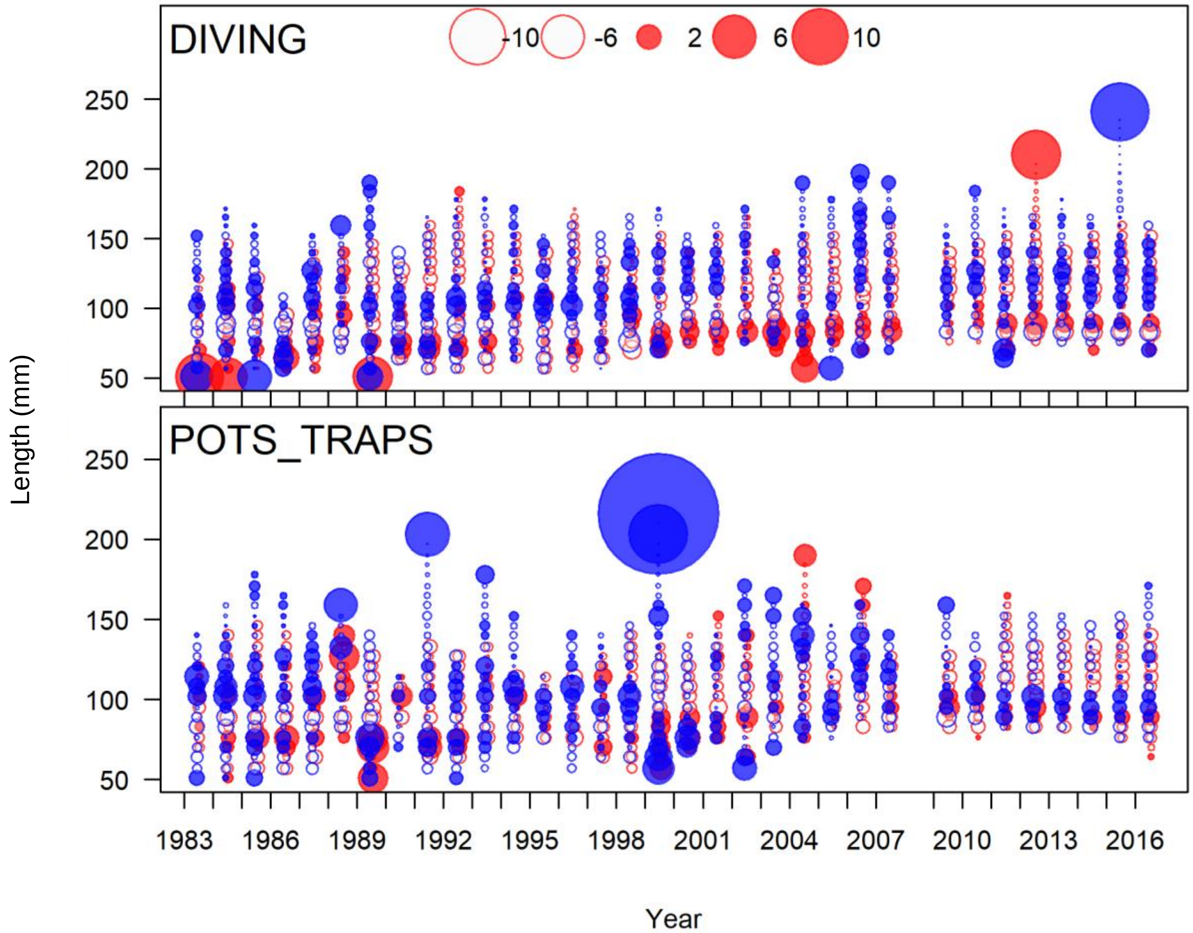

Figure 22. Puerto Rico, residual diagnostic for fits to length composition data. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

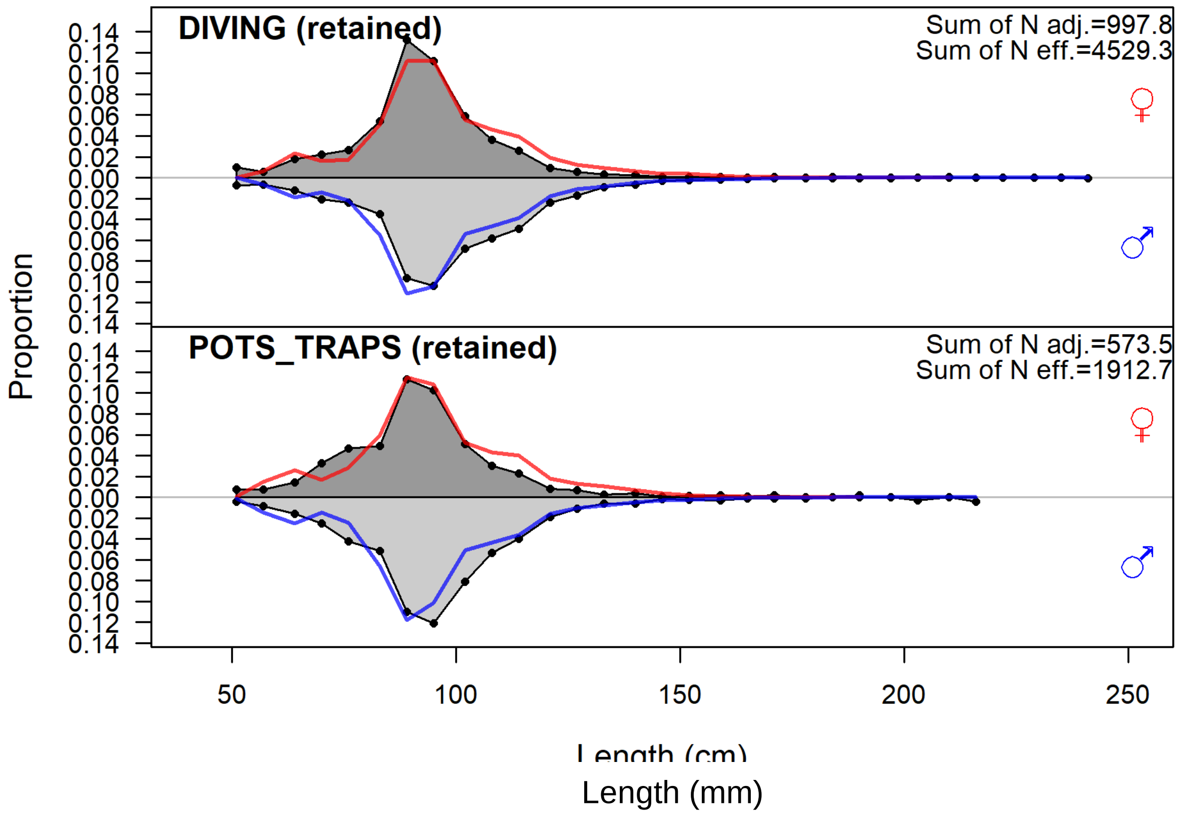

Figure 23. Puerto Rico, aggregate fit to length composition data. Observed (grey histograms) and expected (lines) length frequency distributions.

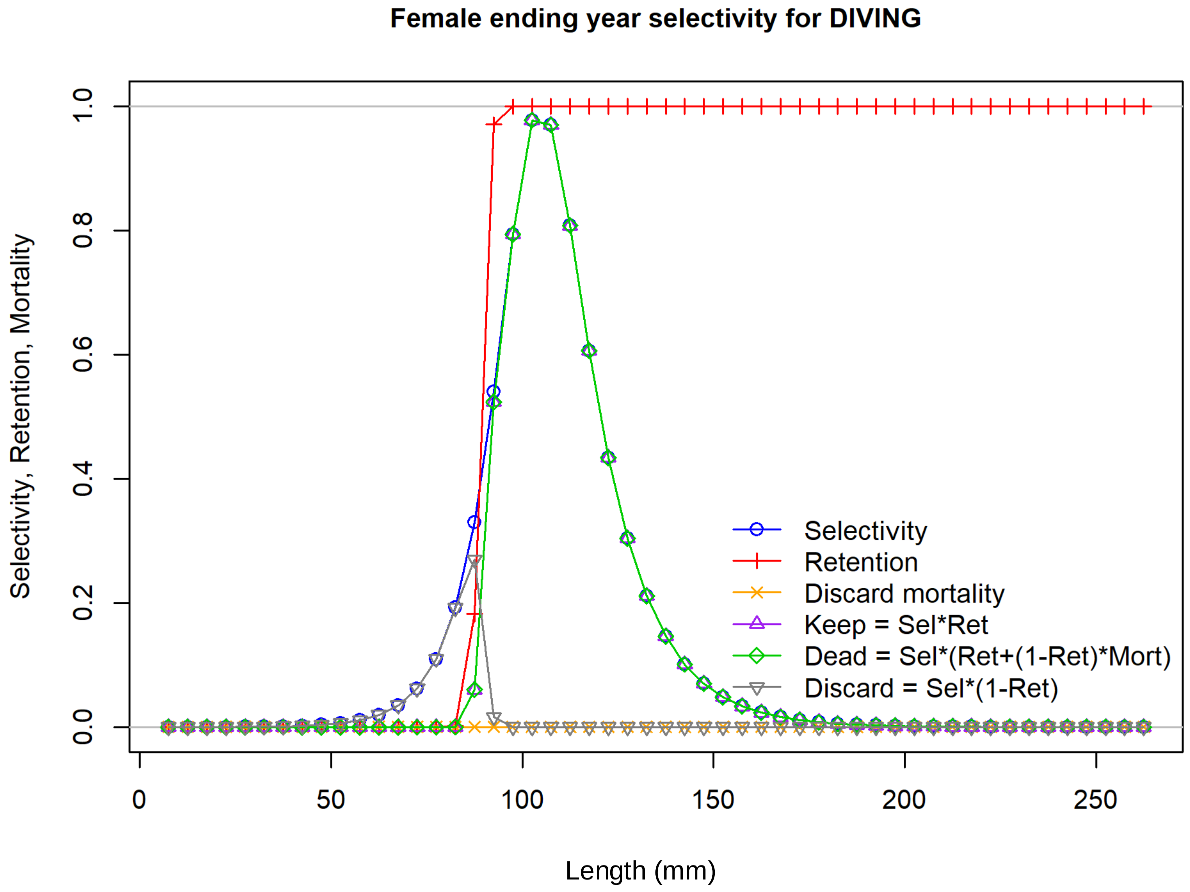

Figure 24. St. Croix, selectivity and retention.

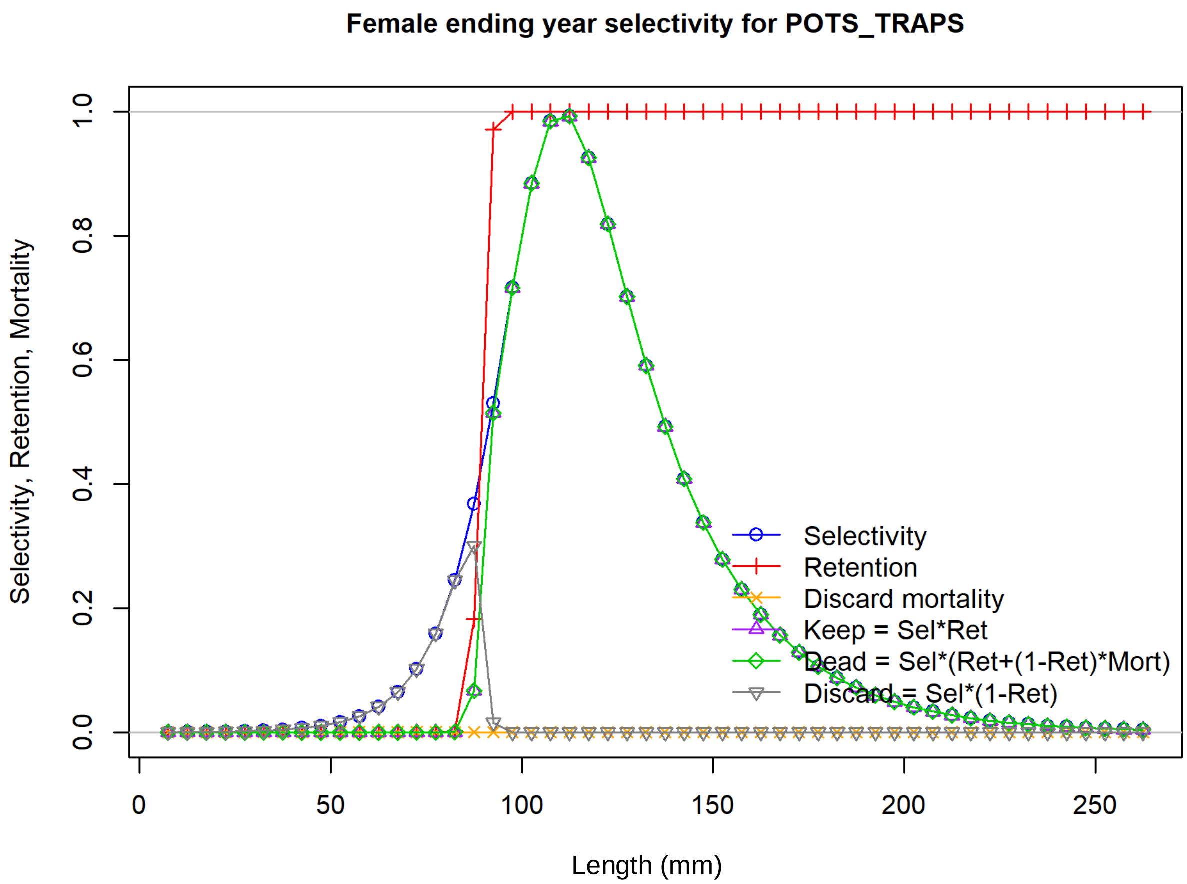

Figure 25. St. Thomas/St. John, selectivity and retention.

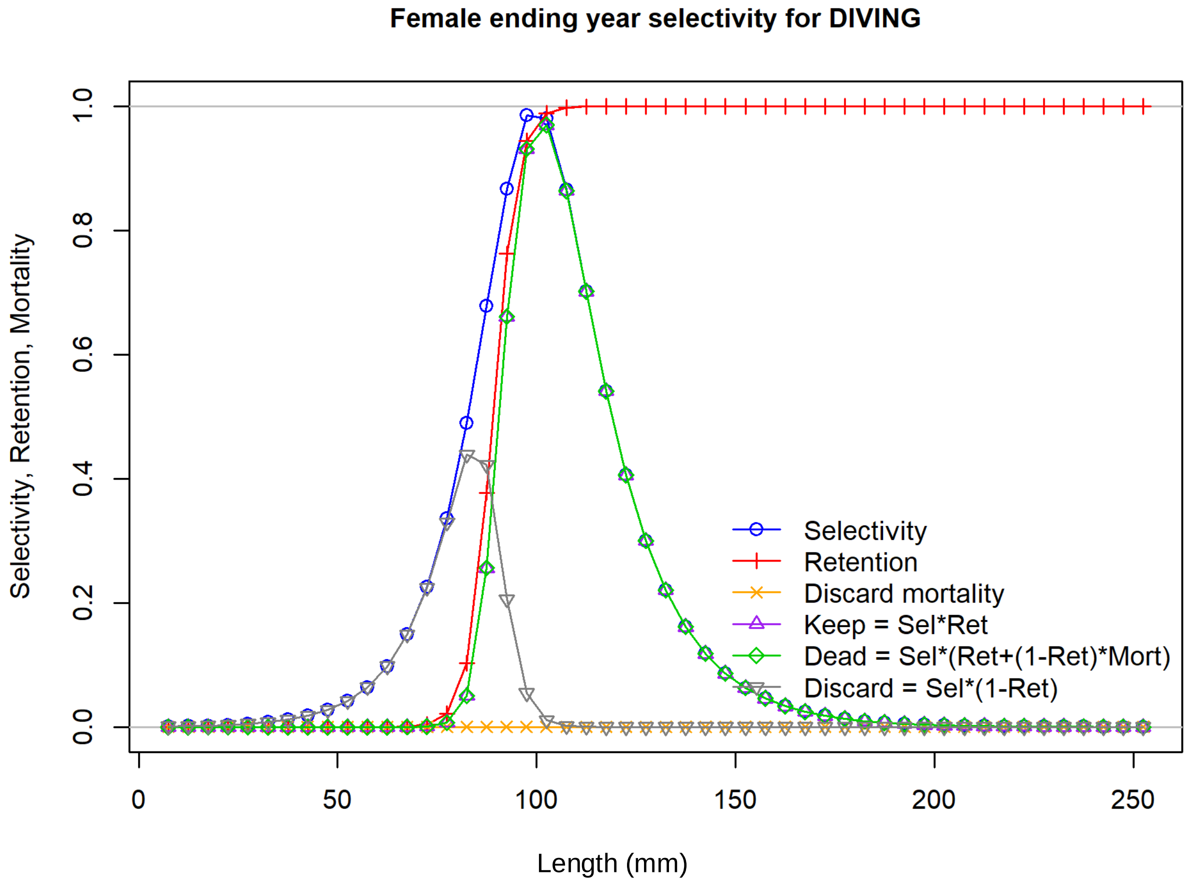

Figure 26. Puerto Rico, diving, selectivity and retention.

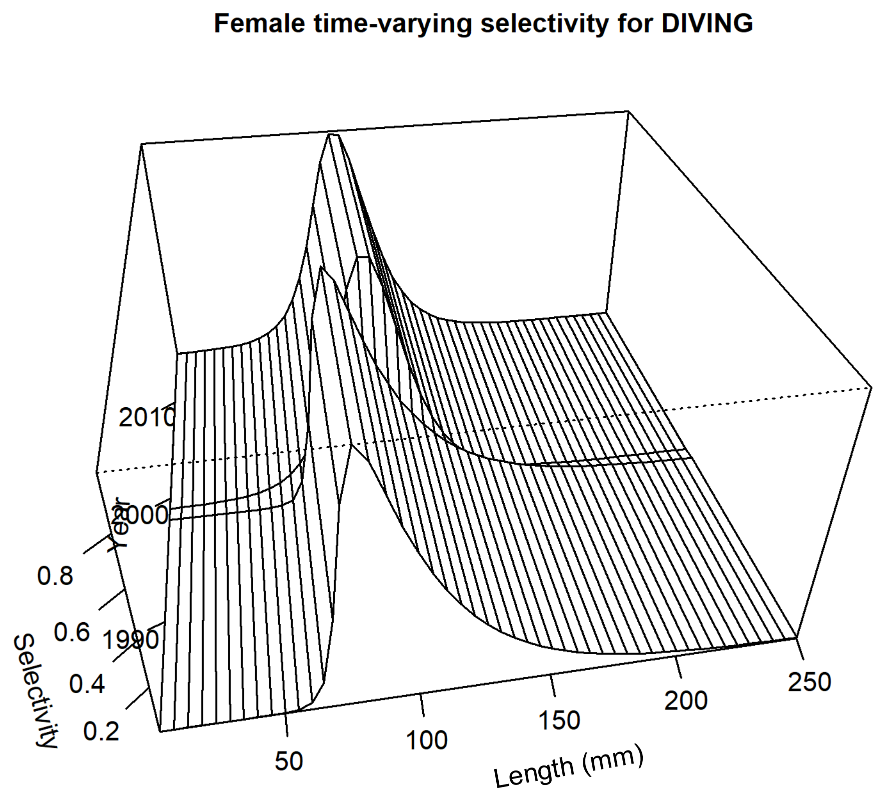

Figure 27. Puerto Rico, diving, time-varying selectivity.

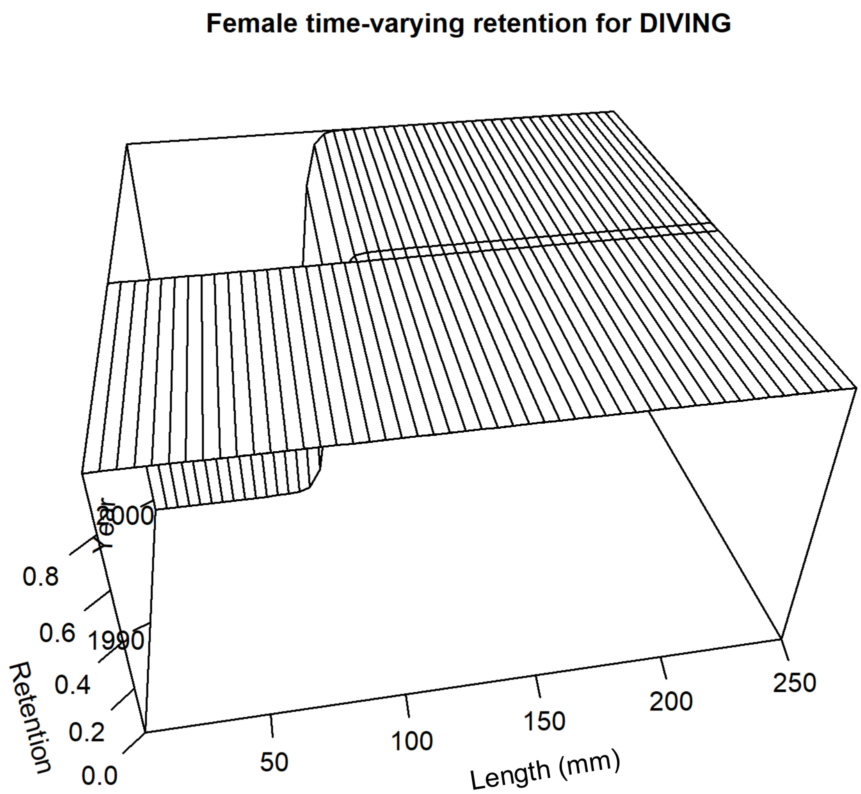

Figure 28. Puerto Rico, diving, time-varying retention.

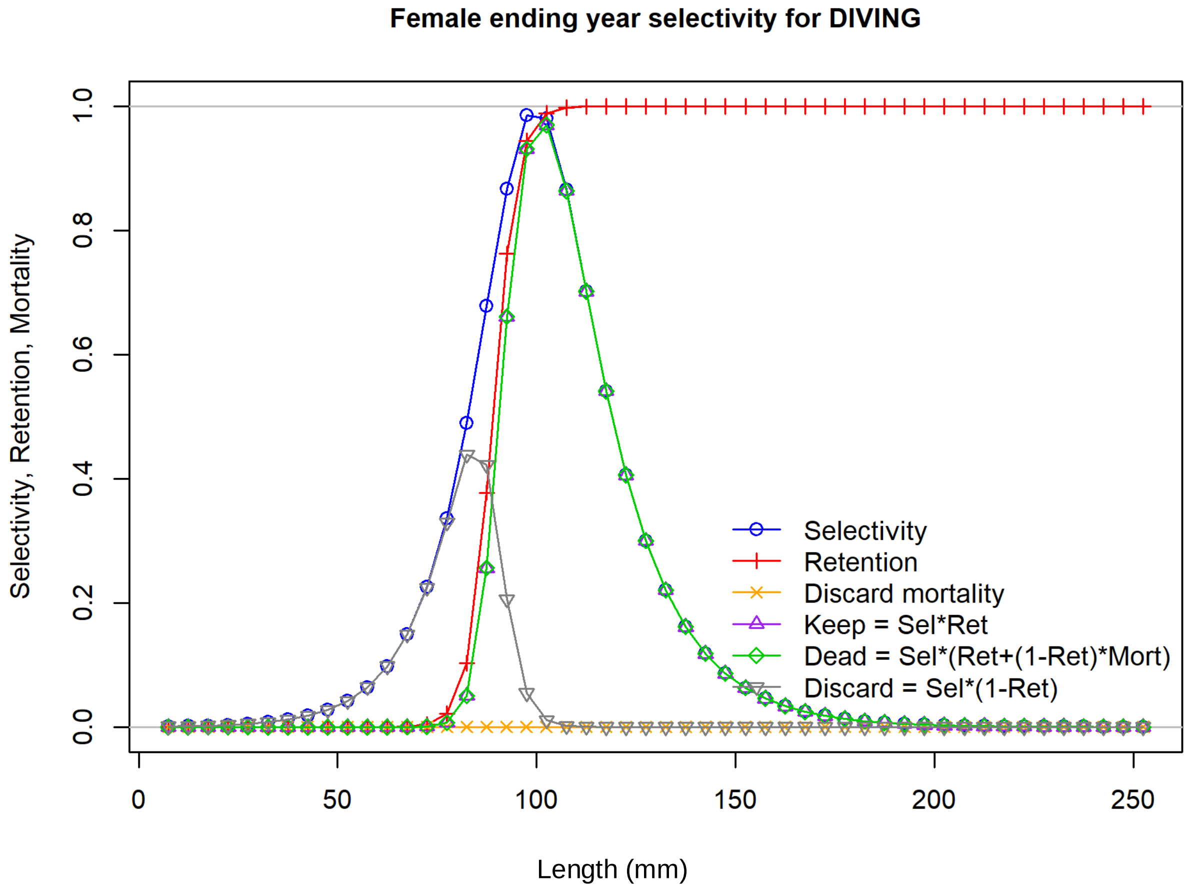

Figure 29. Puerto Rico, pots and traps, selectivity and retention.

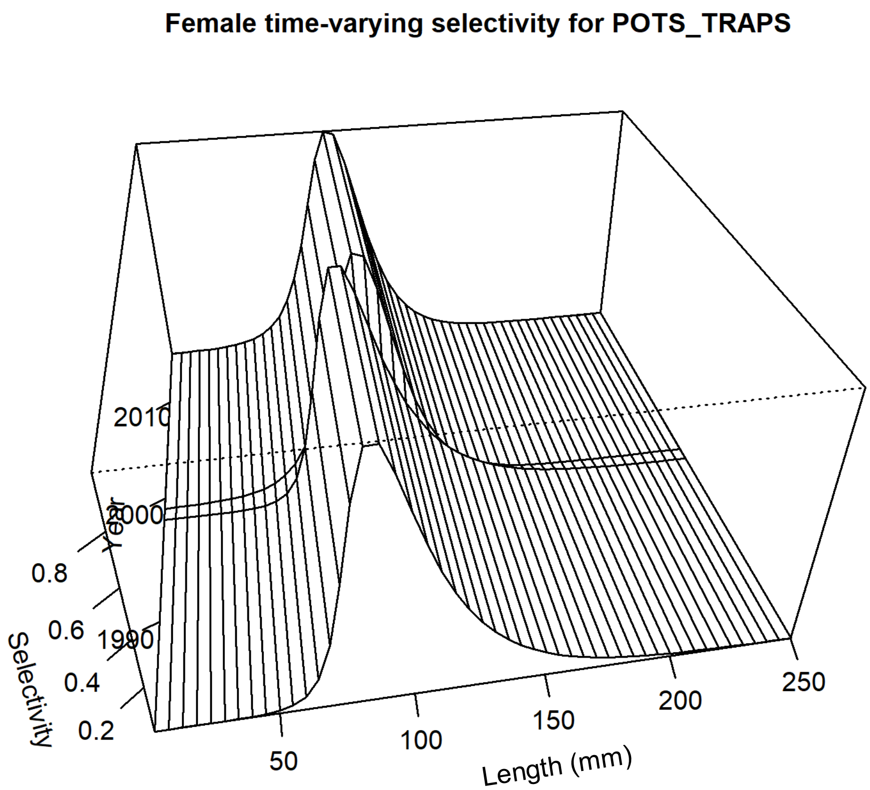

Figure 30. Puerto Rico, pots and traps, time-varying selectivity.

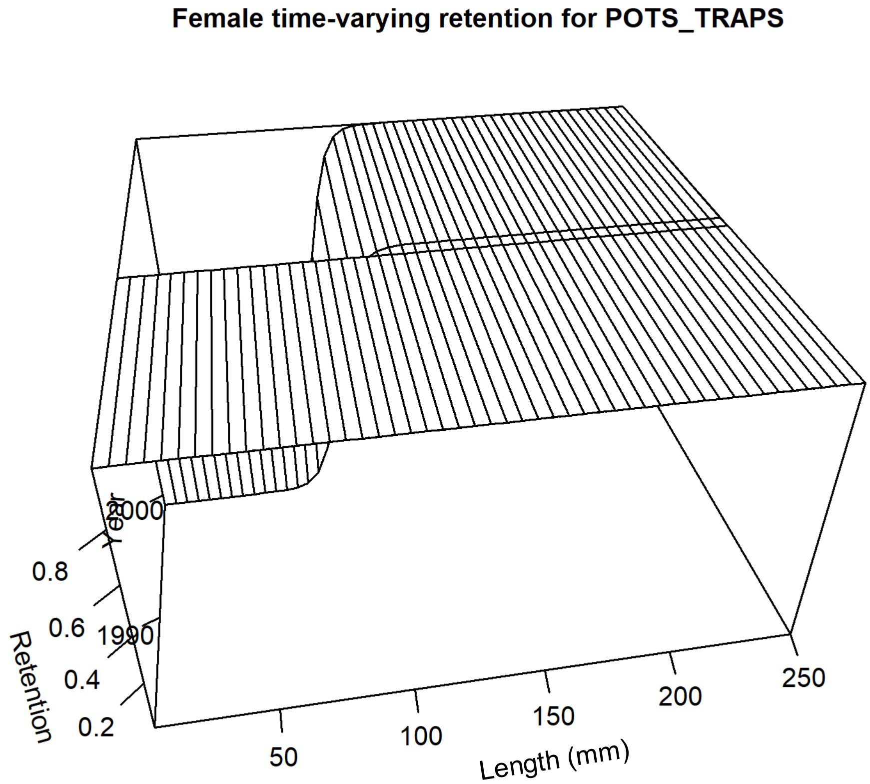

Figure 31. Puerto Rico, pots and traps, time-varying retention.

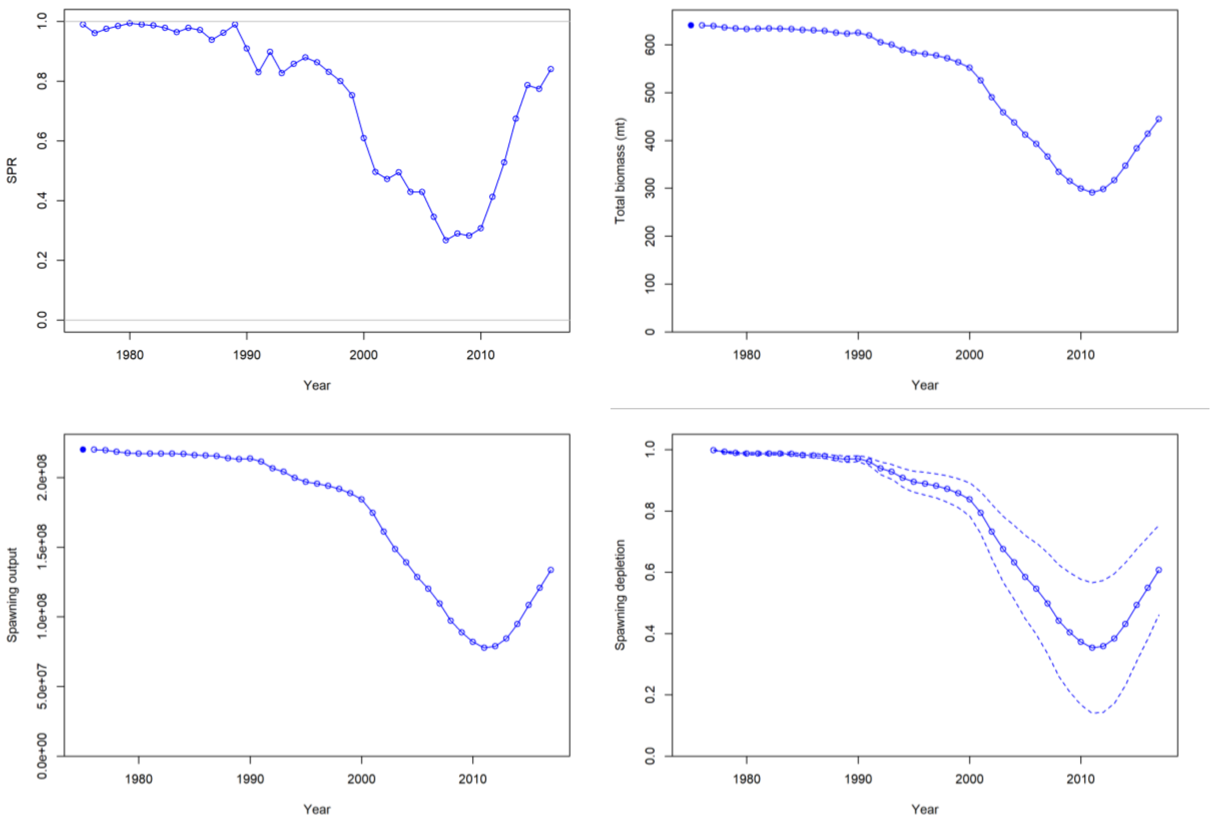

Figure 32. St. Croix, stock trajectories. SPR (top left), total biomass (top right), spawning biomass (lower left), and spawning depletion with 95% confidence interval (lower right).

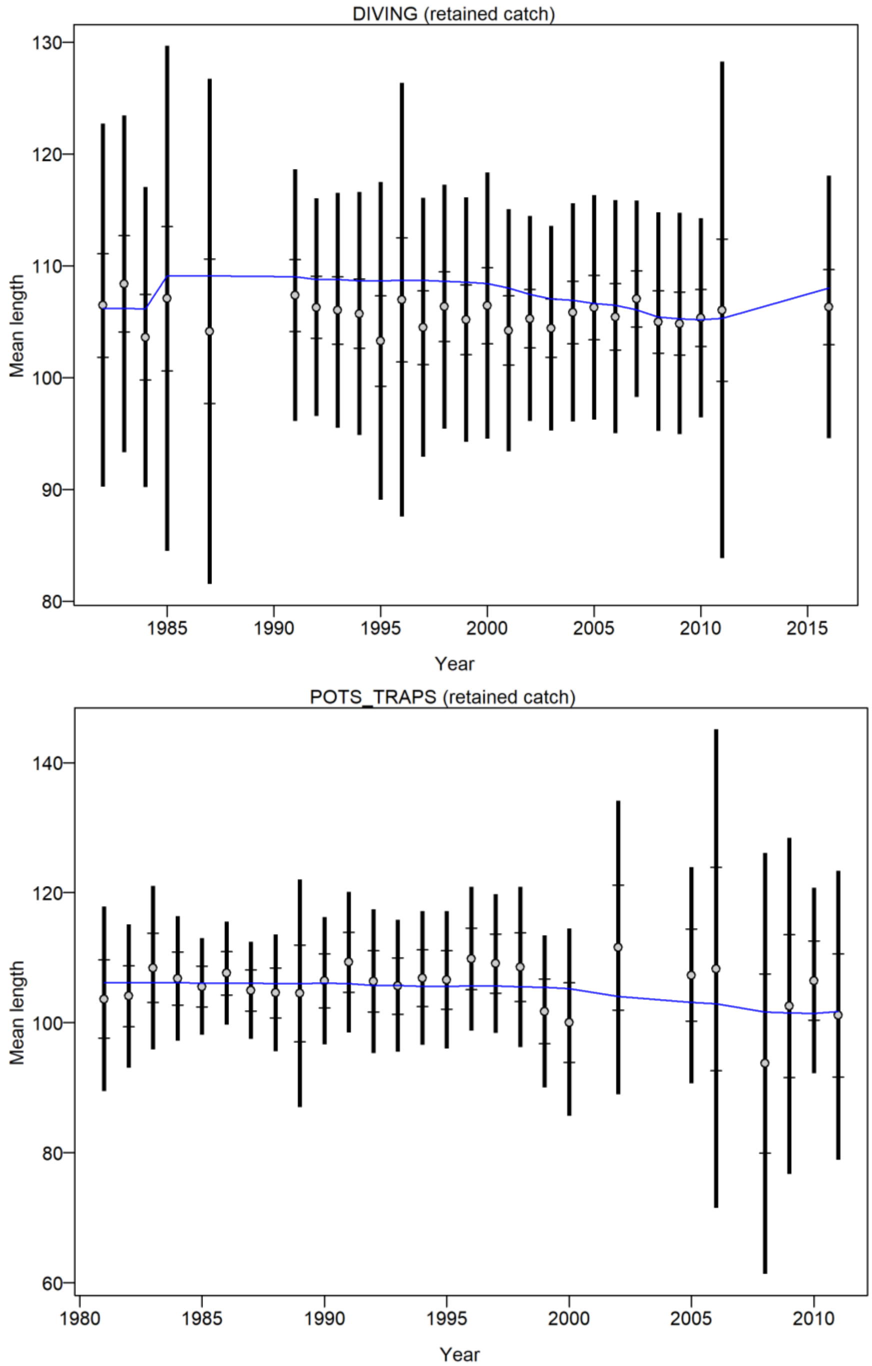

Figure 33. St. Croix, changes in length composition through time for diving (upper panel) and pots and traps (lower panel). Blue line is estimated annual mean length; points are observed means; vertical bars are 95% confidence interval based on current sample sizes.

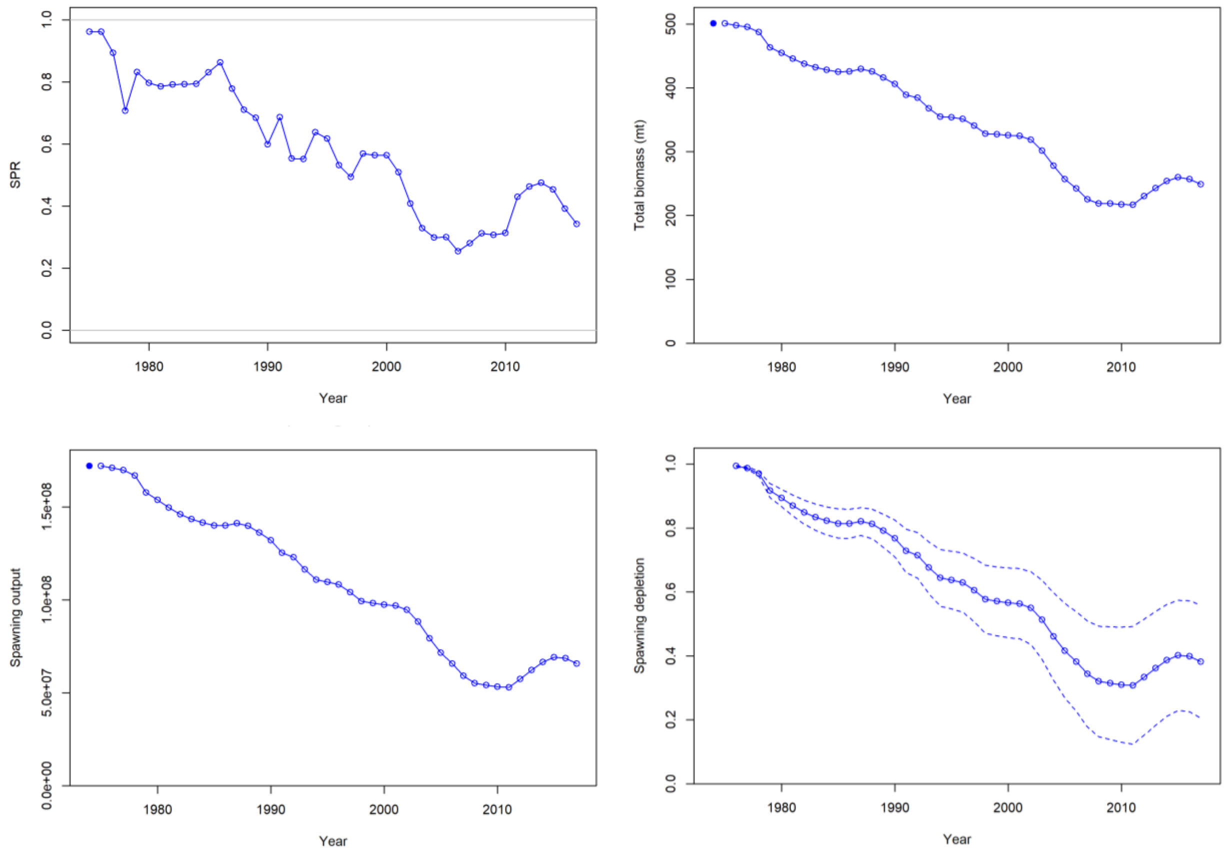

Figure 34. St. Thomas/St. John, stock trajectories. SPR (top left), total biomass (top right), spawning biomass (lower left), and spawning depletion with 95% confidence interval (lower right).

