Review of TACs

Bering Sea Crab:
2022/23 Season

ADF&G presentation to BSAI crab industry, 10 Nov 2022

Join by ZOOM:

https://us02web.zoom.us/j/89415317984?pwd=dkdFMU5McVV1bUQreXN5RjRzR0FBdz09

Meeting ID: 894 1531 7984
Passcode: 096172

2022/23 TAC Summary

Fishery	OFL (mill lb)	ABC (mill lb)	TAC (mill lb)
Pribilof blue king crab	0.0026 (total catch)	0.0020 (total catch)	0 (directed fishery closed)
Pribilof red king crab	1.51 (total catch)	1.13 (total catch)	0 (directed fishery closed)
St. Matthew blue king	0.15 catch)	0.11 (total male catch)	0 (directed fishery closed)
Bristol Bay red king crab	6.70 (total catch)	5.35 (total catch)	0 (directed fishery closed)
Bering Sea Tanner crab	72.34 (total catch)	54.25 (total catch)	1.165 (EBT), 0.850 (WBT) (retained catch)
Bering Sea snow crab	22.71 (total catch)	16.98 (total catch)	0 (directed fishery closed)

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Advisory Announcement

For Immediate Release: **10/10/2022**

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2022/23 Bering Sea Snow Crab Season Closed

The Alaska Department of Fish and Game (ADF&G) and National Marine Fisheries Service (NMFS) have completed analysis of 2022 NMFS trawl survey results for Bering Sea snow crab. The stock is estimated to be below the ADF&G regulatory threshold for opening a fishery. Therefore, Bering Sea snow crab will remain closed for the 2022/23 season.

ADF&G appreciates and carefully considered all input from crab industry stakeholders prior to making this decision. Understanding crab fishery closures have substantial impacts on harvesters, industry, and communities, ADF&G must balance these impacts with the need for long-term conservation and sustainability of crab stocks. Management of Bering Sea snow crab must now focus on conservation and rebuilding given the condition of the stock. Efforts to advance our science and understanding of crab population dynamics are underway. With crab industry input, ADF&G will continue to evaluate options for rebuilding, including potential for sustainably fishing during periods of low abundance. This will allow ADF&G to work on issues related to state and federal co-management, observer coverage, discard mortality, and fishery viability.

BSAI Crab Management Process

May

- Fisheries conclude
- NPFMC Crab Plan Team meets to discuss model scenarios to review in September with new fishery and survey data

June/July

- NOAA EBS bottom trawl survey

August

- Survey data disseminated to assessment authors

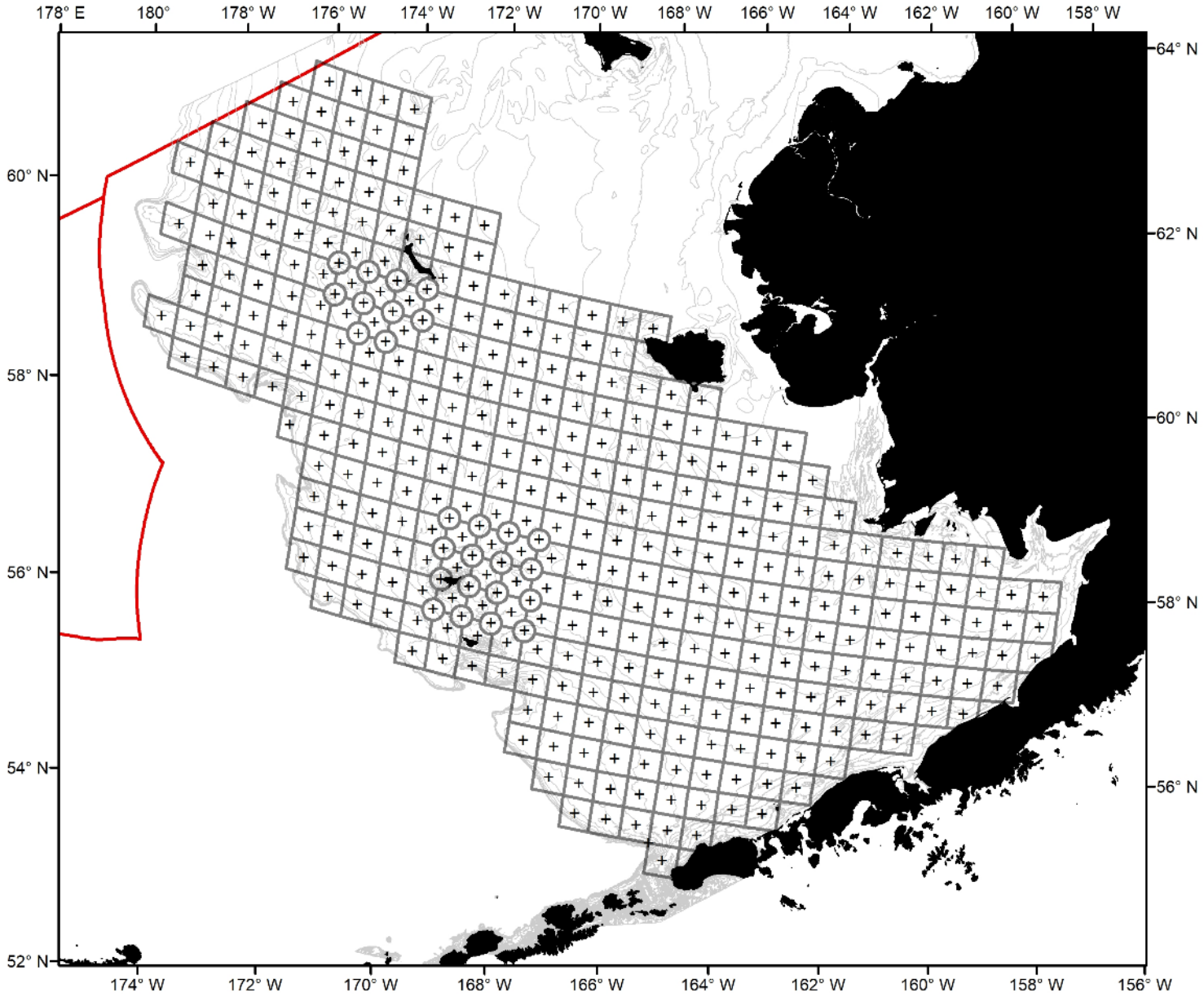
September/October

- NPFMC Crab Plan Team meet to discuss model performance and recommend OFL/ABC
- NPFMC Scientific and Statistical Committee reviews CPT recommendations and advises Council action
- ADF&G reviews all survey, assessment, fishery, environmental information,..... sets TAC

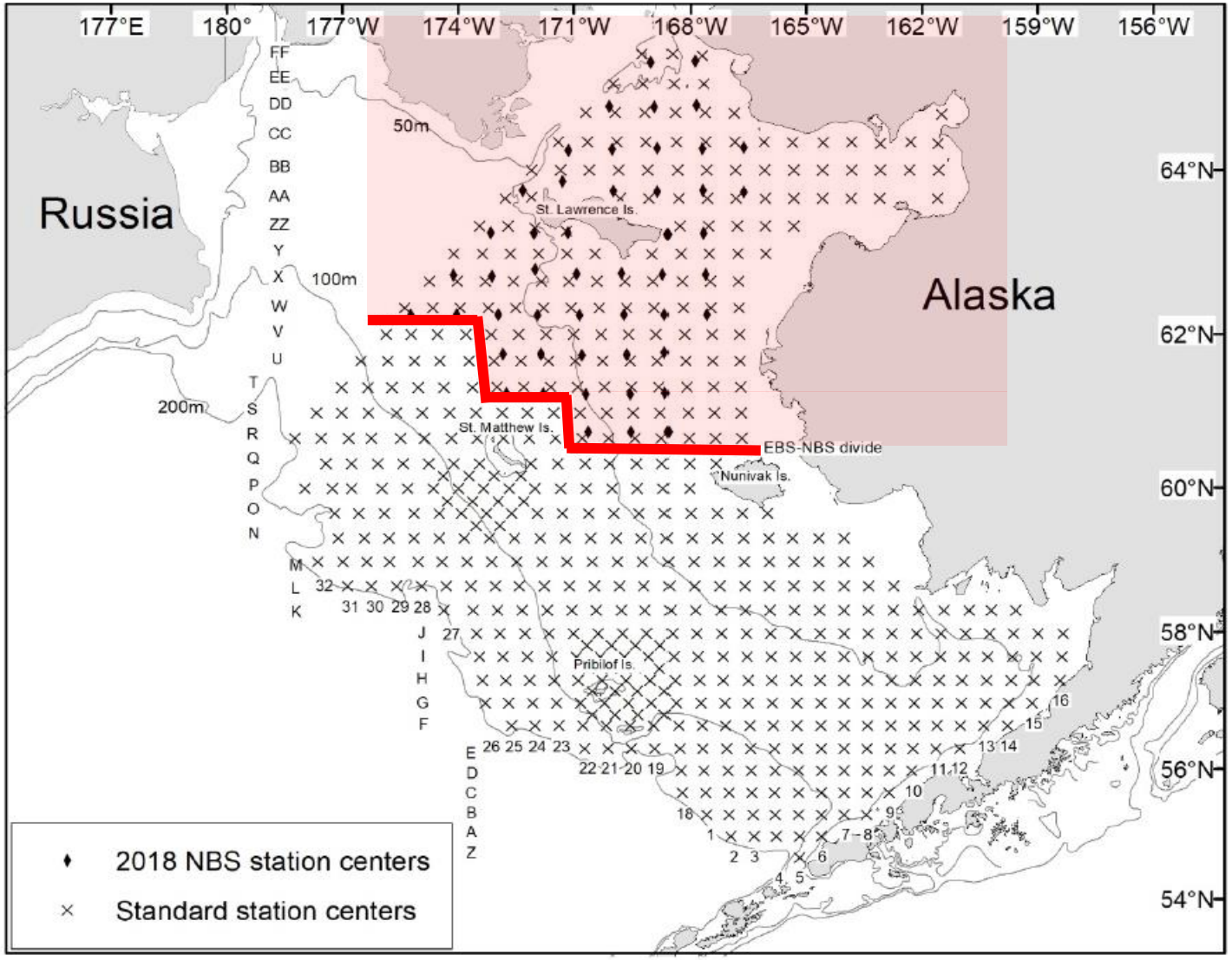
NOAA EBS bottom trawl survey

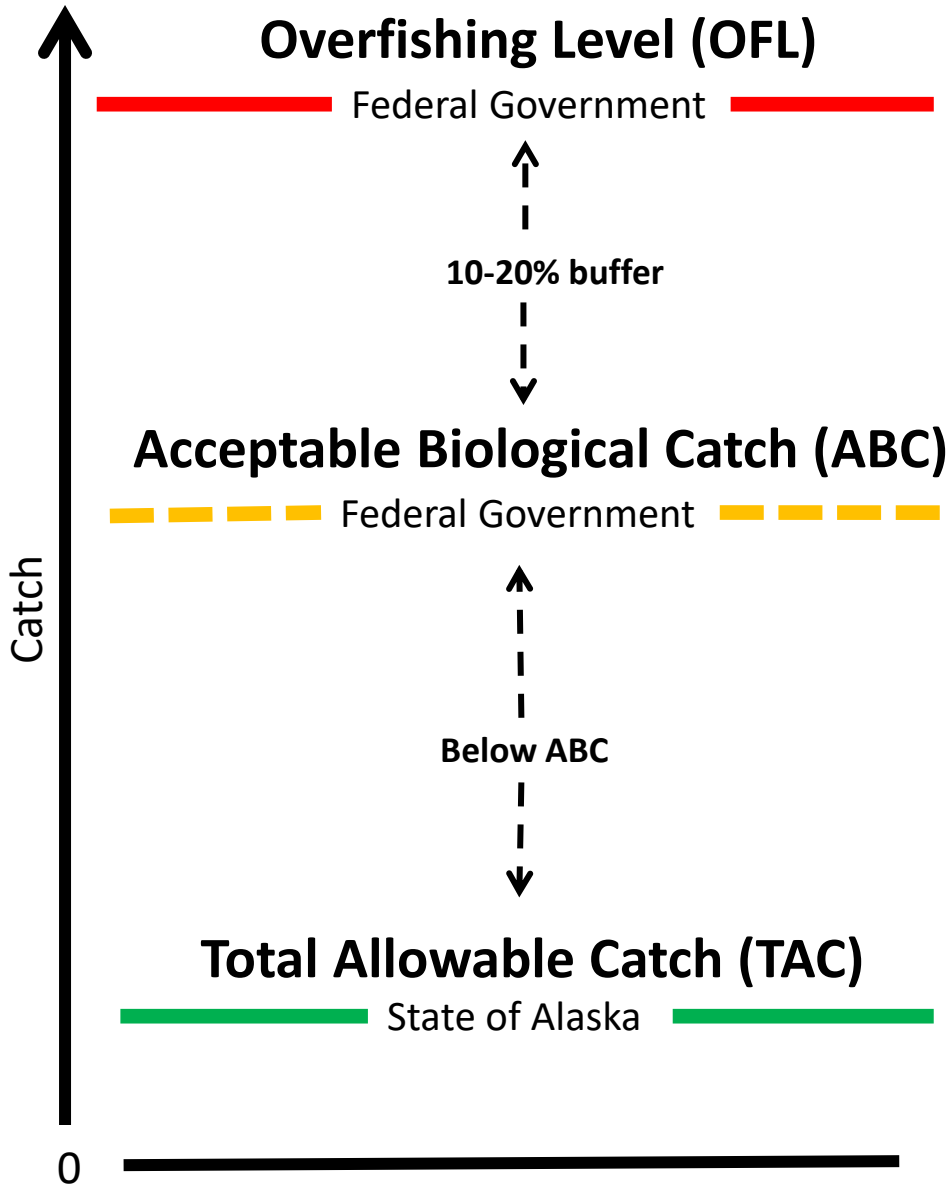
- 375 stations in standardized grid
  - 20 x 20 nmi grid + corner stations (high-density strata)
- Multi-species: crab + groundfish
- 83-112 Eastern otter trawl (83 ft head rope, 112 ft footrope)
  - Same gear since 1982
- Net mensuration gear
  - Bottom contact sensor
  - Net height + *width* sensors
  - GPS used for tow distance
  - Distance fished x net width data yield area-swept estimates for each haul

NOAA EBS bottom trawl survey



NOAA EBS + NBS bottom trawl surveys





OFL: Level of fishing mortality that jeopardizes the capacity of a stock to produce the maximum sustained yield on a continuing basis.

ABC: Level of annual catch that accounts for scientific uncertainty and is set to prevent the OFL from being exceeded.

In practice ABC limits mortality of **ALL** male and female crabs regardless of size, from all sources of fishery mortality (i.e. retained catch, bycatch in directed and nondirected crab fisheries, and groundfish fisheries).

TAC: Annual catch target for the directed fishery, set to prevent exceeding the ABC for that stock. **Limits legal sized males**, but must consider all sources of mortality to ensure the ABC is not exceeded.

Snow crab

2022 Assessment: scenario 22.1a

- SSC + Council adopted CPT recommendations
- Projected stock status: 30% of B_{MSY} (Feb 15, 2023)
  - **"Overfished"**: Below MSST (50% of B_{MSY})
  - Above federal threshold (25% B_{MSY}) for fishery closure
- Current stock status: 23% of B_{MSY} (Feb 15, 2022)

- OFL: 22.71 million lbs
- **ABC: 16.98 million lbs**
  - including bycatch mortality of males and females in all fisheries
  - based on a 25% buffer on OFL

Management Reference Points

B_{MSY}: Biomass that enables a stock to deliver maximum sustainable yield (i.e., the largest catches that can be taken over the long-term without causing population collapse)

- $B_{35\%}$ is proxy for B_{MSY} typically when S-R relationships are unreliable
  - biomass at which spawning biomass per recruit is 35% of unfished levels
- F_{MSY}: Fishing rate that allows for B_{MSY}
- $F_{35\%}$ is proxy for F_{MSY}

MSST (minimum stock size threshold): 50% of B_{MSY}

- MMB threshold for a stock to be declared "overfished"

Closure threshold: 25% of B_{MSY} (see next slide)

MMB: mature male biomass

- Considered "currency" of the stock
- MMB projected to Feb 15, 2023 (proxy time for mating) assuming OFL level removals and M (natural mortality)
- MMB/B_{MSY} is stock status

Federal Control Rule

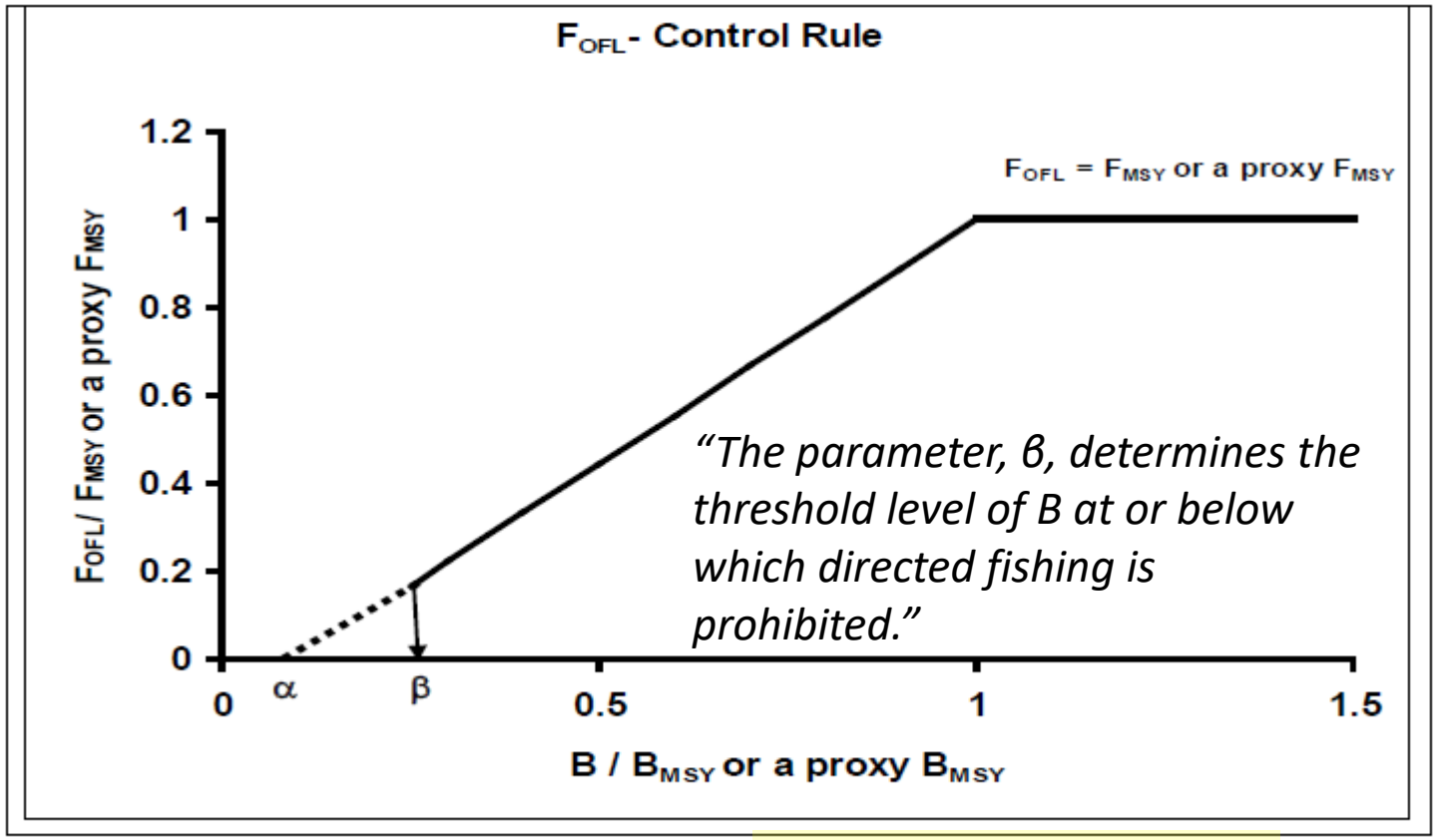


Figure 1. Overfishing control rule for Tiers 1 through 4. Directed fishing mortality is 0 below β.

β = 25%

Stock status = B/B_{MSY}

2022 big-picture situation

- Population collapse 2018-current, major uncertainties about the dynamics of the collapse
- 2020: no survey, 45 million lb TAC
  - Model estimated high M in 2018 + 2019
  - 2022 model estimated that most (>99%) of 4 inch males removed during 2020 fishery
  - Estimates of "*Q*" (catchability) decreased, thereby increasing magnitude of population estimates
  - 2020 US/Russia transboundary movement could mean harvested crab were not part of the assessed EBS population that year

2022 big-picture situation

- Change in model structure: GMACS
  - **G**eneralized **M**odeling for **A**laskan **C**rab **S**tocks (GMACS)
    - ADMB software that implements a generalized stock assessment platform for size-structured assessment
- Model retrospective patterns still present
- Ongoing model convergence issues
  - 2022 model bi-modal jittering analysis, some difficulty in interpreting 2 results (22.1a, 22.1ab)

SSC minutes from October meeting

"The SSC noted that these challenges did not appear to be a function of moving the assessment to GMACS, but rather related to the large number of estimated parameters and the challenge of modeling the complicated population dynamics for this species. However, the SSC highlights that the model instability observed in 2022 when the model was presented with new data is of great concern and underscores the need for continued model refinement."

SSC minutes from October meeting

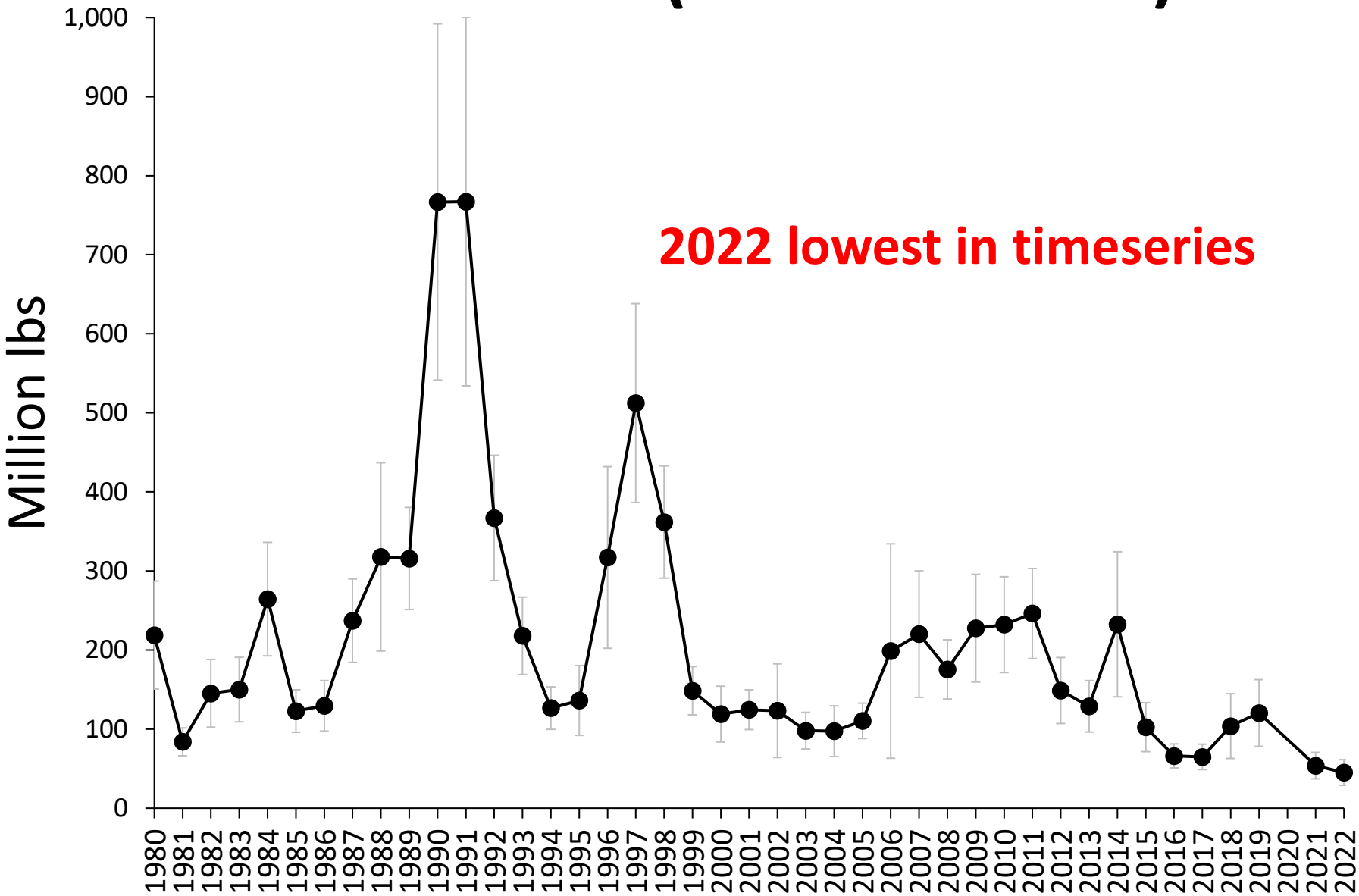
"The SSC renewed its request from 2021 for a Tier 4 calculation, intended to provide a "fall back" in case a clearly acceptable Tier 3 model is not available (as has been the case in 2021 and 2022)."

Tier 4 calculation was presented to CPT and SSC for consideration:

- **While Tier 4 assessment not recommended, the Tier 4 control rule would have resulted in 2022/23 fishery closure**

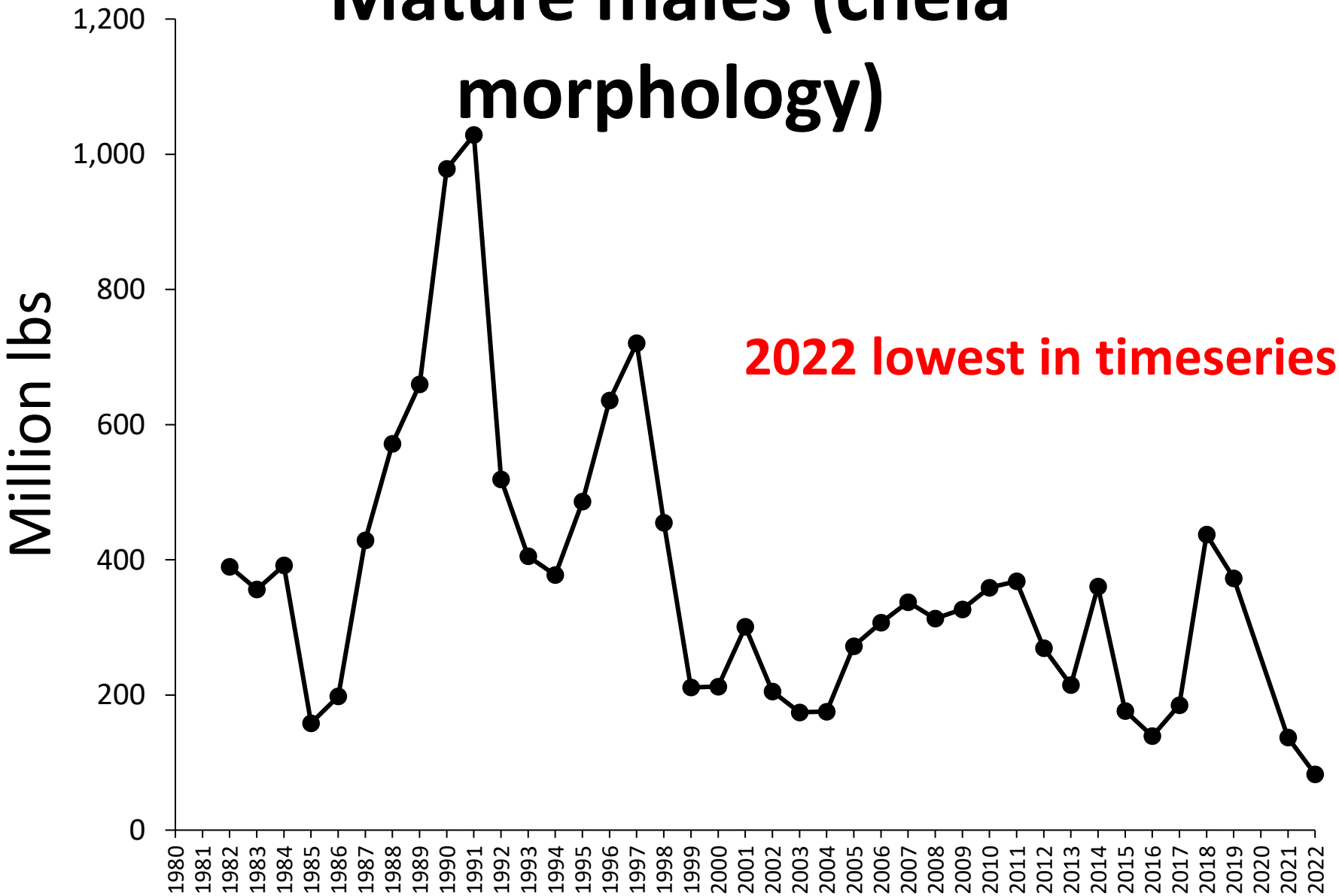
SURVEY DATA:
All components of the population at or near **all-time lows**

Mature males (>= 95 mm CW)