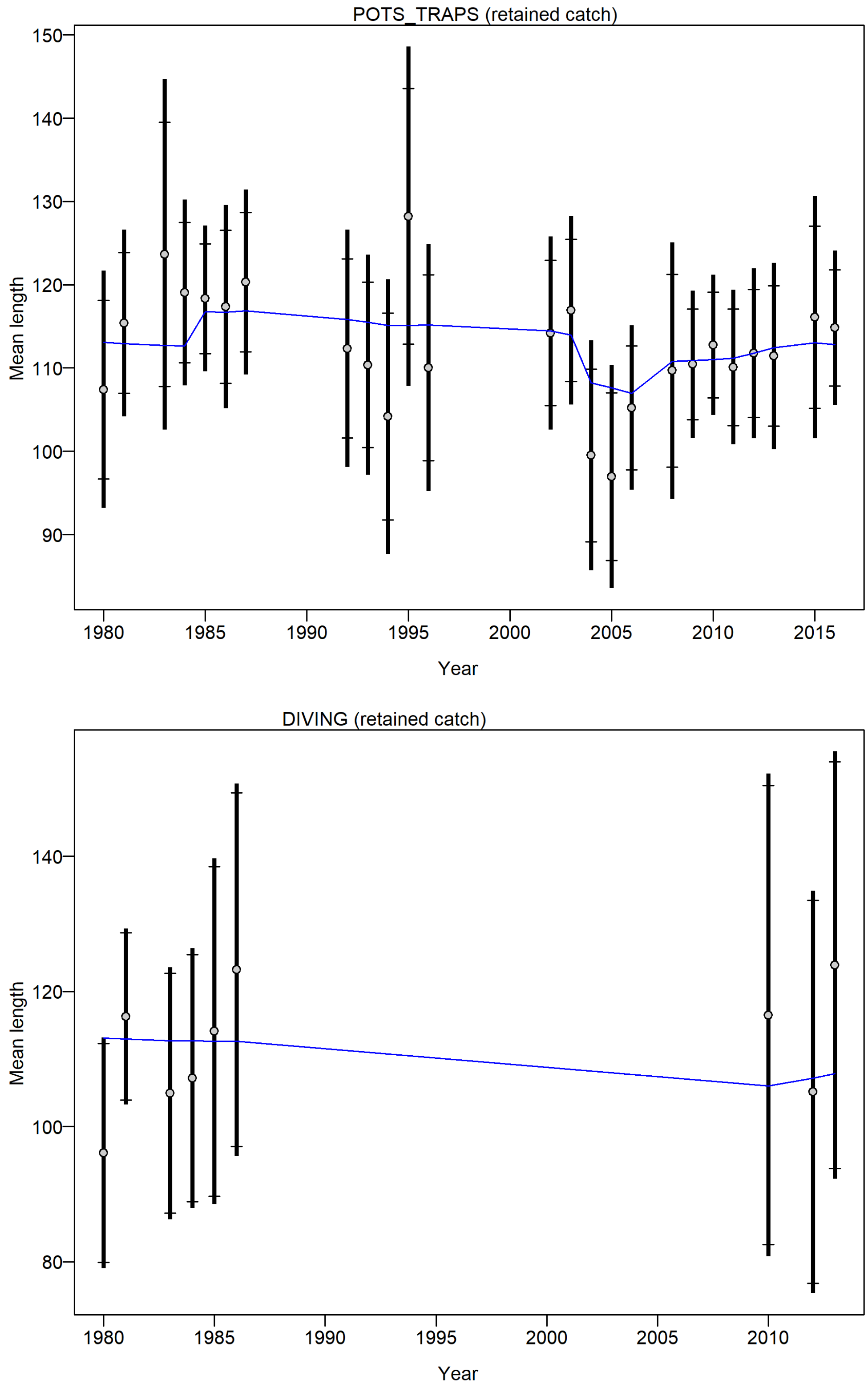

Figure 35. St. Thomas/St. John, changes in length composition through time for pots and traps (upper panel) and diving (lower panel). Blue line is estimated annual mean length; points are observed means; vertical bars are 95% confidence interval based on current sample sizes.

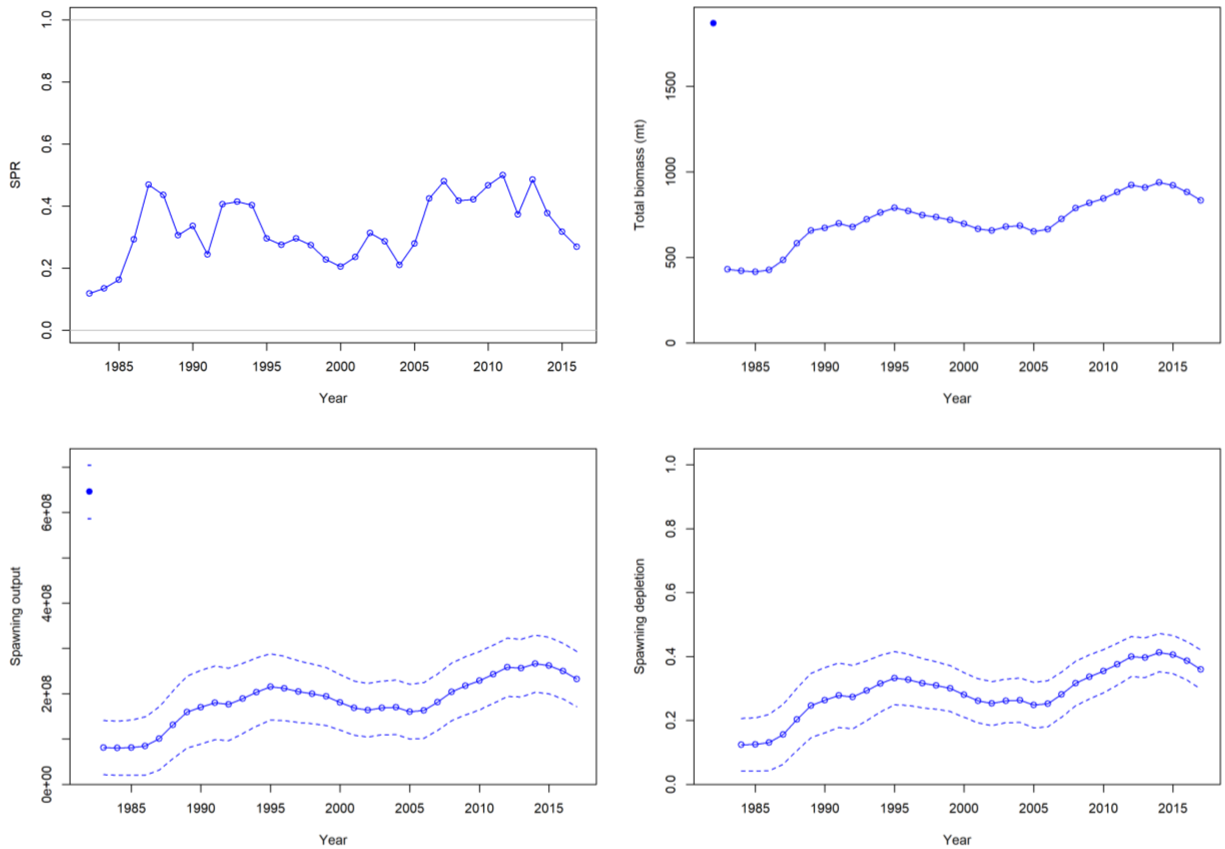

Figure 36. Puerto Rico, stock trajectories. SPR (top left), total biomass (top right), spawning biomass (lower left), and spawning depletion with 95% confidence interval (lower right).

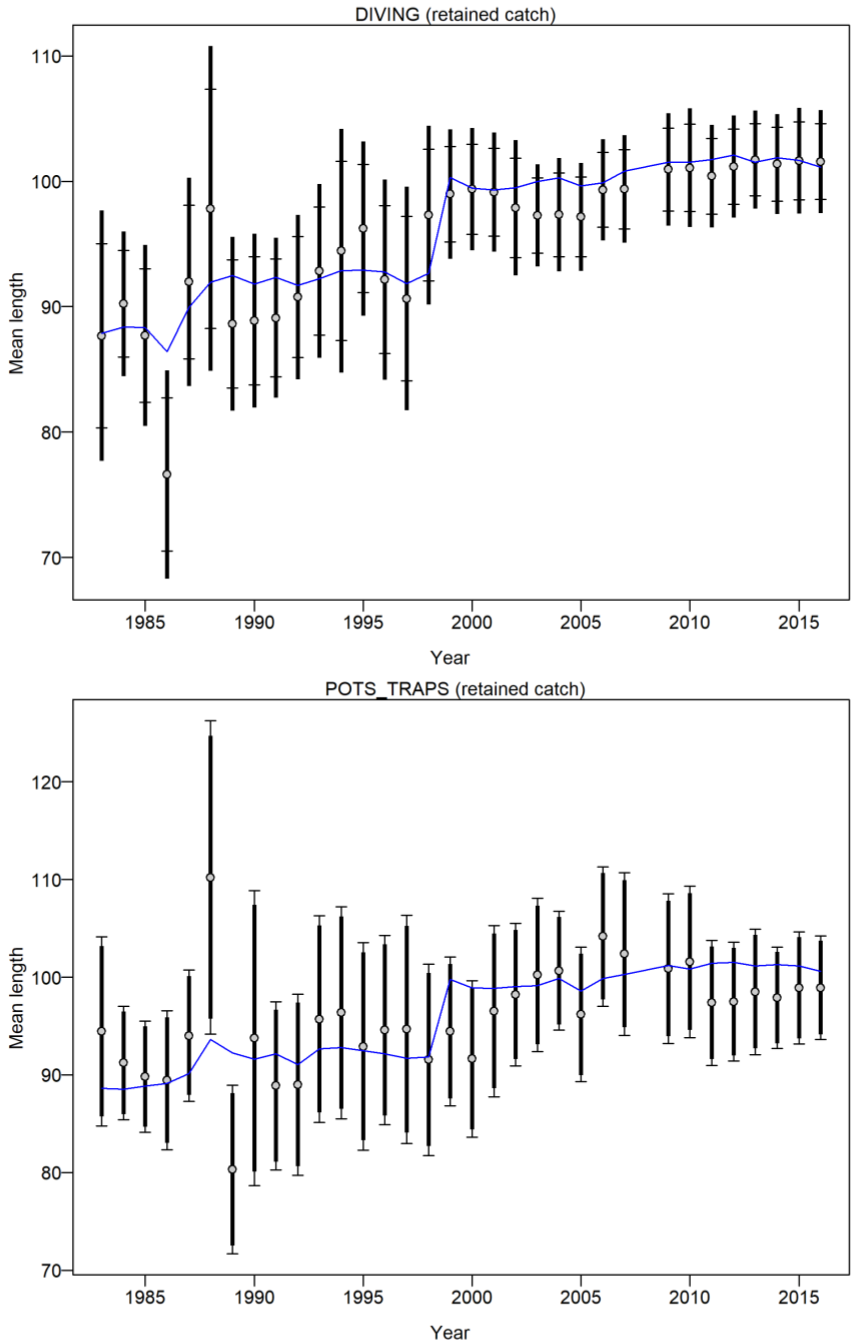

Figure 37. Puerto Rico, changes in length composition through time for diving (upper panel) and pots and traps (lower panel). Blue line is estimated annual mean length; points are observed means; vertical bars are 95% confidence interval based on current sample sizes.

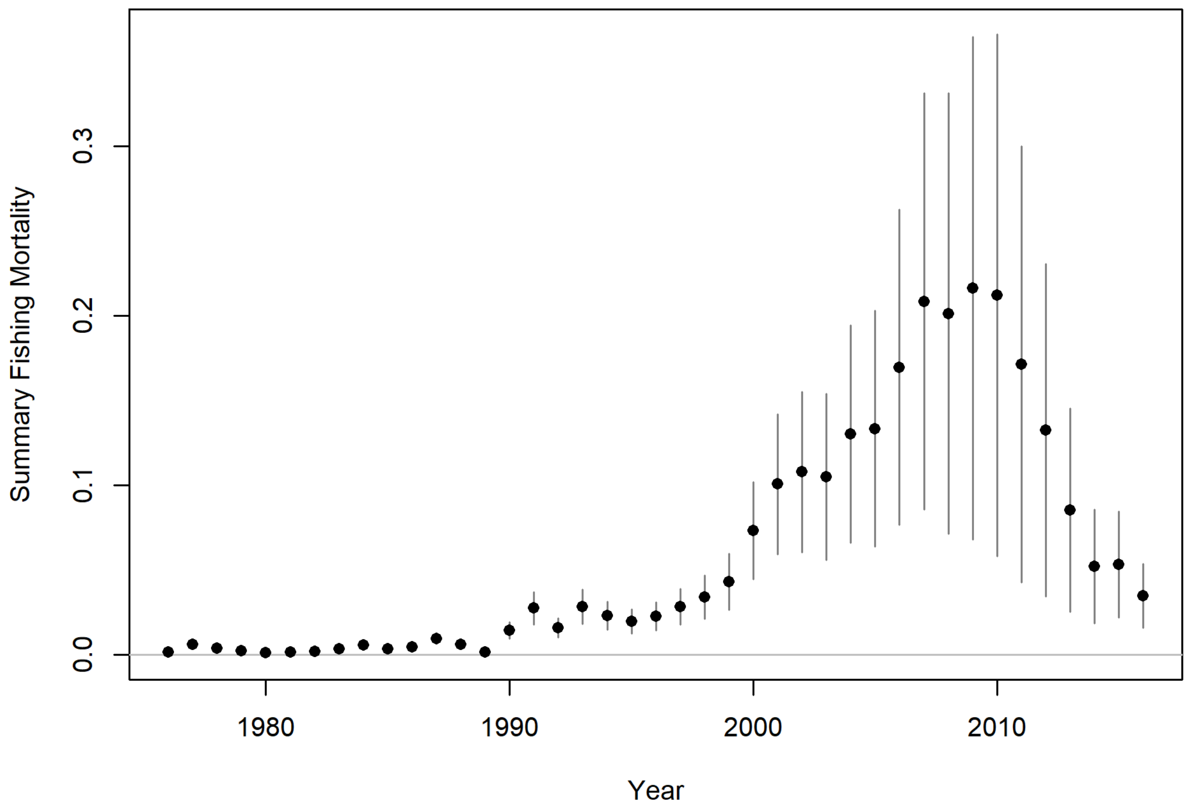

Figure 38. St. Croix, proportion of the stock killed by fishing (i.e., harvest rate in biomass landed / total biomass) and associated 95% confidence intervals (vertical lines).

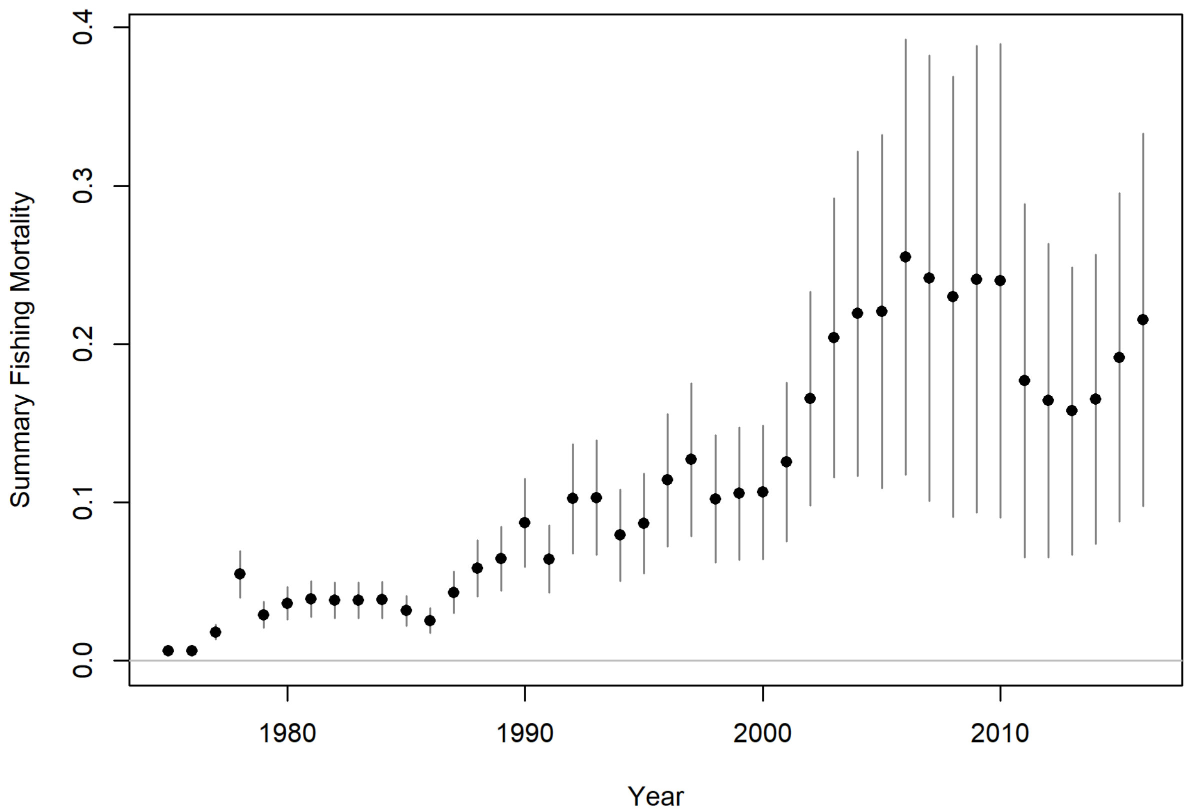

Figure 39. St. Thomas/St. John, proportion of the stock killed by fishing (i.e., harvest rate in biomass landed / total biomass) and associated 95% confidence intervals (vertical lines).

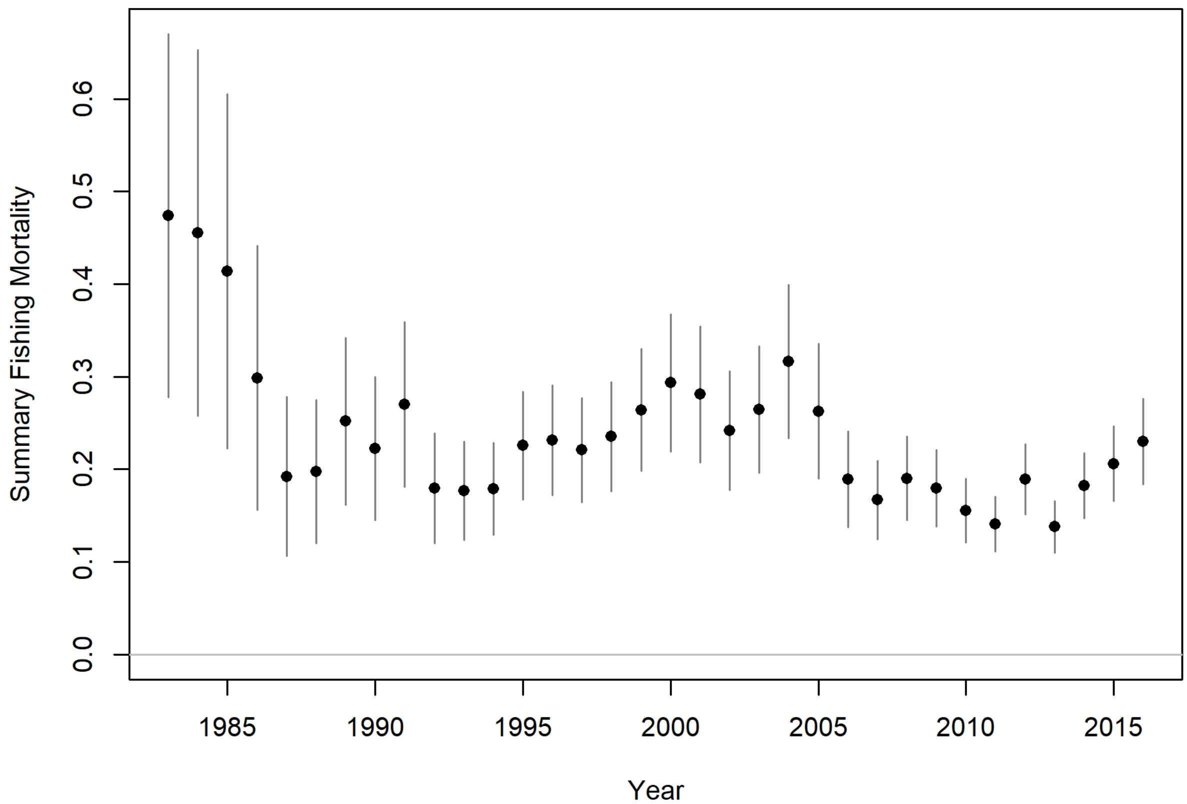

Figure 40. Puerto Rico, proportion of the stock killed by fishing (i.e., harvest rate in biomass landed / total biomass) and associated 95% confidence intervals (vertical lines).

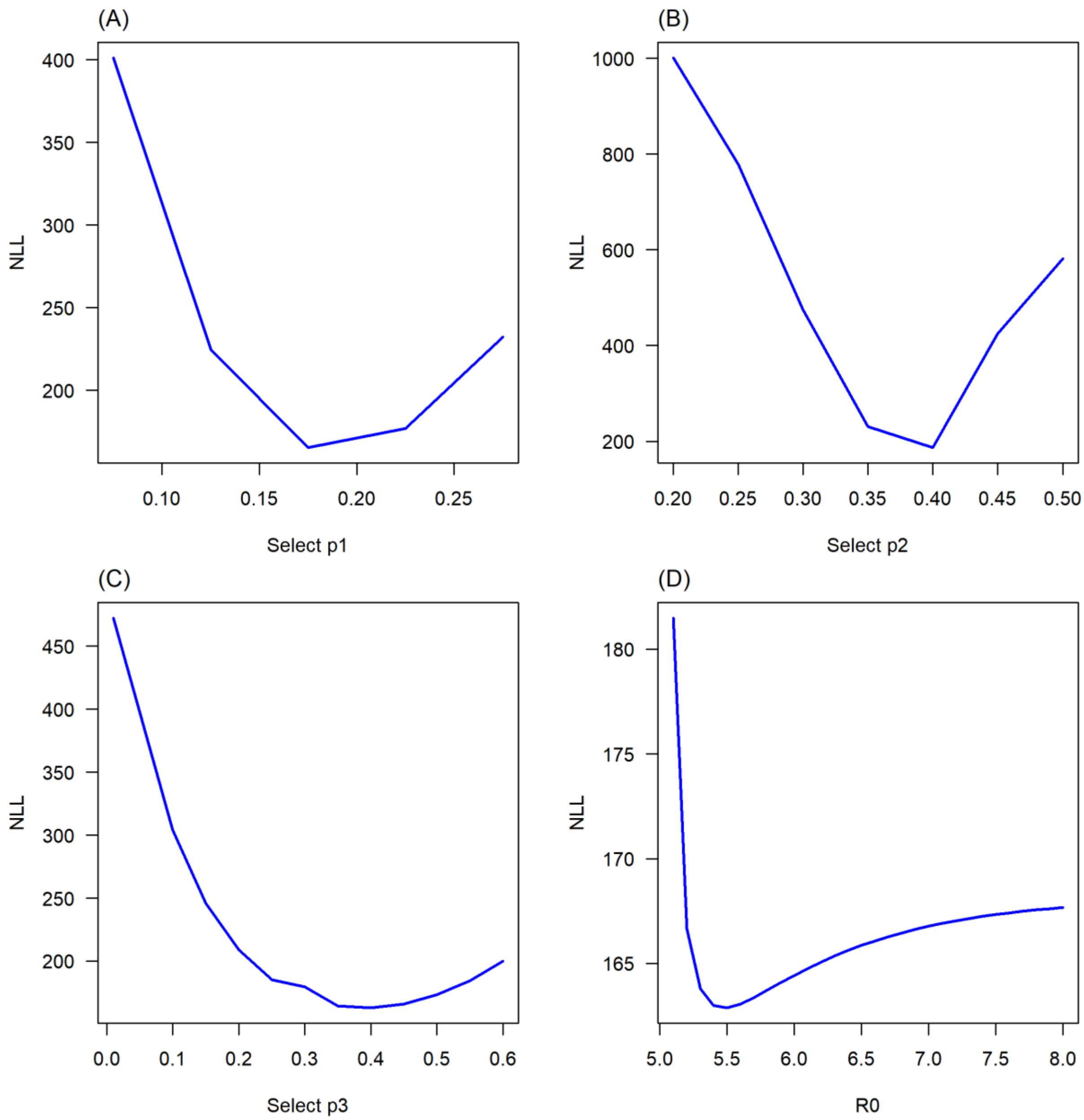

Figure 41. St. Croix likelihood profile. (A) through (D) are parameter profiles of selectivity parameters and R0.

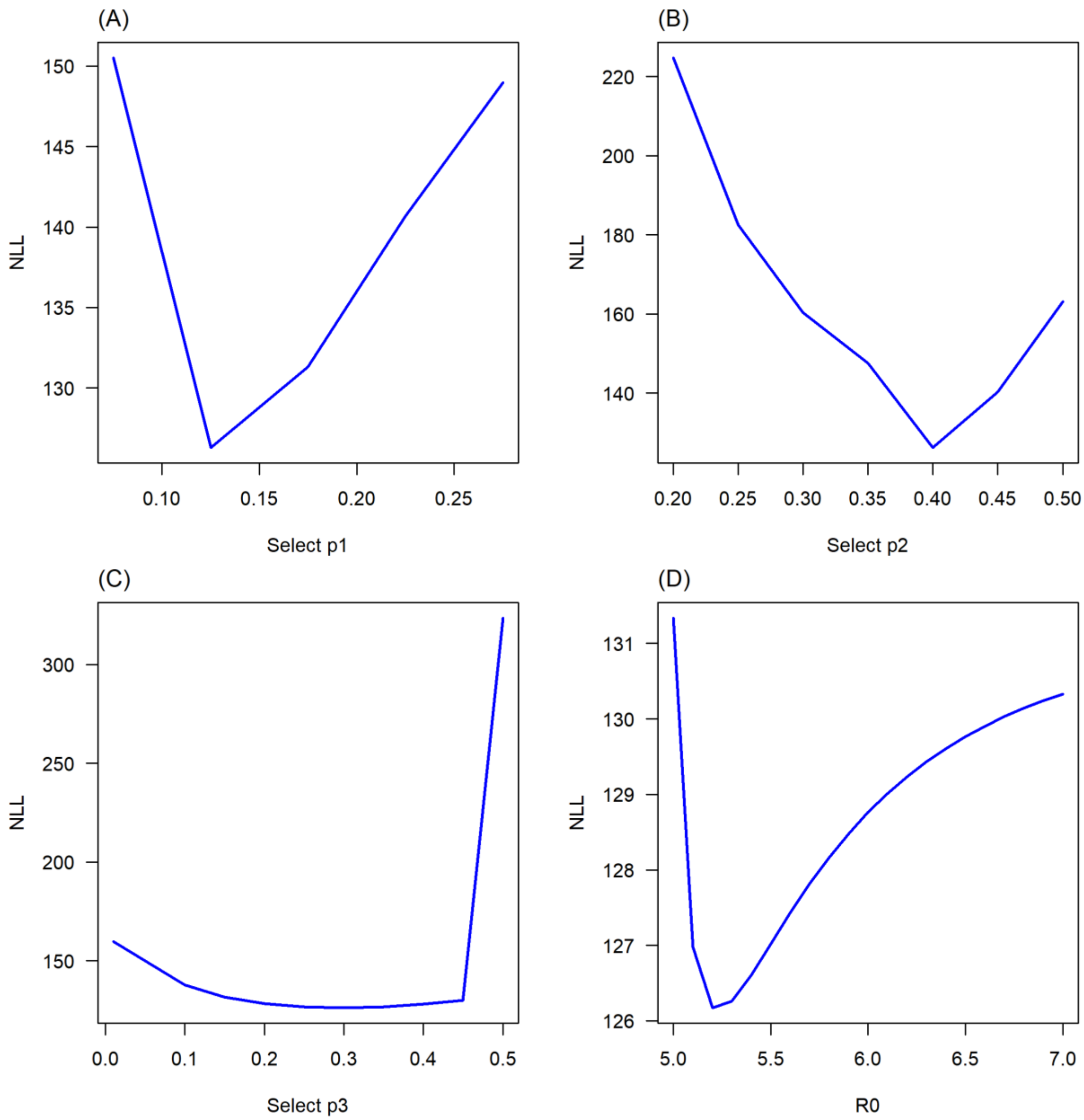

Figure 42. St. Thomas likelihood profile. (A) through (D) are parameter profiles of selectivity parameters and R0.

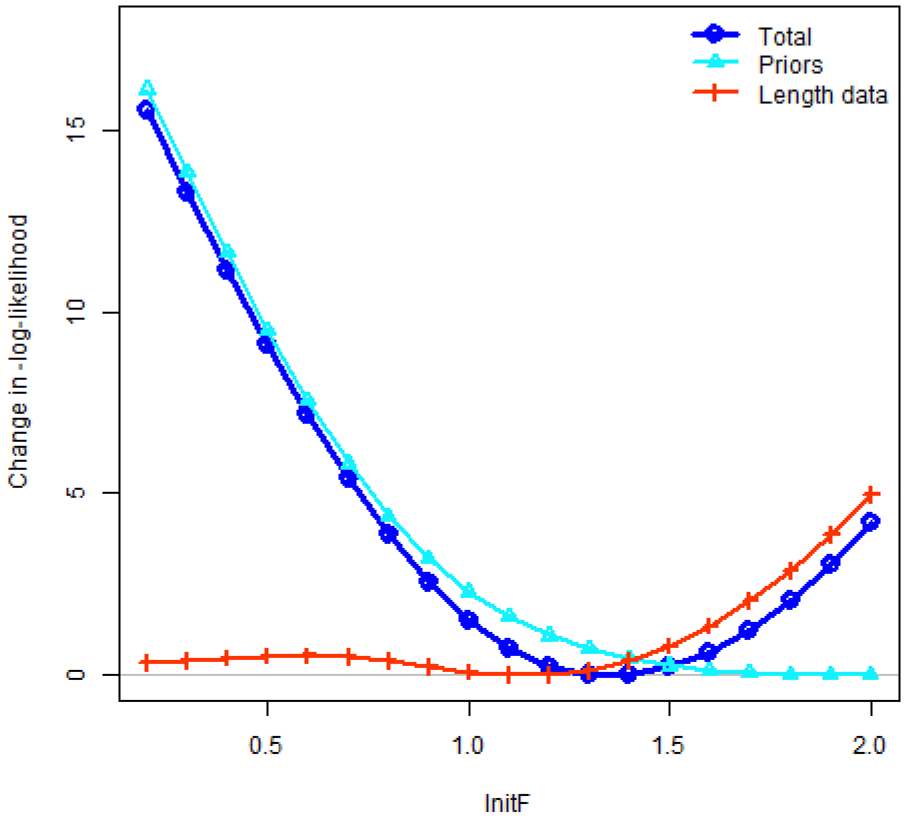

Figure 43. Puerto Rico likelihood profile for initial F.

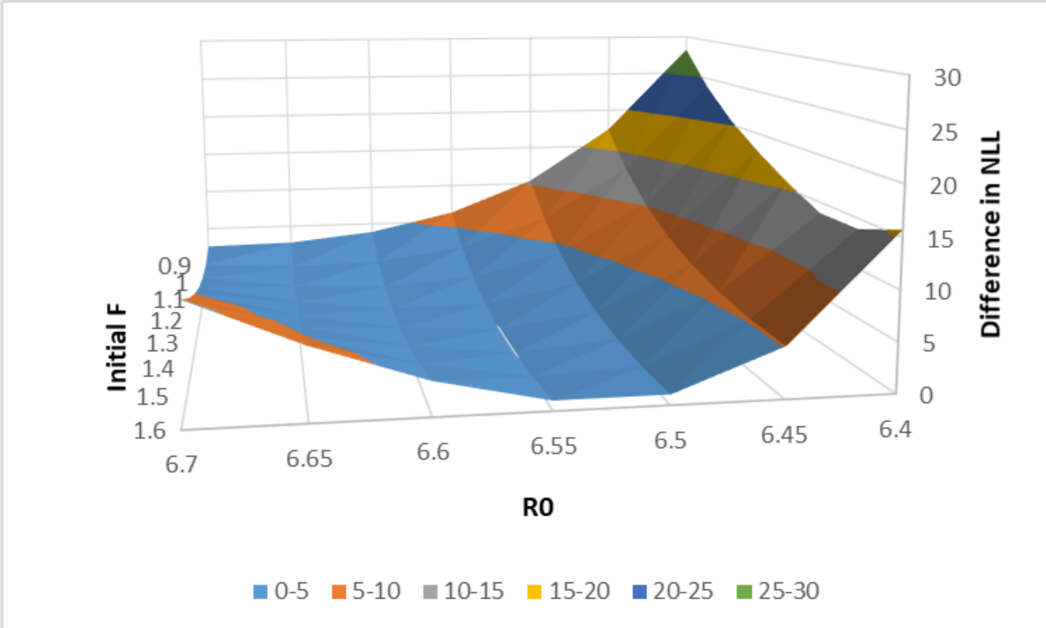

Figure 44. Puerto Rico bivariate likelihood profile for R0 and Initial F.

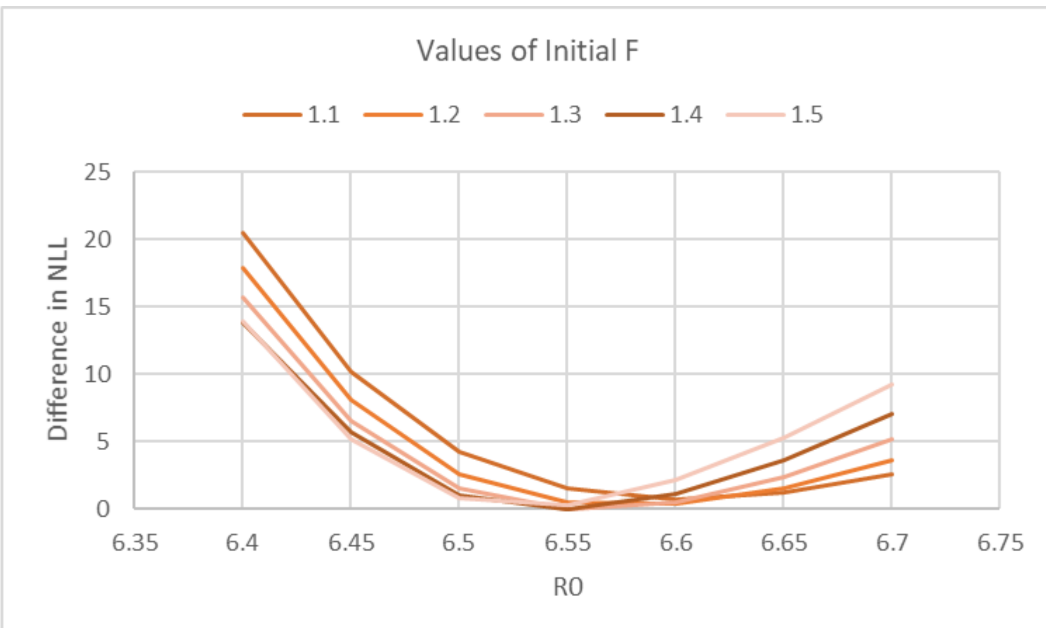

Figure 45. Puerto Rico bivariate likelihood profile for R0 at specified values of initial F.

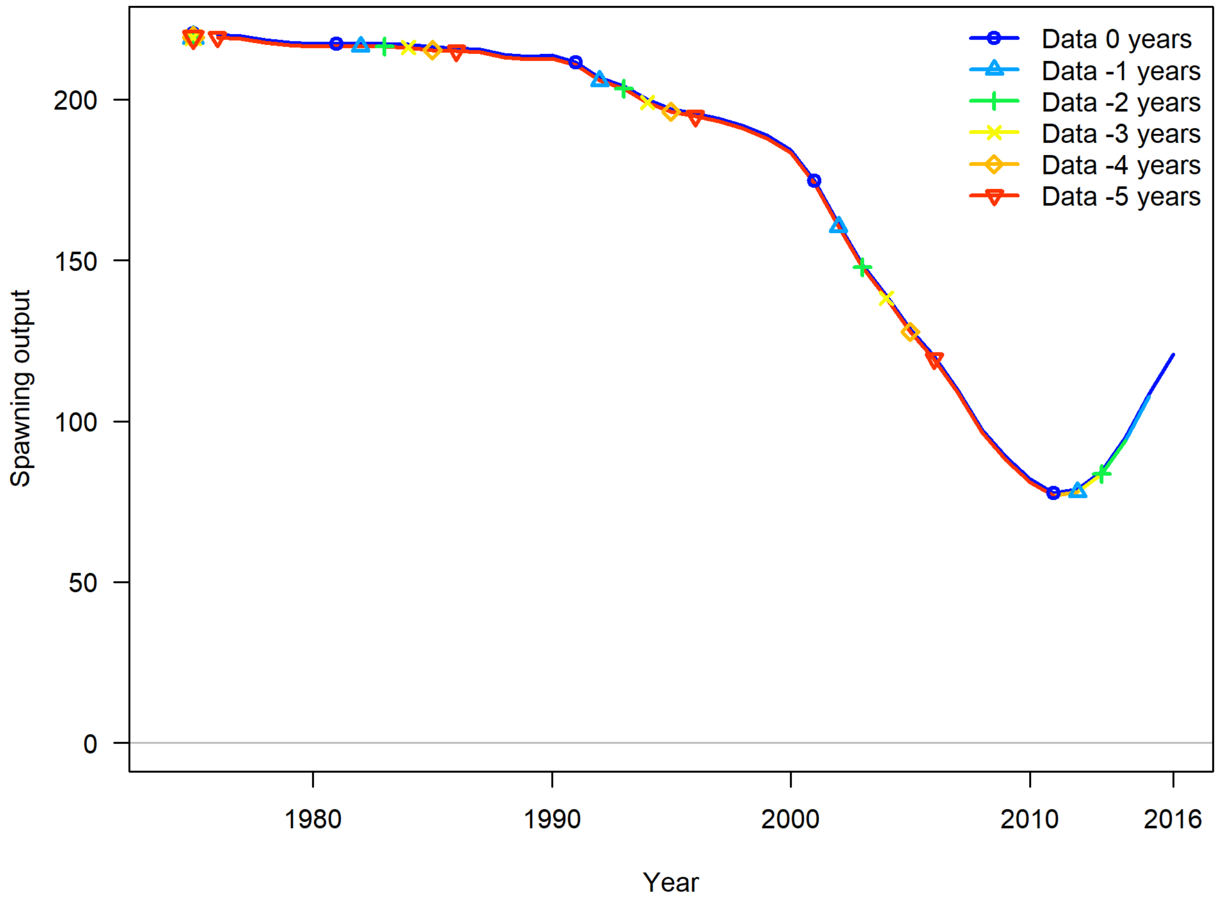

Figure 46. St Croix, retrospective analysis showing biomass trend under sequential removal of up to five most recent years of data.

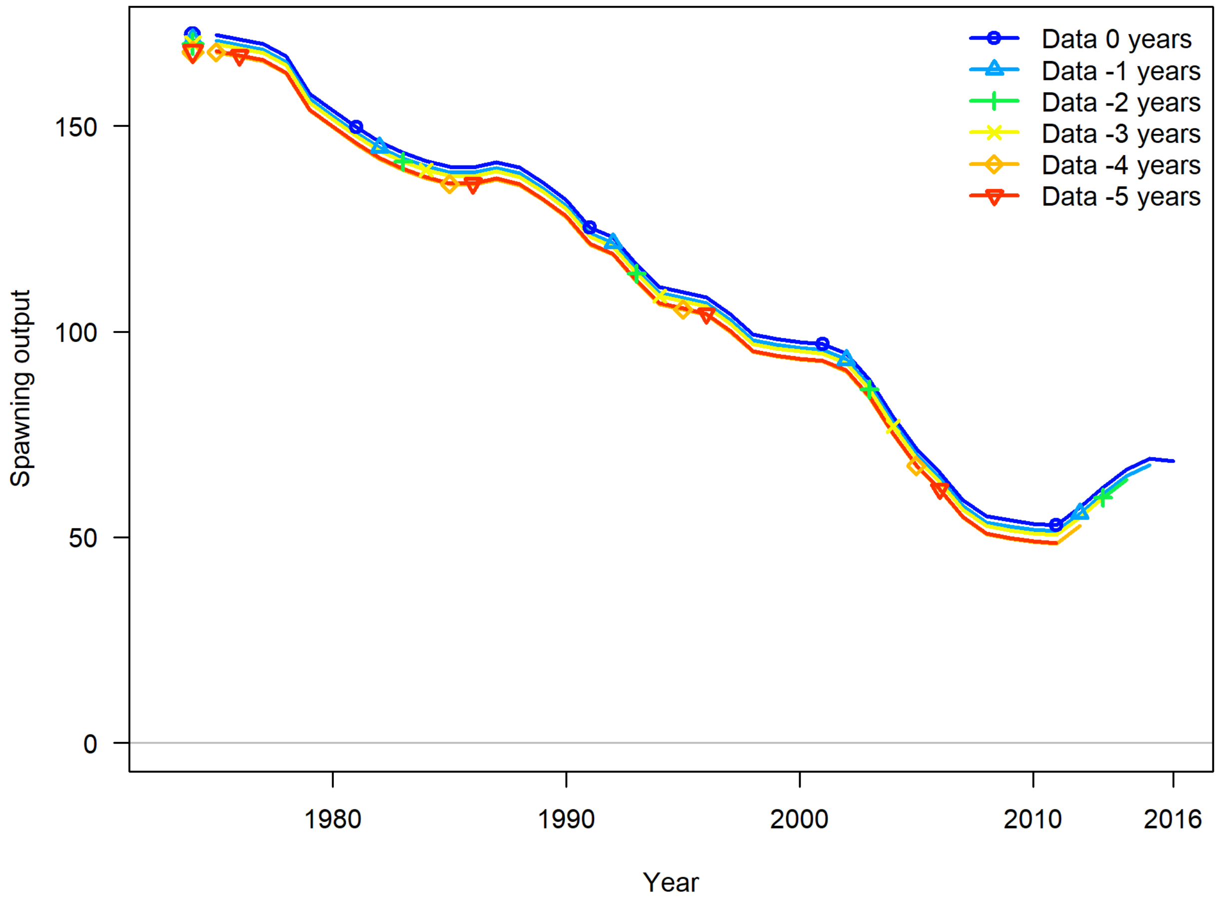

Figure 47. St Thomas/St. John, retrospective analysis showing biomass trend under sequential removal of up to five most recent years of data.

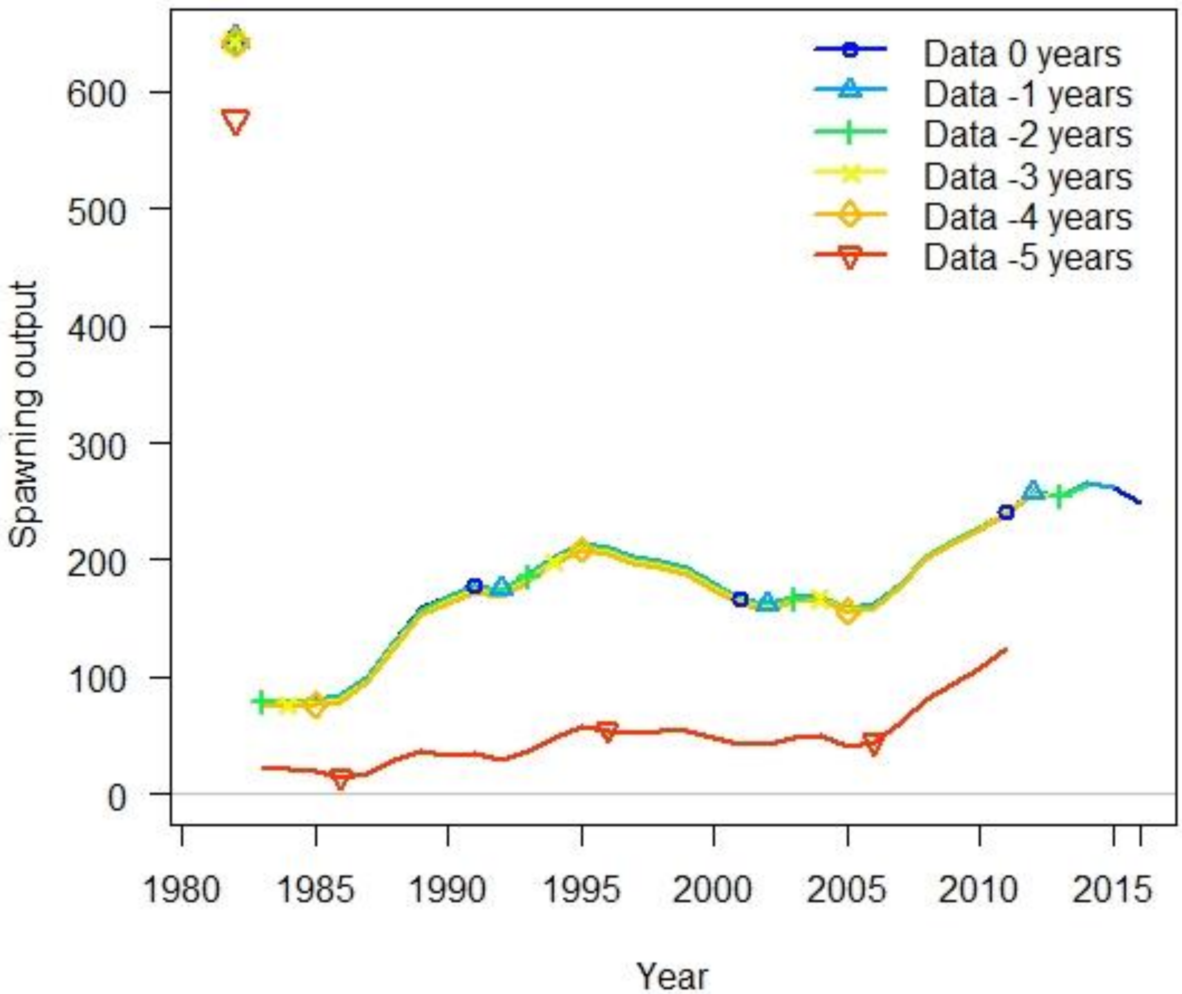

Figure 48. Puerto Rico, base model, retrospective analysis showing biomass trend under sequential removal of up to five most recent years of data.

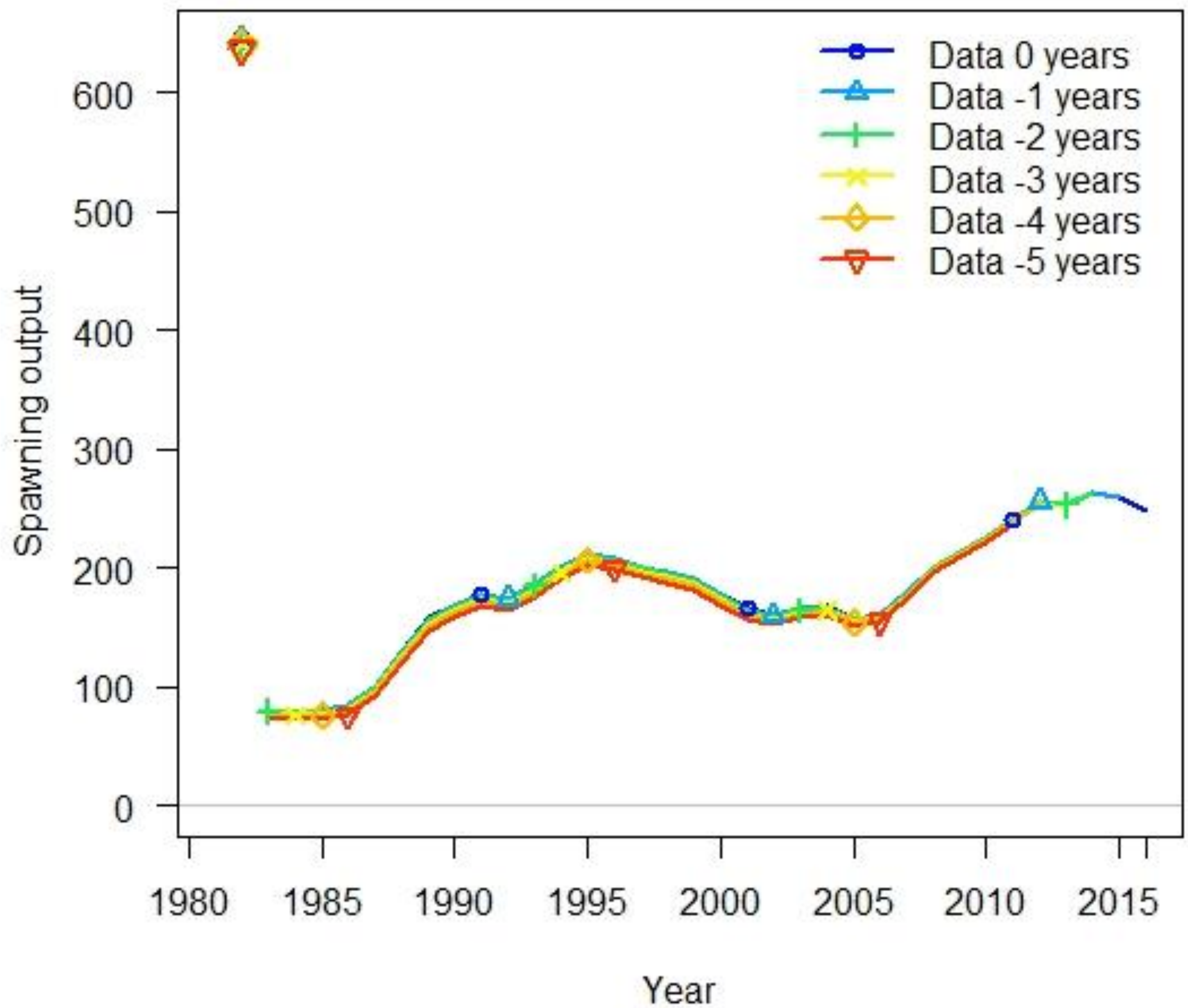

Figure 49. Puerto Rico, model with length composition data filtered to remove years with small sample size ($\sqrt{n} < 8$), retrospective analysis showing biomass trend under sequential removal of up to five most recent years of data.

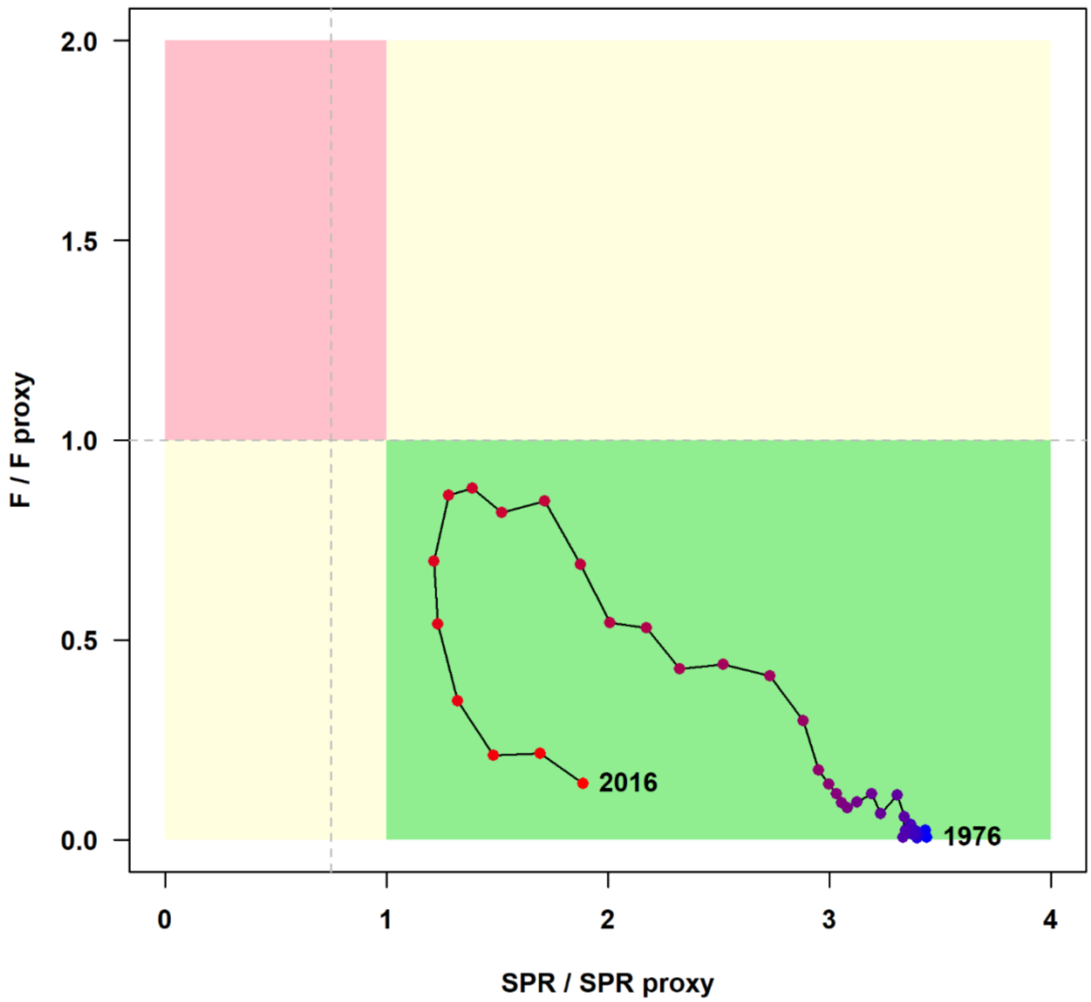

Figure 50. Stock synthesis estimates of spawning output (x-axis) and fishing mortality (y-axis) relative to provisional reference levels of SPR30%, for St. Croix. The vertical gray dotted line shows the reference level associated with Minimum Stock Size Threshold (MSST) and the horizontal gray dotted line shows the Maximum fishing mortality threshold (MFMT).

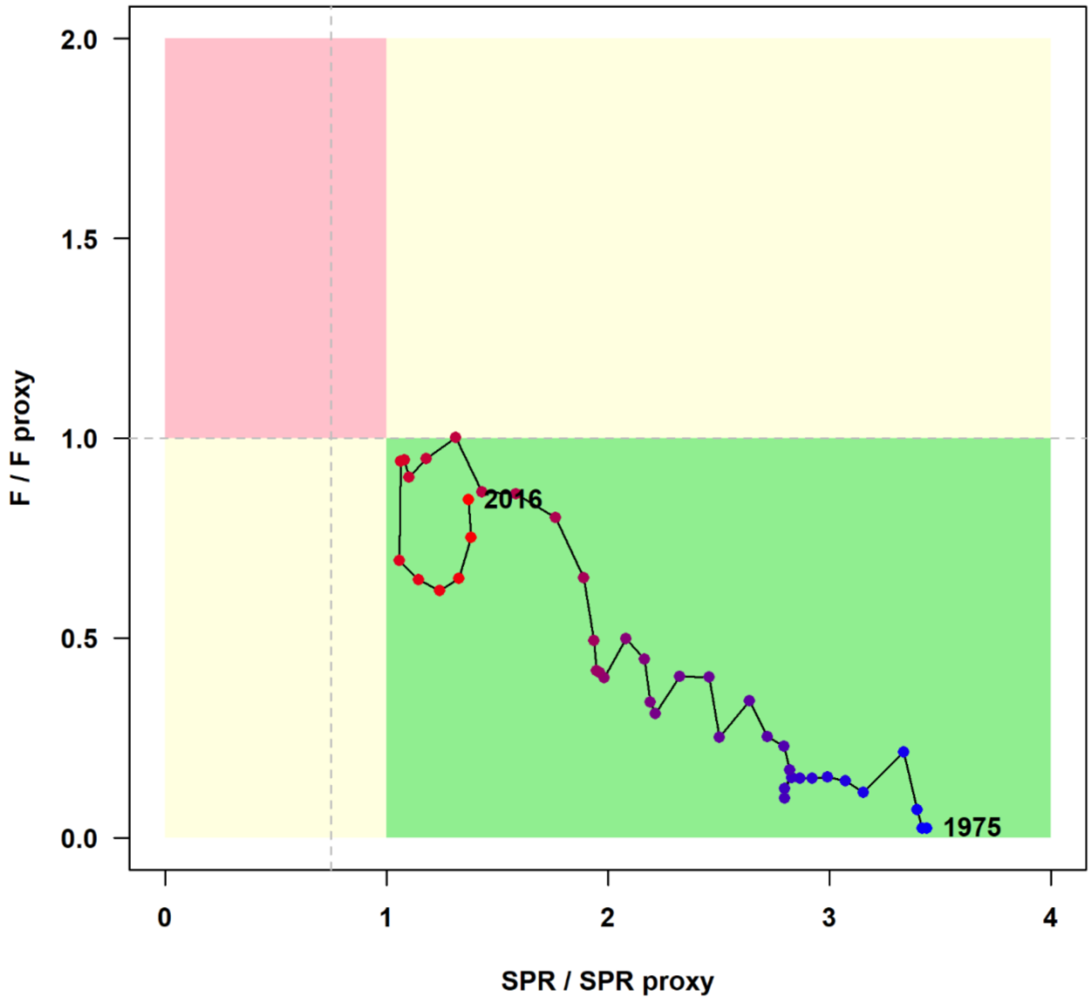

Figure 51. Stock synthesis estimates of spawning output (x-axis) and fishing mortality (y-axis) relative to provisional reference levels of SPR30%, for St. Thomas/St. John. The vertical gray dotted line shows the reference level associated with Minimum Stock Size Threshold (MSST) and the horizontal gray dotted line shows the Maximum fishing mortality threshold (MFMT).

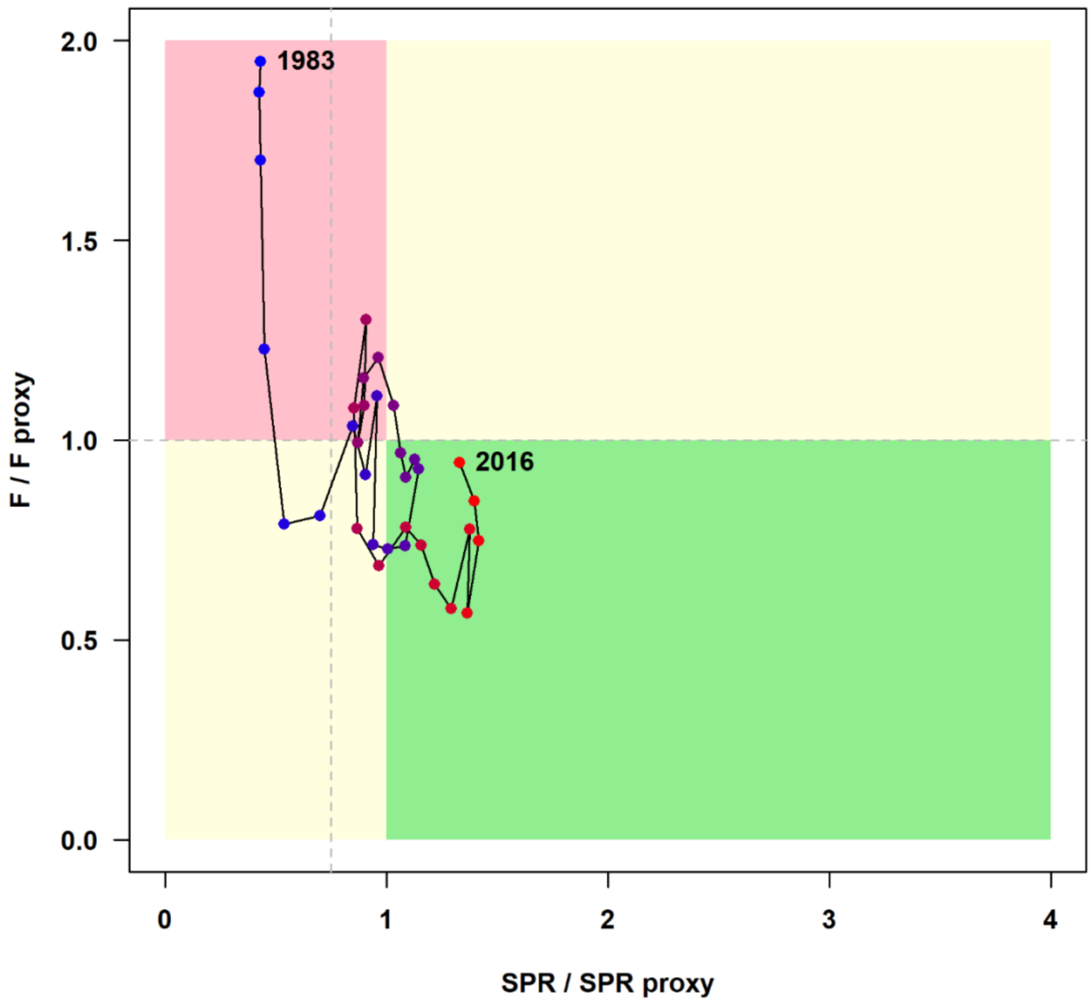

Figure 52. Stock synthesis estimates of spawning output (x-axis) and fishing mortality (y-axis) relative to provisional reference levels of SPR30%, for Puerto Rico. The vertical gray dotted line shows the reference level associated with Minimum Stock Size Threshold (MSST) and the horizontal gray dotted line shows the Maximum fishing mortality threshold (MFMT).

APPENDIX A: CARIBBEAN FISHERY MANAGEMENT COUNCIL ACCEPTABLE BIOLOGICAL CATCH CONTROL RULE FROM ACTION 4, PREFERRED ALTERNATIVE 3.

Tier 1: Data Rich	
Condition for Use	Full stage-structured stock assessment available with reliable time series on (1) catch, (2) stage composition and (3) index of abundance. The assessment provides estimates of minimum stock size threshold (MSST), maximum fishing mortality threshold (MFMT), and the probability density function (PDF) of the overfishing limit (OFL). MSY = long-term yield at F_{MSY} (or, MSY_{proxy} = long-term yield at F_{MSY} proxy); assumes spawner-recruit relationship known MFMT = F_{MSY} or F_{MSY} proxy MSST = 0.75*Spawning Stock Biomass ($SSB_{MSY\ (or\ proxy)}$)
OFL	Catch at MFMT
ABC	ABC = OFL as reduced (buffered) by scientific uncertainty[1] and reflecting the acceptable probability of overfishing[2]. The buffer is applied to the PDF of OFL (σ), where the PDF is determined from the assessment (where $\sigma > \sigma_{min}$) [3]. ABC= d * OFL where $d = \begin{cases} \text{Scalar} \\ \text{if } B \geq B_{msy} \end{cases}$ Scalar = 1 if acceptable probability of overfishing is specified (<0.5), < 1 if not specified (=0.5). $B_{critical}$ is defined as the minimum level of depletion at which fishing would be allowed. [1]Scientific uncertainty would take into account, but not be limited to, the species life history and ecological function. [2]Acceptable probability of overfishing determined by Council. [3] σ_{min} could be equal to coefficient of variation; σ_{min} is in a log scale.
Tier 2: Data Moderate	
Condition for Use	Data-moderate approaches where two of the three time series (catch, stage composition and index of abundance) are deemed informative by the assessment process, and the assessment can provide MSST, MFMT, and PDF of OFL.
	Same as Tier 1, but variation of the PDF of OFL (σ) must be greater than 1.5 σ_{min} (in principle there should be more uncertainty with data-moderate approaches than data-rich approaches).
Tier 3: Data Limited: Accepted Assessment Available	
Conditions for Use	Relatively data-limited or out-of-date assessments
	MSY_{proxy} = long-term yield at F_{MSY} proxy MFMT = F_{MSY} proxy MSST = 0.75*Spawning Stock Biomass $(SSB)_{MSYproxy}$
OFL	OFL = Catch at MFMT

ABC	ABC determined from OFL as reduced (buffered) by scientific uncertainty[4] and reflecting the acceptable probability of overfishing[2] a. Where the buffer is applied to the PDF of OFL when the PDF is determined from the assessment (with $\sigma \geq 2\sigma_{min}$) **OR** b. Where ABC = buffer * OFL, where buffer must be $\leq$ 0.9 [4]Scientific uncertainty would take into account, but not be limited to, the species life history and ecological function, the perceived level of depletion, and vulnerability of the stock to collapse. [2]Acceptable probability of overfishing determined by Council.
Tier 4: Data Limited: No Accepted Assessment Available	
	MSY_{proxy} = long-term yield at F_{MSY} proxy MFMT = F_{MSY} proxy
Tier 4a **Conditions for Use**	No accepted[5] assessment, but the stock has relatively low vulnerability to fishing pressure. A stock's vulnerability to fishing pressure is a combination of its productivity and its susceptibility to the fishery. Productivity refers to the capacity of the stock to produce MSY and to recover if the population is depleted. Susceptibility is the potential for the stock to be impacted by the fishery. If Scientific and Statistical Committee (SSC) consensus[6] cannot be reached on the use of Tier 4a, Tier 4b should be used.
Sustainable Yield Level (SYL)	SYL = Scalar * ***75th percentile*** of reference period landings, where the reference period of landings is chosen by the Council, as recommended by the SSC in consultation with the SEFSC. Scalar $\leq$3 depending on perceived degree of exploitation, life history and ecological function.
ABC	ABC = buffer * SYL, where buffer must be $\leq$ 0.9 (e.g., 0.9, 0.8**,** 0.75, 0.70…) based on the SSC's determination of scientific uncertainty.[7]
Tier 4b **Conditions for Use**	No accepted[6] assessment, but the stock has relatively high vulnerability to fishing pressure (see definition in Tier 4a Condition for Use), or SSC consensus[7] cannot be reached on the use of Tier 4a.
SYL	SYL = Scalar * ***mean*** of the reference period landings, where the reference period of landings is chosen by the Council, as recommended by the SSC in consultation with the SEFSC. Scalar < 2 depending on perceived degree of exploitation, life history, and ecological function.
ABC	ABC = buffer * SYL, where buffer must be $\leq$ 0.9 (e.g., 0.9, 0.8, 0.75, 0.70…) based on the SSC's determination of scientific uncertainty[7]. [5]Accepted means that the assessment was approved by the SSC as being appropriate for management purposes. [6]The SSC defines consensus as having 2/3 of the participating members in favor of a Tier 4a assignment, otherwise the assignment would be Tier 4b of the ABC CR. [7]Scientific uncertainty would take into account, but not be limited to, deficiencies in landings data, availability of ancillary data, species life history and ecological function, perceived level of depletion, and vulnerability of the stock to collapse.

Alternative 3 - Step 2. Establish proxy that will be used when F_{MSY} cannot be determined. If the best scientific information available indicates a more appropriate proxy, that proxy will be used:

Sub-Alternative 3a. The proxy for $F_{MSY} = F_{max}$

Sub-Alternative 3b. The proxy for $F_{MSY} = F_{40\%SPR}$

Sub-Alternative 3c. The proxy for $F_{MSY} = F_{30\%SPR}$

SEDAR

Southeast Data, Assessment, and Review

SEDAR 57

U.S. Caribbean Spiny Lobster

SECTION IV: Research Recommendations

SEDAR
4055 Faber Place Drive, Suite 201
North Charleston, SC 29405

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1. DATA WORKSHOP RESEARCH RECOMMENDATIONS

1.1 LIFE HISTORY RESEARCH RECOMMENDATIONS

Stock Definition and Description

- Research on stock structure is needed, particularly as it relates to connectivity caused by larval dispersal.
- Encountering the right habitat is important for survival of juvenile lobster recruits. Research should be conducted to explore effects of sargassum, water quality, coastal development, and mangrove root communities on the availability and quality of habitat for juvenile spiny lobsters.

Length-Weight Conversions

- Explore plausibility of cause and effect mechanisms that may lead to temporal growth variation.

Discard Mortality

- Investigate potentially unaccounted for discards in the self-reported commercial logbook data to be able to quantify the number of lobster discarded dead, as well as the number of lobster discarded alive.
- Research aimed at quantifying post-release mortality (including post-release predation) of spiny lobster to better understand and propose mechanisms that could potentially mitigate mortality among lobsters that are discarded.

1.2 FISHERY-INDEPENDENT DATA SOURCES

- Development of fishery-independent surveys that are specifically designed for spiny lobster, which would require considerable planning regarding data priorities (e.g., relative abundance versus length), the life stage to target (e.g., adult, juveniles, or larvae), type of gear, sampling design, temporal and spatial resolution, and the availability of funds. In addition to discussing field sampling, planning of how best to record and store data would be beneficial to future analyses and stock assessments.
- Research aimed at identifying correlations between larval and juvenile abundance from the SEAMAP-C surveys and lobster landings could assist in determining the relationship between juvenile abundance and adult abundance (e.g., Butler et al. 2010).

1.3 COMMERCIAL FISHERY STATISTICS RESEARCH RECOMMENDATIONS

- General data improvements are recommended, including continued reporting of specific gear categories (eg. different types of diving).
- Investigate the sensitivity of stock assessment results to landings data associated with high uncertainty.
- Investigate improvements or alternatives to past correction factors in Puerto Rico (2005 in particular).
- Continue SEFSC funded commercial landings validation studies in Puerto Rico and begin similar surveys in the US Virgin Islands.
- General data improvements are recommended, including encouraging complete reporting of discards.

1.4 RECREATIONAL FISHERY STATISTICS RESEARCH RECOMMENDATIONS

- Permanent programs that quantify the recreational effort and landings in the US Caribbean are needed. The results of recent pilot studies (Valle-esquivel and Trumble 2016 and Goedeke et al. 2016) should be used to develop future surveys.

1.5 STAKEHOLDER INPUT RESEARCH RECOMMENDATIONS

- Continue comprehensive bio-socio-economic database of events, compile references and time series of quantitative as available.
- Identify significant EBM quantitative socioeconomic indicators (ex. gravity of the market, network market analyses, population growth, tourism, poaching).
- A Caribbean-specific staff for data statistics and assessments was recommended to aid in establishing and maintaining high expertise of accessing and analyzing past, current, and future data collected in the region.

2. ASSESSMENT WORKSHOP RESEARCH RECOMMENDATIONS

- *Independently estimate availability/selectivity.* There are three main parameters currently estimated in the SEDAR 57 stock assessment for Caribbean spiny lobster in Puerto Rico. They are R0, selectivity, and initial F. Selectivity, as it is used in the model, is both a combination of contact selectivity e.g. selection created by contact with the gear itself such as trap opening diameter and availability which might be a function of depth and habitat. In the base model, selectivity is assumed to be dome-shaped based on information from STT. This is an important assumption since it affects the estimates of both initial F and R0. Knowing more about gear selectivity or having a survey that can provide the underlying size distribution of all lobster in the population, across all habitat and depths, and not just those targeted by the commercial fishery, could greatly improve the stock assessment in Puerto Rico and help determine the appropriateness of the assumed selectivity pattern.
- *Collect data on recreational landings.* The magnitude of recreational removals of spiny lobster on each island platform is unknown.
- *More basic biological studies* to improve understanding of key life history processes such as growth, length/age at maturity, fecundity, and their spatial variability.
- *Improve data on commercial landings and catch and effort***.** Concerns of misreporting should be investigated and corrected where practicable. Commercial catch and effort may provide CPUE indices in the future.

3. REVIEW PANEL RESEARCH RECOMMENDATIONS

The recommendations provided by the Data and Assessment workshops are presented in Appendix 1 of this Consensus Summary Report. Priorities are provided against each of the recommendations although several of the recommendations could be captured in a single research program. The following are the key areas that the RP suggest be the focus of initial research:

(i) Development of an abundance index. An index based on fishery dependent data is complicated by the variety of gears used (fish traps, lobster pots, and various forms of diving), but this would probably be the most cost effective and provide a historical index. This can be done through either standardizing fishery dependent or fishery independent methods.

(ii) It was indicated that there are a number of Marine Protected Areas (MPAs) that have been established for a period of time and are policed for illegal activity. These MPAs represented regions that may provide the closest approximation of an unfished resource. Providing that permits can be obtained, these locations provide opportunities to obtain selectivities that can be used to validate, among other things, the dome-shaped selectivities used in the assessment and an abundance index for an unexploited stock. Size frequency distributions would also assist in determining appropriate growth parameters and should be combined with tagging to improve the estimates of growth.

(iii) An uncertainty in the catch data relates to unreported catch in the form of recreational, illegal and unregulated catch. S57_RD_11 and S57_RD_23 both suggest that unlicensed and recreational fishing are issues for PR. Gaining an understanding of the magnitude of these catches and thus incorporating all forms of harvest in the total catch estimation is a high priority. Discards (identified in the logbook) and their fate should also be investigated and incorporated.

(iv) The RP suggested that the uncertainty within the expansion factors should be explored in detail and be based on species specific expansion factors. Efforts should be targeted to improving reporting rates.

(v) Re-estimate growth parameters using old and new data with more modern techniques.

SEDAR

Southeast Data, Assessment, and Review

SEDAR 57

U.S. Caribbean Spiny Lobster

SECTION IV: Review Workshop Report

August 2019

SEDAR
4055 Faber Place Drive, Suite 201
North Charleston, SC 29405

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1. INTRODUCTION

1.1 WORKSHOP TIME AND PLACE

The SEDAR 57 Review Workshop was held July 9-11, 2019 in Miami, Florida.

1.2 TERMS OF REFERENCE

1. Evaluate the data used in the assessment, addressing the following:
    a. Are data decisions made by the DW and AW sound and robust?
    b. Are data uncertainties acknowledged, reported, and within normal or expected levels?
    c. Are data applied properly within the assessment model?
    d. Are input data series reliable and sufficient to support the assessment approach and findings?
2. Evaluate the methods used to assess the stock, taking into account the available data.
    a. Are methods scientifically sound and robust?
    b. Are assessment models configured properly and used consistent with standard practices?
    c. Are the methods appropriate given the available data?
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    a. Can the results be used to inform management in the U.S. Caribbean (i.e. develop annual catch recommendations)?
    b. Is it likely the stock is overfished? What information helps you reach this conclusion?

   c. Is it likely the stock is undergoing overfishing? What information helps you reach this conclusion?

4. Comment on the degree to which methods used to evaluate uncertainty reflect and capture the significant sources of uncertainty in the population, data sources, and assessment methods. Ensure that the implications of uncertainty in technical conclusions are clearly stated.
5. Consider the research recommendations provided by the Data and Assessment workshops and make any additional recommendations or prioritizations warranted. Clearly denote research and monitoring that could improve the reliability of, and information provided by future assessments.
6. Provide guidance on key improvements in data or modeling approaches which should be considered when scheduling the next assessment.
7. Provide recommendations on possible ways to improve the SEDAR process.
8. Prepare a Peer Review Summary summarizing the Panel's overall conclusions and recommendations.

1.3 LIST OF PARTICIPANTS

Panelists

Cathy Dichmont .... CIE
Stewart Frusher .... CIE
Doug Gregory (Chair) .... SSC
Paul Medley .... CIE
Tarsila Seara .... SSC

Analytic Team

Adyan Rios (Co-Lead analyst) .... NMFS Miami
Bill Harford (Co-Lead analyst) .... Univ. of Miami

Appointed Observers

Julian Magras .... STT/STJ Fisherman
Gerson N. Martinez .... STX Fisherman
Carlos J. Velazquez .... P.R. Fisherman

Attendees

Nicole Carmouze .... NMFS Miami (Intern)

Kevin McCarthy .... NMFS Miami
Matthew Nuttell .... NMFS Miami
Skylar Sagerase .... NMFS Miami
Nathan Vaughn .... NMFS Miami

Staff

Julie Neer .... SEDAR
Graciela Garcia-Moliner .... CFMC
Kathleen Howington .... SEDAR

1.4 LIST OF REVIEW WORKSHOP WORKING PAPERS AND DOCUMENTS

Reference Documents Distributed during the Review Workshop		
SEDAR57-RD21	Portrait of the Spiny Lobster (*Panulirus argus*) Fishery in Puerto Rico during 1998 - 2013	Daniel Matos Caraballo, Martha Ricaute Chica, Jesus León, and Luis A. Rivera
SEDAR57-RD22	Census of licensed fishers of the U.S. Virgin Islands (2016)	Barbara Kojis, Norman Quinn, and Juan J. Agar
SEDAR57-RD23	Assessing socioeconomic impacts of climate change on Puerto Rico's coral reef fisheries through a participatory approach	Tarsila Seara, Karin Jakubowski, Richard Pollnac, and Thomas Webler

2. REVIEW PANEL REPORT

SEDAR 57 U.S. Caribbean Spiny Lobster Review Workshop Summary Report

This Summary Report of the SEDAR 57 U.S. Caribbean Spiny Review Workshop addresses the Terms of Reference as specified in the SEDAR 57 February 2018 document (http://sedarweb.org/sedar-57-caribbean-spiny-lobster-terms-reference). The Review Workshop was held July 9-11, 2019 in Miami, Florida.

Executive Summary

The Review Workshop Panel (RP) reviewed the available data used in the assessment and how it was incorporated into the assessment model. The assessment was considered to be a data moderate (Tier 3) type of assessment. The data used was considered appropriate for a data moderate assessment, although, in some cases sample sizes were small. The data appeared consistent and sufficient to monitor trends in stock size and mortality over the period; however, no abundance indices were available. Each of the management units in Puerto Rico (PR), St. Thomas (STT), and St. Croix (STX) were assessed separately.

The RP changed two aspects of the data originally used in the base case model. The growth information used provided questionable estimates of sex specific L_∞ so growth parameters from a more extensive study conducted in Cuba were used, resulting in an improvement in model fits to available length frequency data. The other data issue identified was the presence of an unusually large expansion factor in 2005 for estimating Puerto Rico landings. The RP decided to reduce 2005 expansion factor by averaging the 2004 and 2006 expansion factors for one region.

The major uncertainties identified by the RP was the lack of recreational and illegal fishing data, the lack of abundance indices, and the application of identical landings expansion factors to reported landings regardless of species. Species specific expansion factors would be preferable.

The method used in the stock assessment was an age structured model fitted to catch and length frequency data separately for each of the three island based management units. The modelling was scientifically sound, given the data moderate nature of the assessment. In addition to modelling sex-specific growth in the assessment, the RP evaluated possible selectivity differences between the trap and dive fisheries. Both gear types had dome shaped selectivity due to trap design, market demands and depth limits to divers.