NOAA survey area-swept data

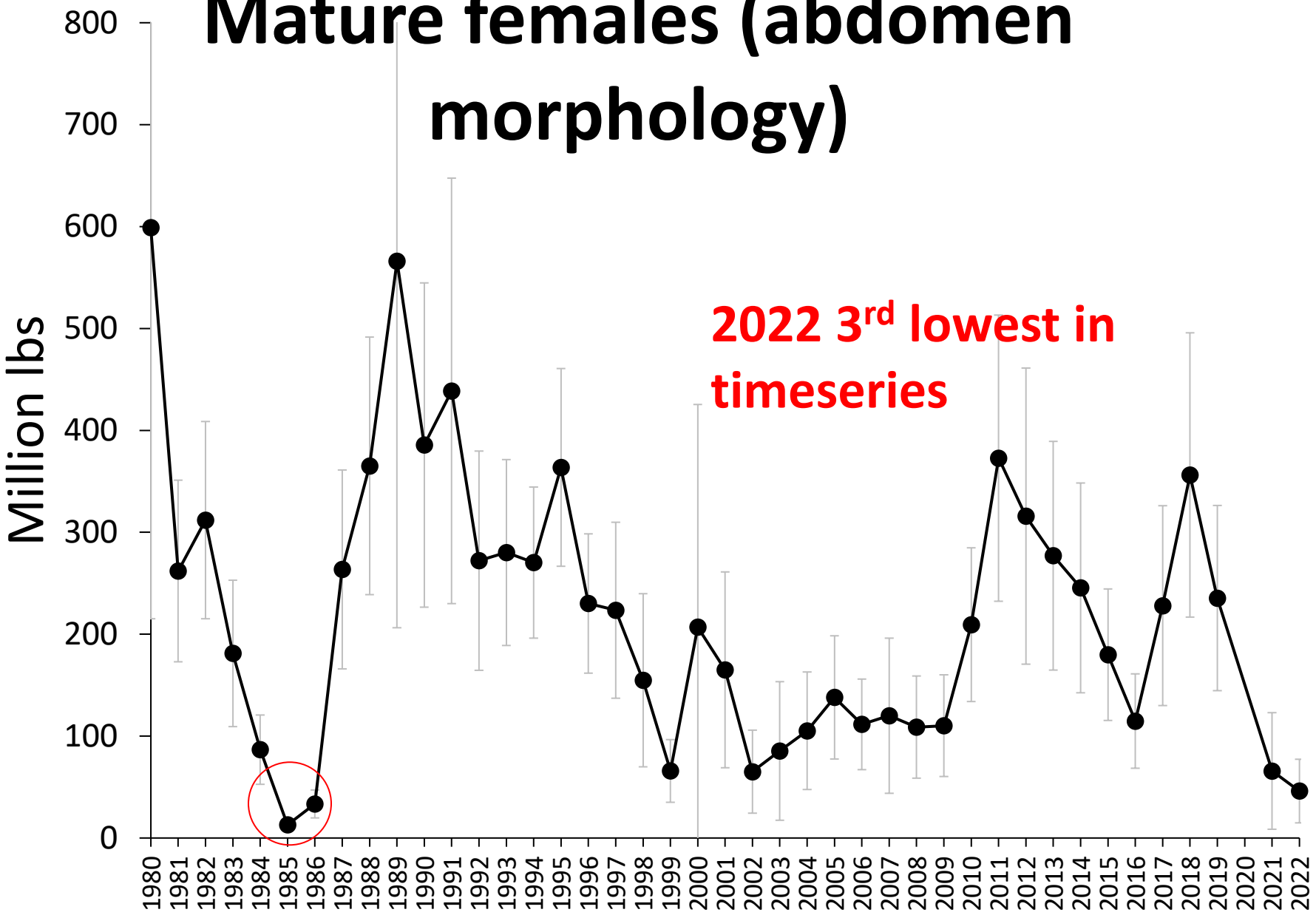
Mature males (chela morphology)



2022 lowest in timeseries

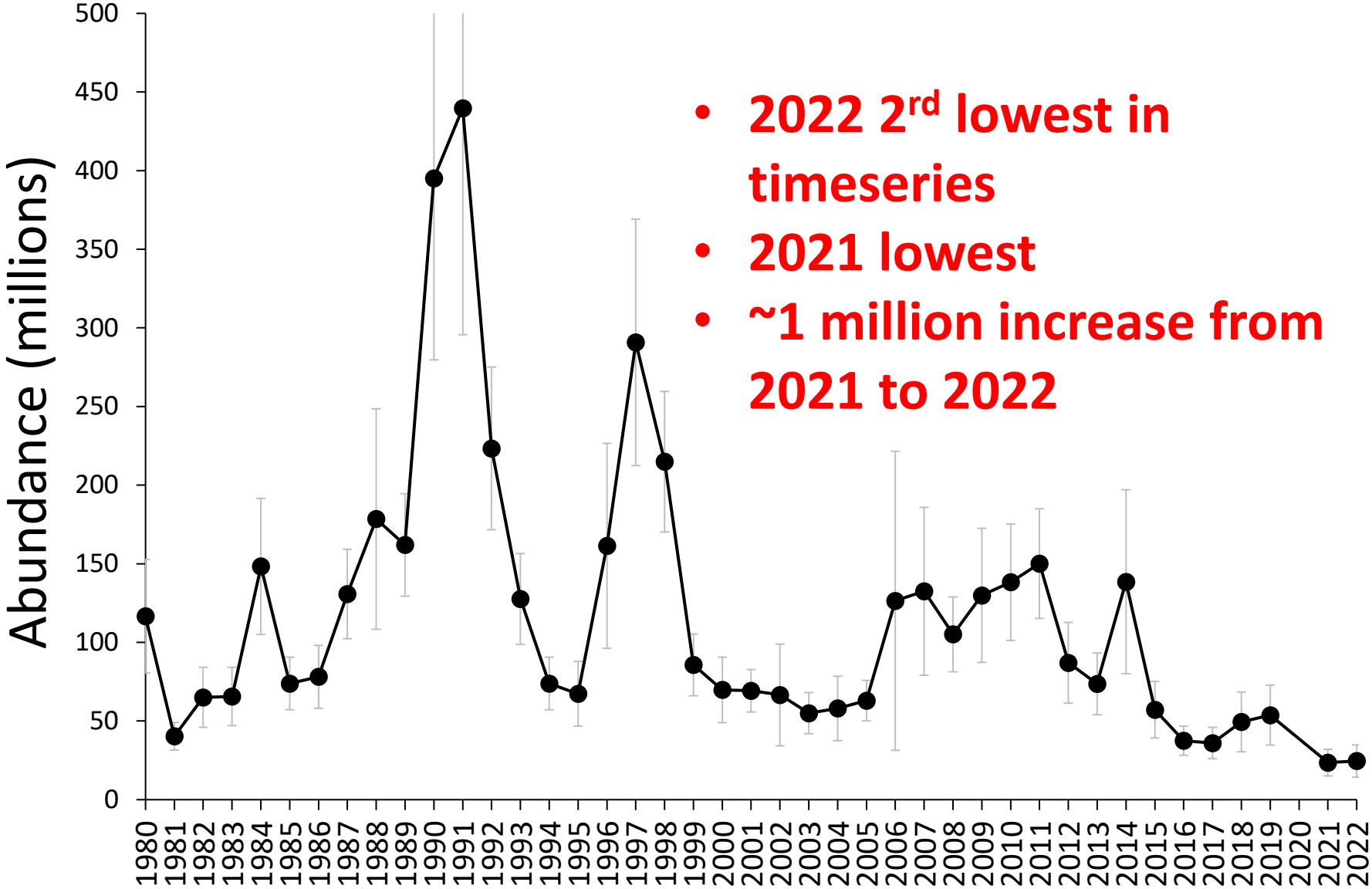
NOAA survey area-swept data (maturity ogive applied)

Mature females (abdomen morphology)



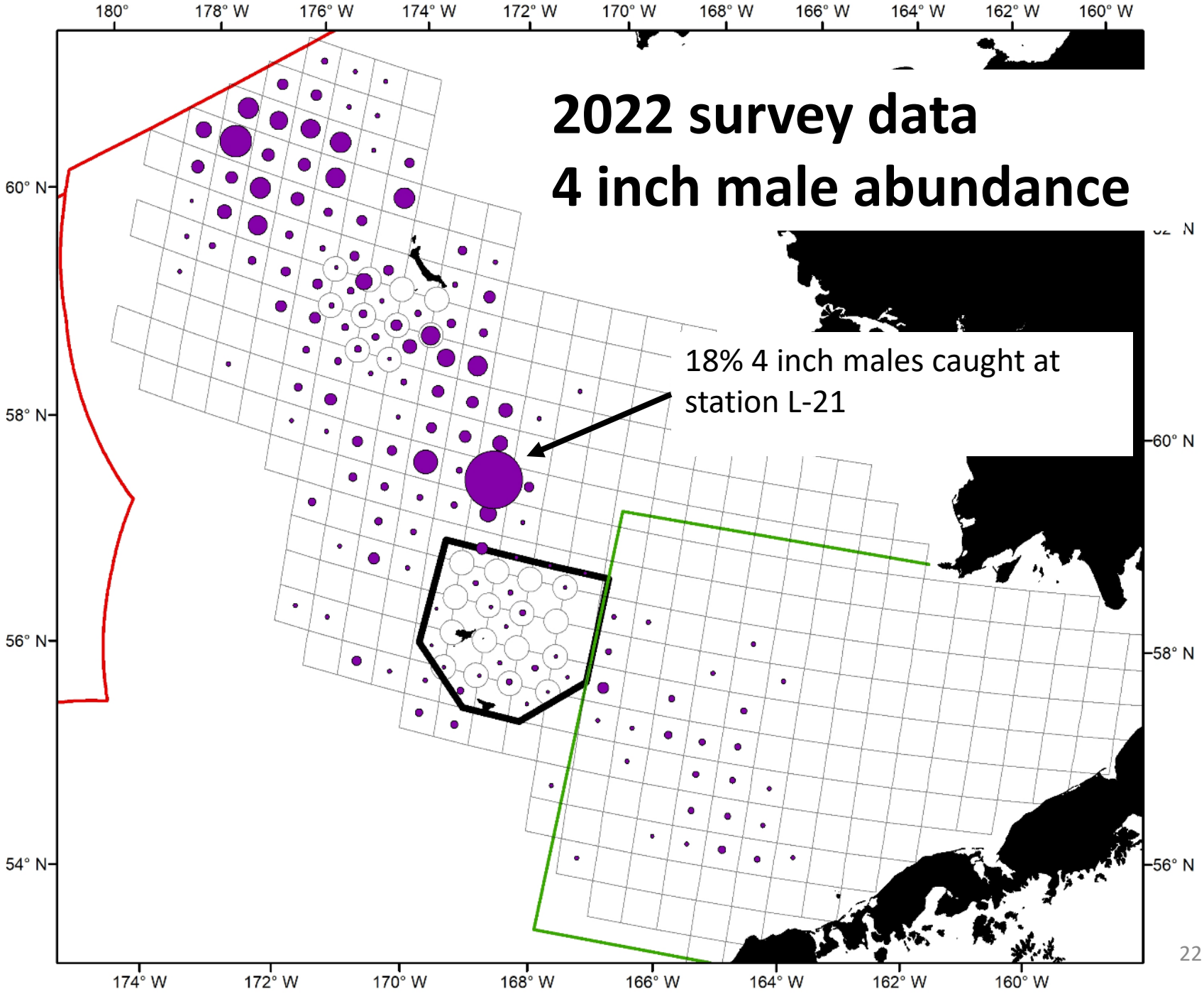
NOAA survey area-swept data

4 inch males



- **2022 2rd lowest in timeseries**
- **2021 lowest**
- **~1 million increase from 2021 to 2022**

NOAA survey area-swept data


2022 survey data
4 inch male abundance
18% 4 inch males caught at station L-21
180°
178° W
176° W
174° W
172° W
170° W
168° W
166° W
164° W
162° W
160° W
60° N
58° N
56° N
54° N

NOAA Technical Memorandum NMFS-AFSC

The 2022 Eastern Bering Sea Continental Shelf Trawl Survey: Results for Commercial Crab Species

By

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U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Alaska Fisheries Science Center
Kodiak Laboratory

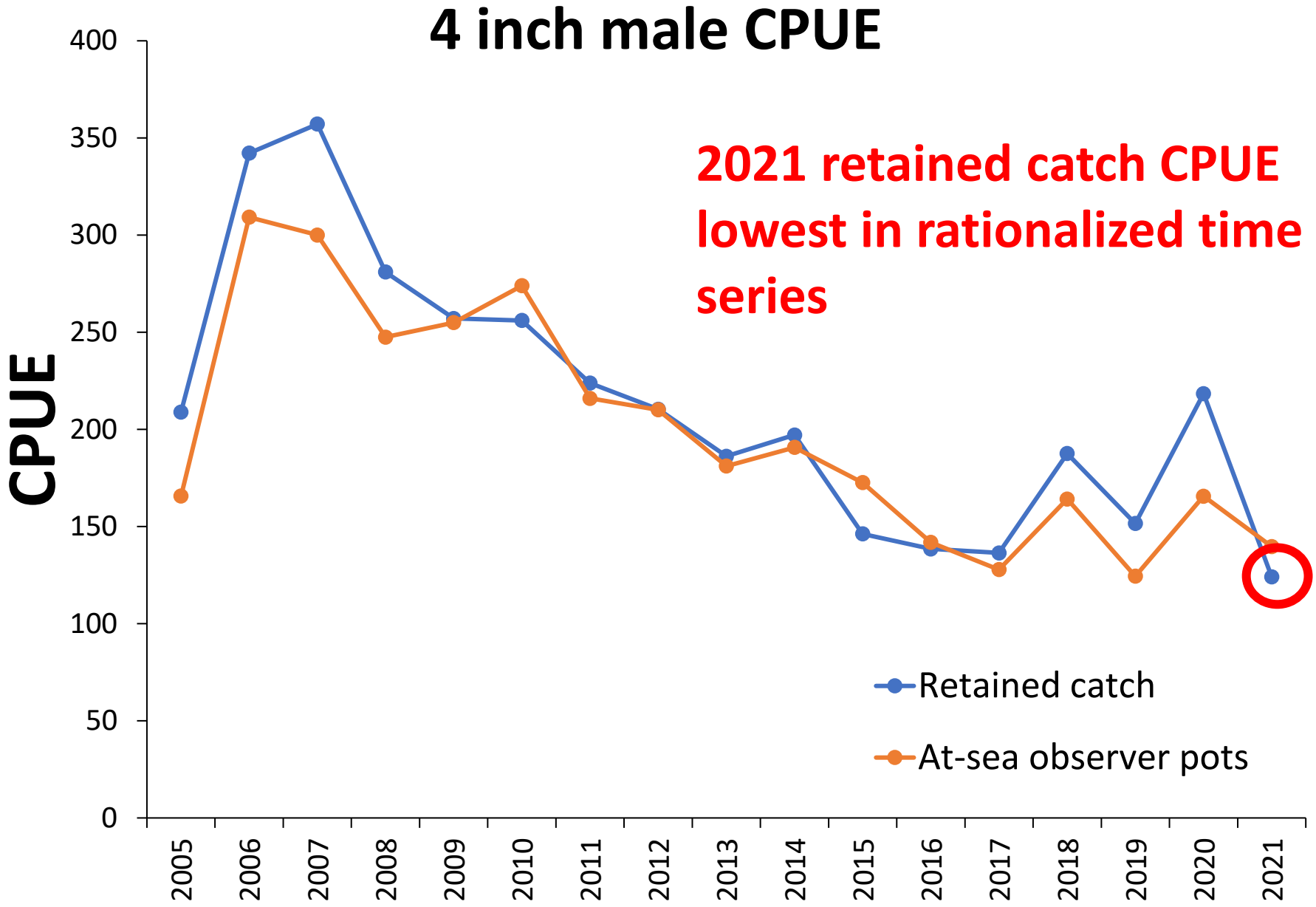
Draft version: September 2, 2022

Table 5. -- Summary of 2022 National Marine Fisheries Service eastern Bering Sea bottom trawl survey details for seven commercial crab stocks. Male size categories are defined in Table 1.