The modelling approach using the Stock Synthesis 3 (SS3) package was appropriate and will allow for future assessments to be conducted with comparable methods. The assessment results seem robust enough for management advice, although uncertainty is likely to be underestimated by the proposed base case. The $SPR_{30\%}$ proxy for MSY was chosen as the basis for management reference points. The assessment concluded that for each of the three island fisheries overfishing was not occurring and that none of the fisheries were currently overfished.

Additional fisheries independent and dependent research is needed to strengthen future assessments. CPUE indices would be very helpful, as would studies of the effectiveness of existing MPAs in enhancing lobster abundance.

Specific Terms of Reference Addressed

1. Evaluate the data used in the assessment, addressing the following:

a. Are data decisions made by the DW and AW sound and robust?

All the data decisions were supported by the RP, with the exception of the initial base case growth parameters and how the PR 2005 total landings were calculated.

The initial base model used growth parameters derived from one of the two years of size composition data undertaken in PR. While using data from the areas being assessed is preferential, the chosen growth estimates were inconsistent with the general knowledge of lobster biology. Male spiny lobsters are known to reach larger sizes than females. On considering the other options of estimates – Mexico and Cuba, the RP recommended the Cuban estimates as these also aligned with the maximum sizes found in the size structure observed in the US Caribbean fishery. Subsequent model runs using these Cuban growth estimates resulted in improvements in the fit to the data.

The RP recommended for one specific region within PR that the average of the 2004 and 2006 expansion factors be used to calculate the total landings for PR in 2005 rather than an average of the estimated landings. Furthermore, it appeared that the odd 2005 expansion factor was not so much a result of low reporting from the lobster fishery as it was from the use of an expansion factor that was combined over all species.

b. Are data uncertainties acknowledged, reported, and within normal or expected levels?

All known data uncertainties were acknowledged and reported. Some uncertainties require further work, notably:

(i) The use of expansion factors that apply across a range of species in the fishery should be avoided and expansion factors based on the spiny lobster fishery be used where possible.

(ii) Other forms of mortality are indicated in the literature provided, including recreational catches and illegal catches. The assessment process report acknowledges that recreational catch may or may not make up a substantial fraction of the total landings. However, recreational catches were not represented in the assessment as very limited data existed. The lack of all forms of mortality imply a need to estimate spiny lobster total catch with errors using more formal statistical methods.

(iii) The lack of abundance indices may lead to under-estimating the uncertainty in this assessment.

c. Are data applied properly within the assessment model?

The data have been applied properly within the assessment model. However, the effective sample size for the length data may be better defined using methods related to the internal correlation structure of the sampling. This could become a more important issue if other data sources (i.e. CPUE) are included in the stock assessment.

d. Are input data series reliable and sufficient to support the assessment approach and findings?

The input data series used are reliable in the context of a data moderate assessment (Tier 3). While in some cases sample sizes are small, the data appear consistent and provide sufficient cover to monitor trends in stock size and mortality over the period. However, only two out of the three main data types were available; no abundance indices were available.

2. **Evaluate the methods used to assess the stock, taking into account the available data.**

   a. **Are methods scientifically sound and robust?**

The methods used were scientifically sound and robust. The method applied was an age structure population model fitted to the available total catch and length frequency data separately for each of the three management units.

The model was fitted using Stock Synthesis version 3 (SS3), which is a widely used and tested software model from the NFMS toolbox. SS3 provides a flexible platform for this type of analysis.

   b. **Are assessment models configured properly and used consistent with standard practices?**

The assessment models were configured properly and used in accordance with standard practice. Parameters that could not be fitted were fixed at values based upon published estimates. These and other important assumptions, were tested using sensitivity analyses.

The RP recommended some changes to the base case as a result of findings in the sensitivity runs during the Review Workshop. The sensitivity runs were used to test the assumptions made in the base configuration.

The recommended base case configurations are limited by data, but consistent with life history knowledge within these limits. So, for example, growth differences between the sexes is accounted for, and island platforms are treated as separate management units. However, the possibility that the management unit is shared between the US and British Virgin Islands has not been accounted for, because British Virgin Island data were not available. No problems were identified by the RP that would prevent the recommended base case assessment being used for management advice.

The model has two critical features: sex-specific growth and domed shaped selectivity for the main gear-types. The larger male maximum carapace length has been widely observed, and can be accounted for in the model. Independent support for the dome-shaped selectivity was not available, but it does fit the data better, and can be justified based on known life history characteristics of spiny lobster. Spiny lobster move from shallow to deeper water as they grow, so the availability of lobsters to the fishery will vary over depth.

While there may be configurations that would, in the longer term, explain the observations better, the data were unable to support estimating these differences. For example, anecdotal evidence suggested that the diving fishery may select differently for each sex, but data were inadequate to test this hypothesis within the model. In the RP opinion, the effects of these differences are not likely to be critical and can be addressed in the future.

   c. **Are the methods appropriate given the available data?**

The method used for the stock assessment was appropriate. The stock assessment was data limited for all fisheries. No abundance index was available, and data were limited to total catches and length frequencies. In an integrated model, these data are, at best, sufficient to obtain estimates of recruitment, selectivity and mortality. Stock synthesis (SS3) provides a suitable method to use these data since the model can be configured to fix parameters that cannot be estimated. Using SS3 also has the advantage that as more data become available in the future, it can be incorporated into the same model so improvements should be seamless.

Simpler “data-limited” models were considered. However, these rely on data or assumptions that do not apply in this case. There was no index of abundance available, methods based on mean length do not allow for dome-shaped selectivity that applies in this case, and changes in selectivity (retention) discourage using catch-only methods. In addition, an integrated model resolves conflicts between different sources of information internally using model structures and statistics, making this a better approach.

3. **Evaluate the assessment findings with respect to the following:**

   a. **Can the results be used to inform management in the U.S. Caribbean (i.e. develop annual catch recommendations)?**

The results from both the recommended base case and original base case can be used to inform management for all three management units (STT, STX and PR) in terms of defining whether the fisheries were overfished or overfishing was occurring. However, only the recommended base case should be used for allowable catch recommendations. The recommended base case is the preferred RP base case.

The recommended base case uses a different growth curve to the original base case as described above. With these changes, several other inputs could be changed, especially those associated with the selectivity functions in that the size frequency data for the specific management unit became more informative, allowing less reliance on the STT selectivity. This model set up is more appropriate. However, the sensitivity tests showed that F_{MSY} is often poorly estimated (including for the recommended base case) for all of the management units, so the RP proposes that the $SPR_{30\%}$ proxy is used as the alternative.

Given the data moderate nature of these assessments, the model PDF is likely to be underestimating the uncertainty and therefore it is not recommended that it be used.

   b. **Is it likely the stock is overfished? What information helps you reach this conclusion?**

It is not likely that the management unit associated with each island fishery was overfished in 2016. The recommended base case for all island fisheries show the respective management unit was not overfished. The original base case also showed that all the management units were not overfished.

Several tests were undertaken to examine model uncertainty:

- Sensitivity of the base models to assumptions such as natural mortality, growth, first year fishing mortality, and selectivity options;
- Retrospective analyses on the effect of removing recent data; and
- Likelihood profiles to test components of the likelihood against different parameter values.

All the relevant tests showed that the spiny lobster population was not overfished for any of the management units.

   c. **Is it likely the stock is undergoing overfishing? What information helps you reach this conclusion?**

It is not likely that the management unit associated with each island fishery was undergoing overfishing in 2016. The recommended base case showed that the spiny lobster population in the different management units was not subject to overfishing. The original base case also showed that all the management units were not subject to overfishing.

None of the sensitivity test suggested that overfishing was occurring.

4. **Comment on the degree to which methods used to evaluate uncertainty reflect and capture the significant sources of uncertainty in the population, data sources, and assessment methods. Ensure that the implications of uncertainty in technical conclusions are clearly stated.**

The uncertainty was adequately evaluated in context of a data moderate assessment. The uncertainty in parameter estimates was estimated from the normality assumption and observation error. Process error, in this case recruitment deviates, was explored but could not be estimated. The more important structural error was evaluated using sensitivity analyses.

The model diagnostics and sensitivity analyses undertaken before and during the Review Workshop provided adequate information on the uncertainty in data, assessment and parameters to draw conclusions on stock status. The range of stock size and fishing mortality was clearly presented in graphs and other stock assessment output.

5. **Consider the research recommendations provided by the Data and Assessment workshops and make any additional recommendations or prioritizations warranted. Clearly denote research and monitoring that could improve the reliability of, and information provided by future assessments.**

The recommendations provided by the Data and Assessment workshops are presented in Appendix 1 of this Consensus Summary Report. Priorities are provided against each of the recommendations although several of the recommendations could be captured in a single research program. The following are the key areas that the RP suggest be the focus of initial research:

(i) Development of an abundance index. An index based on fishery dependent data is complicated by the variety of gears used (fish traps, lobster pots, and various forms of diving), but this would probably be the most cost effective and provide a historical index. This can be done through either standardizing fishery dependent or fishery independent methods.

(ii) It was indicated that there are a number of Marine Protected Areas (MPAs) that have been established for a period of time and are policed for illegal activity. These MPAs represented regions that may provide the closest approximation of an unfished resource. Providing that permits can be obtained, these locations provide opportunities to obtain selectivities that can be used to validate, among other things, the dome-shaped selectivities used in the assessment and an abundance index for an unexploited stock. Size frequency distributions would also assist in determining appropriate growth parameters and should be combined with tagging to improve the estimates of growth.

(iii) An uncertainty in the catch data relates to unreported catch in the form of recreational, illegal and unregulated catch. S57_RD_11 and S57_RD_23 both suggest that unlicensed and recreational fishing are issues for PR. Gaining an understanding of the magnitude of these catches and thus incorporating all forms of harvest in the total catch estimation is a high priority. Discards (identified in the logbook) and their fate should also be investigated and incorporated.

(iv) The RP suggested that the uncertainty within the expansion factors should be explored in detail and be based on species specific expansion factors. Efforts should be targeted to improving reporting rates.

(v) Re-estimate growth parameters using old and new data with more modern techniques.

6. **Provide guidance on key improvements in data or modeling approaches which should be considered when scheduling the next assessment.**

A key uncertainty in this data moderate assessment is its relatively limited data. As a result, transitioning to an assessment incorporating additional data would be greatly beneficial in addressing key uncertainties. In all the management units, there was a reasonably large contrast regarding the stock status of the resource over the past decade. Even though the recording of effort in the logbook has changed over the whole time series, logbook formats have been reasonably consistent for the last ten years or so. Thus CPUE could be useful to either a) help select between different sensitivity tests as a nominal index or, if standardised, be incorporated into the stock assessment as an index of abundance. A further uncertainty was in the selectivity and growth models. As per ToR 5, given that the Marine Protected Areas (MPAs) have been in place for some time, research within them would be very useful, most notably undertaking: a) selectivity studies to test for dome shaped selectivity and to provide the data to estimate selectivity within the model, and b) regularly collect unfished population size frequency information (preferably with gear that does not have such strong dome shaped selectivity) that can be used to compare with size frequency data from the fishery. These data should provide more information on parameters in the model and enable more accurate estimates of the assessment's uncertainties.

The current model and software, Stock Synthesis (SS3), would still provide an adequate framework for modelling with these data improvements.

7. Provide recommendations on possible ways to improve the SEDAR process.

Make CIE reports available as quickly as possible to the SEDAR process. While the assessment scientists have said that they eventually receive the reports, there appears to be considerable delay.

8. Prepare a Peer Review Summary summarizing the Panel's overall conclusions and recommendations.

This report summarizes the RP's overall conclusions and recommendations.

Appendix 1: Combined DW and AW Recommendations

Life History

1. Research on stock structure is needed, particularly as it relates to connectivity caused by larval dispersal. Low
2. Encountering the right habitat is important for survival of juvenile lobster recruits. Research should be conducted to explore effects of sargassum, water quality, coastal development, and mangrove root communities on the availability and quality of habitat for juvenile spiny lobsters. Low
3. Explore plausibility of cause and effect mechanisms that may lead to temporal growth variation. Low
4. Investigate potentially unaccounted for discards in the self-reported commercial logbook data to be able to quantify the number of lobster discarded dead, as well as the number of lobster discarded alive. High
5. Research aimed at quantifying post-release mortality (including post-release predation) of spiny lobster to better understand and propose mechanisms that could potentially mitigate mortality among lobsters that are discarded. Low

Fishery Dependent

9. General data improvements are recommended, including continued reporting of specific gear categories (e.g. different types of diving). High – needs to also include different trap and pot configurations to enable CPUE estimations.
10. Investigate the sensitivity of stock assessment results to landings data associated with high uncertainty. High
11. Investigate improvements or alternatives to past correction factors in Puerto Rico (2005 in particular). High (combine with above)
12. Continue SEFSC funded commercial landings validation studies in Puerto Rico and begin similar surveys in the US Virgin Islands. High

13. General data improvements are recommended, including encouraging complete reporting of discards. High (as per LH 4)
14. Further explore TIP data for possible data entry and/or measurement errors, particularly regarding the number of individuals associated with a given length entry and associated with potentially miscoded species. Low (Initial focus needs to be on data quality)
15. Permanent programs that quantify the recreational effort and landings in the US Caribbean are needed. The results of recent pilot studies (Valle-esquivel and Trumble 2016; Goedeke et al. 2016) should be used to develop future surveys. High
16. Continue comprehensive bio-socio-economic database of events, compile references and time series of quantitative data as available. High (emphasis on post hurricane recovery effects, qualification and, where possible, quantification of recreational, unreported and unregulated catches, and market-driven fisher behavior).
17. Identify significant EBM quantitative socioeconomic indicators (ex. gravity of the market, network market analyses, population growth, tourism, poaching). Medium (see 16 above)
18. A Caribbean-specific staff for data statistics and assessments was recommended to aid in establishing and maintaining high technical expertise. High

Fishery-Independent

19. Development of fishery-independent surveys that are specifically designed for spiny lobster, which would require considerable planning regarding data priorities (e.g., relative abundance versus length), the life stage to target (e.g., adult, juveniles, or larvae), type of gear, sampling design, temporal and spatial resolution, and the availability of funds. In addition to discussing field sampling, planning of how best to record and store data would be beneficial to future analyses and stock assessments. Low (costly) – see above MPA RP recommendations
20. Research aimed at identifying correlations between larval and juvenile abundance from the SEAMAP-C surveys and lobster landings could assist in determining the relationship between juvenile abundance and adult abundance (e.g., Butler et al. 2010). Low

Overall

21. Where possible, the research recommended above should consider ecosystem linkages toward developing capacity in the region for ecosystem based fisheries management.

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SECTION VI: Post-Review Workshop Addendum Report

August 2019

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EXECUTIVE SUMMARY

This addendum to the SEDAR 57 report documents changes requested by RW and conducted by analysts. All of the requested changes were made and full diagnostics conducted for the revised models. The primary and most substantive change was to model male and female growth separately with the growth parameters derived from a study in Cuba (Leon et al. 1995) where females exhibit substantially smaller asymptotic size (155 mm CL) than males (184 mm CL) and smaller sizes at younger ages. The RW panel felt that the growth parameters from the Leon et al. (1995) study better represent the sexual dimorphism of growth in lobsters. The resulting models show substantially improved fits to the sex-specific length composition and similar diagnostic performance as the previous AW base models. The resulting change in growth resulted in higher virgin recruitment levels, slightly lower $F_{spr30\%}$ and slightly (-6 to 14%) higher yields at equilibrium. Stock status as estimated for 2016 remains the same (not overfished, nor undergoing overfishing) for the RW-preferred models. Given the improved fit and no evidence of problematic diagnostics, the analytical team considers that the RW-preferred model is a preferable candidate for the new base models.

INTRODUCTION

The SEDAR 57 Review Workshop (RW) took place 9-11 July 2019. During the RW, the SEDAR 57 Review Panel requested additional clarifications on data inputs and additional analyses of the analytical team. Specific topics and requests are documented in this report and are summarized below:

1. **Updated AW report page 27 broken hyperlinks**
2. 2012 Acceptable Biological Catch (ABCs)
3. 2018 Sustainable Yield Level (SYL) derived Commercial ABCs
4. New values for partial data replacement for 2005 landings in Puerto Rico
5. Sensitivity runs for each island platform using growth parameters derived in Cuba
    a. St. Thomas/St. John
    b. St. Croix: with new St. Thomas/St. John selectivity priors
    c. Puerto Rico: with new 2005 methodology for landings, without selectivity priors, and without time block on selectivity

ANALYSES REQUESTED BY REVIEW PANEL

1. **Updated AW report page 27 broken hyperlinks.**
    a. Page 21: “insert mean” changed to “170.9 mt; 376,661 lbs”
    b. Page 27: “Error! Reference source not found” changed to “Figure 51”
    c. Page 27: “Error! Reference source not found” changed to “Figure 52”
    d. Page 27: “Error! Reference source not found” changed to “Figure 53”

2. **2012 ABCs** in pounds (lbs) and metric tons (mt) whole weight

Island Platform	Reference Years	ABC (lbs)	ABC (mt)
St. Croix	1999 – 2008	107,307	48.7
St. Thomas/St. John	2000 – 2008	104,199	47.3
Puerto Rico	1988 – 2009	327,920	148.7

3. **2018 SYL derived Commercial ABCs** in pounds (lbs) and metric tons (mt) whole weight. See Appendix A in the Assessment Report for details on the SYL.

Island Platform	Reference Years	ABC (lbs)	ABC (mt)
St. Croix	2000 - 2010	207,925	94.3
St. Thomas/St. John	2000 - 2010	220,221	99.9
Puerto Rico	1988 – 2011*	554,981	251.7

*Excludes 2005

4. **New 2005 landings values** for Puerto Rico commercial time series in pounds (lbs) and metric tons (mt) whole weight.

Method	Diving (lbs)	Pots and Traps (lbs)	Total (lbs)
Raw 2005 Landings	95,808	77,538	173,346
Expanded Normal 2005 Landings	287,027	487,519	774,546
Average of 2004 & 2006 Expanded Landings	190,038	186,623	376,661
Expanded 2005 Landings using Average of 2004 & 2006 for East Coast Expansion Factor	**200,479**	**271,485**	**471,964**

Method	Diving (mt)	Pots and Traps (mt)	Total (mt)
Raw 2005 Landings	43.5	35.2	78.6
Expanded Normal 2005 Landings	130.2	221.1	351.3

Average of 2004 & 2006 Expanded Landings	86.2	84.7	170.9
Expanded 2005 Landings using Average of 2004 & 2006 for East Coast Expansion Factor	**90.9**	**123.1**	**214.1**

5. Sensitivity runs for each island platform using growth parameters derived in Cuba.

The analytical team developed model runs for each island platform during the RW but required further time to perform the full suite of diagnostics. The results of these model runs are documented herein. One of the largest changes requested by the RW Panel was to re-evaluate the growth parameters used for each island platform. The RW Panel recommended using the Cuban growth parameters for all three island platforms because these estimates appeared more plausible and they demonstrate the expected difference between male and female spiny lobster.

Growth Parameters chosen during Assessment Process (Puerto Rico; Mateo 2004):

Female Linf = 191 mm CL Male Linf = 195 mm CL
Female K = 0.25 year-1 Male K = 0.24 year-1

Growth Parameters Recommended by Review (Cuba; Leon et al. 1995)

Female Linf = 155 mm CL Male Linf = 184 mm CL
Female K = 0.22 year-1 Male K = 0.24 year-1

SUMMARY OF RESULTS

Updated tables and figures below are presented in the same order as in the Assessment Report for ease of comparisons. Here we briefly summarize key differences in model results between model runs for each island platform.

For all three island-platforms, the negative log-likelihood was reduced in the RW models (Table 1). The largest difference was noted for Puerto Rico, where multiple changes were recommended for this model including removing the selectivity block, using Cuban growth parameters, revising the 2005 landings, and removing priors on selectivity. However, the greatest change in log-likelihood for all models was due to the change in growth parameters, indicating that accounting for sexual dimorphism in growth improved the fit, particularly for Puerto Rico and for St Thomas/St John. Puerto Rico landings in 2005 were associated with low reporting and large expansion factors. The expanded 2005 Puerto Rico landings were revised using the requested methodology: replacing the 2005 east coast expansion factor with an average of the 2004 and 2006 east coast expansion factors for treating the 2005 landings estimate (Figure 1). Selectivity parameters were similar between AW base models and the RW models (Table 2) and R0 was slightly higher for each of the RW models. The main difference was for initial F in Puerto Rico where the revised growth resulted in lower initial F and less contrast between initial F and terminal F (Table 3).

Model fits to Length Composition

No major changes to the length composition fits or residuals were noted for St. Thomas/St. John and St. Croix, whereas some larger residuals were noted in the Puerto Rico models for both sexes and for both diving and pots-traps fleets (Figures 2-13). Trends in selectivity and retention were similar between St. Thomas/St. John and St. Croix models (Figures 14-15). Some differences were evident in the selectivity and discards between Puerto Rico models for the diving fleet (Figure 16-19).

Trends in Population Dynamics

Revised parameter estimates, recruitment estimates, spawning output, total biomass (mt), and fishing mortality are provided in Tables 1-7. In general, the trends in population outputs were similar for St. Croix (Figures 20-21), St. Thomas/St. John (Figures 22-23), and Puerto Rico (Figures 24-25). Fishing mortality trends were also similar between models for each island platform, although some F was lower initially and throughout the time series for Puerto Rico (Figures 26-28).

Model Diagnostics

Model diagnostics were relatively similar between the St. Croix models with the exception of R0, which revealed much higher likelihood values at lower R0 compared to the base model (Figure 29). For St. Croix, the jitter analysis suggested that the global minimum has been obtained in model fitting, although 1 of the 50 jitters resulted in a model 10 NLL units higher, due largely to a slightly worse fit to the length composition. Model diagnostics were relatively similar between the St. Thomas/St. John models with the exception of R0, which revealed much higher likelihood values at lower R0 compared to the base model (Figure 30). For St. Thomas/St. John, no alternative runs were evident in the jitter analysis, as all 50 models landed on the same solution and NLL. Larger differences were noted for the diagnostics of the Puerto Rico model, specifically the Initial F, which was much lower in the RW model (Figure 31-33). For Puerto Rico, the jitter analysis suggested that the global minimum has been obtained in model fitting, although 1 of the 50 jitters resulted in a much worse model fit, due largely to worse fits to the length composition.

Retrospective patterns were similar for the St. Croix (Figure 34), but slightly more pronounced for the St. Thomas/St. John (Figure 35) and the Puerto Rico (Figure 36).

Stock Status

For the RW models, current stock status remains unchanged for St. Croix, St. Thomas/St. John and Puerto Rico (Figure 37-39; Tables 8-10). However, changes during the time series were noted for St. Croix, where a few years displayed F/Fproxy ratios above 1 (Figure 37). For Puerto Rico, the RW model resulted higher SPR/SPRproxy ratios, with only a few years showing

F/Fproxy ratios above 1 (Figure 39). Provisional estimates of the catches corresponding to the overfishing limit (OFL) were calculated using the median of the projection at FSPR30% and are summarized in Table 12.

CONCLUSION

The most impactful change recommended by the RW was to change the growth parameters to those from the Leon et al (1995) study conducted in Cuba rather than the parameters from Mateo et al (2004) from Puerto Rico. While Cuba is, by distance further from the Virgin Islands and Puerto Rico, the RW considered that capturing the sexual dimorphism in growth of spiny lobsters was important (Leon et al. 1995, Muller et al. 1997, Ehrhardt 2005, Alzugaray et al. 2018), and the improved fit to the length composition clearly justifies this change.

The resulting change did not change selectivities greatly but the inference on stock status changed slightly with lower initial Fs for Puerto Rico as a result of the change in growth parameters. This resulted in higher mean age in the population (Figures 40-42) and less contrast in mean age over the time series for the RW model than for the AW model in Puerto Rico. Hence, the population in Puerto Rico was estimated to have not been undergoing as high of fishing mortality at the start of the time series and the reduction in F has been less over time.

The primary result of the change in growth parameters was to increase virgin recruitment level and reduce $F_{spr30\%}$. These changes offset resulting in only slightly different equilibrium yields (slightly lower for St Croix (-6%) and slightly higher for St Thomas/St John (14%) and Puerto Rico (+14). These also resulted in slightly different short-term yields at $F_{spr30\%}$ (Table 13).

Given that the RW models show acceptable diagnostic performance and that the fits are substantially improved, the analytical team considers that the RW-preferred model is a preferable candidate for the new base models.

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TABLES

Table 1. Comparison of model runs explored during Review Workshop. Note: model progression during the assessment process is detailed in Table 5 in the Assessment Report.

Config.	Description	NLL	Notes
STT			
2	Exponential-logistic selectivity on diving, traps mirrored selectivity, no female offset, retention blocks 1985-2003 and 2007 to 2016, initial unfished equilibrium	126.1	**Assessment Base model**
RW	Cuba von Bertalanffy growth parameters	105.2	RW model
STX			
7	Exponential-logistic selectivity on diving, traps mirrored selectivity, no female offset, retention blocks 1985 to 2016, initial unfished equilibrium	162.9	**Assessment Base model**
RW	Cuba von Bertalanffy growth parameters	158.5	RW model
PR			
8	Config 7 + selectivity time block	249.41	**Assessment Base model**
14	Config 8 + Cuba growth (8 priors)	200.1	
16	Config 14 + 2005 (8 priors)	199.93	
18	Config 16 - sel time block (2 priors)	182.36	
21	Config 18 + free all (no priors)	182.84	**RW model**

Table 2. Parameter estimates for RW models, St. Croix and St. Thomas/St. John. Est. is the maximum likelihood estimate; SE is standard error of the estimator.

Parameter	St. Croix		St. Thomas/St. John	
	Est.	SE	Est.	SE
Log(R0)	5.70	0.12	5.63	0.13
Sel. P1	0.20	0.01	0.13	0.01
Sel. P2	0.37	0.00	0.40	0.01
Sel. P3	0.29	0.02	0.16	0.05

Table 3. Parameter estimates for RW model, Puerto Rico. Est. is the maximum likelihood estimate; SE is standard error of the estimator.

Parameter	Puerto Rico		Puerto Rico Diving 1983-2016		Puerto Rico Diving 1999-2016		Puerto Rico Trap 1983-2016		Puerto Rico Trap 1999-2016	
	Est.	SE	Est.	SE	Est.	SE	Est.	SE	Est.	SE
Log(R0)	7.01	0.11	-	-	-	-	-	-	-	-
Initial F	0.60	0.12	-	-	-	-	-	-	-	-
Sel. P1	-	-	0.18	0.01	-	-	0.18	0.01	-	-
Sel. P2	-	-	0.35	0.01	-	-	0.36	0.01	-	-
Sel. P3			0.28	0.03	-	-	0.34	0.04	-	-
Ret. P2	-	-	-	-	1.85	0.25	-	-	2.95	0.55

Table 4. Recruitment estimates (1000s of Age-0 lobster) and standard deviation from Stock Synthesis RW models.

	St. Croix		St. Thomas/St. John		Puerto Rico	
YEAR	Recruits (1000s)	Std. Dev.	Recruits (1000s)	Std. Dev.	Recruits (1000s)	Std. Dev.
1975	-	-	278.21	37.30	-	-
1976	298.89	36.99	278.18	37.30	-	-
1977	298.88	36.99	278.16	37.30	-	-
1978	298.84	36.99	278.09	37.30	-	-
1979	298.82	36.99	277.85	37.30	-	-
1980	298.82	36.99	277.76	37.30	-	-
1981	298.82	36.99	277.66	37.30	-	-
1982	298.82	36.99	277.57	37.30	-	-
1983	298.82	36.99	277.50	37.30	1060.73	125.68
1984	298.81	36.99	277.45	37.30	1060.34	125.86
1985	298.79	36.99	277.41	37.30	1061.14	125.55
1986	298.78	36.99	277.42	37.30	1063.40	124.78
1987	298.77	36.99	277.47	37.30	1068.80	122.93
1988	298.73	36.99	277.42	37.30	1075.45	120.89
1989	298.72	36.99	277.29	37.30	1079.47	119.85
1990	298.73	36.99	277.15	37.31	1079.93	119.82
1991	298.67	36.99	276.90	37.32	1080.45	119.71
1992	298.52	37.00	276.84	37.32	1078.89	120.11
1993	298.46	37.00	276.56	37.34	1080.40	119.64
1994	298.33	37.00	276.34	37.36	1081.83	119.22
1995	298.26	37.00	276.33	37.36	1082.74	118.96
1996	298.23	37.00	276.30	37.36	1081.61	119.21
1997	298.19	37.00	276.09	37.38	1080.11	119.55
1998	298.11	37.01	275.83	37.41	1079.24	119.73
1999	298.01	37.01	275.82	37.42	1078.15	119.97
2000	297.84	37.02	275.80	37.42	1075.42	120.62
2001	297.42	37.04	275.80	37.42	1073.05	121.18
2002	296.75	37.10	275.65	37.44	1072.54	121.24
2003	296.05	37.19	275.23	37.50	1074.36	120.69
2004	295.52	37.26	274.57	37.61	1074.80	120.60
2005	294.77	37.39	273.98	37.74	1072.59	121.31
2006	294.13	37.52	273.51	37.86	1070.34	122.05
2007	293.04	37.77	272.84	38.05	1074.75	120.69
2008	291.36	38.26	272.45	38.18	1078.92	119.59
2009	290.23	38.64	272.48	38.18	1080.64	119.22
2010	289.19	39.02	272.50	38.18	1081.93	118.96
2011	288.69	39.23	272.55	38.19	1083.58	118.62
2012	289.49	38.94	273.18	38.02	1085.21	118.29
2013	290.91	38.45	273.71	37.89	1084.49	118.42
2014	292.64	37.94	274.09	37.81	1085.63	118.18
2015	294.19	37.57	274.26	37.77	1084.91	118.30
2016	295.14	37.38	274.13	37.80	1083.26	118.61

Table 5. Spawning Output (1000s of eggs) and standard deviation from Stock Synthesis RW models. Note: Unlike other Stock Synthesis estimates that are typically computed midyear, Stock Synthesis estimates of spawning output are "beginning of the year". Therefore, the 2017 estimate is provided in this table.

	St. Croix		St. Thomas/St. John		Puerto Rico	
YEAR	Spawning Output (1000s eggs)	Std. Dev.	Spawning Output (1000s eggs)	Std. Dev.	Spawning Output (1000s eggs)	Std. Dev.
1975	-	-	9.79E+07	1.31E+07	-	-
1976	1.05E+08	1.30E+07	9.72E+07	1.31E+07	-	-
1977	1.05E+08	1.30E+07	9.65E+07	1.31E+07	-	-
1978	1.04E+08	1.30E+07	9.47E+07	1.31E+07	-	-
1979	1.03E+08	1.30E+07	8.90E+07	1.30E+07	-	-
1980	1.03E+08	1.30E+07	8.71E+07	1.29E+07	-	-
1981	1.03E+08	1.30E+07	8.50E+07	1.29E+07	-	-
1982	1.03E+08	1.30E+07	8.32E+07	1.28E+07	-	-
1983	1.03E+08	1.30E+07	8.19E+07	1.28E+07	9.64E+07	3.47E+07
1984	1.03E+08	1.30E+07	8.10E+07	1.27E+07	9.57E+07	3.46E+07
1985	1.03E+08	1.30E+07	8.04E+07	1.27E+07	9.71E+07	3.48E+07
1986	1.03E+08	1.30E+07	8.05E+07	1.27E+07	1.01E+08	3.53E+07
1987	1.02E+08	1.30E+07	8.13E+07	1.27E+07	1.13E+08	3.64E+07
1988	1.01E+08	1.30E+07	8.04E+07	1.27E+07	1.32E+08	3.77E+07
1989	1.01E+08	1.30E+07	7.82E+07	1.27E+07	1.46E+08	3.86E+07
1990	1.01E+08	1.30E+07	7.58E+07	1.26E+07	1.48E+08	3.90E+07
1991	9.97E+07	1.30E+07	7.20E+07	1.25E+07	1.50E+08	3.92E+07
1992	9.61E+07	1.30E+07	7.11E+07	1.25E+07	1.44E+08	3.89E+07
1993	9.49E+07	1.30E+07	6.74E+07	1.24E+07	1.50E+08	3.88E+07
1994	9.21E+07	1.30E+07	6.46E+07	1.24E+07	1.56E+08	3.88E+07
1995	9.06E+07	1.29E+07	6.45E+07	1.24E+07	1.60E+08	3.88E+07
1996	9.00E+07	1.29E+07	6.41E+07	1.23E+07	1.55E+08	3.85E+07
1997	8.93E+07	1.29E+07	6.18E+07	1.23E+07	1.49E+08	3.81E+07
1998	8.79E+07	1.29E+07	5.92E+07	1.22E+07	1.45E+08	3.78E+07
1999	8.59E+07	1.29E+07	5.90E+07	1.23E+07	1.41E+08	3.75E+07
2000	8.30E+07	1.29E+07	5.89E+07	1.23E+07	1.32E+08	3.67E+07
2001	7.65E+07	1.28E+07	5.88E+07	1.23E+07	1.24E+08	3.59E+07
2002	6.80E+07	1.27E+07	5.74E+07	1.23E+07	1.23E+08	3.56E+07
2003	6.09E+07	1.25E+07	5.37E+07	1.22E+07	1.28E+08	3.58E+07
2004	5.63E+07	1.24E+07	4.87E+07	1.20E+07	1.30E+08	3.60E+07
2005	5.10E+07	1.22E+07	4.50E+07	1.19E+07	1.23E+08	3.58E+07
2006	4.72E+07	1.20E+07	4.24E+07	1.19E+07	1.17E+08	3.56E+07
2007	4.18E+07	1.18E+07	3.92E+07	1.18E+07	1.30E+08	3.62E+07
2008	3.55E+07	1.14E+07	3.76E+07	1.18E+07	1.44E+08	3.69E+07
2009	3.22E+07	1.12E+07	3.77E+07	1.19E+07	1.51E+08	3.74E+07
2010	2.96E+07	1.10E+07	3.77E+07	1.19E+07	1.57E+08	3.78E+07
2011	2.85E+07	1.09E+07	3.79E+07	1.20E+07	1.64E+08	3.81E+07
2012	3.03E+07	1.11E+07	4.08E+07	1.22E+07	1.73E+08	3.84E+07
2013	3.41E+07	1.15E+07	4.35E+07	1.24E+07	1.69E+08	3.82E+07
2014	4.01E+07	1.19E+07	4.57E+07	1.25E+07	1.75E+08	3.83E+07
2015	4.75E+07	1.24E+07	4.68E+07	1.26E+07	1.71E+08	3.81E+07
2016	5.36E+07	1.27E+07	4.59E+07	1.26E+07	1.63E+08	3.77E+07
2017	6.00E+07	1.29E+07	4.40E+07	1.25E+07	1.52E+08	3.71E+07

Table 6. Total biomass (mt) from Stock Synthesis RW models.

	St. Croix	St. Thomas/St. John	Puerto Rico
YEAR	Total Biomass (mt)	Total Biomass (mt)	Total Biomass (mt)
1975	-	542.002	-
1976	582.283	539.137	-
1977	581.316	536.745	-
1978	577.878	529.444	-
1979	576.299	506.993	-
1980	575.896	500.513	-
1981	576.459	492.927	-
1982	576.676	486.21	-
1983	576.626	481.58	908.687
1984	575.8	478.283	902.18
1985	573.734	475.879	904.146
1986	573.341	477.016	923.133
1987	572.429	480.704	984.069
1988	568.641	476.838	1075.79
1989	567.598	467.75	1138.82
1990	569.376	458.5	1142.27
1991	563.579	443.117	1155.09
1992	550.896	440.123	1125.63
1993	547.063	424.962	1161.7
1994	537.343	413.856	1190.46
1995	532.5	413.947	1207.72
1996	530.881	412.184	1180.06
1997	528.266	402.318	1151.72
1998	523.199	391.184	1138.84
1999	516.075	390.961	1119.86
2000	505.628	390.277	1094.11
2001	481.644	389.737	1064.19
2002	449.626	383.712	1056.82
2003	423.003	367.706	1079.84
2004	405.64	346.266	1082.69
2005	383.788	328.04	1050.64
2006	367.825	316.102	1023.15
2007	344.274	301.294	1083.41
2008	315.706	296.664	1145.56
2009	300.03	297.836	1173.42
2010	286.609	297.284	1199.05
2011	279.84	297.538	1234.86
2012	287.034	310.493	1272.56
2013	303.662	322.279	1255.96
2014	330.561	331.79	1285.86
2015	362.78	336.309	1268.55
2016	388.226	332.702	1233.26

Table 7. Fishing mortality (% of the total stock biomass removed by fishing) and standard deviation from Stock Synthesis RW models.

	St. Croix		St. Thomas/St. John		Puerto Rico	
YEAR	F	Std. Dev.	F	Std. Dev.	F	Std. Dev.
1975	-	-	0.01	0.00	-	-
1976	0.00	0.00	0.01	0.00	-	-
1977	0.01	0.00	0.02	0.00	-	-
1978	0.00	0.00	0.05	0.01	-	-
1979	0.00	0.00	0.03	0.00	-	-
1980	0.00	0.00	0.03	0.00	-	-
1981	0.00	0.00	0.04	0.01	-	-
1982	0.00	0.00	0.03	0.01	-	-
1983	0.00	0.00	0.03	0.01	0.22	0.06
1984	0.01	0.00	0.03	0.01	0.21	0.05
1985	0.00	0.00	0.03	0.00	0.19	0.05
1986	0.00	0.00	0.02	0.00	0.14	0.03
1987	0.01	0.00	0.04	0.01	0.09	0.02
1988	0.01	0.00	0.05	0.01	0.11	0.02
1989	0.00	0.00	0.06	0.01	0.15	0.03
1990	0.02	0.00	0.08	0.01	0.13	0.03
1991	0.03	0.00	0.06	0.01	0.16	0.03
1992	0.02	0.00	0.09	0.01	0.11	0.02
1993	0.03	0.00	0.09	0.02	0.11	0.02
1994	0.03	0.00	0.07	0.01	0.11	0.02
1995	0.02	0.00	0.07	0.01	0.15	0.03
1996	0.02	0.00	0.10	0.02	0.15	0.03
1997	0.03	0.00	0.11	0.02	0.14	0.03
1998	0.04	0.01	0.09	0.02	0.15	0.03
1999	0.05	0.01	0.09	0.02	0.17	0.03
2000	0.08	0.01	0.09	0.02	0.19	0.04
2001	0.11	0.02	0.10	0.02	0.18	0.04
2002	0.12	0.02	0.14	0.03	0.15	0.03
2003	0.11	0.02	0.17	0.03	0.17	0.03
2004	0.14	0.02	0.18	0.04	0.20	0.04
2005	0.14	0.03	0.17	0.04	0.20	0.04
2006	0.18	0.04	0.20	0.05	0.12	0.03
2007	0.22	0.05	0.18	0.04	0.11	0.02
2008	0.21	0.05	0.17	0.04	0.13	0.03
2009	0.23	0.05	0.18	0.04	0.13	0.02
2010	0.22	0.06	0.18	0.04	0.11	0.02
2011	0.18	0.05	0.13	0.03	0.10	0.02
2012	0.14	0.04	0.12	0.03	0.14	0.02
2013	0.09	0.02	0.12	0.03	0.10	0.02
2014	0.05	0.01	0.13	0.03	0.13	0.02
2015	0.06	0.01	0.15	0.03	0.15	0.03
2016	0.04	0.01	0.17	0.04	0.16	0.03

Table 8. St. Croix: Estimated spawning output and fishing mortality relative to various reference levels (i.e. unfished, SPR30%) and management thresholds. The provisional minimum stock size threshold (MSST) was assumed to be 75% of $SSB_{SPR30\%}$. The provisional maximum fishing mortality threshold was assumed to be equal to $F_{SPR30\%}$.

YEAR	SSB	S/S0	S/S_SPR30	S/MSST	F	F/FSPR30	F/MFMT
1976	1.05E+08	1.00	3.44	4.57	0.00	0.01	0.01
1977	1.05E+08	1.00	3.43	4.56	0.01	0.03	0.03
1978	1.04E+08	0.99	3.40	4.52	0.00	0.02	0.02
1979	1.03E+08	0.99	3.38	4.50	0.00	0.01	0.01
1980	1.03E+08	0.98	3.38	4.49	0.00	0.01	0.01
1981	1.03E+08	0.98	3.38	4.50	0.00	0.01	0.01
1982	1.03E+08	0.99	3.38	4.50	0.00	0.01	0.01
1983	1.03E+08	0.99	3.38	4.50	0.00	0.02	0.02
1984	1.03E+08	0.98	3.37	4.49	0.01	0.03	0.03
1985	1.03E+08	0.98	3.36	4.46	0.00	0.02	0.02
1986	1.03E+08	0.98	3.35	4.46	0.00	0.02	0.02
1987	1.02E+08	0.97	3.34	4.45	0.01	0.05	0.05
1988	1.01E+08	0.96	3.31	4.40	0.01	0.03	0.03
1989	1.01E+08	0.96	3.29	4.38	0.00	0.01	0.01
1990	1.01E+08	0.96	3.31	4.40	0.02	0.08	0.08
1991	9.97E+07	0.95	3.26	4.33	0.03	0.15	0.15
1992	9.61E+07	0.92	3.14	4.18	0.02	0.09	0.09
1993	9.49E+07	0.90	3.10	4.12	0.03	0.15	0.15
1994	9.21E+07	0.88	3.01	4.01	0.03	0.12	0.12
1995	9.06E+07	0.86	2.96	3.94	0.02	0.11	0.11
1996	9.00E+07	0.86	2.94	3.91	0.02	0.12	0.12
1997	8.93E+07	0.85	2.92	3.88	0.03	0.15	0.15
1998	8.79E+07	0.84	2.87	3.82	0.04	0.18	0.18
1999	8.59E+07	0.82	2.81	3.73	0.05	0.23	0.23
2000	8.30E+07	0.79	2.71	3.61	0.08	0.39	0.39
2001	7.65E+07	0.73	2.50	3.33	0.11	0.54	0.54
2002	6.80E+07	0.65	2.22	2.96	0.12	0.58	0.58
2003	6.09E+07	0.58	1.99	2.65	0.11	0.56	0.56
2004	5.63E+07	0.54	1.84	2.45	0.14	0.69	0.69
2005	5.10E+07	0.49	1.67	2.22	0.14	0.71	0.71
2006	4.72E+07	0.45	1.54	2.05	0.18	0.89	0.89
2007	4.18E+07	0.40	1.37	1.82	0.22	1.09	1.09
2008	3.55E+07	0.34	1.16	1.54	0.21	1.05	1.05
2009	3.22E+07	0.31	1.05	1.40	0.23	1.12	1.12
2010	2.96E+07	0.28	0.97	1.29	0.22	1.09	1.09
2011	2.85E+07	0.27	0.93	1.24	0.18	0.88	0.88
2012	3.03E+07	0.29	0.99	1.32	0.14	0.68	0.68
2013	3.41E+07	0.32	1.11	1.48	0.09	0.44	0.44
2014	4.01E+07	0.38	1.31	1.74	0.05	0.27	0.27
2015	4.75E+07	0.45	1.55	2.07	0.06	0.28	0.28
2016	5.36E+07	0.51	1.75	2.33	0.04	0.18	0.18
2017	6.00E+07	0.57	1.96	2.61	-	-	-

Table 9. St. Thomas/St. John: Estimated spawning output and fishing mortality relative to various reference levels (i.e. unfished, SPR30%) and management thresholds. The provisional minimum stock size threshold (MSST) was assumed to be 75% of $SSB_{SPR30\%}$. The provisional maximum fishing mortality threshold was assumed to be equal to $F_{SPR30\%}$.

YEAR	SSB	S/S0	S/S_SPR30	S/MSST	F	F/FSPR30	F/MFMT
1975	9.79E+07	1.00	3.45	4.60	0.01	0.02	0.02
1976	9.72E+07	0.99	3.42	4.56	0.01	0.02	0.02
1977	9.65E+07	0.99	3.40	4.53	0.02	0.07	0.07
1978	9.47E+07	0.97	3.33	4.44	0.05	0.21	0.21
1979	8.90E+07	0.91	3.13	4.18	0.03	0.11	0.11
1980	8.71E+07	0.89	3.07	4.09	0.03	0.13	0.13
1981	8.50E+07	0.87	2.99	3.99	0.04	0.14	0.14
1982	8.32E+07	0.85	2.93	3.91	0.03	0.14	0.14
1983	8.19E+07	0.84	2.89	3.85	0.03	0.14	0.14
1984	8.10E+07	0.83	2.85	3.80	0.03	0.14	0.14
1985	8.04E+07	0.82	2.83	3.77	0.03	0.11	0.11
1986	8.05E+07	0.82	2.83	3.78	0.02	0.09	0.09
1987	8.13E+07	0.83	2.86	3.82	0.04	0.16	0.16
1988	8.04E+07	0.82	2.83	3.78	0.05	0.21	0.21
1989	7.82E+07	0.80	2.75	3.67	0.06	0.23	0.23
1990	7.58E+07	0.77	2.67	3.56	0.08	0.32	0.32
1991	7.20E+07	0.74	2.53	3.38	0.06	0.23	0.23
1992	7.11E+07	0.73	2.50	3.34	0.09	0.37	0.37
1993	6.74E+07	0.69	2.37	3.16	0.09	0.37	0.37
1994	6.46E+07	0.66	2.28	3.03	0.07	0.28	0.28
1995	6.45E+07	0.66	2.27	3.03	0.07	0.30	0.30
1996	6.41E+07	0.65	2.26	3.01	0.10	0.40	0.40
1997	6.18E+07	0.63	2.18	2.90	0.11	0.44	0.44
1998	5.92E+07	0.60	2.08	2.78	0.09	0.35	0.35
1999	5.90E+07	0.60	2.08	2.77	0.09	0.36	0.36
2000	5.89E+07	0.60	2.07	2.76	0.09	0.36	0.36
2001	5.88E+07	0.60	2.07	2.76	0.10	0.43	0.43
2002	5.74E+07	0.59	2.02	2.70	0.14	0.56	0.56
2003	5.37E+07	0.55	1.89	2.52	0.17	0.69	0.69
2004	4.87E+07	0.50	1.72	2.29	0.18	0.72	0.72
2005	4.50E+07	0.46	1.59	2.11	0.17	0.71	0.71
2006	4.24E+07	0.43	1.49	1.99	0.20	0.80	0.80
2007	3.92E+07	0.40	1.38	1.84	0.18	0.74	0.74
2008	3.76E+07	0.38	1.32	1.76	0.17	0.69	0.69
2009	3.77E+07	0.38	1.33	1.77	0.18	0.72	0.72
2010	3.77E+07	0.39	1.33	1.77	0.18	0.72	0.72
2011	3.79E+07	0.39	1.34	1.78	0.13	0.53	0.53
2012	4.08E+07	0.42	1.44	1.92	0.12	0.50	0.50
2013	4.35E+07	0.44	1.53	2.04	0.12	0.49	0.49
2014	4.57E+07	0.47	1.61	2.15	0.13	0.52	0.52
2015	4.68E+07	0.48	1.65	2.20	0.15	0.61	0.61
2016	4.59E+07	0.47	1.62	2.16	0.17	0.68	0.68
2017	4.40E+07	0.45	1.55	2.07	-	-	-

Table 10. Puerto Rico: Estimated spawning output and fishing mortality relative to various reference levels (i.e. unfished, SPR30%) and management thresholds. The provisional minimum stock size threshold (MSST) was assumed to be 75% of $SSB_{SPR30\%}$. The provisional maximum fishing mortality threshold was assumed to be equal to $F_{SPR30\%}$.

YEAR	SSB	S/S0	S/S_SPR30	S/MSST	F	F/FSPR30	F/MFMT
1975	-	-	-	-	-	-	-
1976	-	-	-	-	-	-	-
1977	-	-	-	-	-	-	-
1978	-	-	-	-	-	-	-
1979	-	-	-	-	-	-	-
1980	-	-	-	-	-	-	-
1981	-	-	-	-	-	-	-
1982	-	-	-	-	-	-	-
1983	9.64E+07	0.25	0.85	1.14	0.22	1.14	1.14
1984	9.57E+07	0.25	0.85	1.13	0.21	1.08	1.08
1985	9.71E+07	0.25	0.86	1.14	0.19	0.96	0.96
1986	1.01E+08	0.26	0.90	1.20	0.14	0.70	0.70
1987	1.13E+08	0.29	1.00	1.33	0.09	0.48	0.48
1988	1.32E+08	0.34	1.17	1.55	0.11	0.54	0.54
1989	1.46E+08	0.38	1.29	1.72	0.15	0.74	0.74
1990	1.48E+08	0.38	1.31	1.74	0.13	0.66	0.66
1991	1.50E+08	0.39	1.33	1.77	0.16	0.83	0.83
1992	1.44E+08	0.37	1.27	1.70	0.11	0.55	0.55
1993	1.50E+08	0.39	1.33	1.77	0.11	0.56	0.56
1994	1.56E+08	0.40	1.38	1.84	0.11	0.58	0.58
1995	1.60E+08	0.41	1.42	1.89	0.15	0.75	0.75
1996	1.55E+08	0.40	1.37	1.83	0.15	0.77	0.77
1997	1.49E+08	0.38	1.32	1.75	0.14	0.73	0.73
1998	1.45E+08	0.37	1.29	1.71	0.15	0.77	0.77
1999	1.41E+08	0.36	1.25	1.66	0.17	0.86	0.86
2000	1.32E+08	0.34	1.16	1.55	0.19	0.95	0.95
2001	1.24E+08	0.32	1.10	1.47	0.18	0.89	0.89
2002	1.23E+08	0.32	1.09	1.45	0.15	0.76	0.76
2003	1.28E+08	0.33	1.14	1.51	0.17	0.85	0.85
2004	1.30E+08	0.33	1.15	1.53	0.20	1.02	1.02
2005	1.23E+08	0.32	1.09	1.45	0.20	1.04	1.04
2006	1.17E+08	0.30	1.03	1.38	0.12	0.62	0.62
2007	1.30E+08	0.33	1.15	1.53	0.11	0.57	0.57
2008	1.44E+08	0.37	1.27	1.70	0.13	0.66	0.66
2009	1.51E+08	0.39	1.34	1.78	0.13	0.64	0.64
2010	1.57E+08	0.40	1.39	1.85	0.11	0.56	0.56
2011	1.64E+08	0.42	1.45	1.94	0.10	0.51	0.51
2012	1.73E+08	0.45	1.53	2.04	0.14	0.70	0.70
2013	1.69E+08	0.44	1.50	1.99	0.10	0.51	0.51
2014	1.75E+08	0.45	1.55	2.07	0.13	0.67	0.67
2015	1.71E+08	0.44	1.52	2.02	0.15	0.76	0.76
2016	1.63E+08	0.42	1.44	1.92	0.16	0.83	0.83
2017	1.52E+08	0.39	1.35	1.80	-	-	-

Table 11. MSRA Table: Provisional status indicators, benchmarks, and related quantities from the Stock Synthesis RW runs for each island platform.

Value	Definition	Units	STX	STT	PR
S_{MSY}	Spawning Output using proxy of SSPR30	1000s eggs	3.06E+07 (3.78E+06)	2.84E+07 (3.81E+06)	1.13E+08 (1.19E+07)
F_{MSY}	Fishing Mortality that produces MSY in equilibrium using proxy of S_{SPR30}	Proportion of Stock removed by fishing	0.203 (0.002)	0.244 (0.005)	0.197 (0.003)
MSST	Min. Stock Size Threshold (75% of SSPR30)	1000s eggs	2.30E+07	2.13E+07	8.48E+07
MFMT	Max. Fishing Mortality Threshold (F_{SPR30})	Proportion of Stock removed by fishing	0.203 (0.002)	0.244 (0.005)	0.197 (0.003)
MSY	Equilibrium Retained Yield at proxy of S_{SPR30}	lbs	1.28E+05 (1.54E+04)	1.34E+05 (1.67E+04)	4.33E+05 (4.15E+04)
S_0	Unfished Stock Output	1000s eggs	1.05E+08 (1.30E+07)	9.79E+07 (1.31E+07)	3.88E+08 (4.10E+07)
$S_{Current}$	Spawning Output at Beginning of 2017	1000s eggs	6.00E+07 (1.29E+07)	4.40E+07 (1.25E+07)	1.52E+08 (3.71E+07)
$S_{Current}/S_0$	Calculated from definitions above	proportion	0.571	0.449	0.392
$S_{Current}/S_{MSY}$	Calculated from definitions above	proportion	1.961	1.549	1.345
$S_{Current}$/MSST	Calculated from definitions above	proportion	2.609	2.066	1.792
$F_{Current}$	Fishing Mortality in 2016	Proportion of Stock removed by fishing	0.037 (0.007)	0.166 (0.038)	0.164 (0.030)
$F_{Current}/F_{MSY}$	Calculated from definitions above	proportion	0.182	0.680	0.832
$F_{Current}$/MFMT	Calculated from definitions above	proportion	0.182	0.680	0.832

Table 12. Provisional RW model OFL projections (and standard deviations). Provisional landings for 2017 and 2018, highlighted by the asterisk, were set to the estimates of landings for 2017 that were available as of August 2018.

a) in metric tons.

	St. Croix	St. Thomas/St. John	Puerto Rico
2017*	11.64	41.64	129.76
2018*	11.64	41.64	129.76
2019	87.01 (11.91)	84.34 (17.12)	233.61 (32.22)
2020	70.49 (9.59)	72.77 (12.74)	212.92 (26.19)
2021	64.39 (9.02)	67.17 (10.94)	205.33 (24.86)
2022	61.92 (8.84)	64.47 (10.18)	202.18 (24.31)

b) in pounds.

	St. Croix	St. Thomas/St. John	Puerto Rico
2017*	25,671	91,801	286,081
2018*	25,671	91,801	286,081
2019	191,834 (26,257)	185,943 (37,743)	515,017 (71,033)
2020	155,412 (21,142)	160,433 (28,087)	469,402 (57,739)
2021	141,965 (19,886)	148,088 (24,119)	452,682 (54,807)
2022	136,512 (19,489)	142,134 (22,443)	445,728 (53,594)

Table 13. Comparison of summary parameters/benchmarks from St. Croix, St. Thomas/St. John, and Puerto Rico base models presented at the Assessment Workshop (AW) with recommended revisions applied for the Review Workshop (RW). R0 is the virgin recruitment in number of lobster (models were fit to log(R0)), FSPR30% is the fishing mortality rate associated with the 30% SPR benchmark, and short-term yield is the average yield from 2017-2021 under FSPR30%.

	St. Croix		**St. Thomas/St. John**		**Puerto Rico**	
	AW	**RW**	**AW**	**RW**	**AW**	**RW**
log(R0)	5.474	5.700	5.228	5.628	6.551	7.006
R0 (no. lobster)	238,367	298,885	186,429	278,208	700,203	1,102,979
FSPR30%	0.246	0.203	0.255	0.244	0.243	0.197
Equil. Yield at FSPR30 (lbs)	141,212	127,741	117,551	133,601	390,727	432,500
Short-term Yield at FSPR30 (lbs)	114,128	107,287	114,420	135,604	365,471	401,848

FIGURES

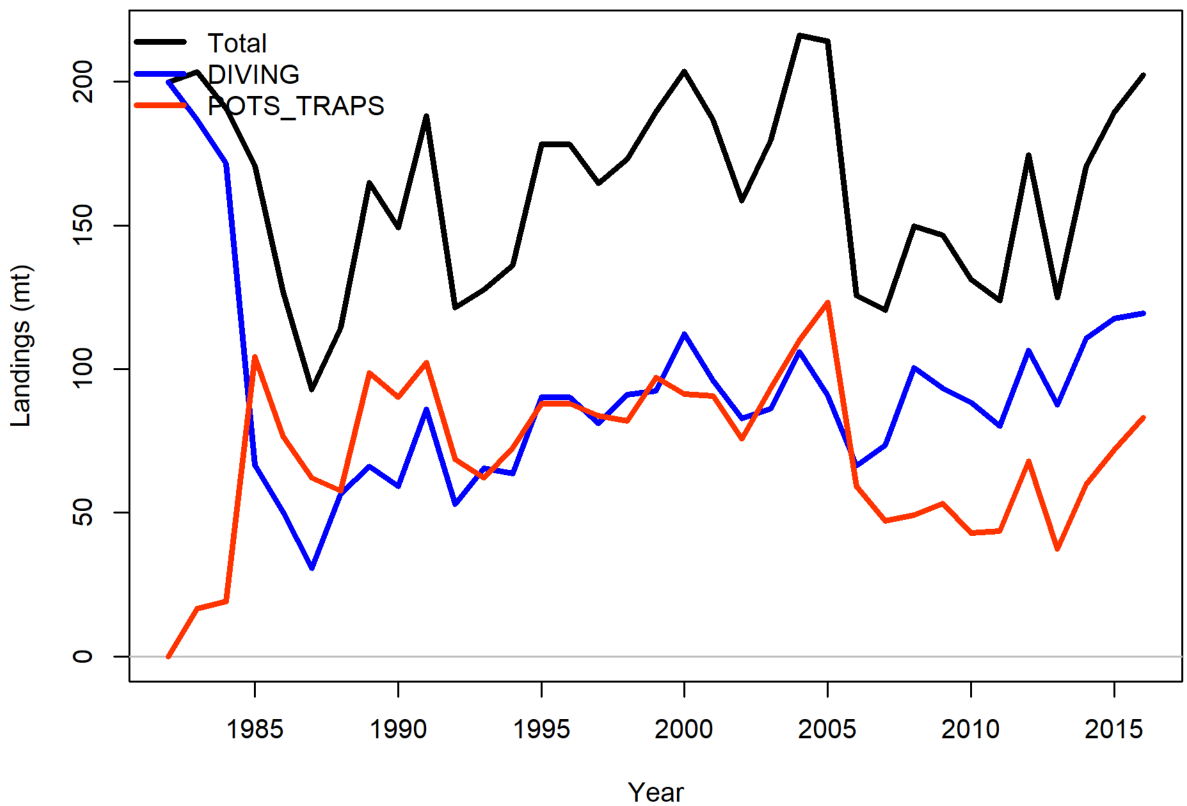


Figure 1. Landings history for Puerto Rico. The original expanded landings values in 2005 were associated with low reporting and large expansion factors and are not plotted here (**Error! Reference source not found.** of Assessment Report). The 2005 expanded landings values plotted here were estimated using the mean of the 2004 and 2006 expansion factors.

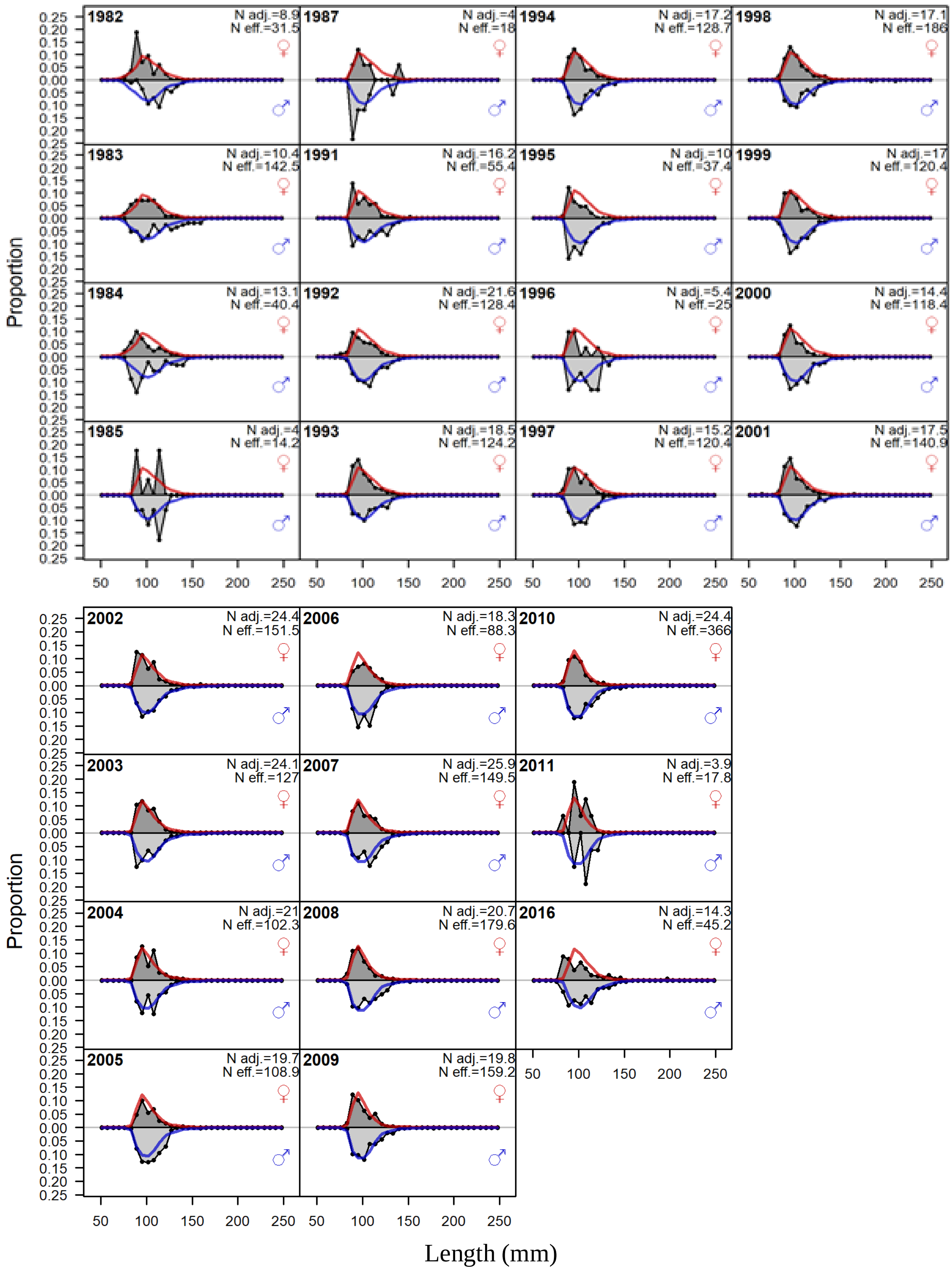


Figure 2. St. Croix, diving fleet. Observed (grey histograms) and expected (lines) length frequency distributions.

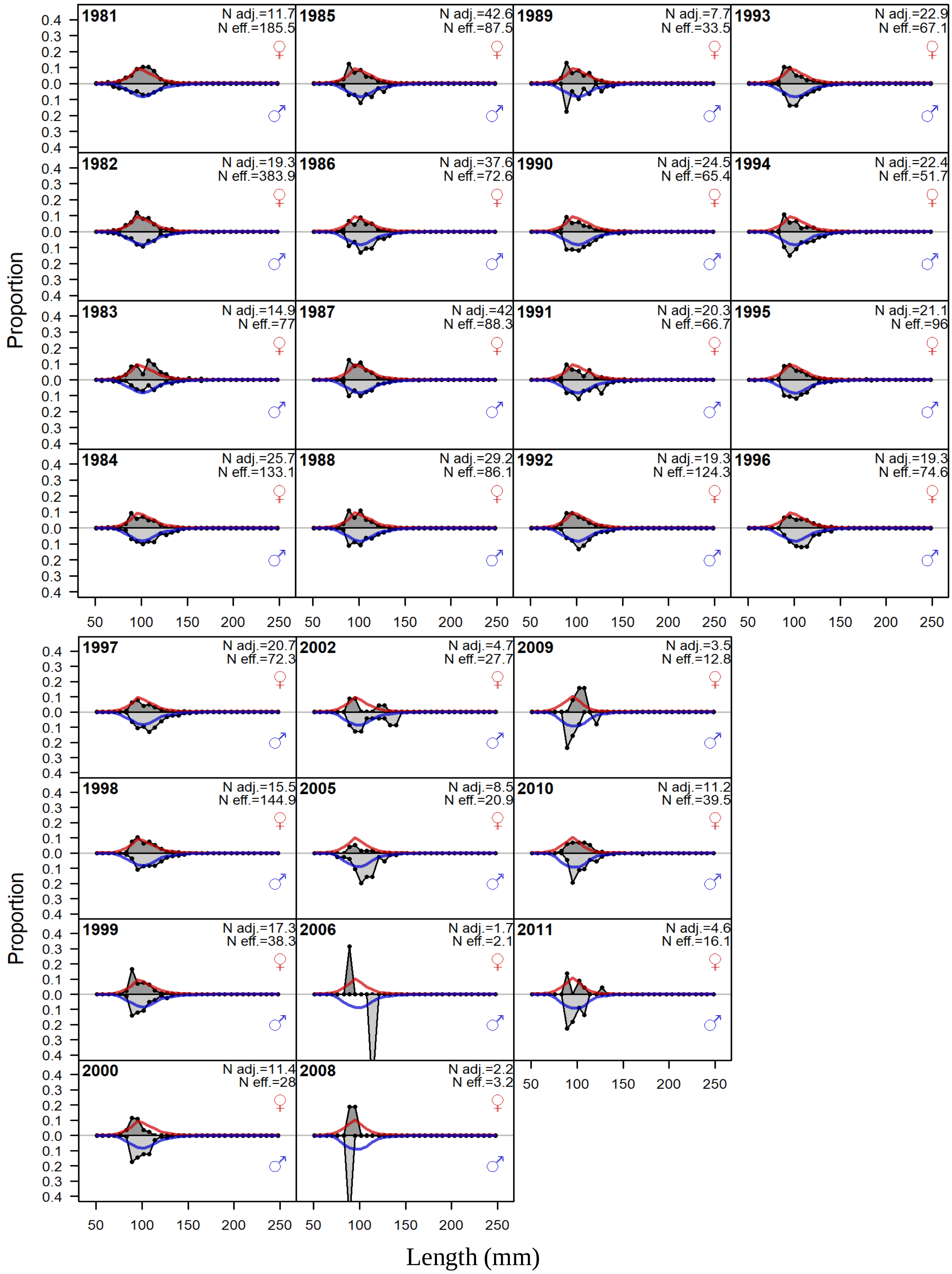


Figure 3. St. Croix, pots and traps fleet. Observed (grey histograms) and expected (lines) length frequency distributions.

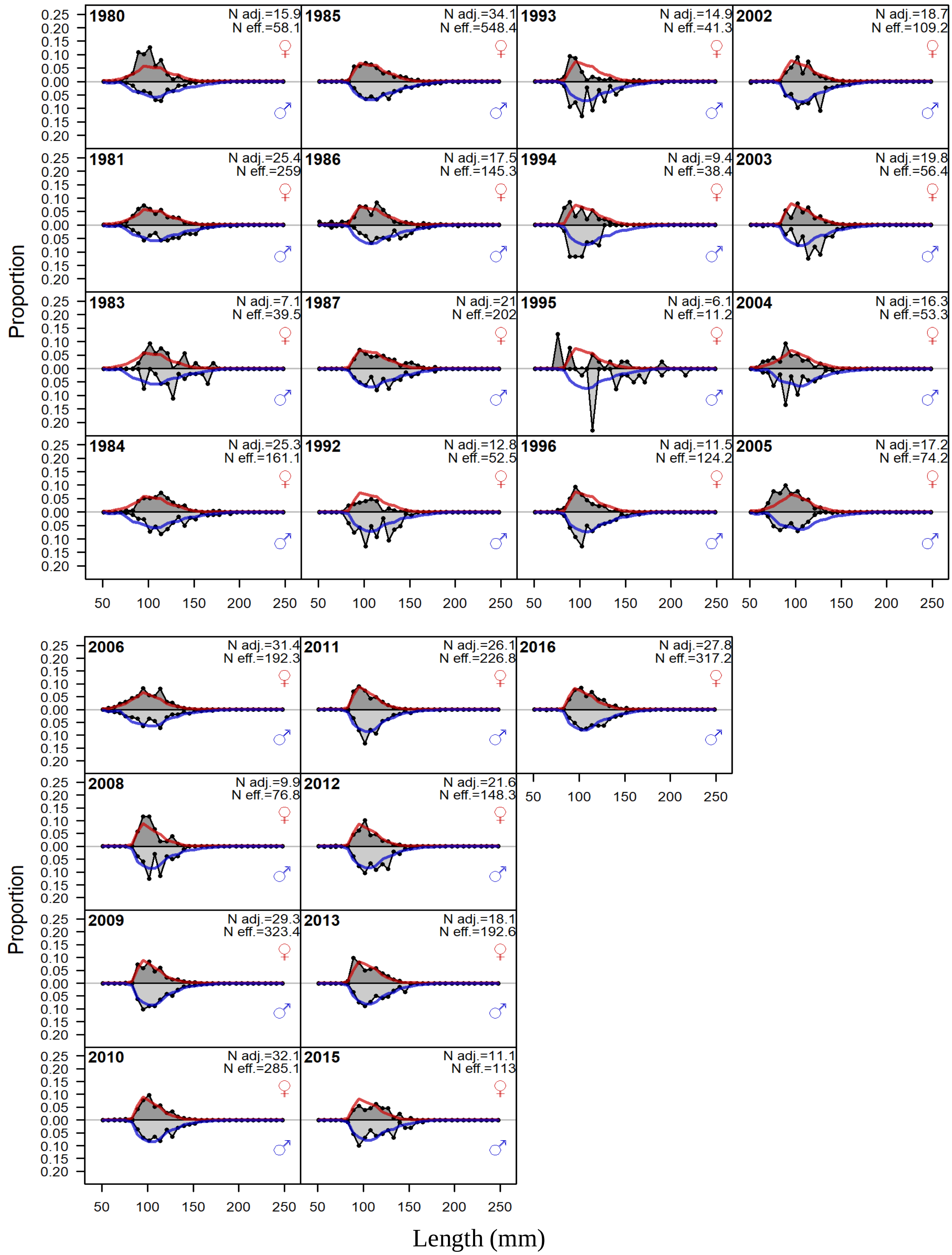


Figure 4. St. Thomas/St. John, pots and traps fleet. Observed (grey histograms) and expected (lines) length frequency distributions.

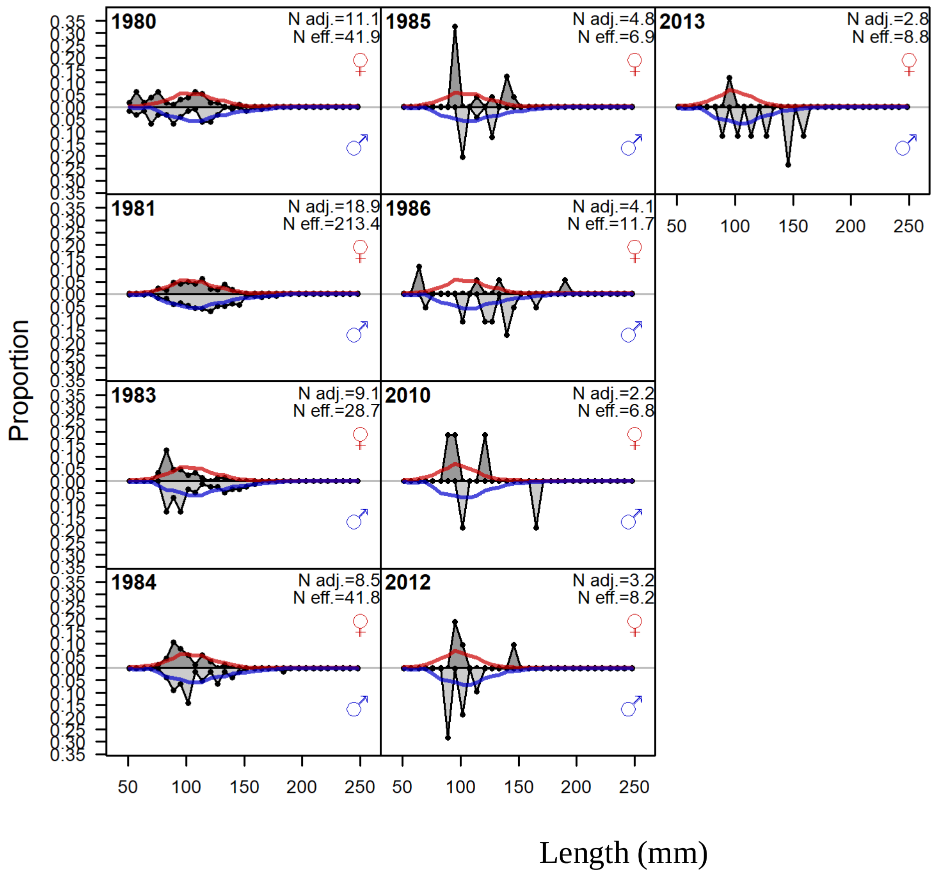


Figure 5. St. Thomas/St. John, diving fleet. Observed (grey histograms) and expected (lines) length frequency distributions.

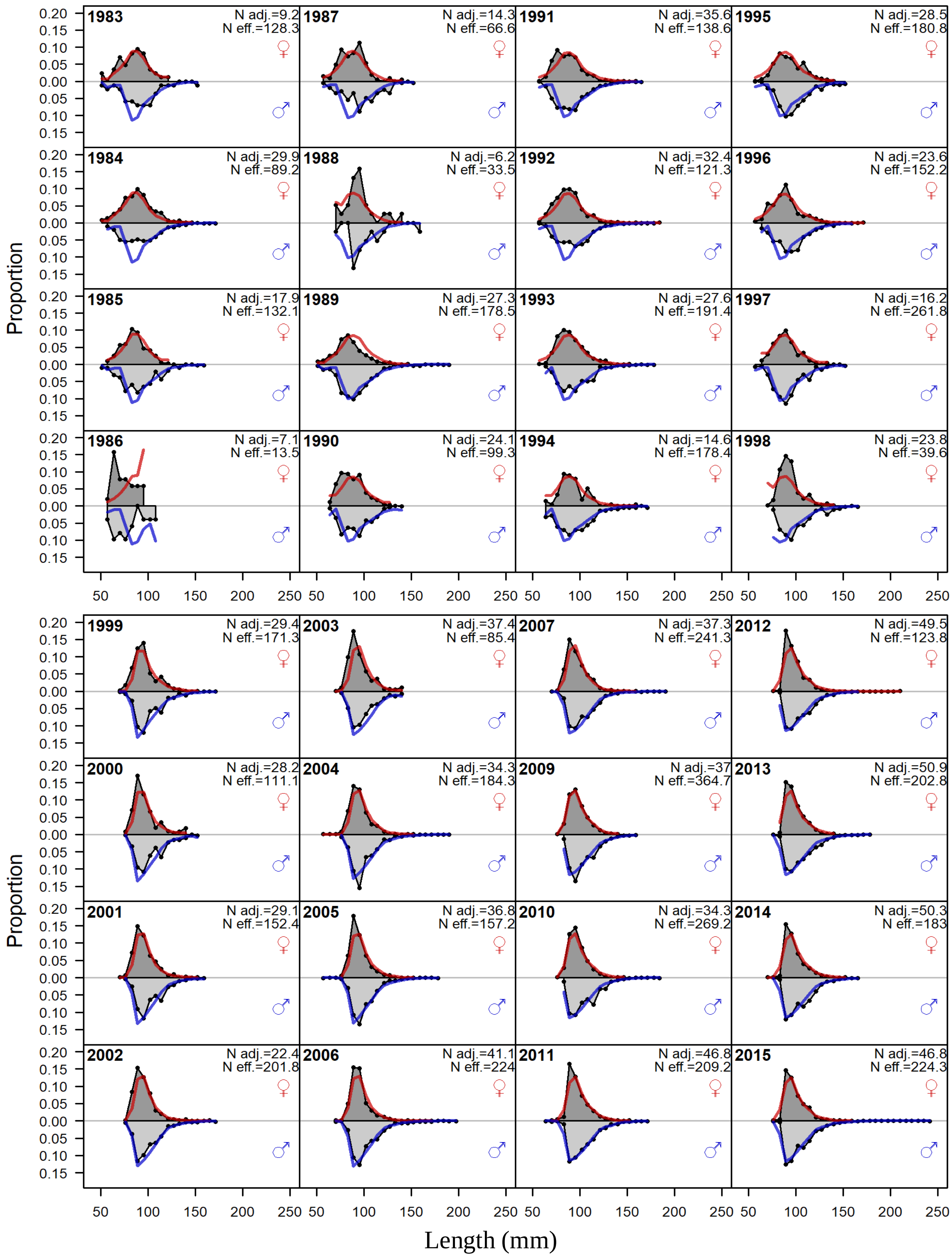
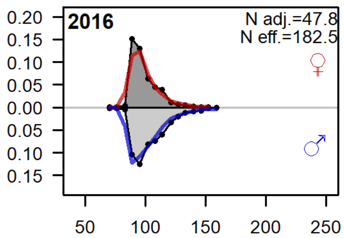


Figure 6. Puerto Rico, diving. Observed (grey histograms) and expected (lines) length frequency distributions.



Length (mm)

Figure 6 (Continued) Puerto Rico, diving. Observed (grey histograms) and expected (lines) length frequency distributions.

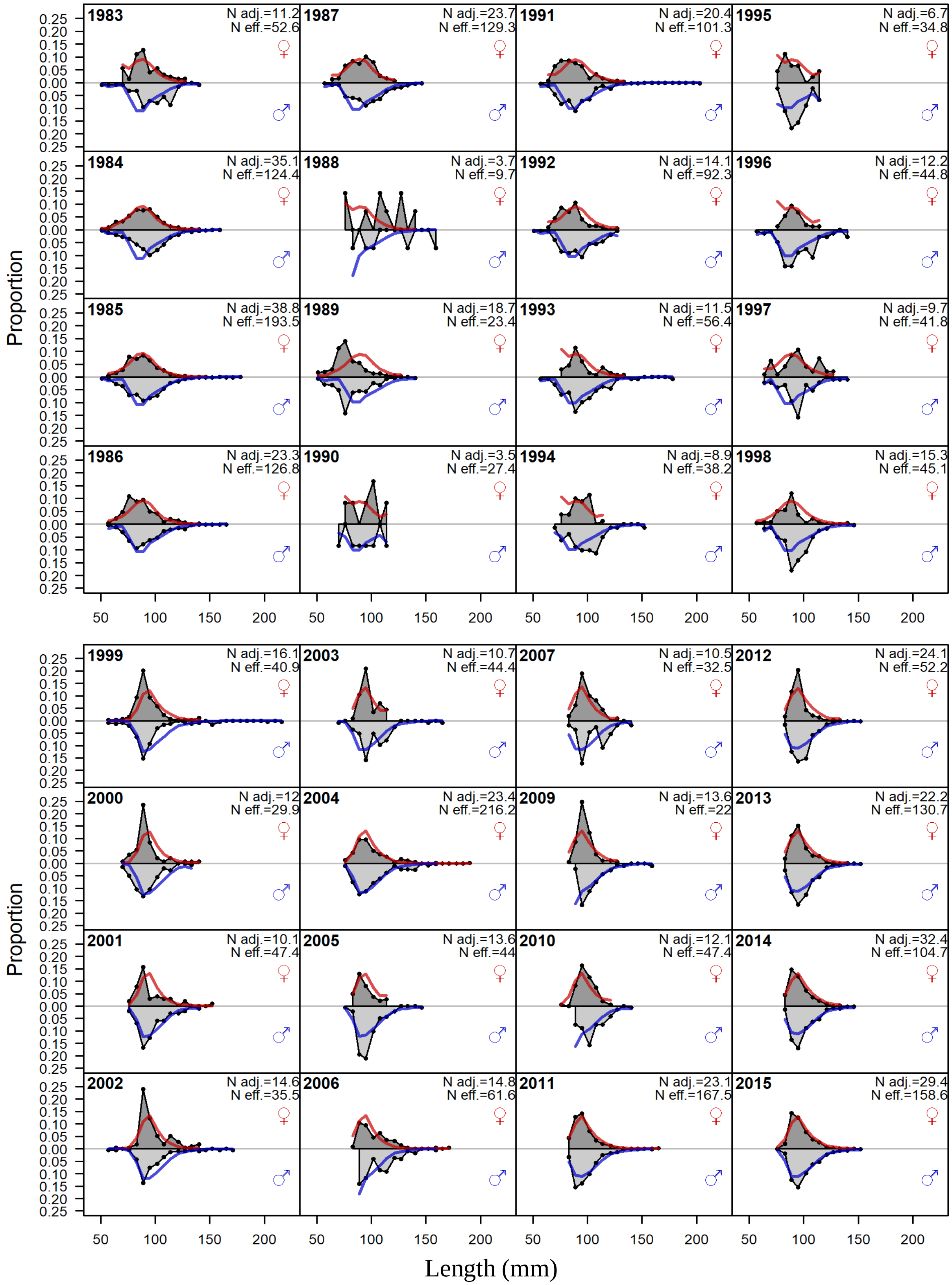


Figure 7. Puerto Rico, pots and traps. Observed (grey histograms) and expected (lines) length frequency distributions.