		Tows in District	Tows with crab	Crab caught	Crab measured	Biomass (t)	CI (± 95%)
Bristol Bay District Red King Crab	Immature male	136	34	136	136	3,129	1,295
	Mature Male	136	59	270	270	21,832	8,610
	Legal	136	55	196	196	18,060	7,616
	Immature female	136	19	78	78	946	642
	Mature female	136	44	245	245	10,280	4,991
Pribilof District Red King Crab	Immature male	77	1	1	1	0	0
	Mature Male	77	22	76	76	5,105	2,973
	Legal	77	22	75	75	5,075	2,973
	Immature female	77	0	0	0	0	0
	Mature female	77	12	31	31	989	768
Pribilof District Blue King Crab	Immature male	86	0	0	0	0	0
	Mature Male	86	2	2	2	111	152
	Legal	86	2	2	2	111	152
	Immature female	86	0	0	0	0	0
	Mature female	86	4	7	7	145	189
St. Matthew Is. Blue King Crab	Immature male	56	8	133	133	1352	1,354
	Mature Male	56	10	51	51	1,902	2,036
	Legal	56	8	34	34	1,467	1,734
	Immature female	56	5	50	50	360	511
	Mature female	56	5	37	37	549	612
Tanner Crab east of 166°W	Immature male	120	71	1,557	2,161	6,036	2,165
	Mature Male	120	60	499	499	8,725	3,457
	Legal	120	54	330	330	6,450	2,805
	Preferred	120	47	217	217	4,676	2,142
	Immature female	120	37	885	1381	690	509
	Mature female	120	51	345	345	1,800	811
Tanner Crab west of 166°W	Immature male	255	160	3,079	4,791	7,676	2,510
	Mature Male	255	115	593	593	6,816	1,715
	Legal	255	102	401	401	5,131	1,330
	Preferred	255	50	94	94	1,576	517
	Immature female	255	124	2,141	3,668	1,975	910
	Mature female	255	91	827	1,240	4,767	2,490
Snow Crab	Immature male	375	228	6,953	23,431	37,727	14,414
	Mature Male	375	191	1,594	1,730	20,403	7,374
	Legal	375	223	3,399	3,800	33,447	9,780
	Preferred	375	155	920	1,000	13,494	5,731
	Immature female	375	130	3,902	35,851	26,219	17,548
	Mature female	375	74	1,810	18,591	20,941	14,162

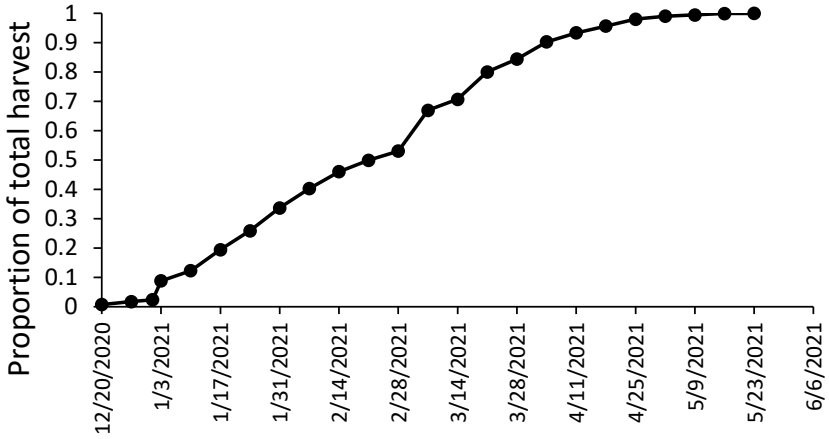
SSC minutes from October meeting

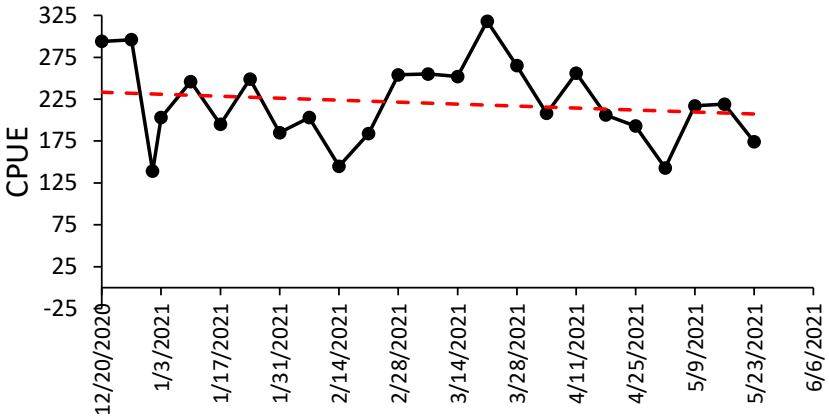
"The SSC emphasizes that, despite missing survey data in 2020 and complex population response to warming waters, a critical conclusion from this assessment is the continued low abundance of larger snow crab in the EBS based on both the available data and modeled dynamics. This supports the explanation of a large mortality event rather than a distributional shift or change in catchability."


4 inch male CPUE
2021 retained catch CPUE lowest in rationalized time series
CPUE
400
350
300
250
200
150
100
50
0
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
Retained catch
At-sea observer pots

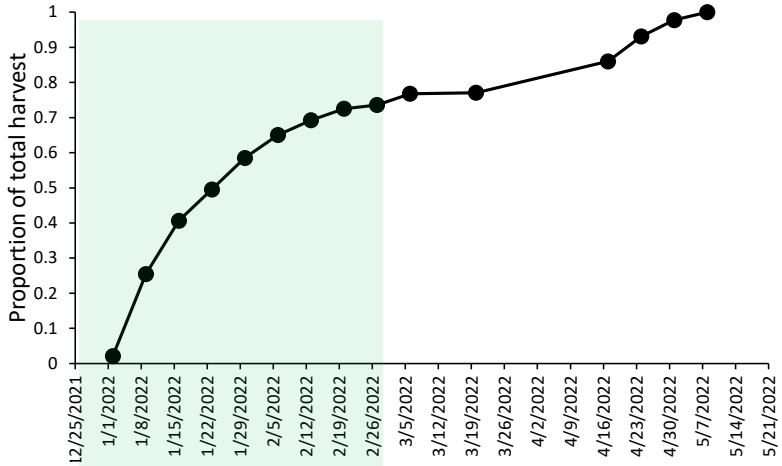
Within Season fishery performance

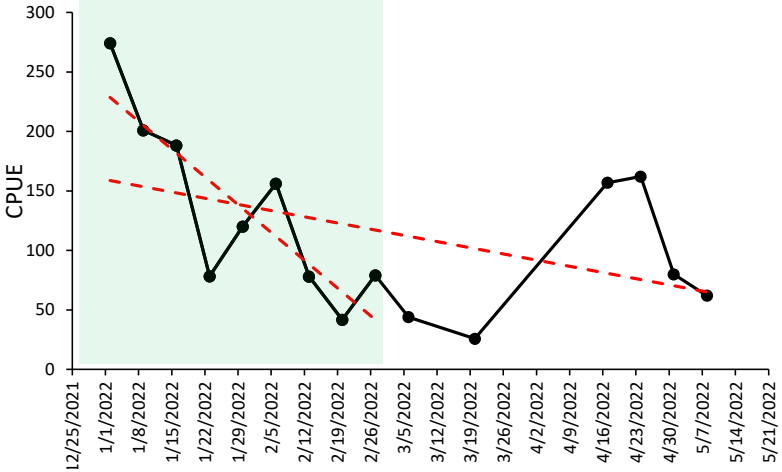
2020/21 season: 45 mill lb TAC



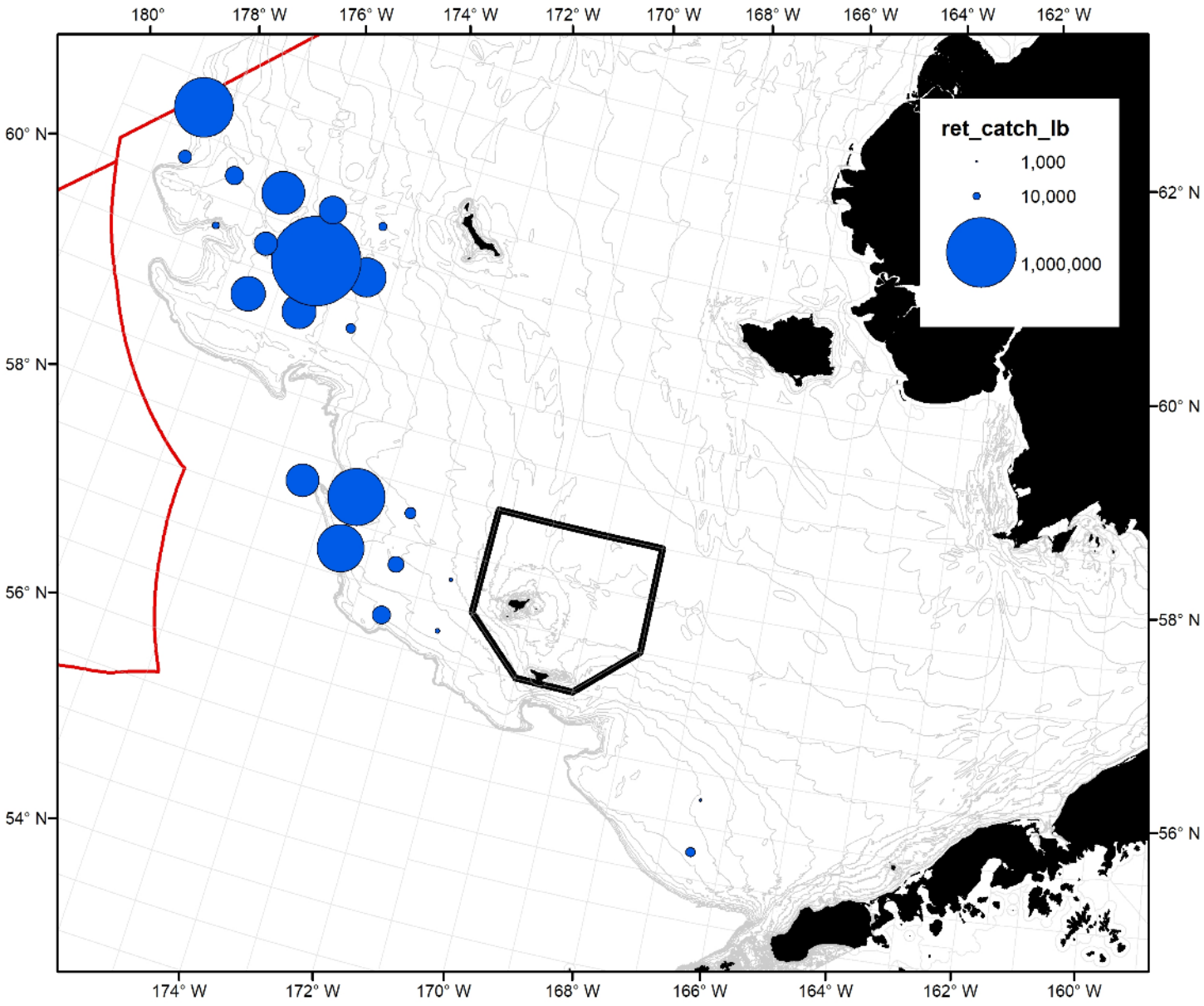


2021/22 season: 5.6 mill lb TAC



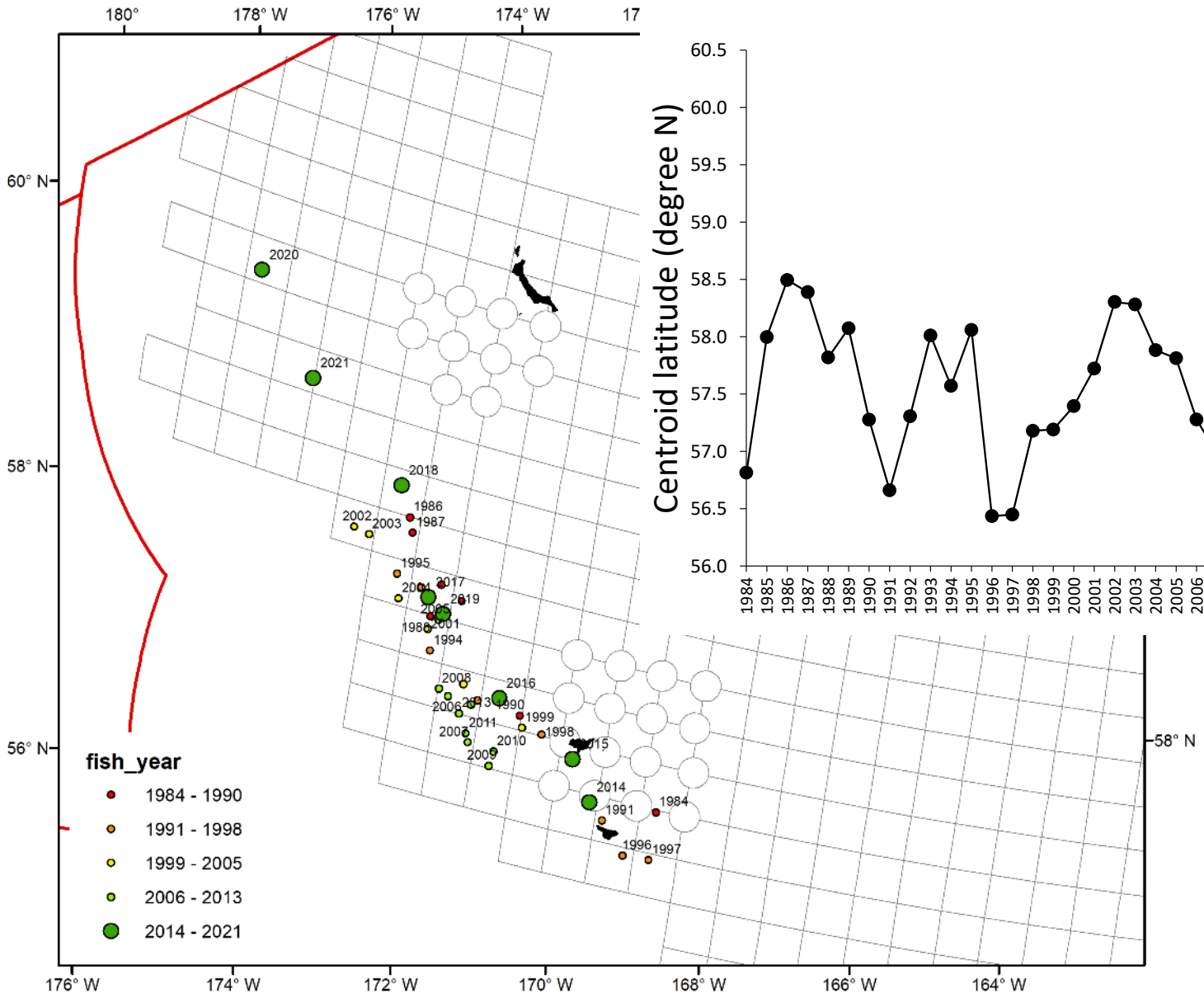


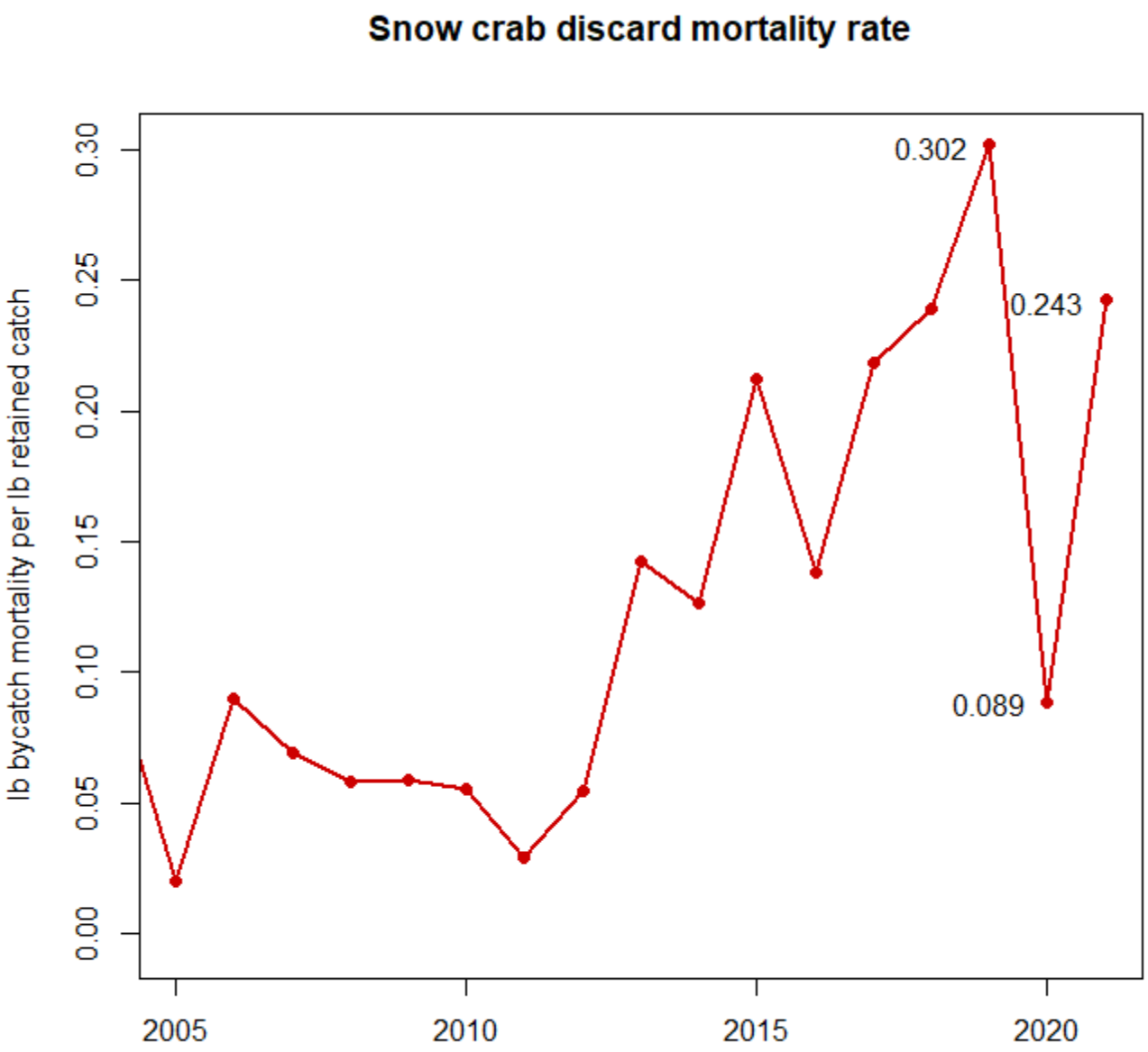
2021/22 snow crab retained catch



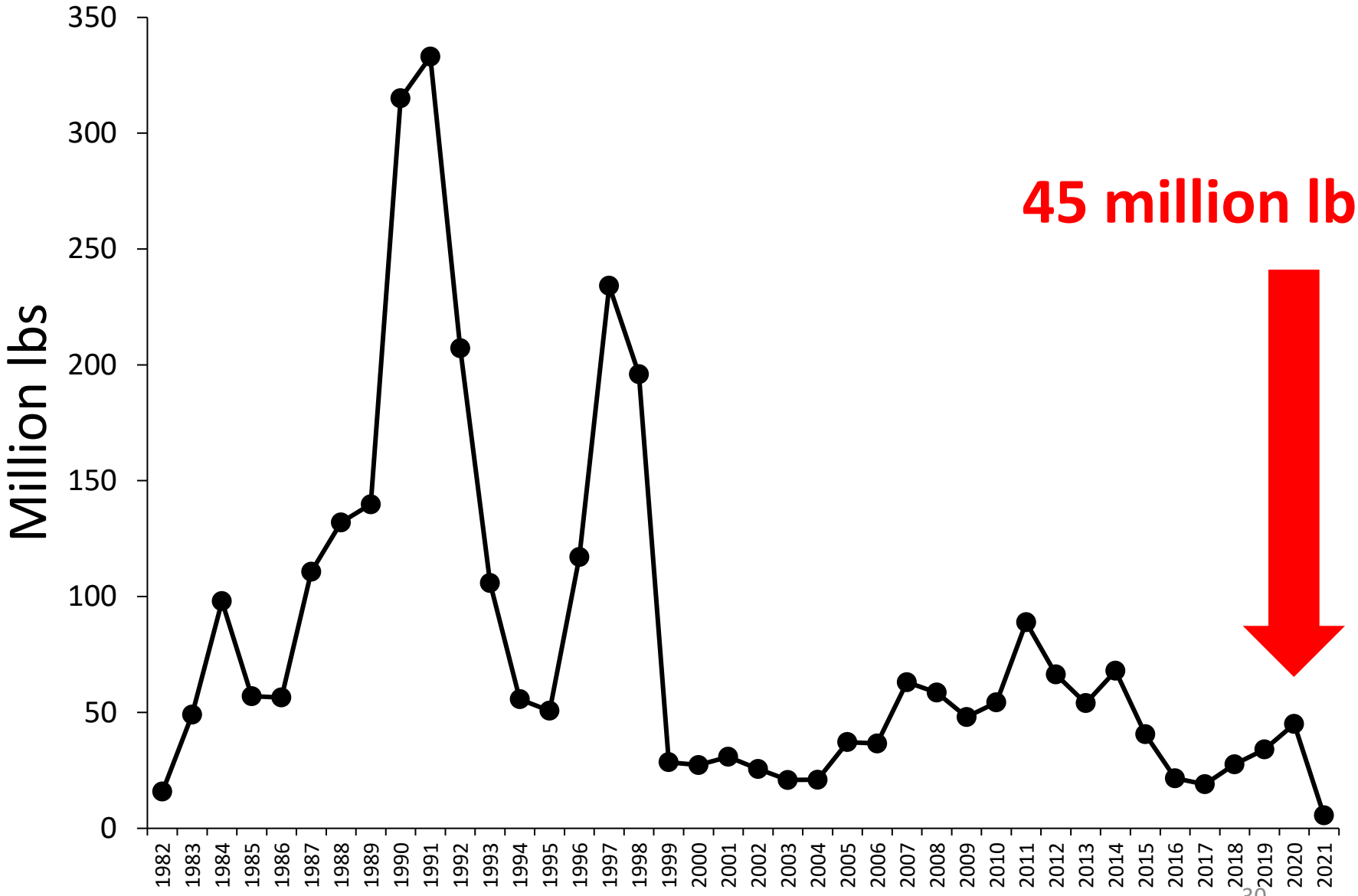
* Excludes stat areas with <3 vessels

Snow crab weighted mean centers of catch

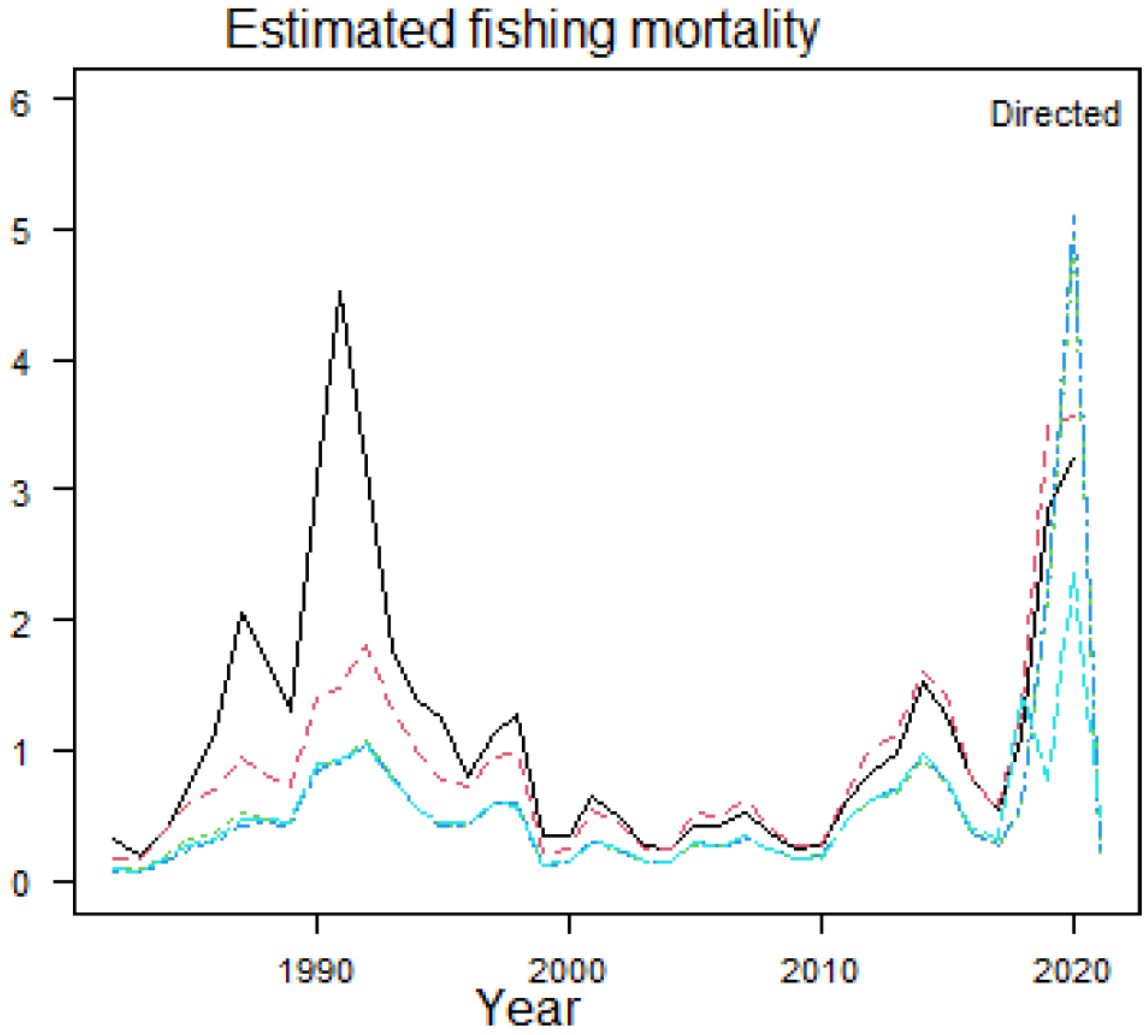



Snow crab discard mortality rate
lb bycatch mortality per lb retained catch
0.00
0.05
0.10
0.15
0.20
0.25
0.30
2005
2010
2015
2020
0.302
0.243
0.089

Historical TACs



Uncertainty in characterizing 2018-current collapse



Two potential histories:

22.1a:
- ~3 recruitments
- Two large mortalities on MMB
- Implausibly high F

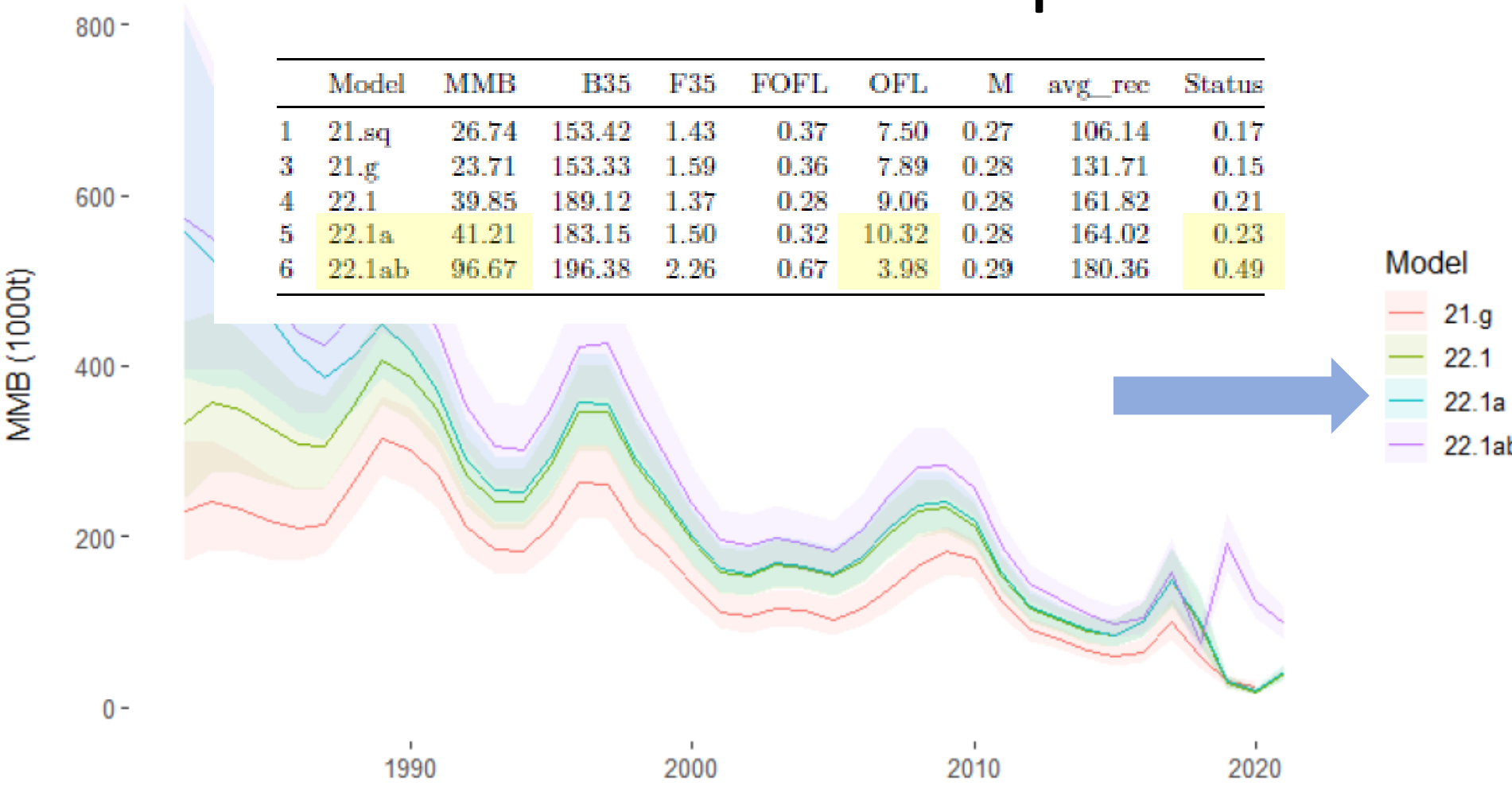
22.1ab:
- One recruitment
- One large mortality on MMB
- More reasonable Fs