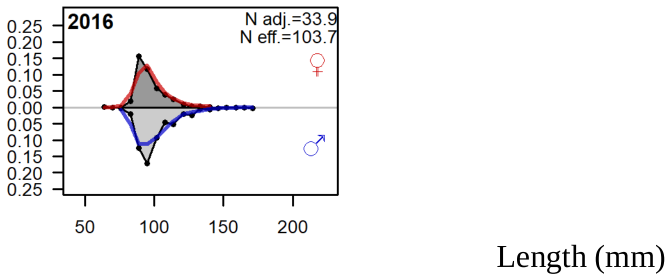


Figure 7 (Continued) Puerto Rico, pots and traps. Observed (grey histograms) and expected (lines) length frequency distributions.

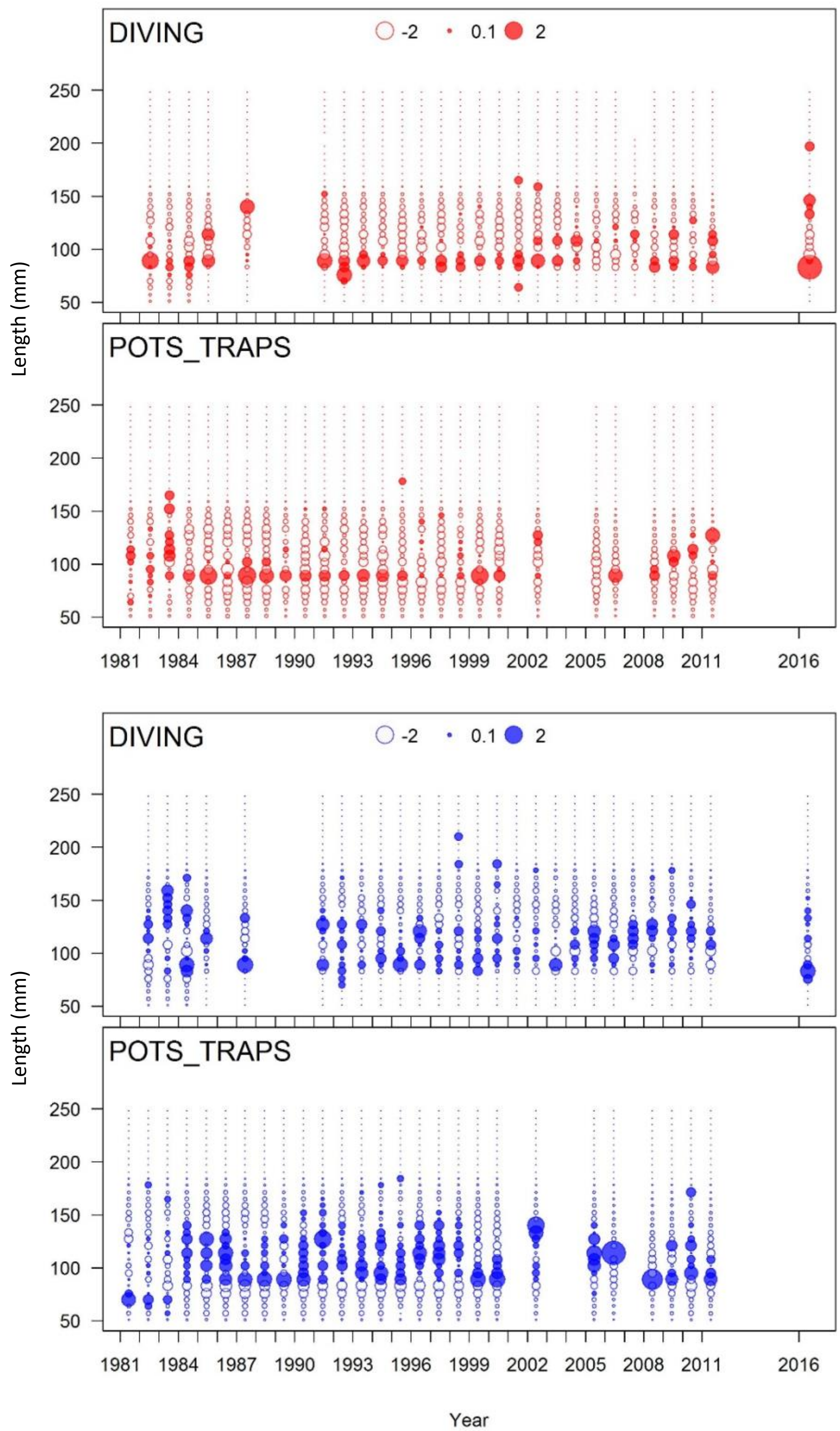
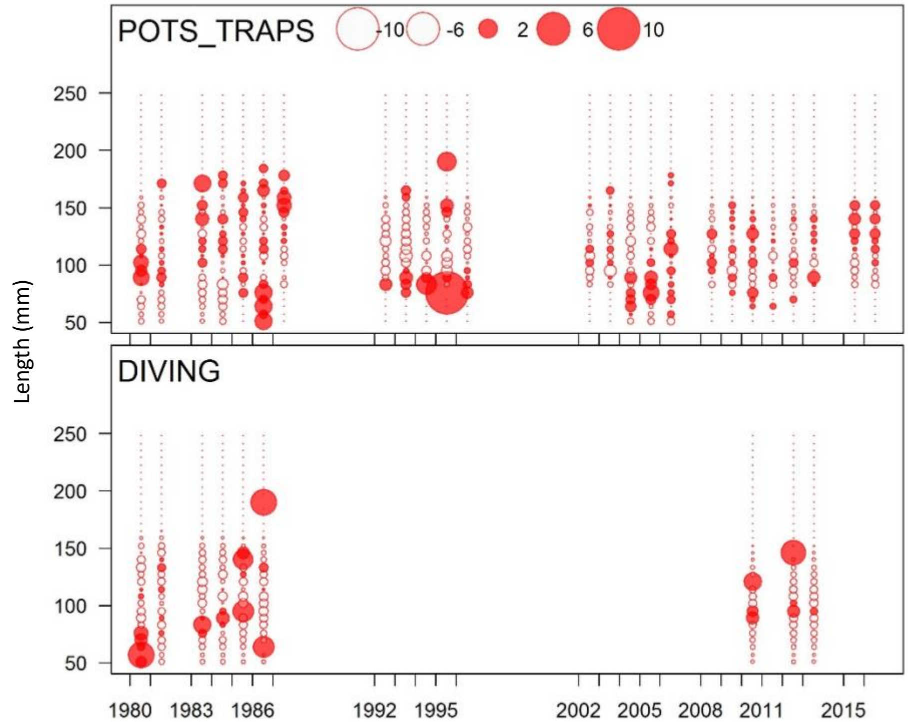


Figure 8. St. Croix, residual diagnostic for fits to length composition data for females (red) and males (blue). Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).



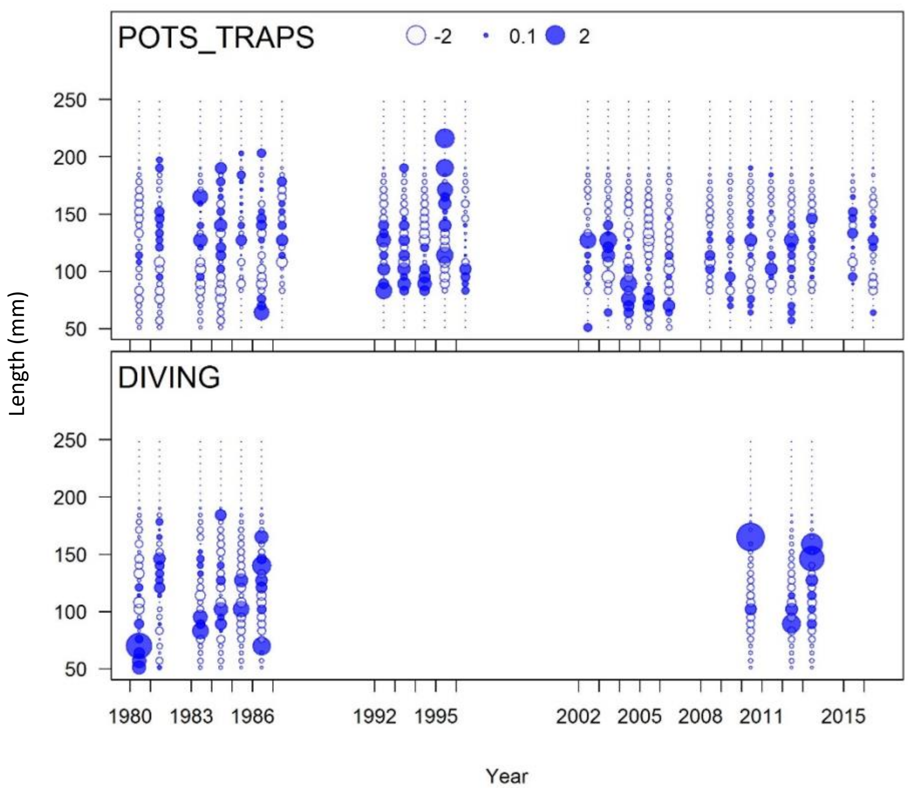


Figure 9. St. Thomas/St. John, residual diagnostic for fits to length composition data for females (red) and males (blue). Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

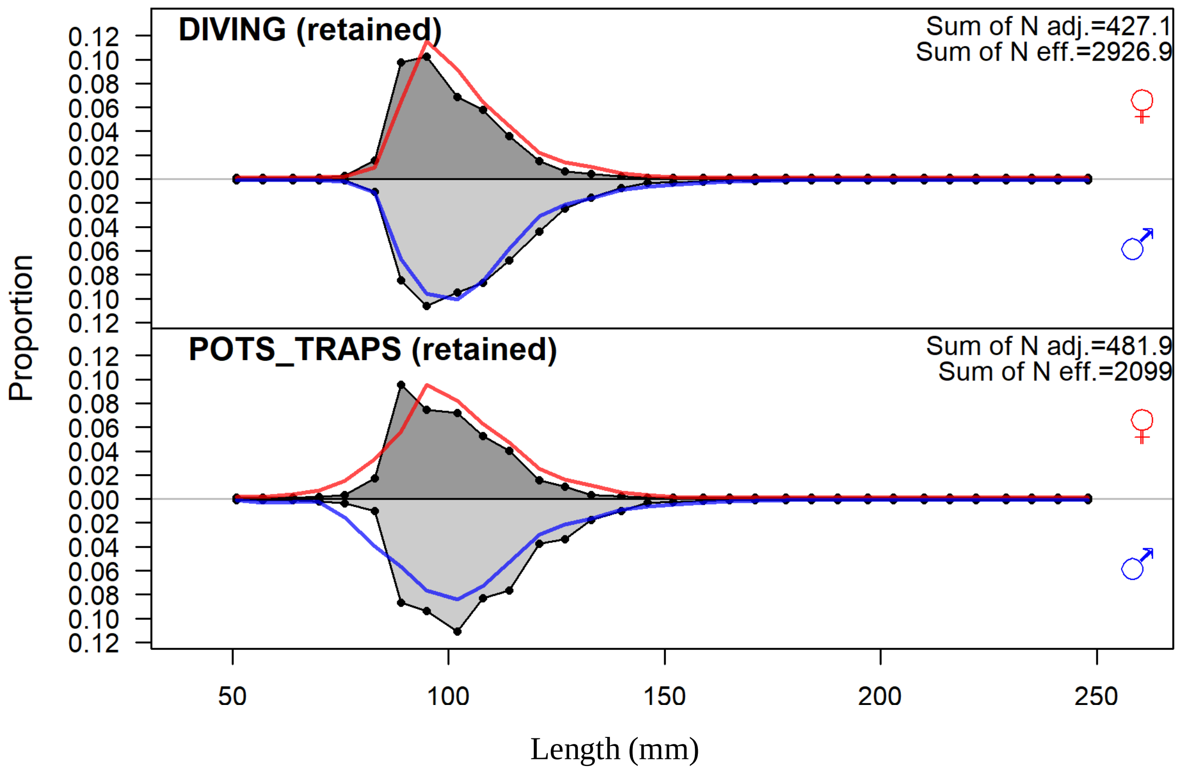


Figure 10. St. Croix, aggregate fit to length composition data. Observed (grey histograms) and expected (lines) length frequency distributions.

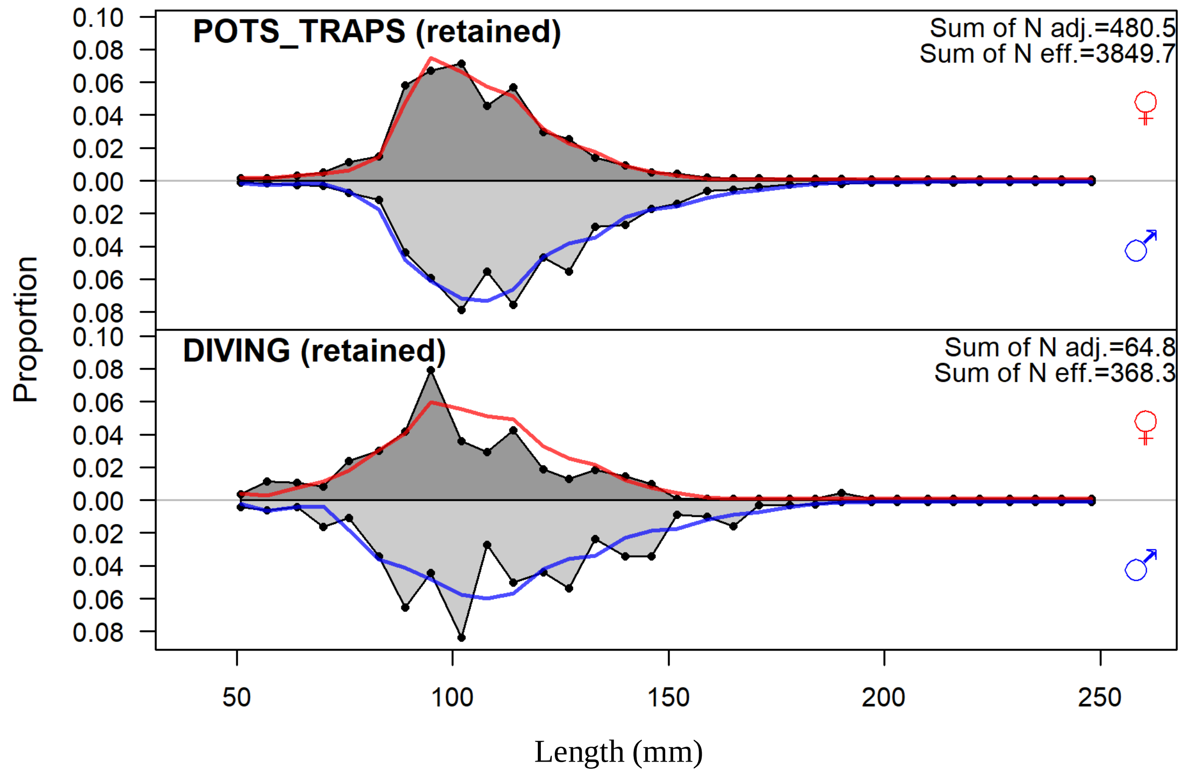


Figure 11. St. Thomas/St. John, aggregate fit to length composition data. Observed (grey histograms) and expected (lines) length frequency distributions.

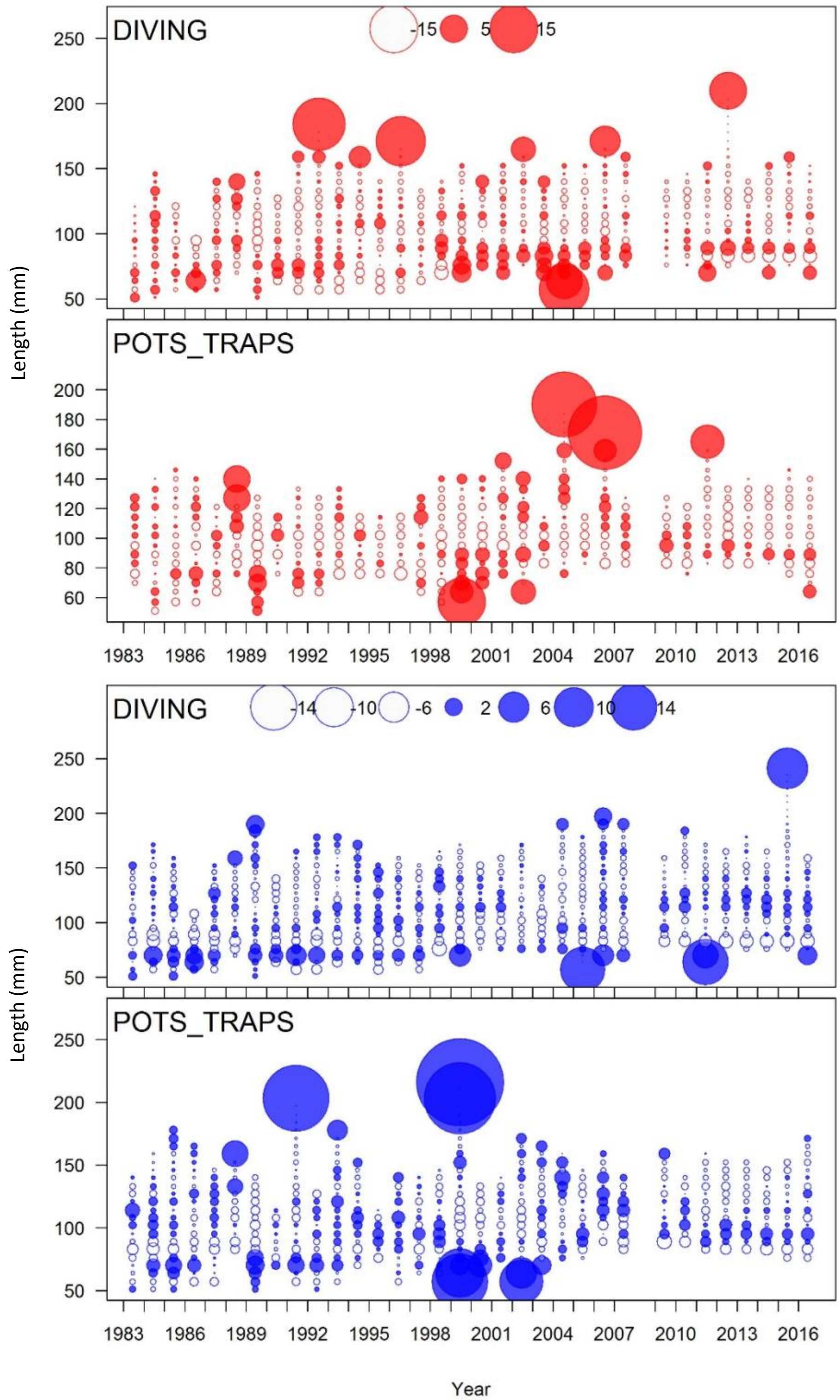


Figure 12. Puerto Rico, residual diagnostic for fits to length composition data for females (red) and males (blue). Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

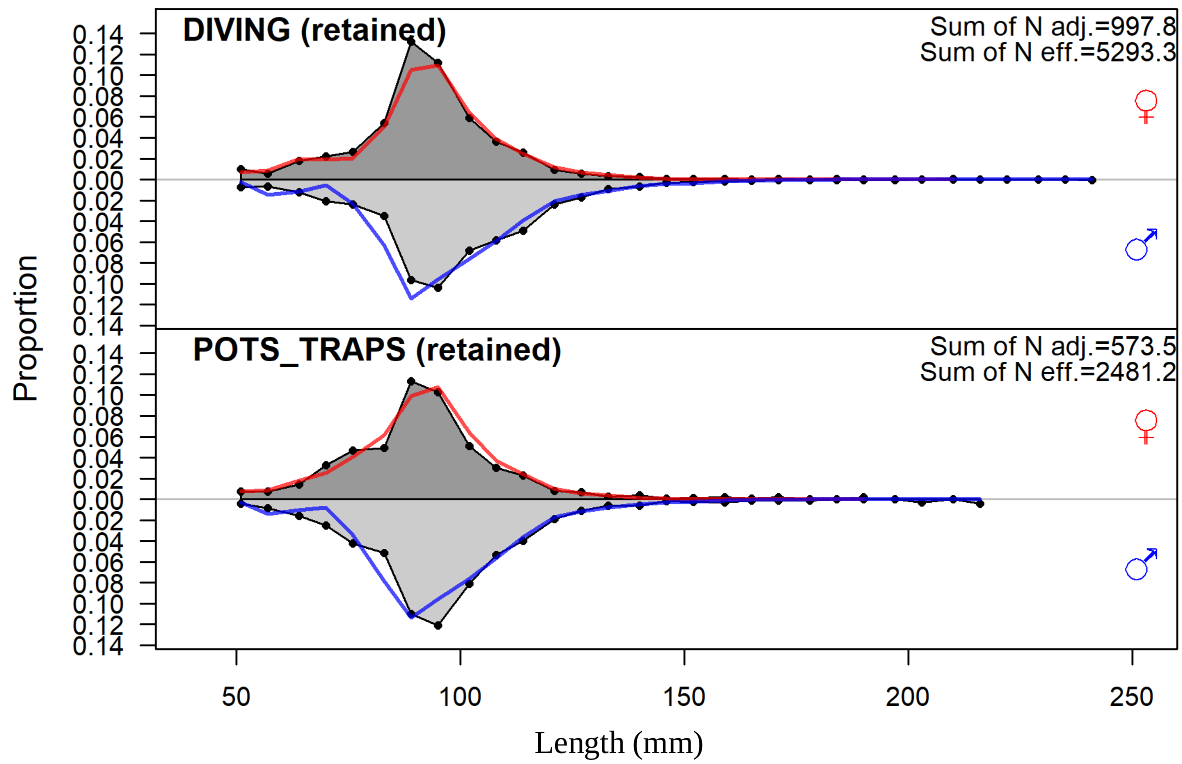


Figure 13. Puerto Rico, aggregate fit to length composition data. Observed (grey histograms) and expected (lines) length frequency distributions.

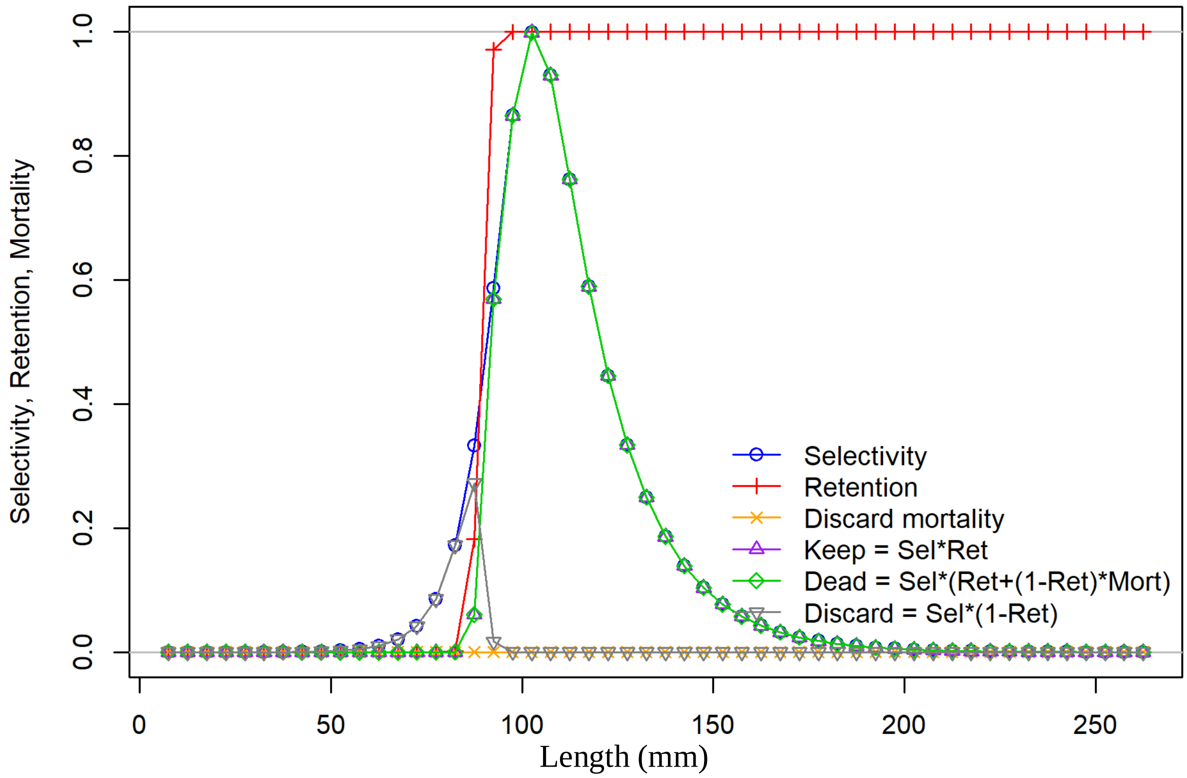


Figure 14. St. Croix, selectivity and retention.

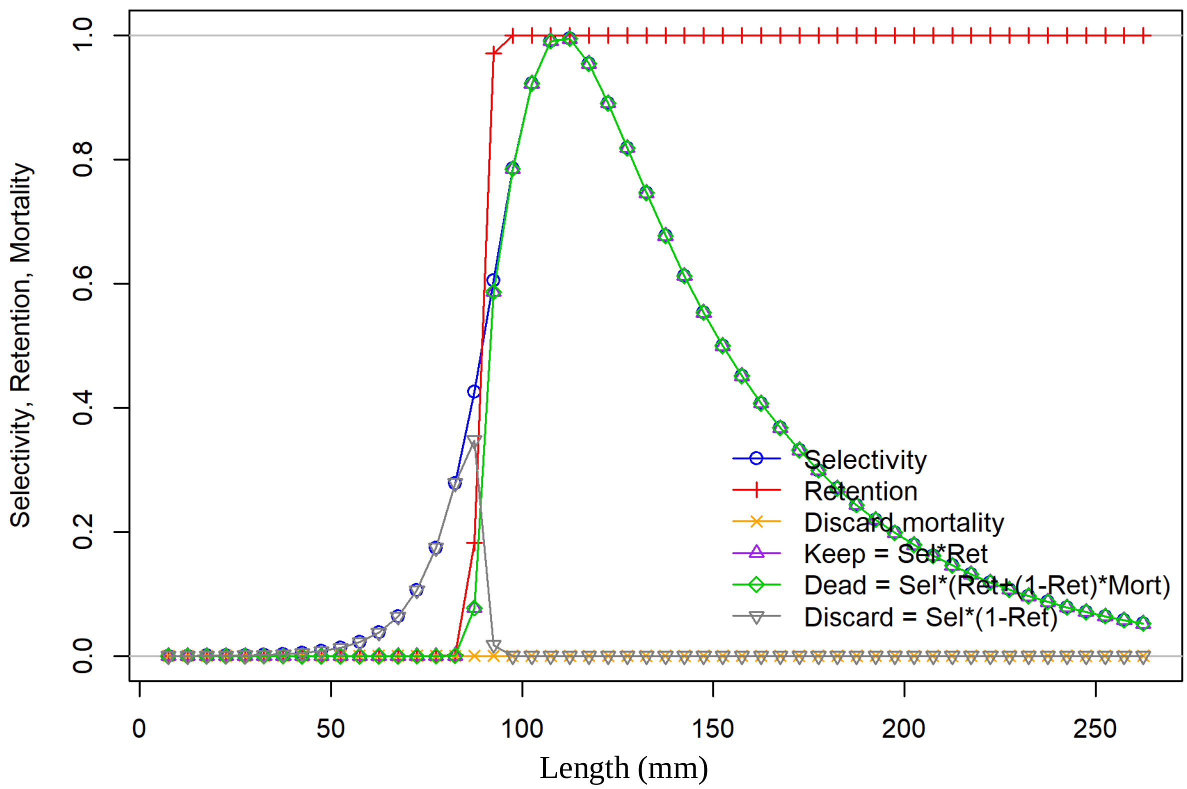


Figure 15. St. Thomas/St. John, selectivity and retention.

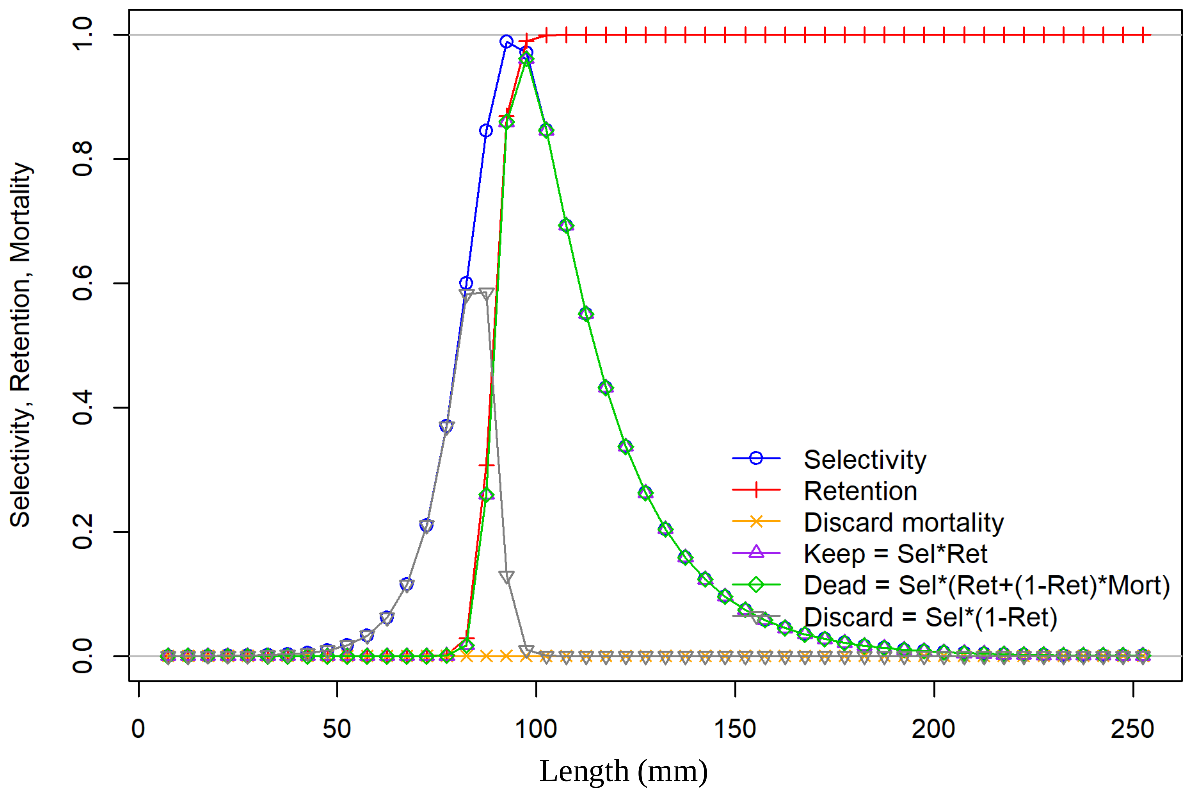


Figure 16. Puerto Rico, diving, selectivity and retention.

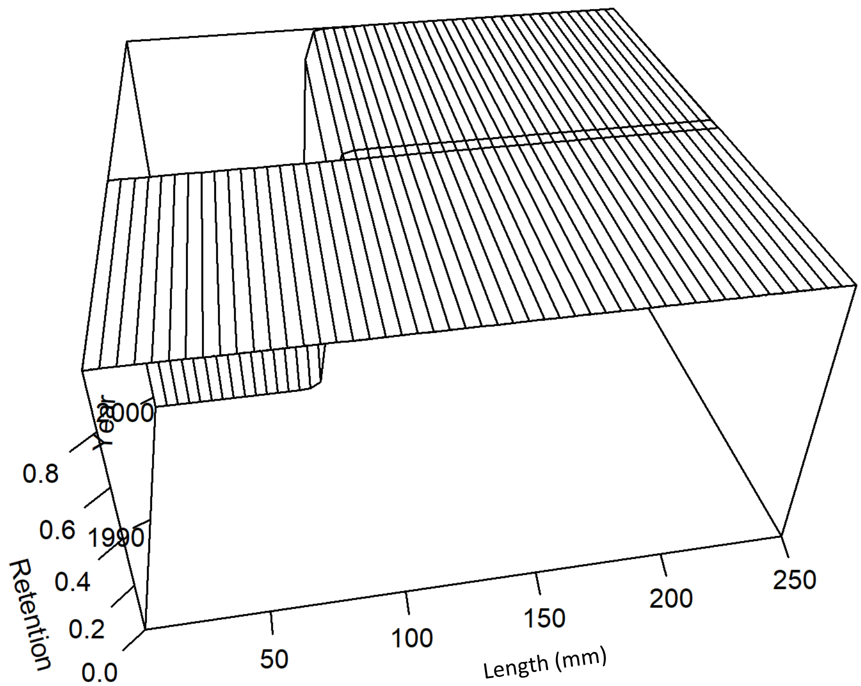


Figure 17. Puerto Rico, diving, time-varying retention. Note length is in mm.

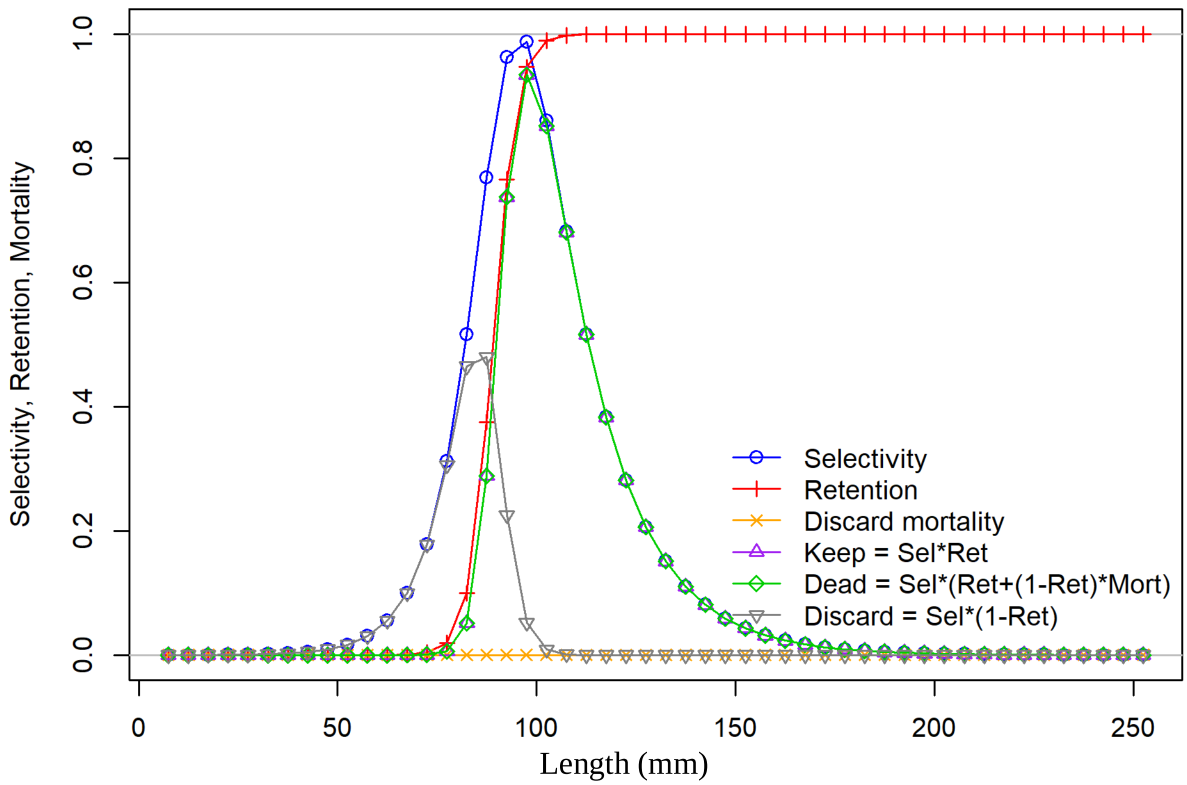


Figure 18. Puerto Rico, pots and traps, selectivity and retention.

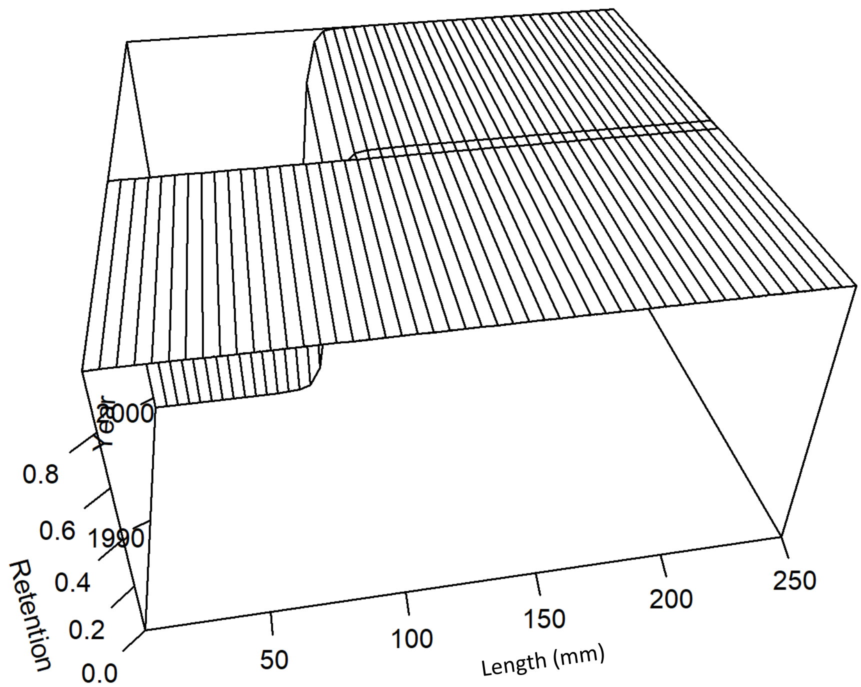


Figure 19. Puerto Rico, pots and traps, time-varying retention. Note length is in mm.

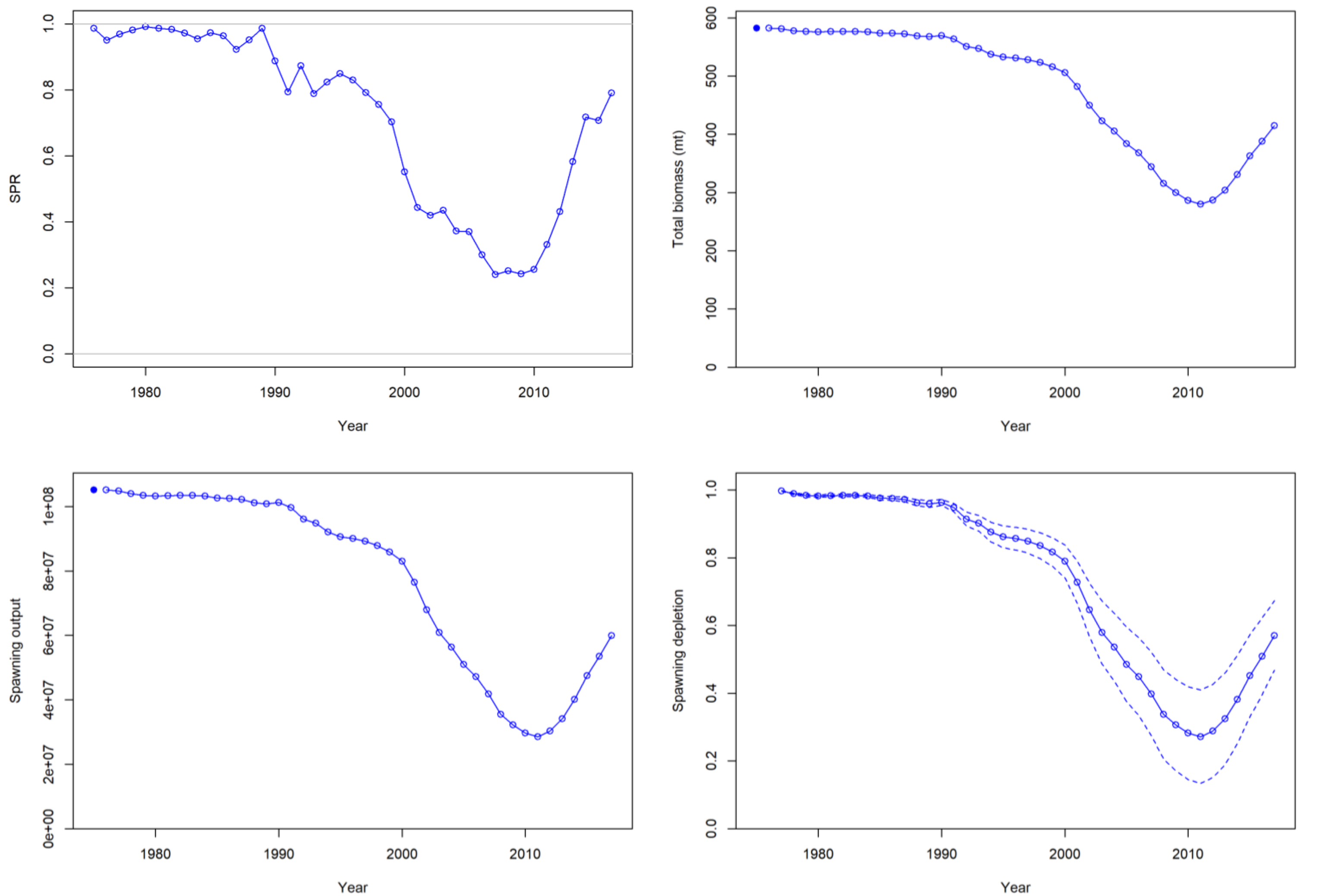


Figure 20. St. Croix, stock trajectories. SPR (top left), total biomass (top right), spawning biomass (lower left), and spawning depletion with 95% confidence interval (lower right).

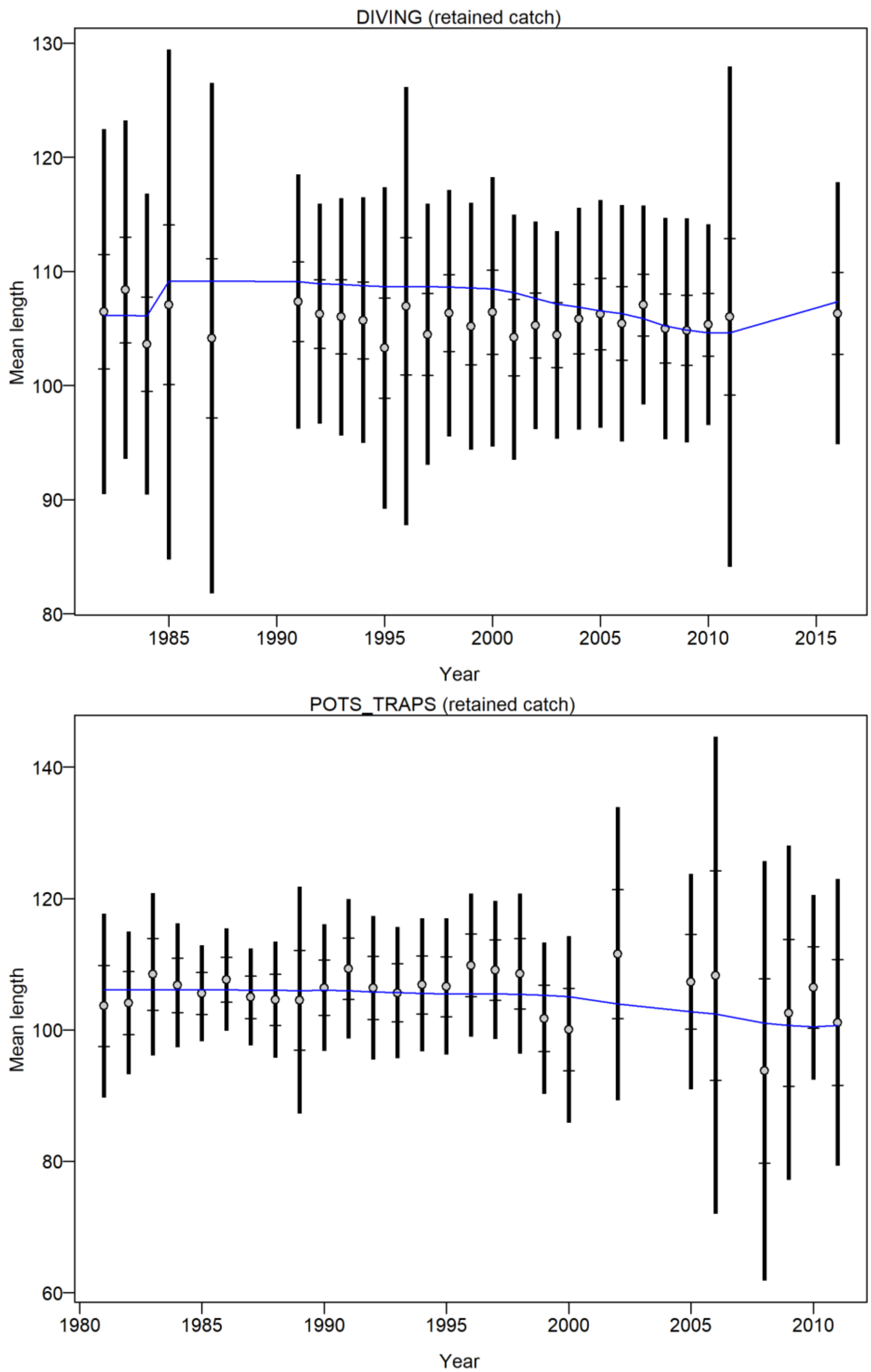


Figure 21. St. Croix, changes in length composition through time for diving (upper panel) and pots and traps (lower panel). Blue line is estimated annual mean length; points are observed means; vertical bars are 95% confidence interval based on current sample sizes.

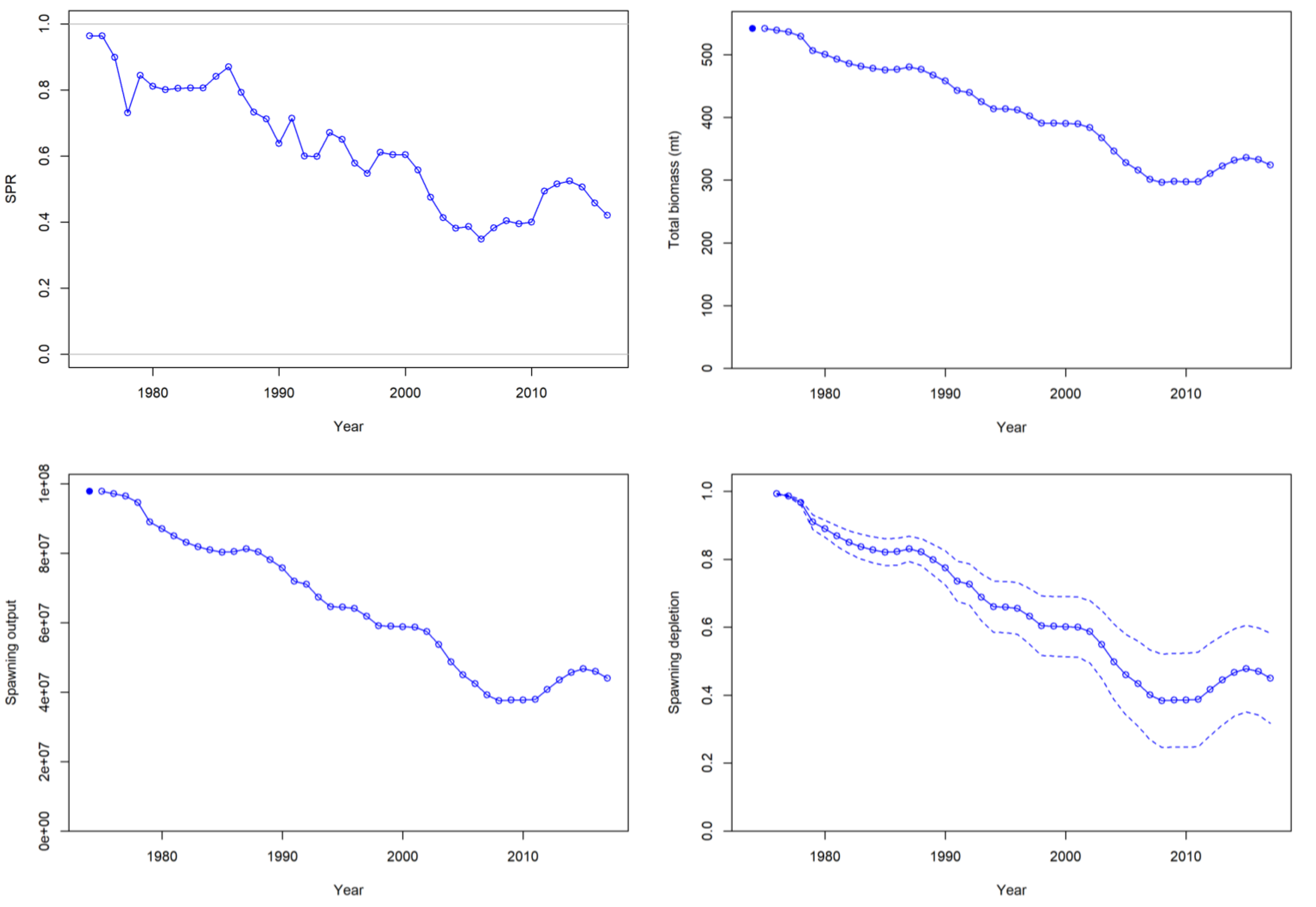


Figure 22. St. Thomas/St. John, stock trajectories. SPR (top left), total biomass (top right), spawning biomass (lower left), and spawning depletion with 95% confidence interval (lower right).

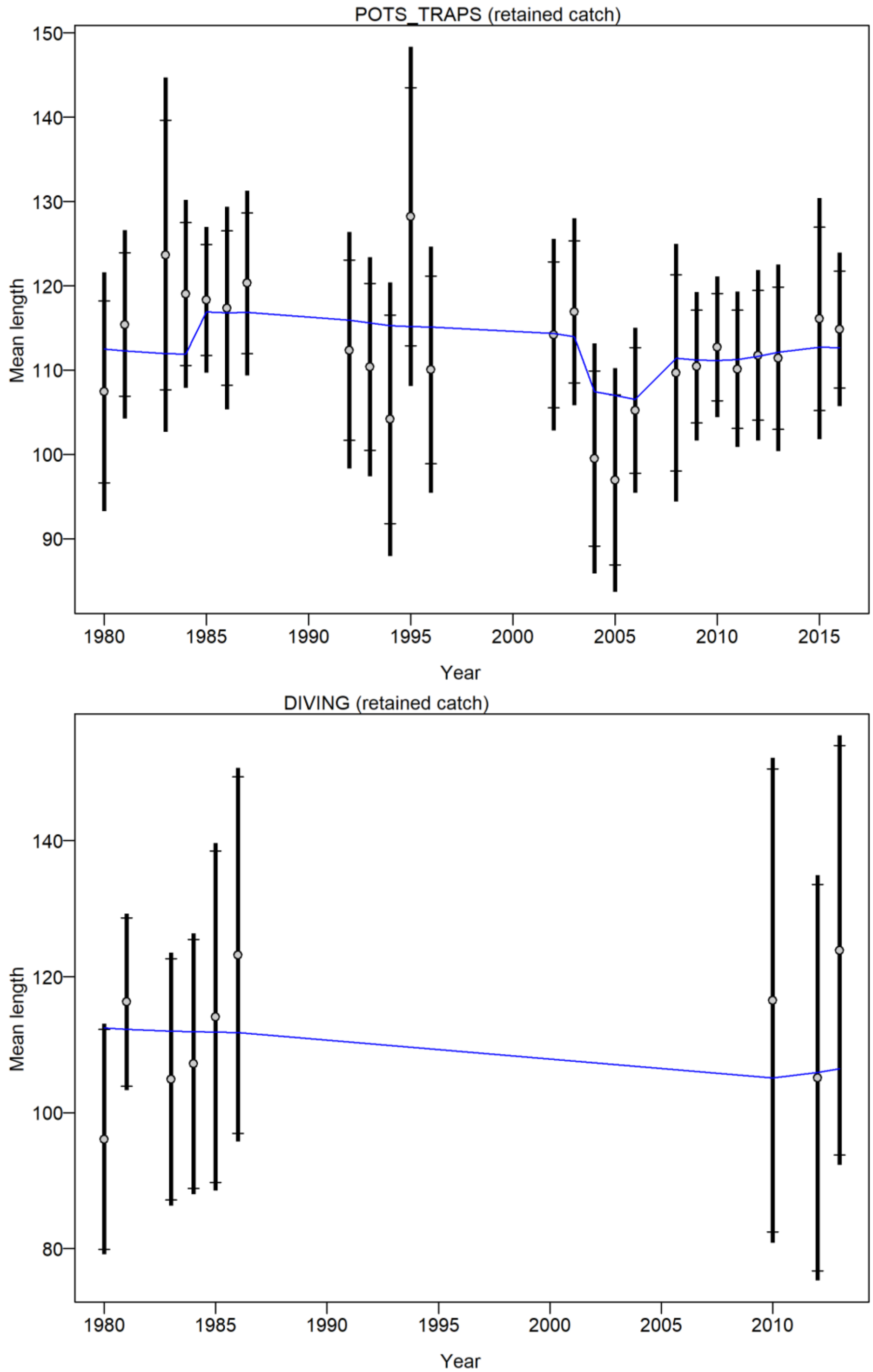


Figure 23. St. Thomas/St. John, changes in length composition through time for pots and traps (upper panel) and diving (lower panel). Blue line is estimated annual mean length; points are observed means; vertical bars are 95% confidence interval based on current sample sizes.

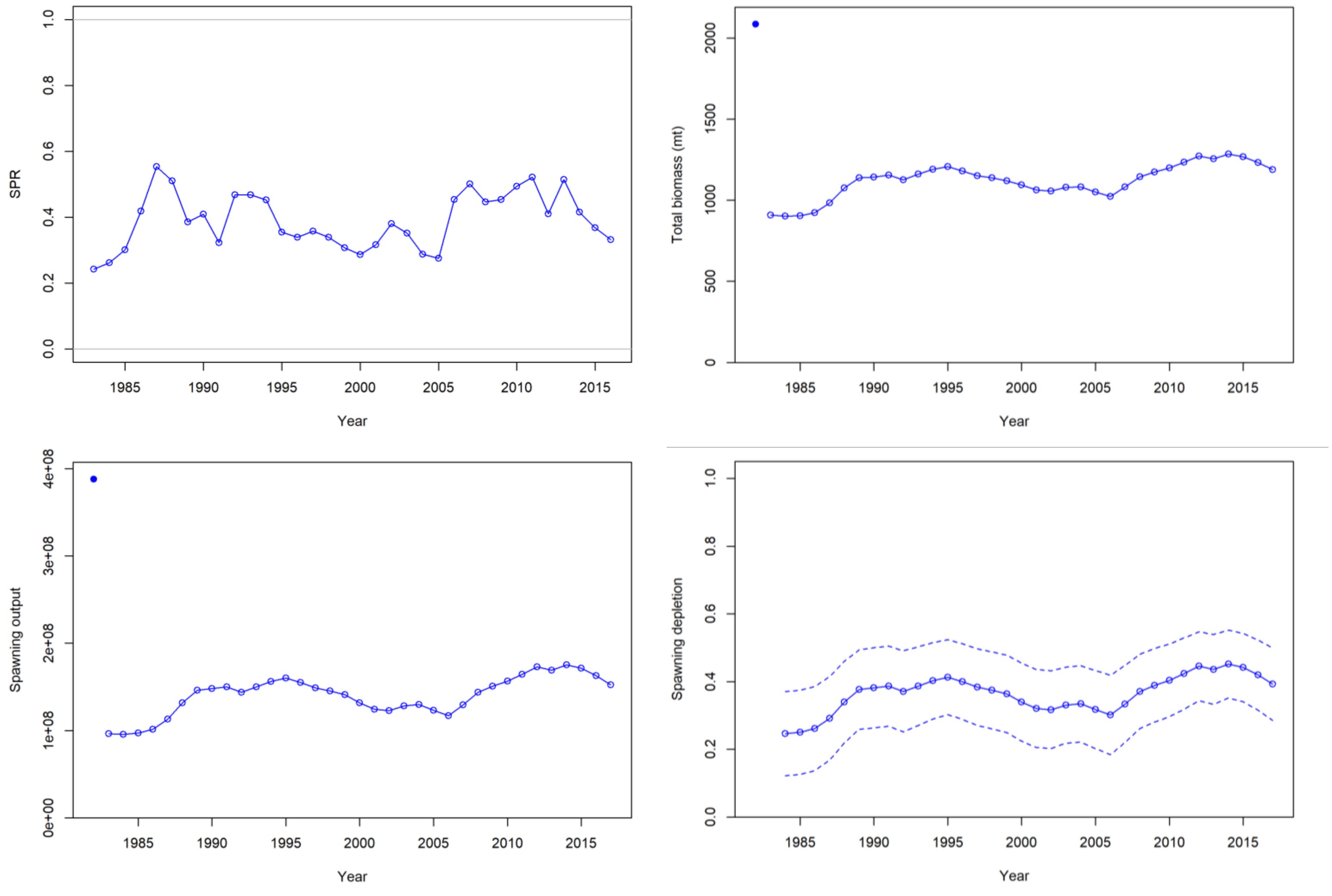


Figure 24. Puerto Rico, stock trajectories. SPR (top left), total biomass (top right), spawning biomass (lower left), and spawning depletion with 95% confidence interval (lower right).

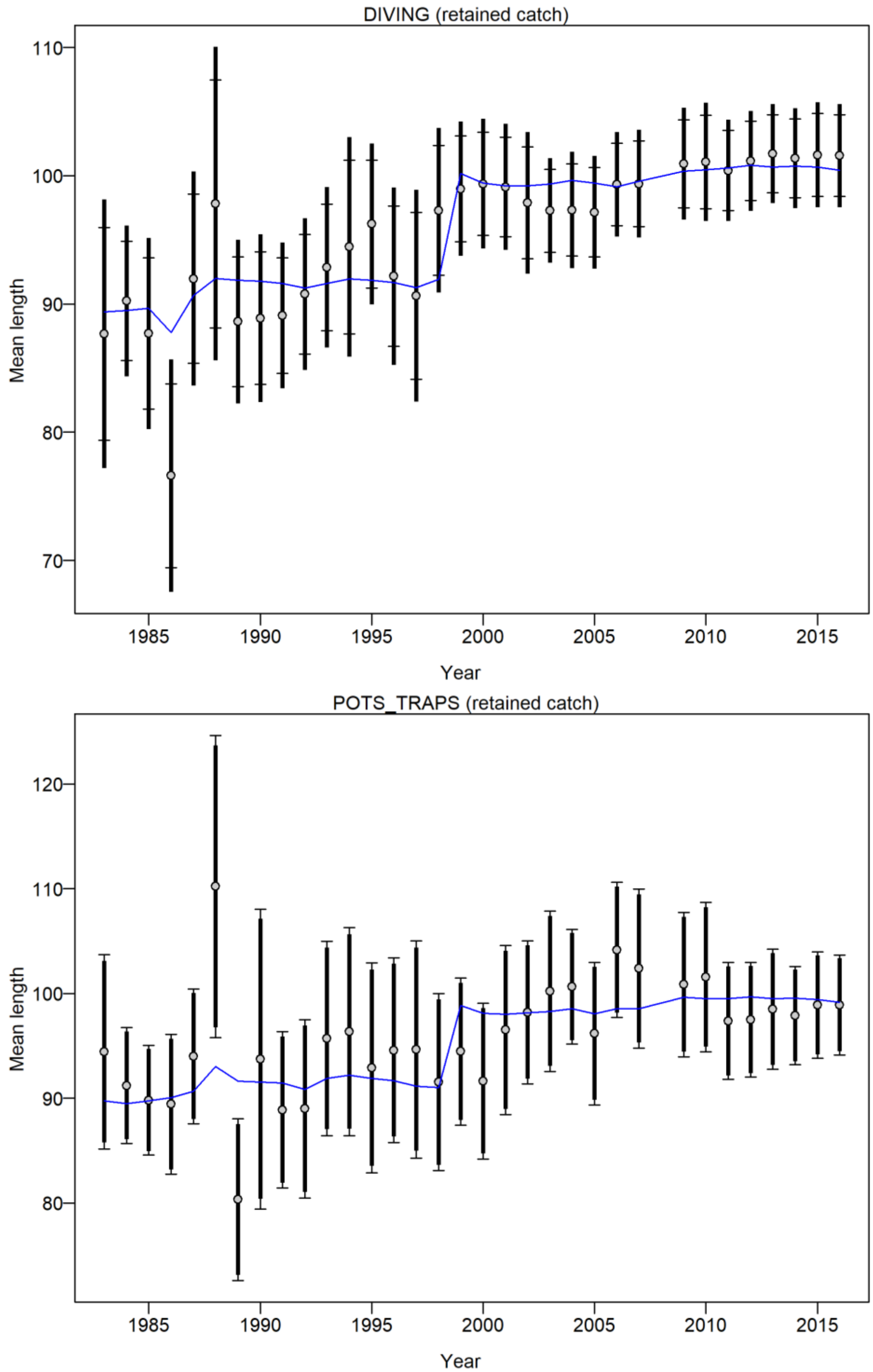


Figure 25. Puerto Rico, changes in length composition through time for diving (upper panel) and pots and traps (lower panel). Blue line is estimated annual mean length; points are observed means; vertical bars are 95% confidence interval based on current sample sizes.

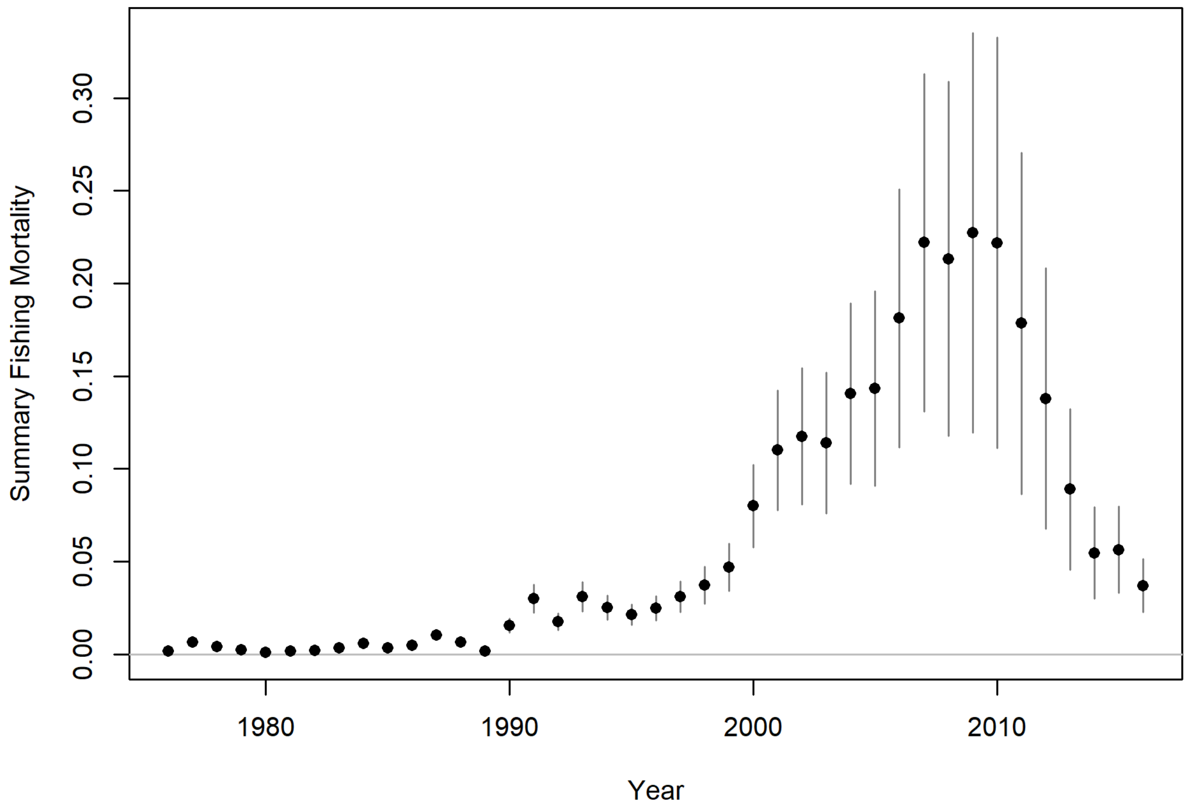


Figure 26. St. Croix, proportion of the stock killed by fishing (i.e., harvest rate in biomass landed / total biomass) and associated 95% confidence intervals (vertical lines).

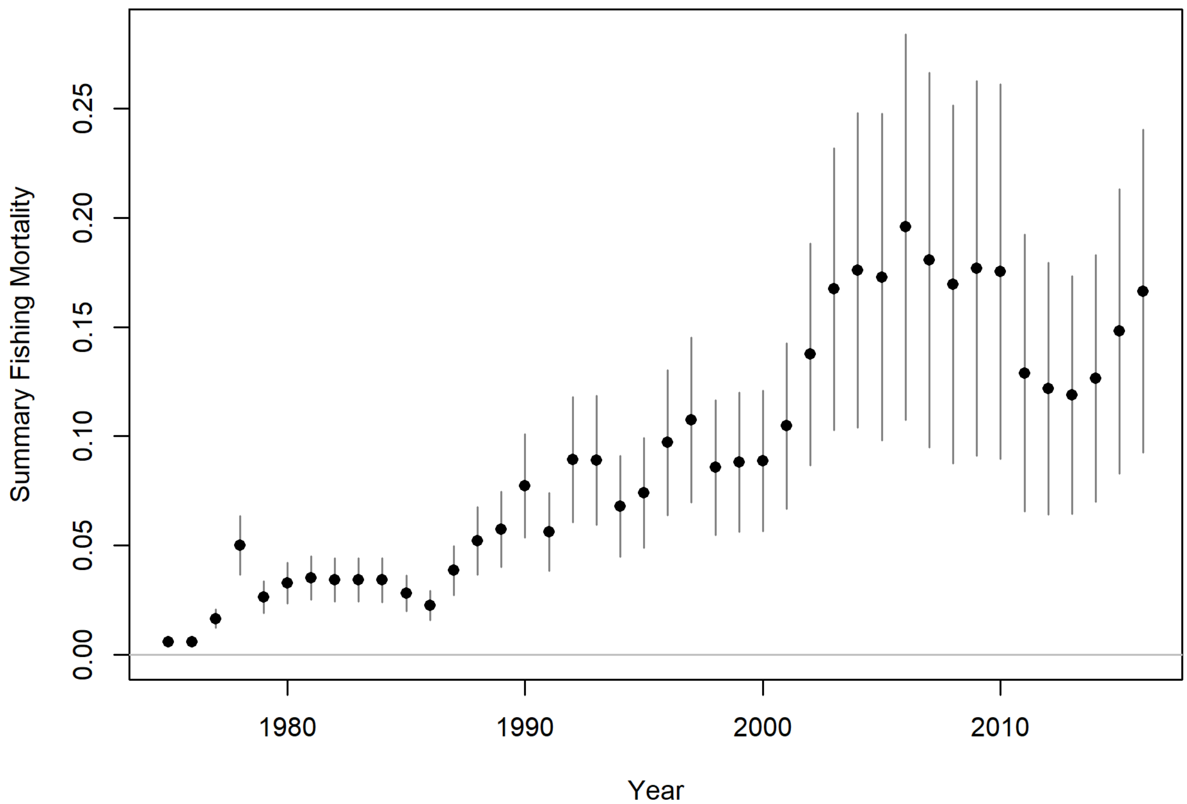


Figure 27. St. Thomas/St. John, proportion of the stock killed by fishing (i.e., harvest rate in biomass landed / total biomass) and associated 95% confidence intervals (vertical lines).

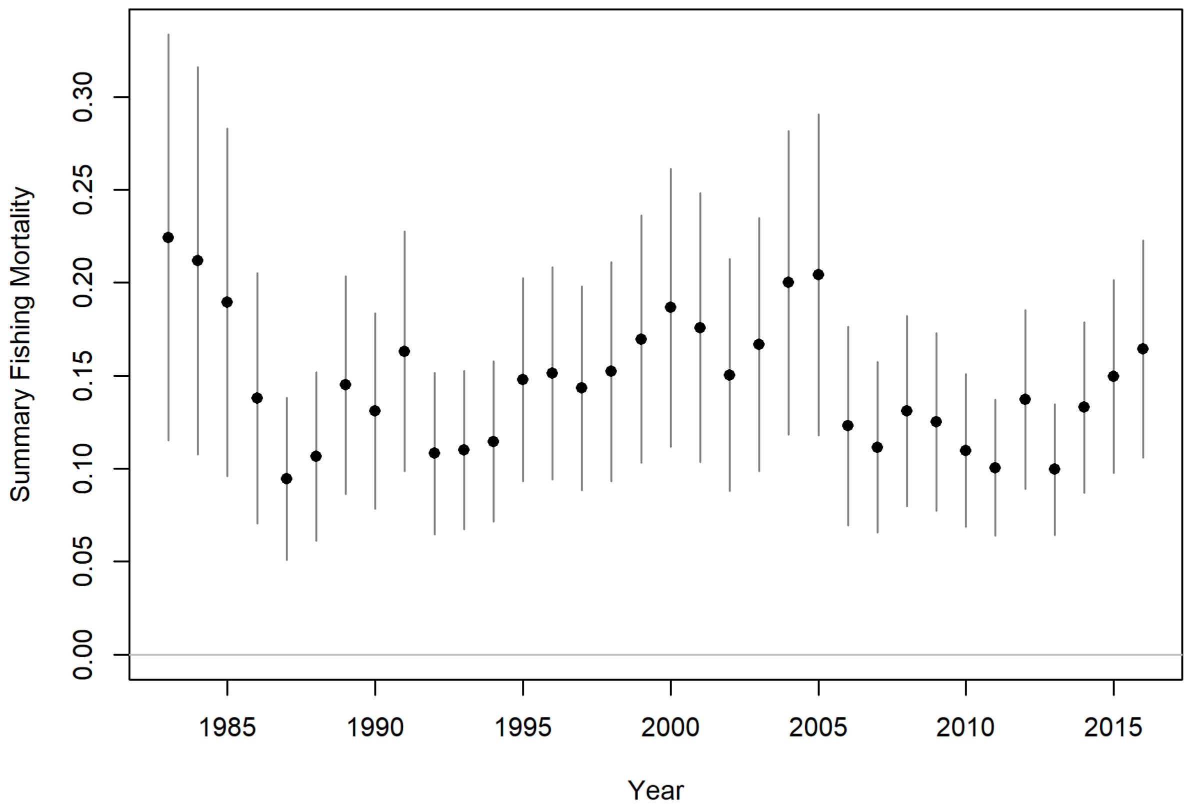


Figure 28. Puerto Rico, proportion of the stock killed by fishing (i.e., harvest rate in biomass landed / total biomass) and associated 95% confidence intervals (vertical lines).

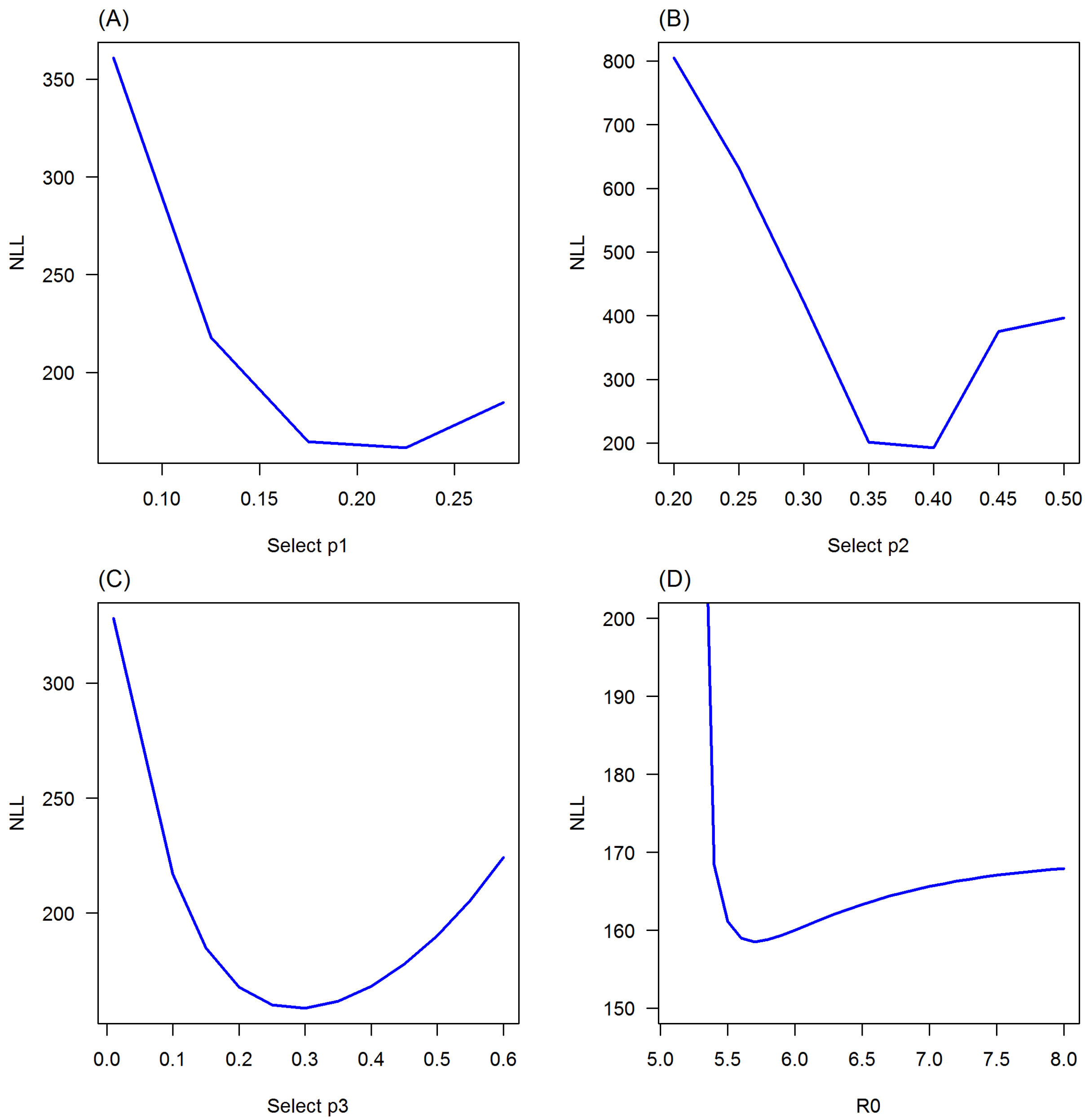


Figure 29. St. Croix likelihood profile. (A) through (D) are parameter profiles of selectivity parameters and R0.

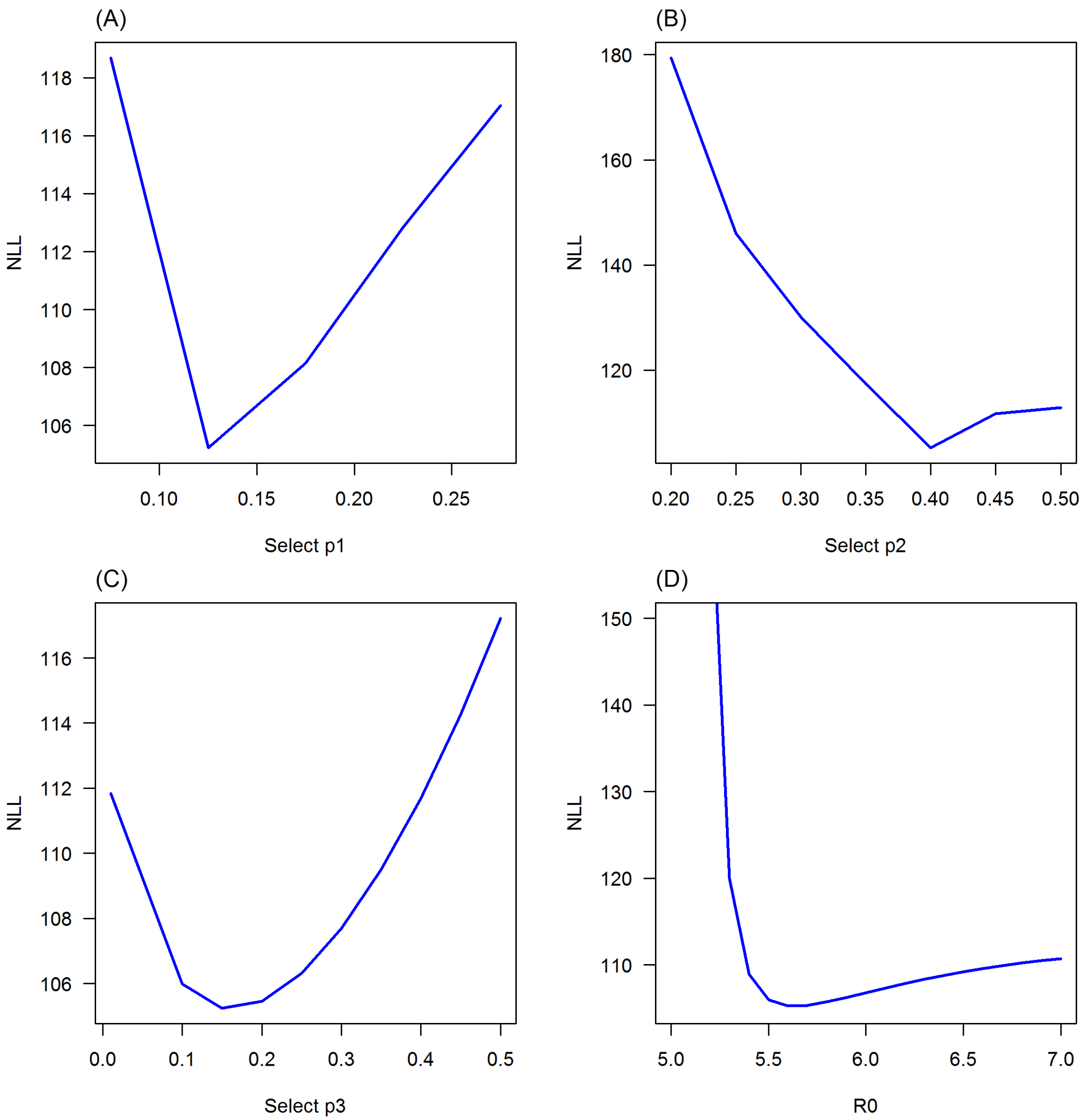


Figure 30. St. Thomas/St. John likelihood profile. (A) through (D) are parameter profiles of selectivity parameters and R0.