22.1a estimates 99.5% of 4 inch males removed in 2020 fishery

Slide from Szuwalski presentation to CPT, Sept 2022

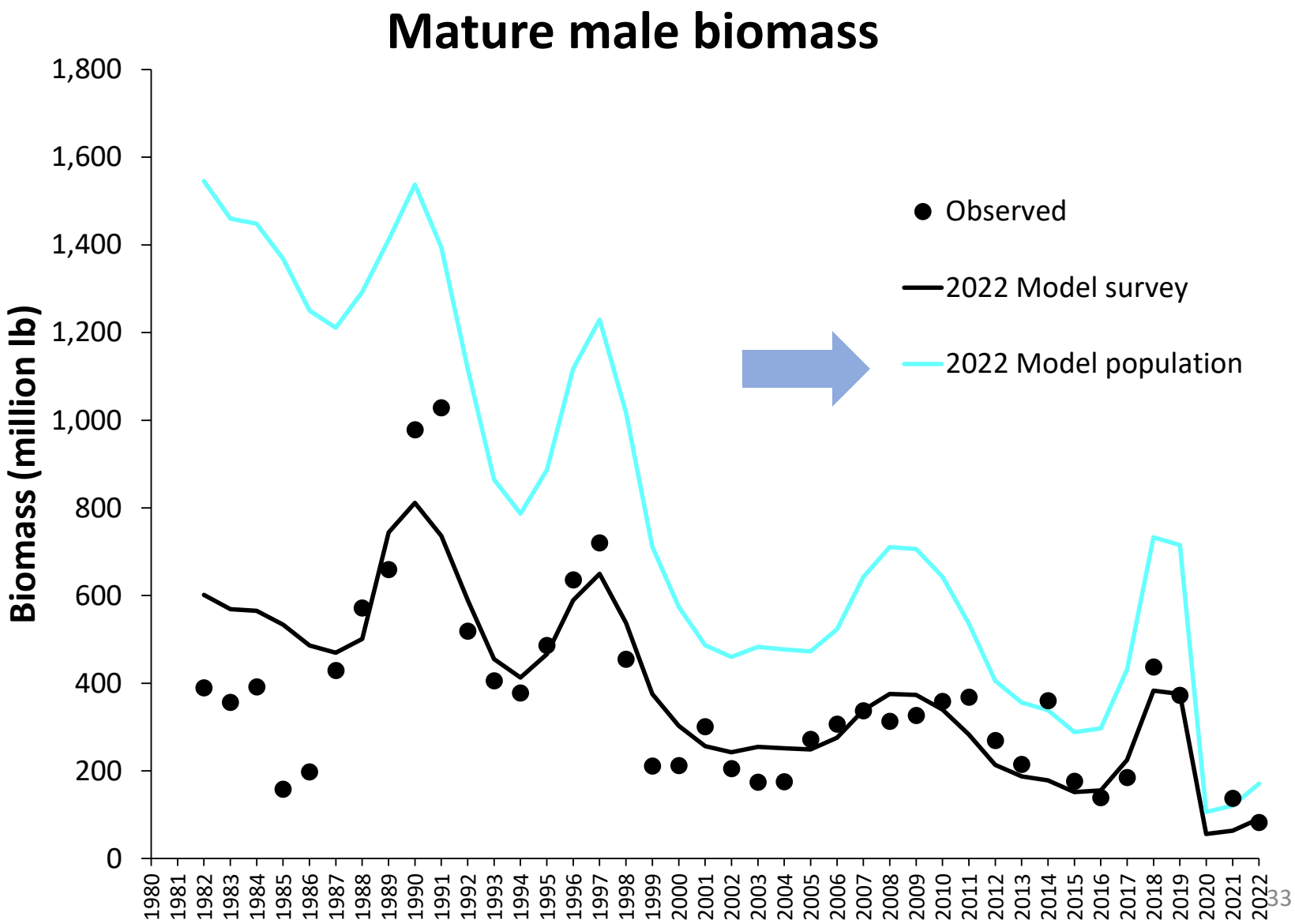
Uncertainty in characterizing 2018-current collapse

	Model	MMB	B35	F35	FOFL	OFL	M	avg_rec	Status
1	21.sq	26.74	153.42	1.43	0.37	7.50	0.27	106.14	0.17
3	21.g	23.71	153.33	1.59	0.36	7.89	0.28	131.71	0.15
4	22.1	39.85	189.12	1.37	0.28	9.06	0.28	161.82	0.21
5	22.1a	41.21	183.15	1.50	0.32	10.32	0.28	164.02	0.23
6	22.1ab	96.67	196.38	2.26	0.67	3.98	0.29	180.36	0.49

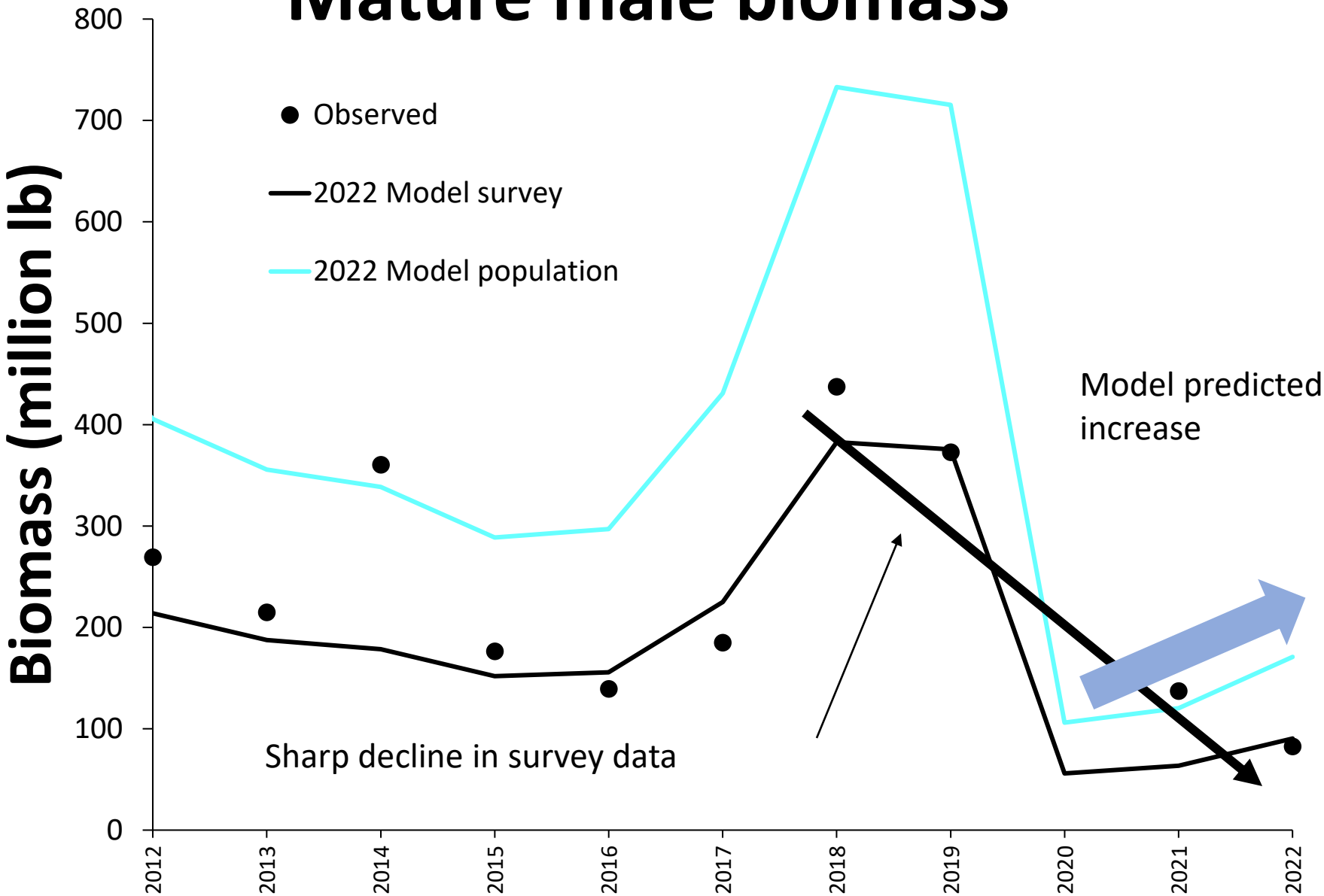


Slide from Szuwalski presentation to CPT, Sept 2022

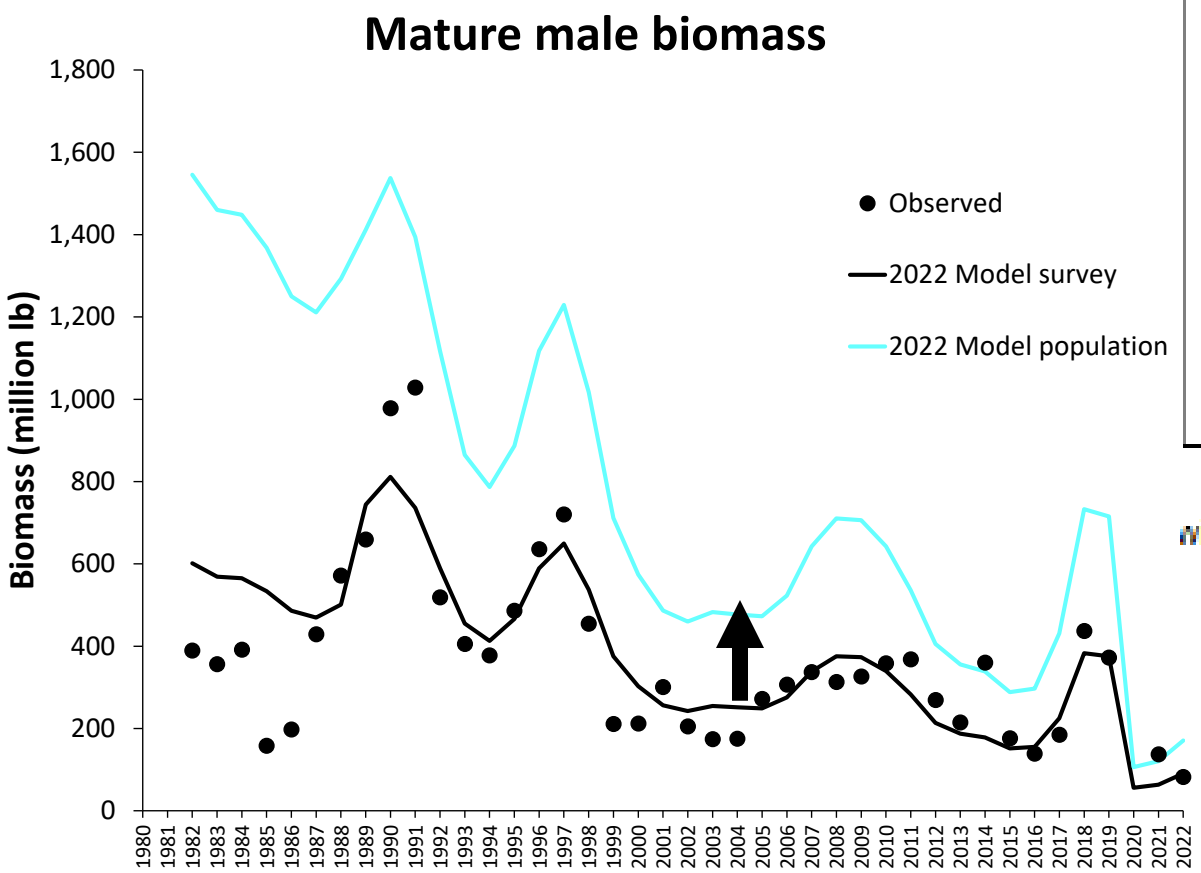
Model Estimates: MMB

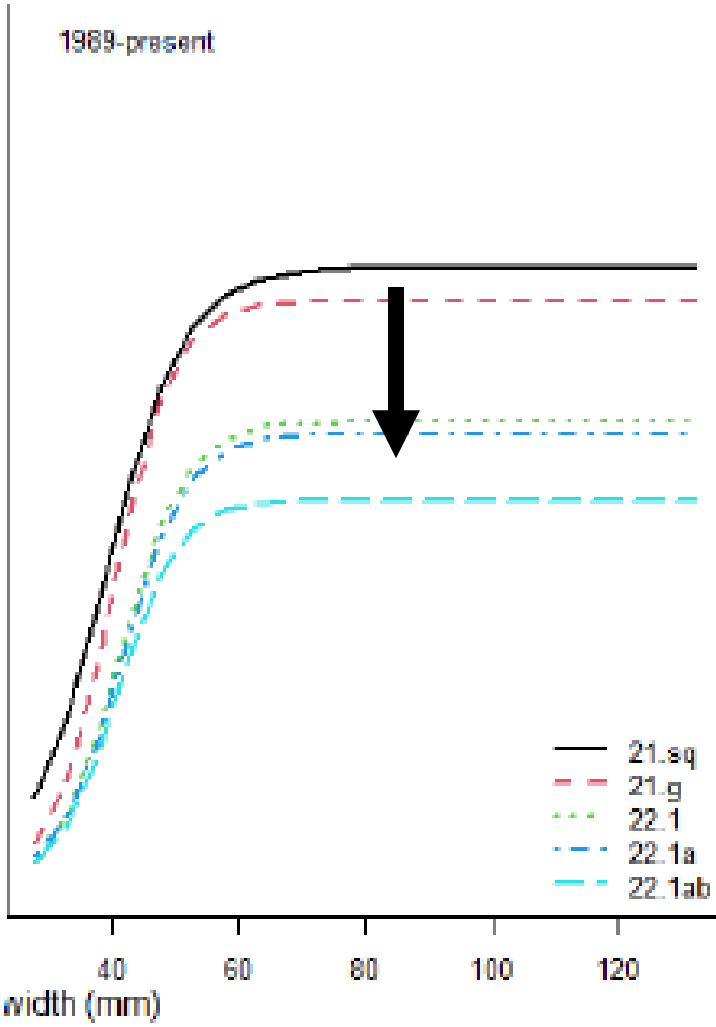


Mature male biomass



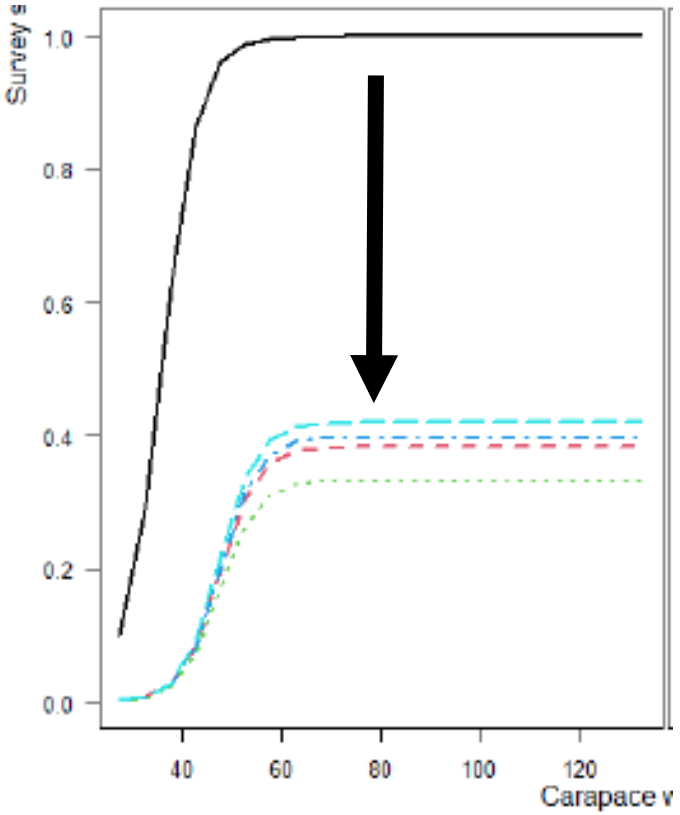
Catchability Q decrease increases magnitude of model population estimates