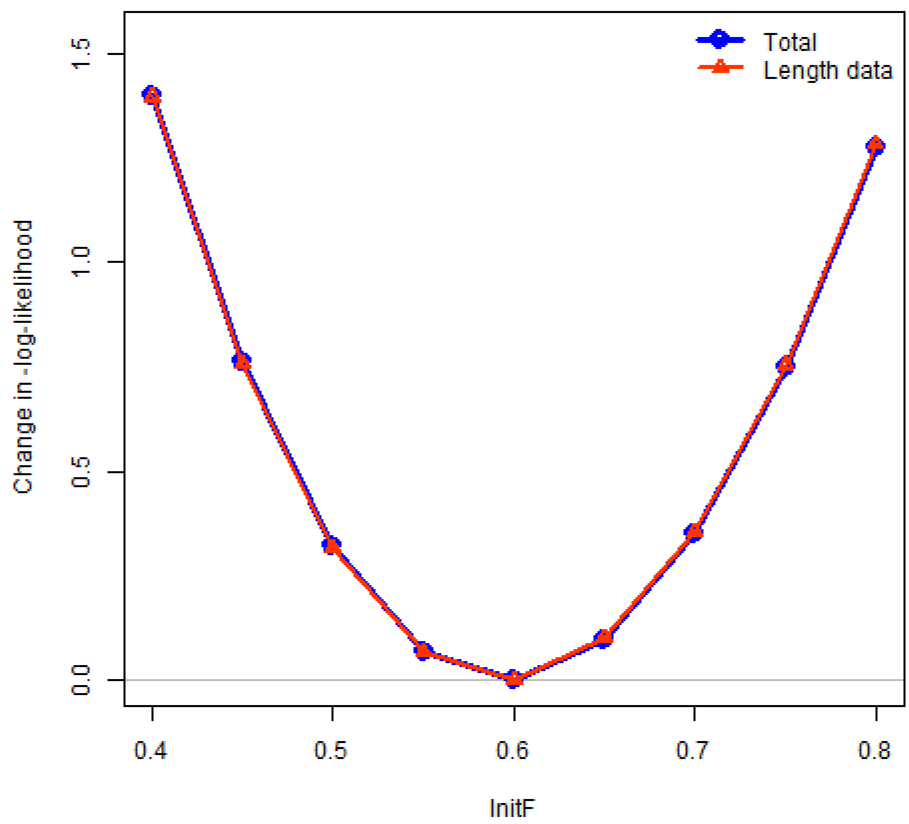


Figure 31. Puerto Rico likelihood profile for initial F.

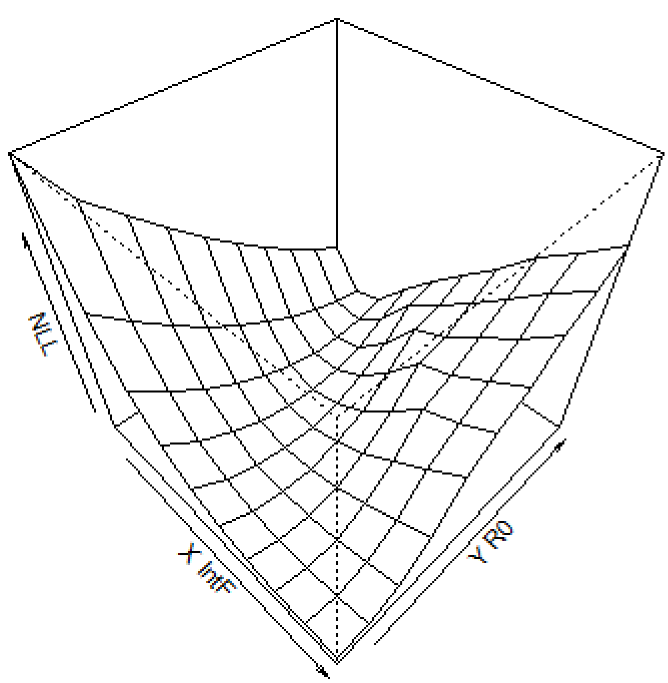


Figure 32. Puerto Rico bivariate likelihood profile for R0 and Initial F.

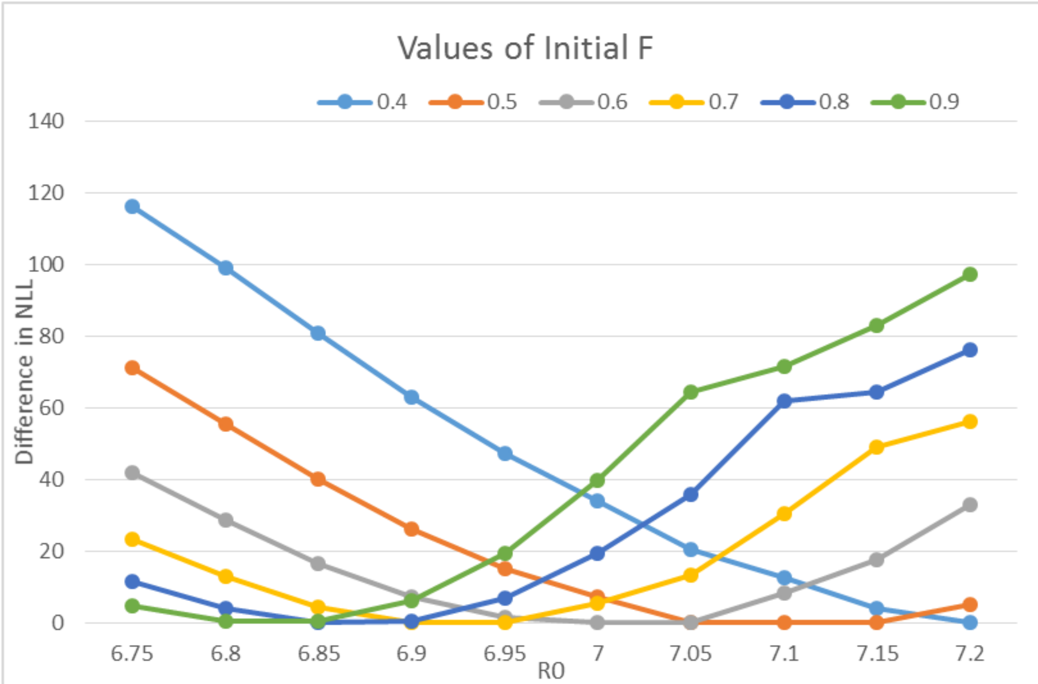


Figure 33. Puerto Rico bivariate likelihood profile for R0 at specified values of initial F.

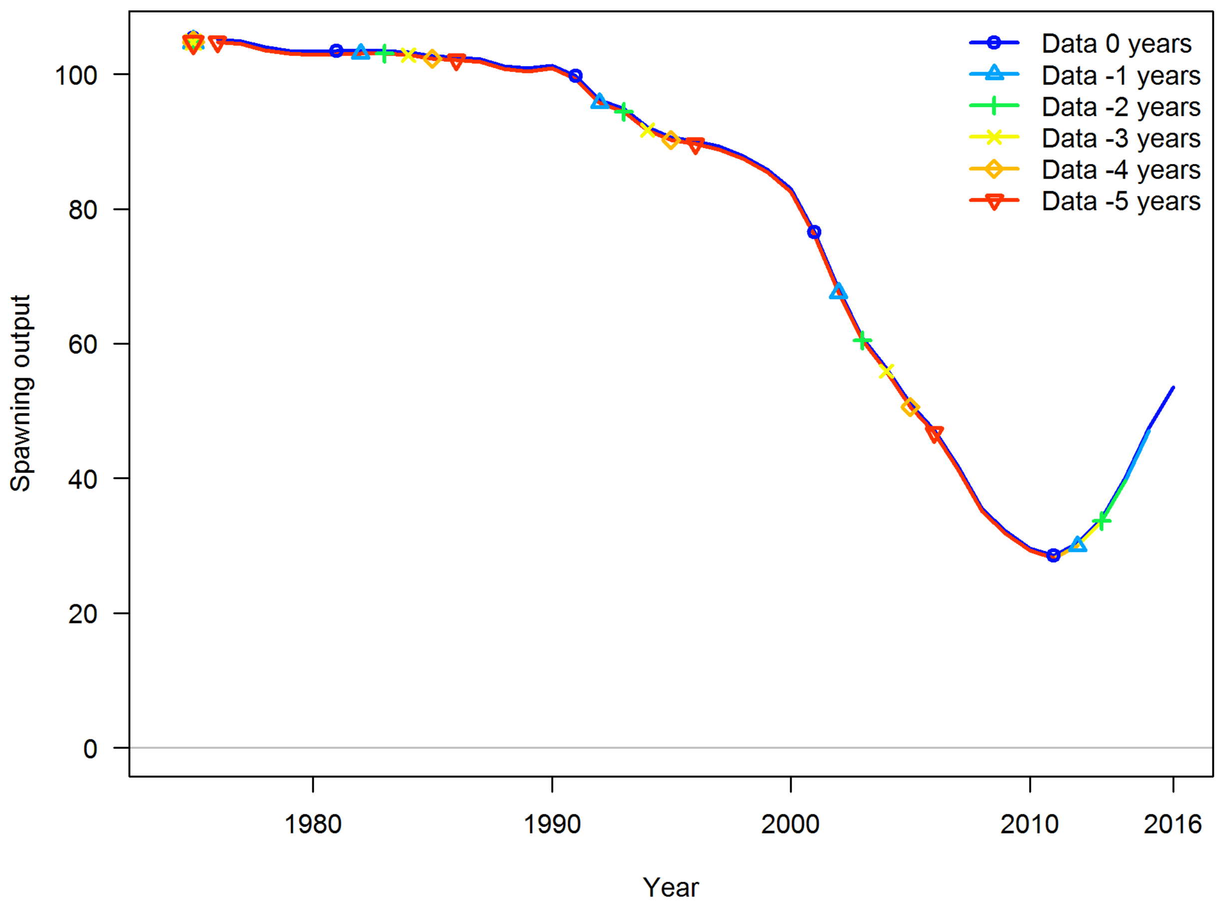


Figure 34. St Croix, RW model, retrospective analysis showing biomass trend under sequential removal of up to five most recent years of data.

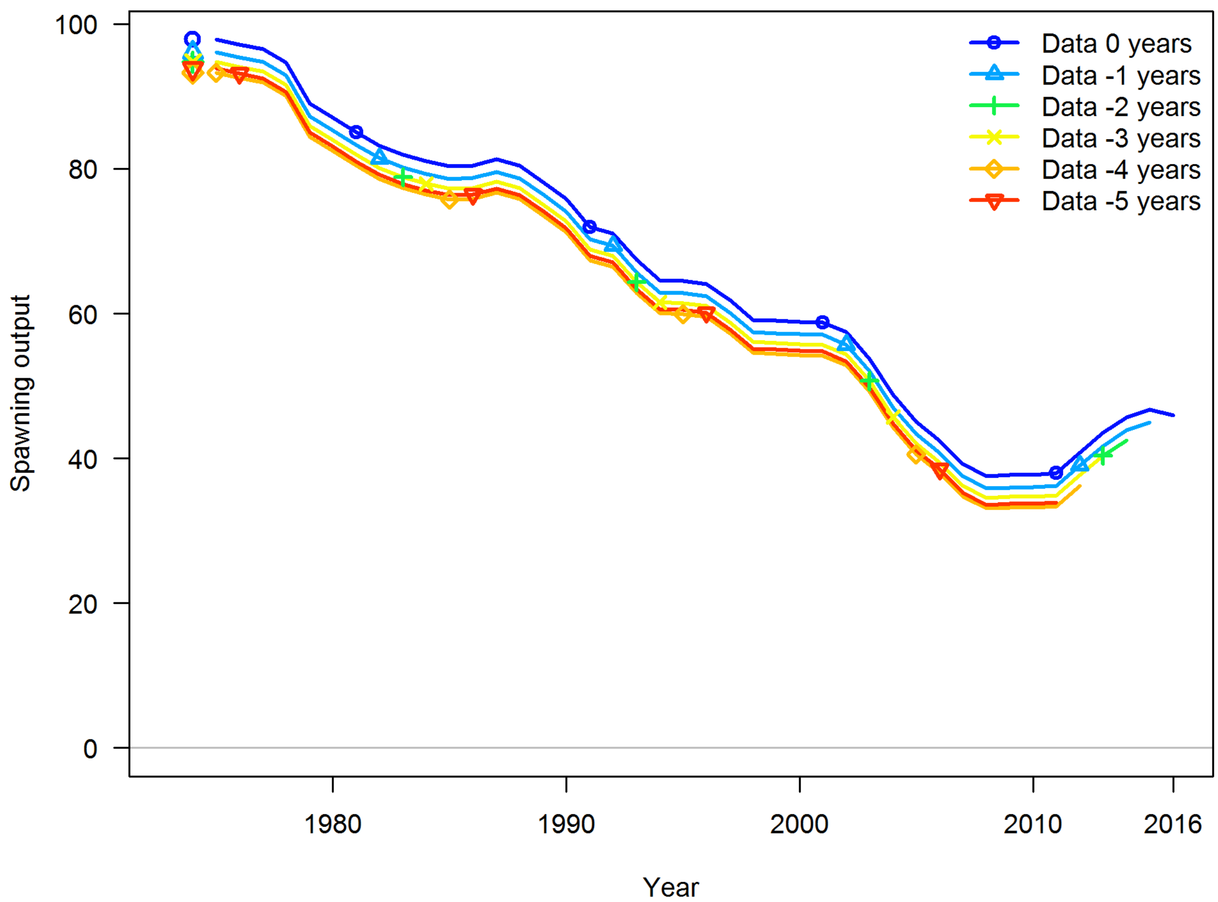


Figure 35. St Thomas/St. John, RW model, retrospective analysis showing biomass trend under sequential removal of up to five most recent years of data.

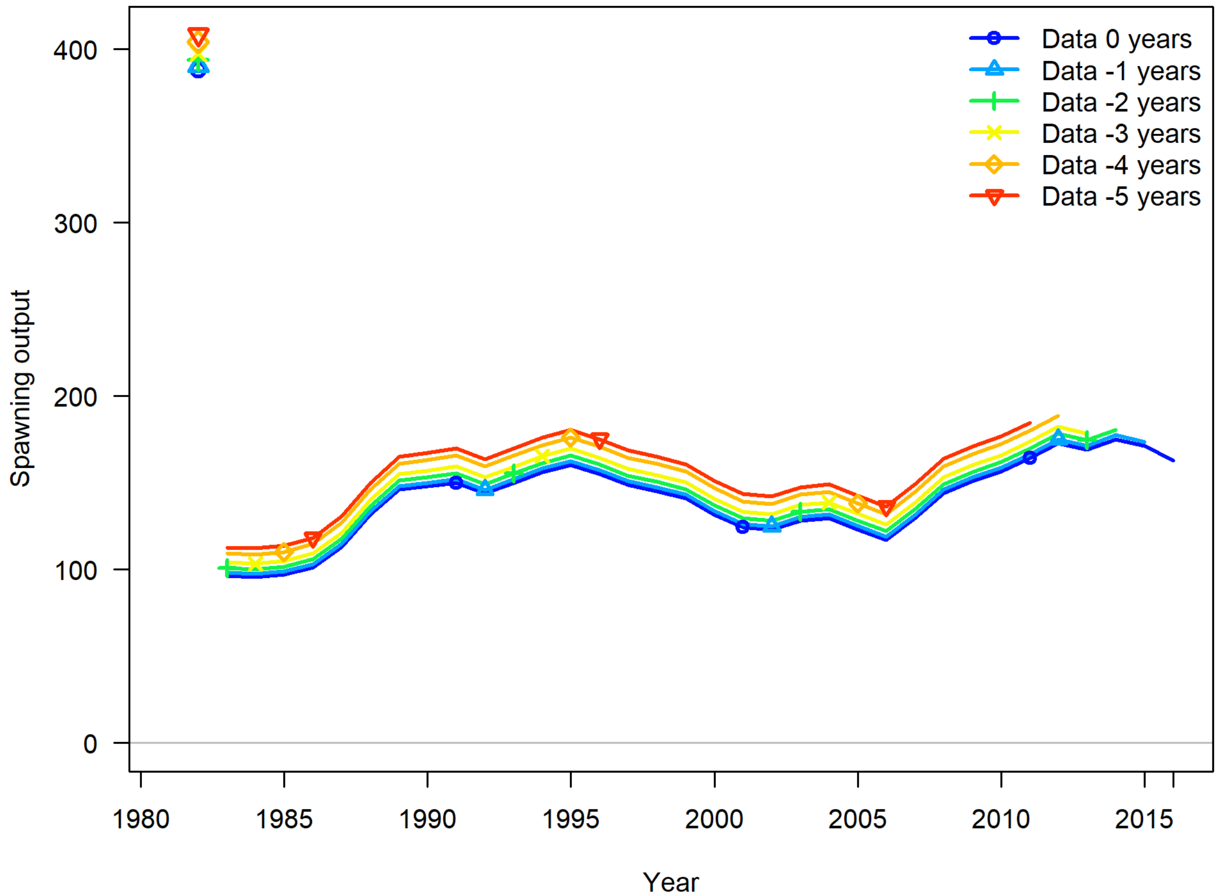


Figure 36. Puerto Rico, RW model, retrospective analysis showing biomass trend under sequential removal of up to five most recent years of data.

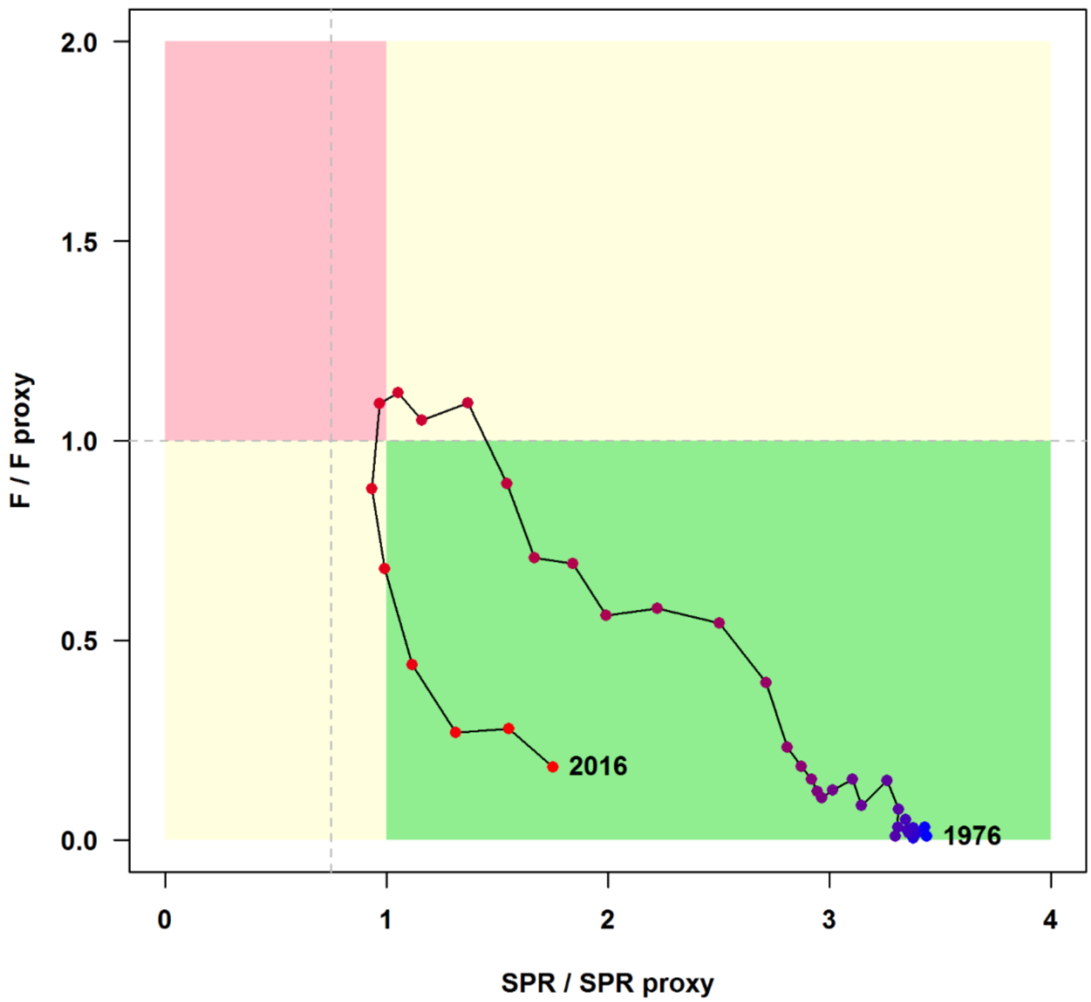


Figure 37. Stock synthesis estimates of spawning output (x-axis) and fishing mortality (y-axis) relative to provisional reference levels of SPR30%, for St. Croix. The vertical gray dotted line shows the reference level associated with Minimum Stock Size Threshold (MSST) and the horizontal gray dotted line shows the Maximum fishing mortality threshold (MFMT).

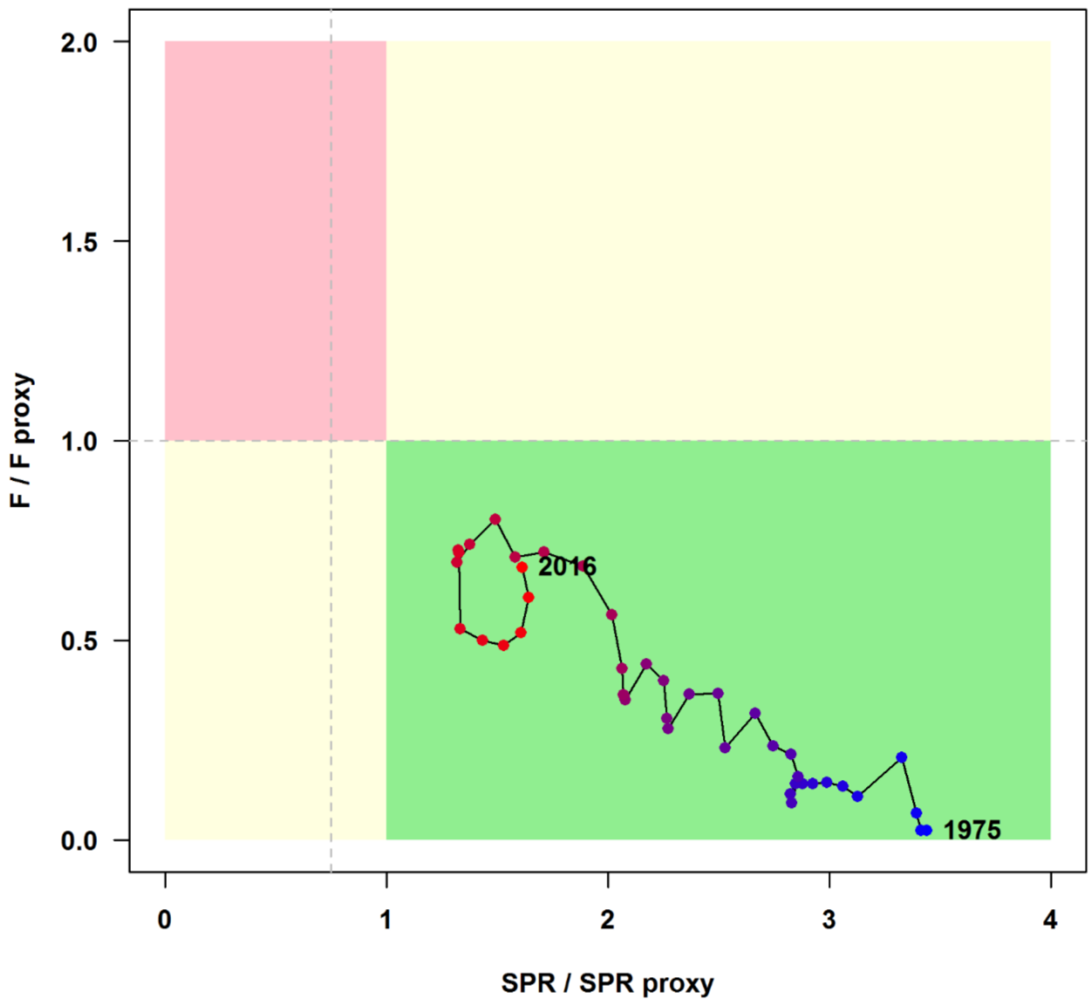


Figure 38. Stock synthesis estimates of spawning output (x-axis) and fishing mortality (y-axis) relative to provisional reference levels of SPR30%, for St. Thomas/St. John. The vertical gray dotted line shows the reference level associated with Minimum Stock Size Threshold (MSST) and the horizontal gray dotted line shows the Maximum fishing mortality threshold (MFMT).

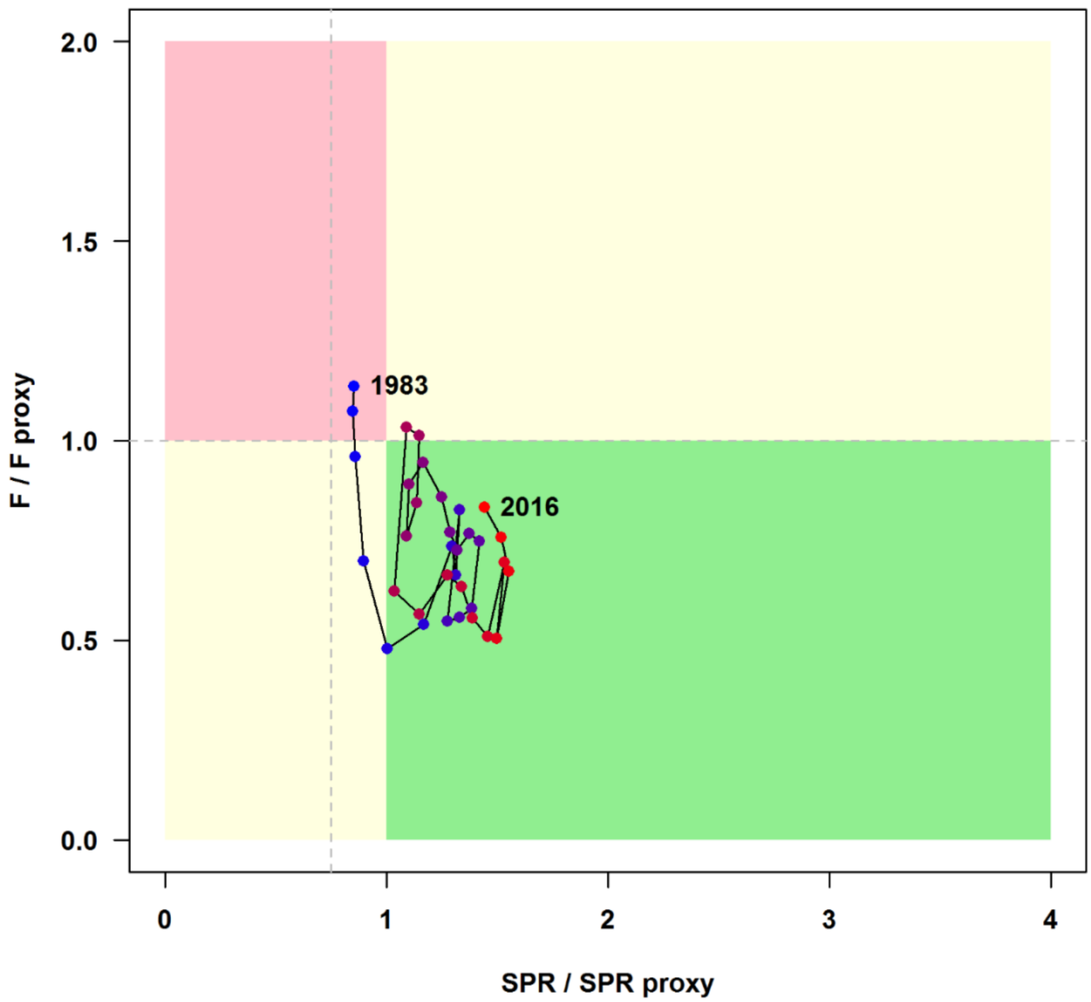


Figure 39. Stock synthesis estimates of spawning output (x-axis) and fishing mortality (y-axis) relative to provisional reference levels of SPR30%, for Puerto Rico. The vertical gray dotted line shows the reference level associated with Minimum Stock Size Threshold (MSST) and the horizontal gray dotted line shows the Maximum fishing mortality threshold (MFMT).

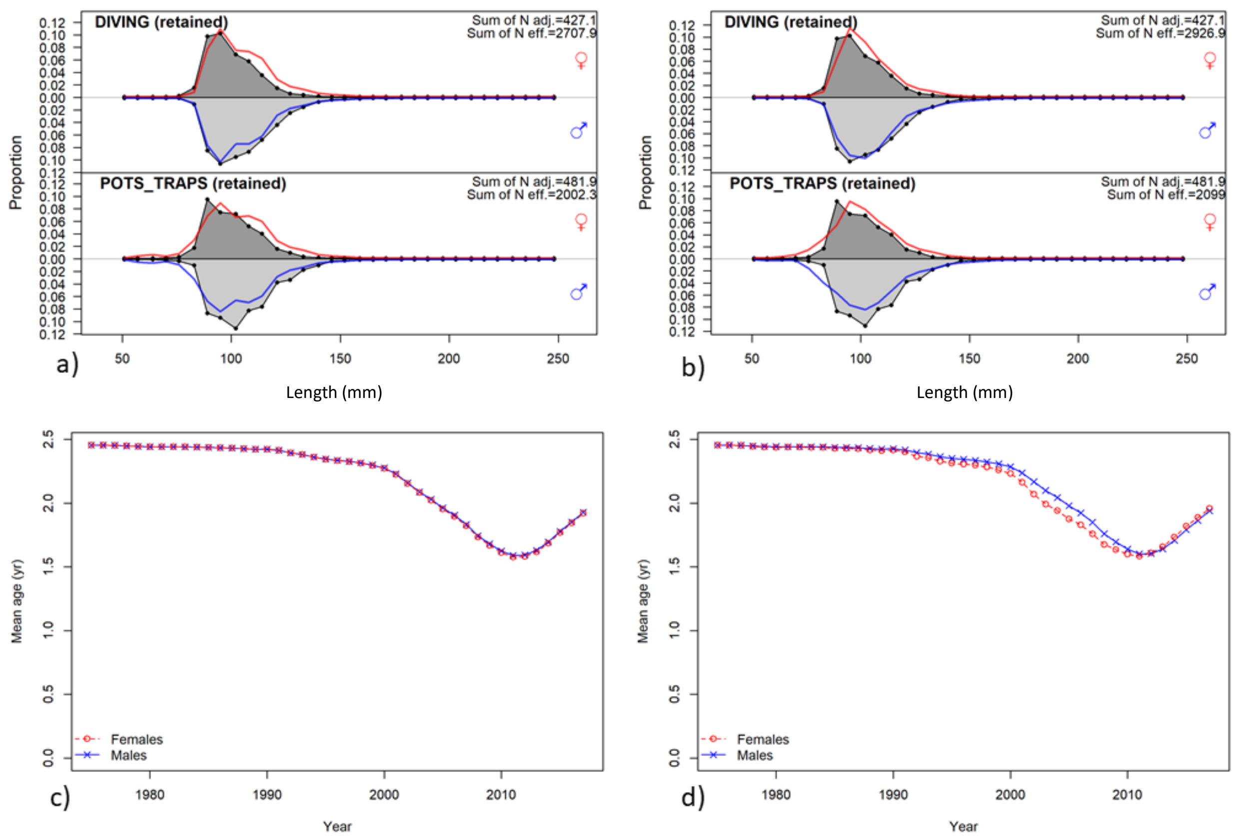


Figure 40. St. Croix, top panels show aggregate fit to length composition data with observed and expected length frequency distributions for the base model (a) and the recommended model (b). Bottom panels show the estimated mean age through time for the base model (c) and recommended model (d).

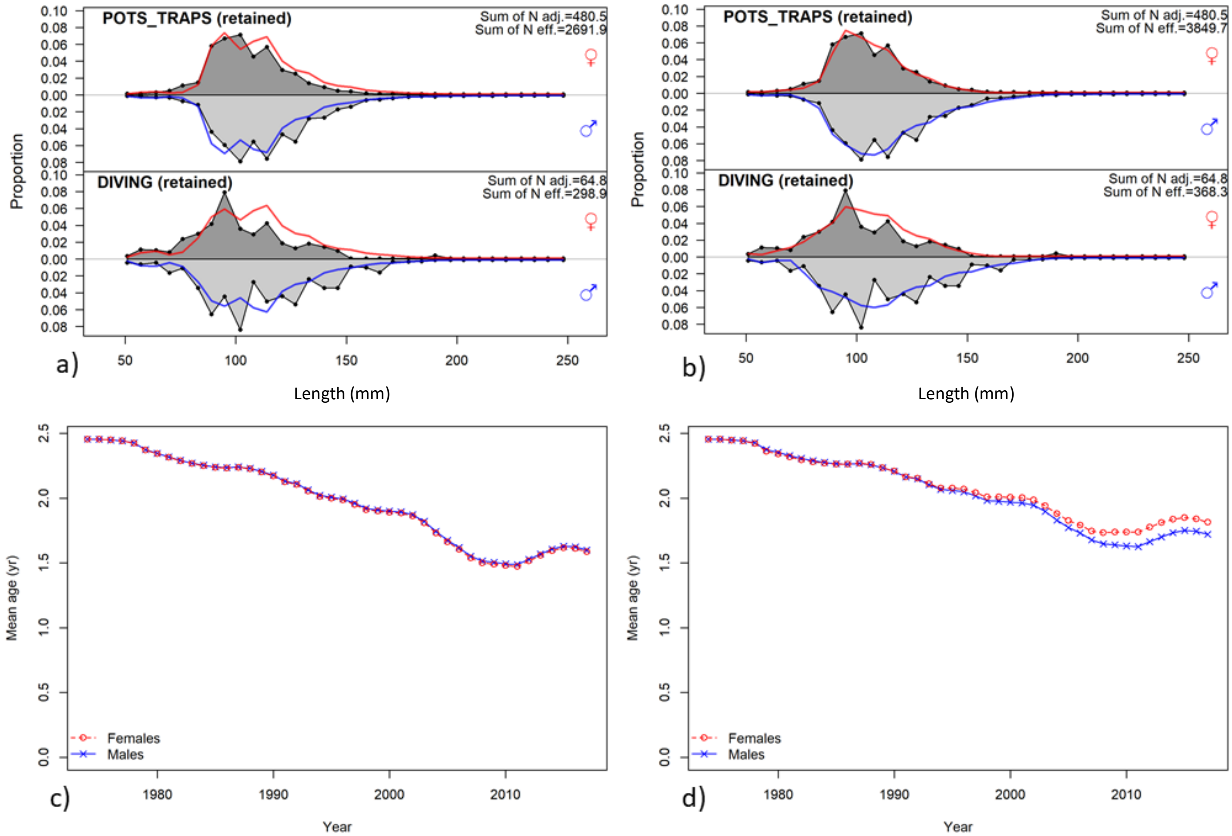


Figure 41. St. Thomas, top panels show aggregate fit to length composition data with observed and expected length frequency distributions for the base model (a) and the recommended model (b). Bottom panels show the estimated mean age through time for the base model (c) and recommended model (d).

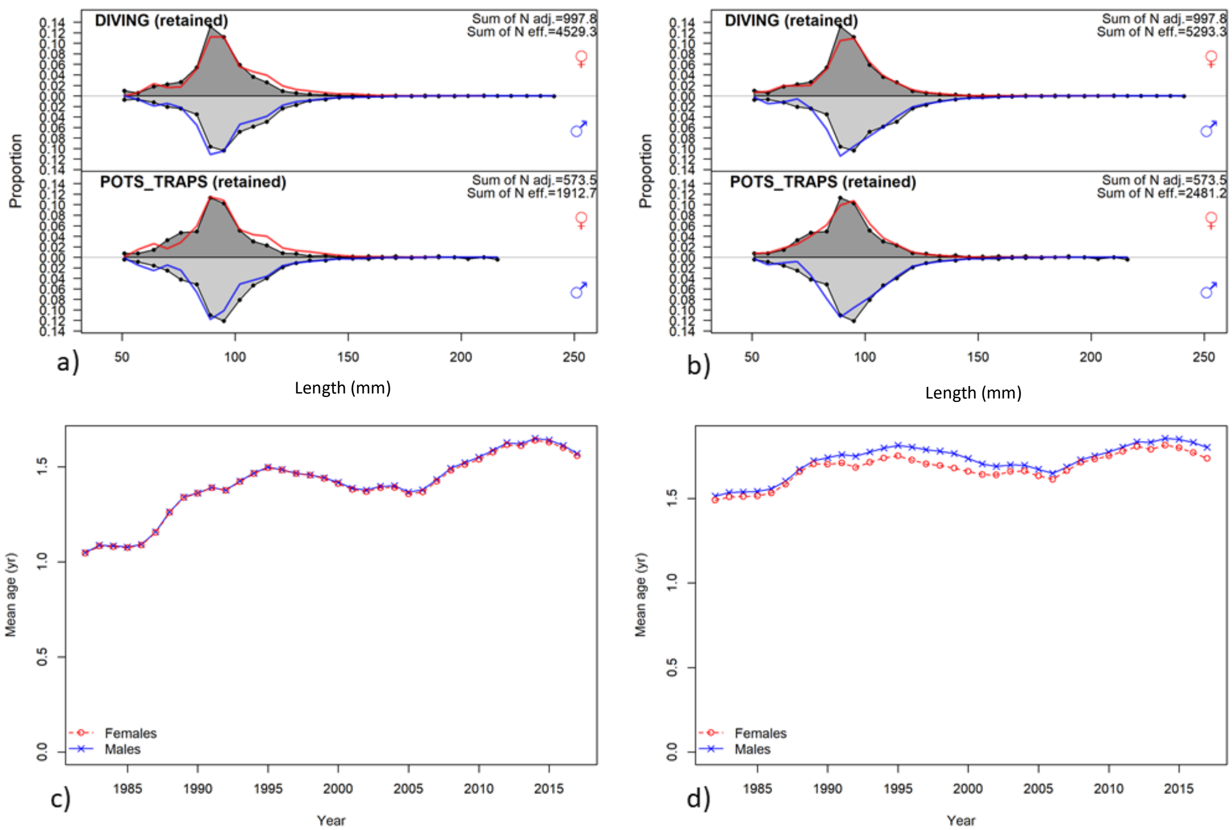


Figure 42. Puerto Rico, top panels show aggregate fit to length composition data with observed and expected length frequency distributions for the base model (a) and the recommended model (b). Bottom panels show the estimated mean age through time for the base model (c) and recommended model (d).