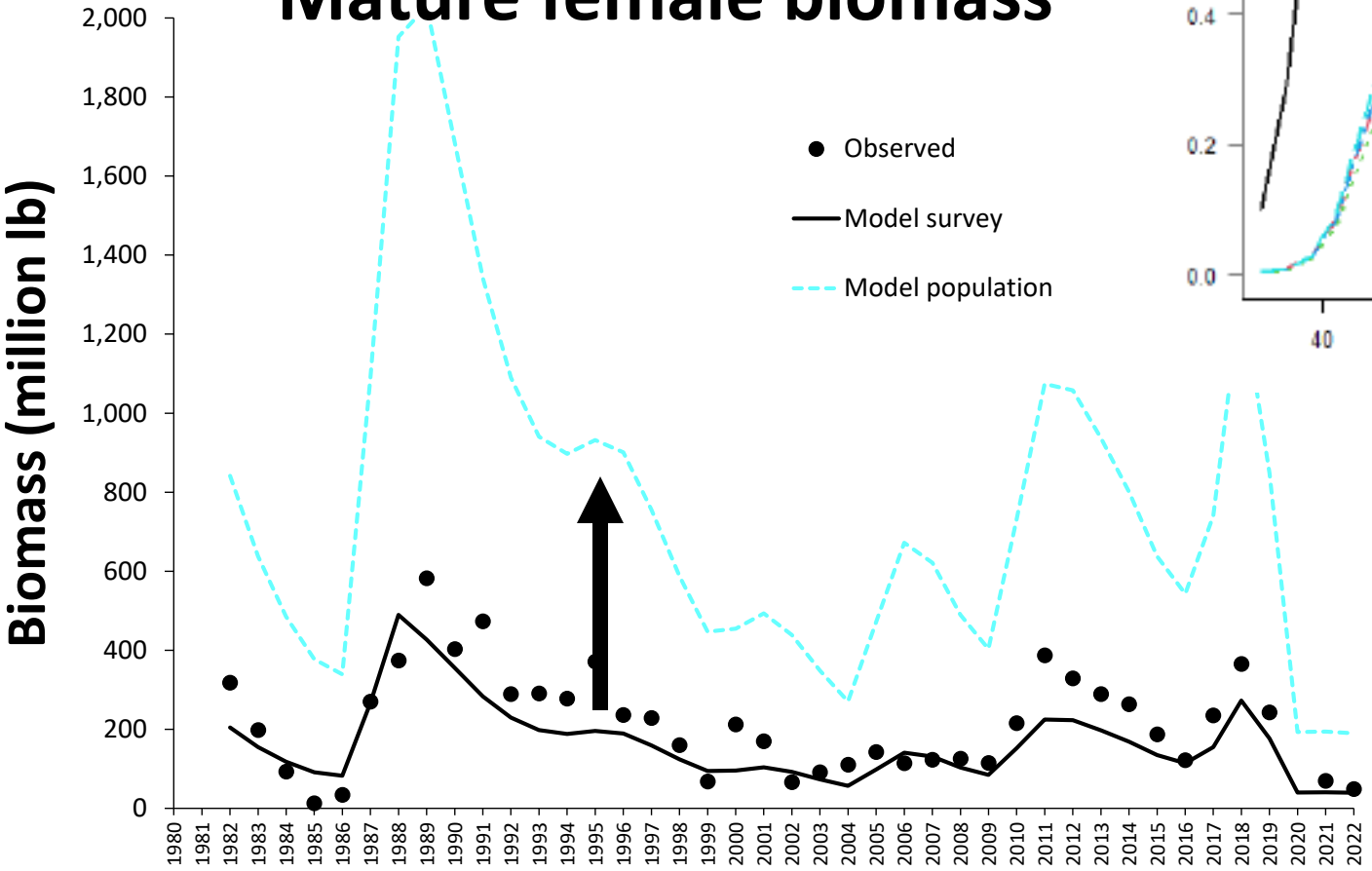


Q closer to that implied by BSFRF data, and comparable to that in Tanner crab assess.

Catchability Q decrease increases magnitude of model population estimates

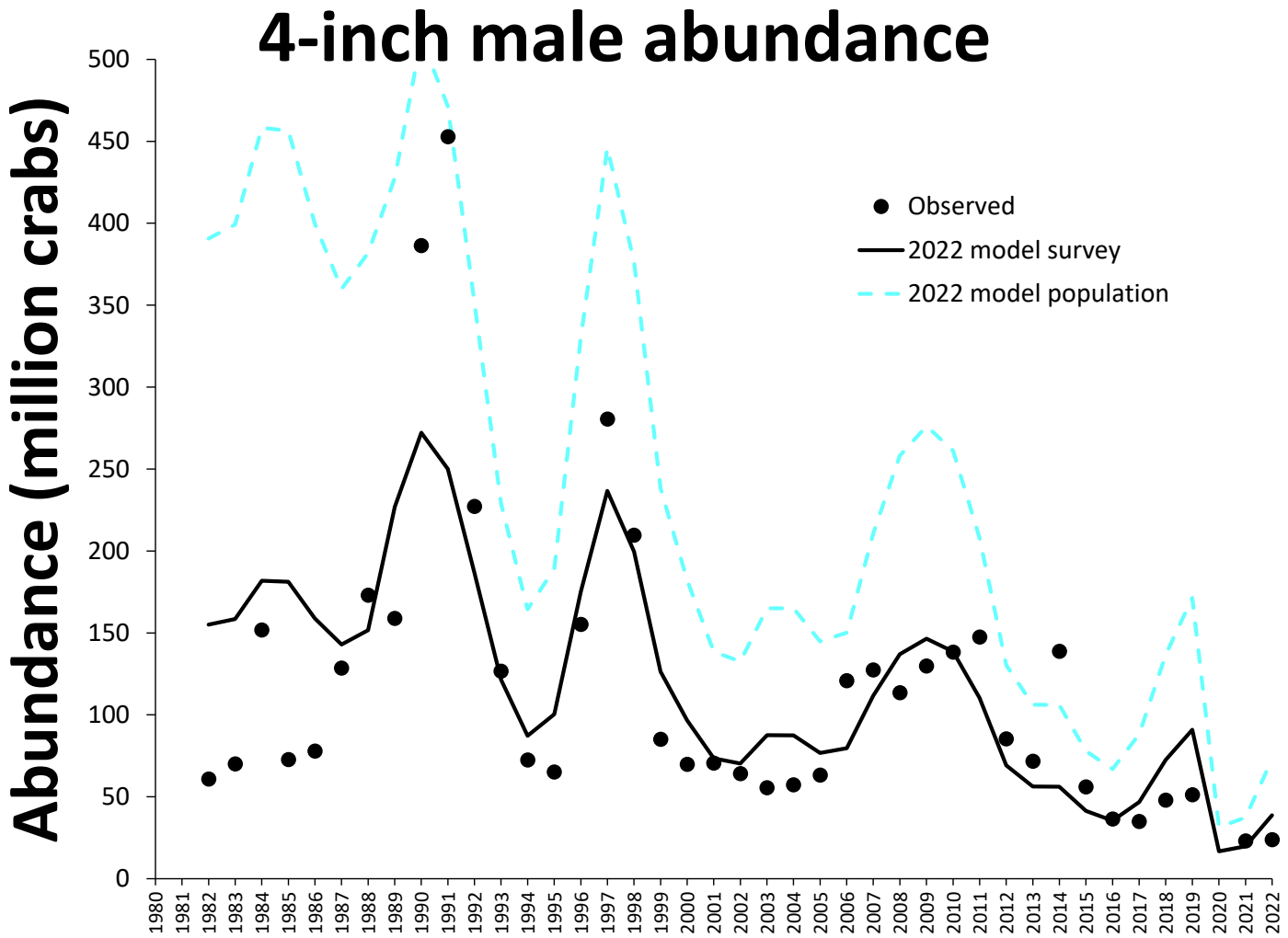


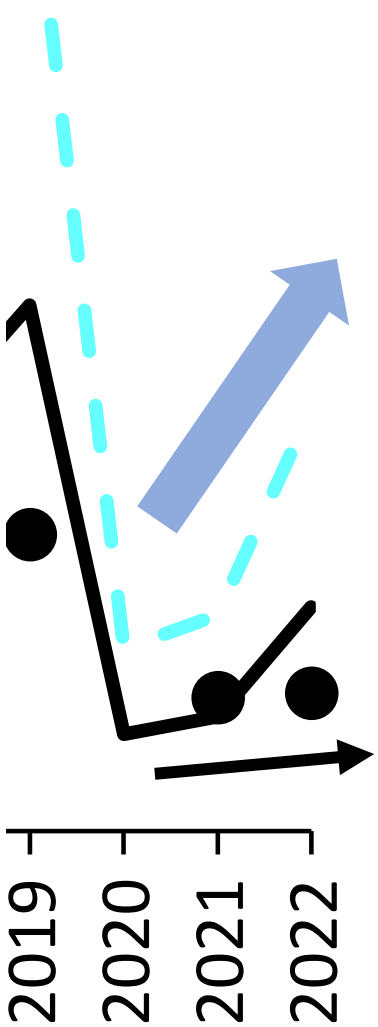
Mature female biomass



Q closer to that implied by BSFRF data, and comparable to that in Tanner crab assess.

Model estimates larger increase in 4 inch males than survey data





Inter-annual population changes

Additions

- Recruitment (R): "new" individuals entering population or size class
  - Good female fertilization, larval survival, settlement, growth to stages detectable by survey
- Growth: existing individuals transitioning from one size class to the next

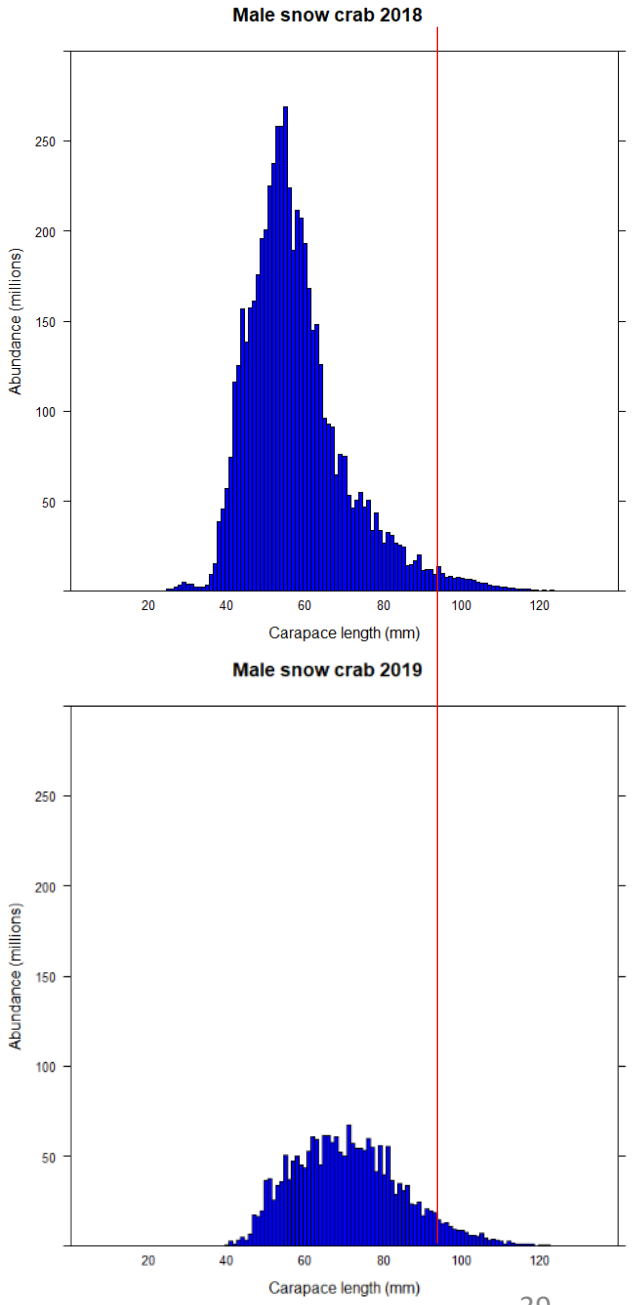
Subtractions

- Fishing mortality (F): removals from retention + discarding/bycatch
- Natural mortality (M): individuals dying of "natural" causes such as predation, starvation, disease, senescence, thermal stress, etc, etc, etc,
- Movement: individuals leaving surveyed area (generally assume neutral effect, but was discussed as potential cause of recent decline given environmental changes)

Characterizing the 2018-2022 collapse

2018-2019:

- 2018 strongest juvenile cohort in timeseries
- Most of 2019 decline was in the juvenile sizes: net loss of ~2.5 billion juvenile males (not accounting for survey selectivity)
- Retained catch 27.7 mill lbs
- MMB (>95 mm CW) increased from 104 million lbs to 120 million lbs
- Lots of M in juvenile sizes, but juvenile size class was so strong in 2018 that growth exceeded M

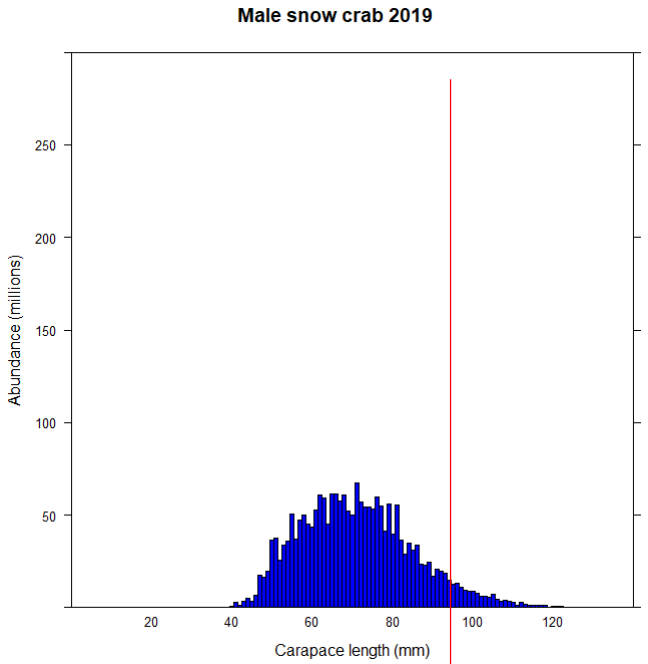


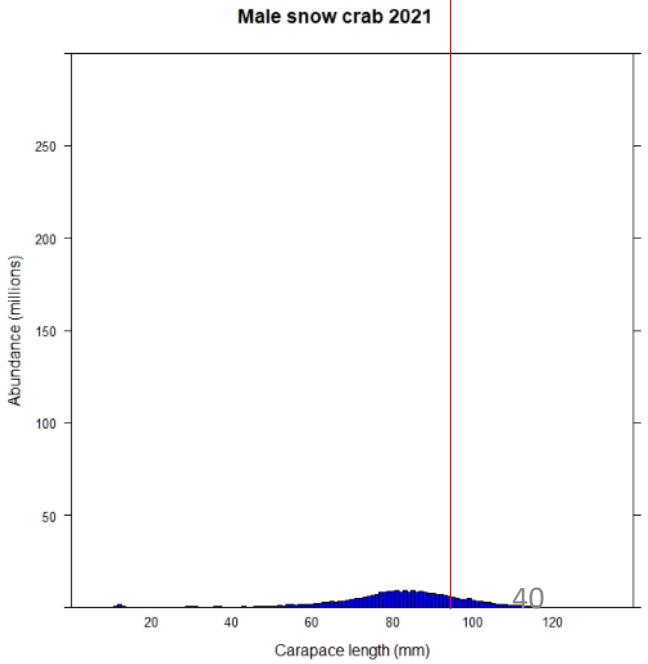
NOAA survey area-swept data

Characterizing the 2018-2022 collapse

2019-2021:

- No strong recruitment
- Juvenile size classes dissipate
- Retained catch during that period 79 million lbs (104 total catch)
- Natural mortality and fishery mortality exceeds Growth and R into mature males sizes (≥95 mm CW)
- MMB declines from 120 to 54 million lbs (66 mill lb loss)



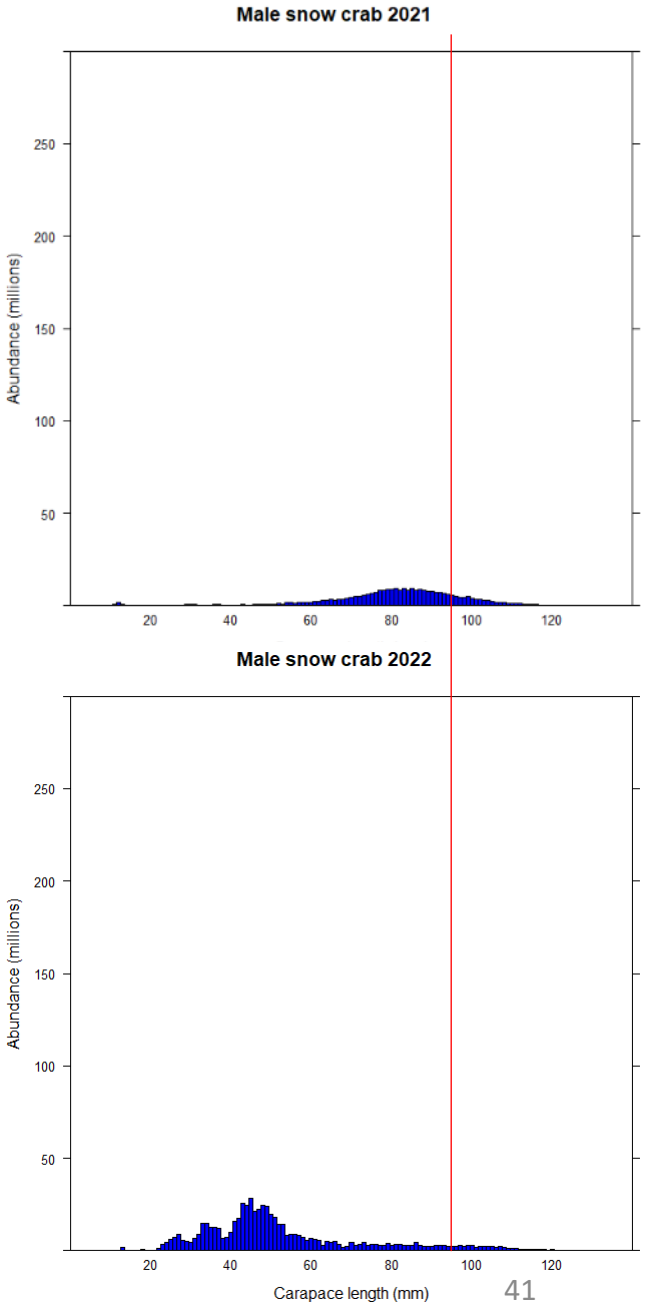


NOAA survey area-swept data

Characterizing the 2018-2022 collapse

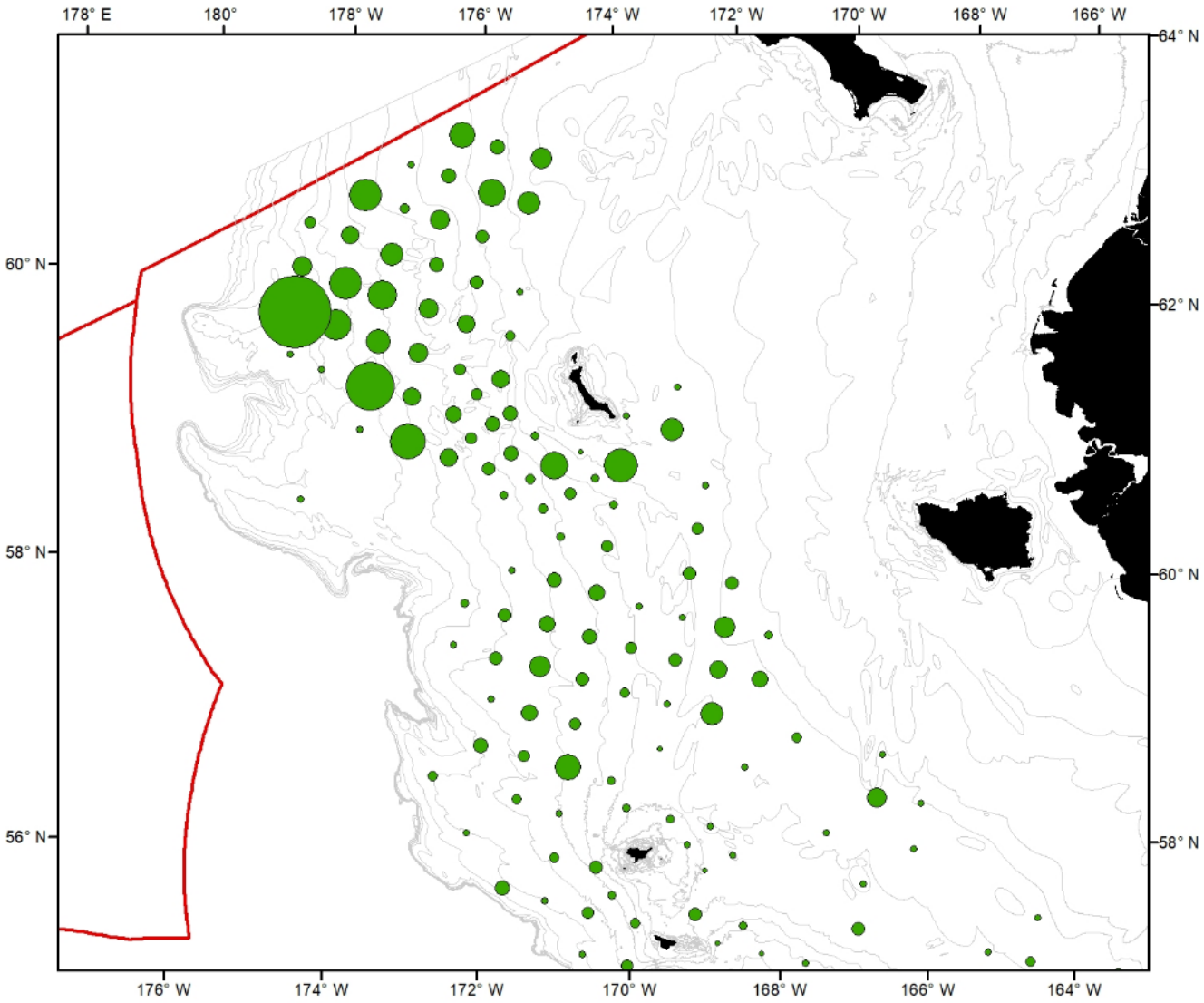
2021-2022:

- >50 mm size classes dissipate
- Natural mortality and fishery mortality exceeds Growth and R into mature males sizes (≥95 mm CW)
- MMB declines from 54 to 45 million lbs
  - **9 mill lb decline**, fishery removals in 2021 were 5.5 mill lb (**total catch ~8 mill lbs**)
- Some R to small juvenile sizes
- **2019-2022 total fishery removals: 112 million lbs!!**

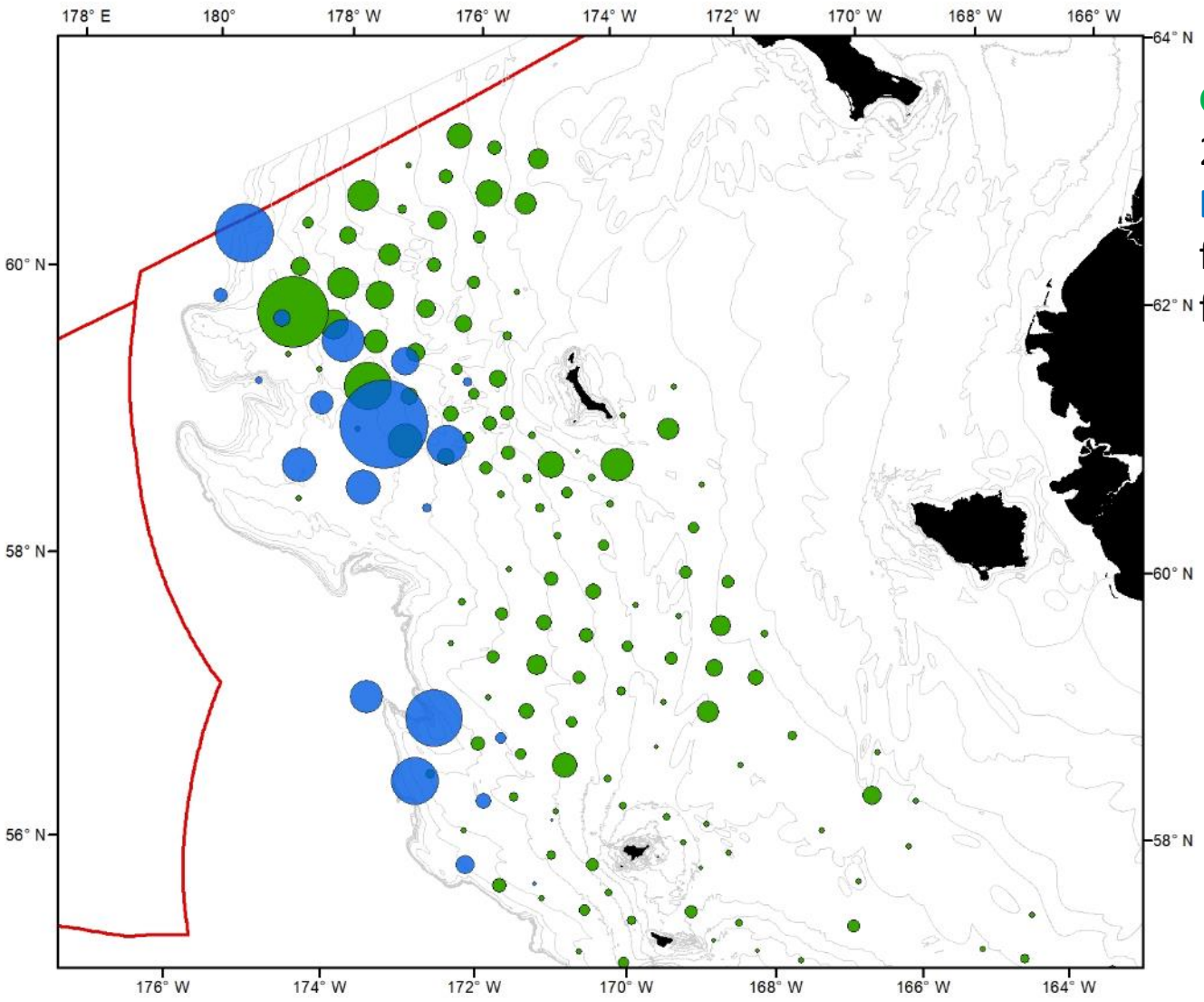


NOAA survey area-swept data

2021 survey 4 inch males

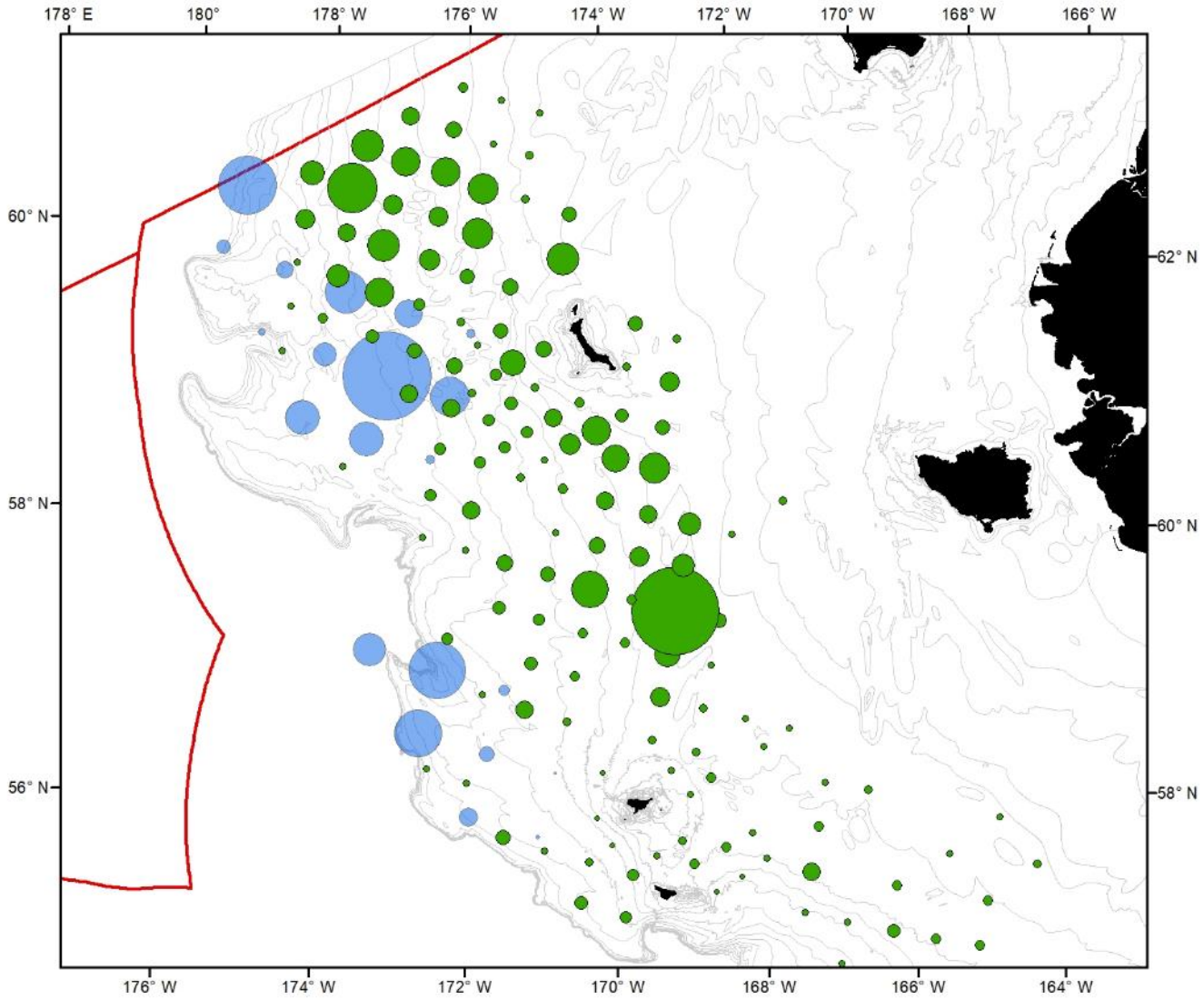


Overlay **winter 2022 fishery**



Green = 2021 survey
Blue = following fishery

Winter 2022 fishery + **2022 summer** 4 inch males



Blue = 2021/22 fishery
Green = 2022 (following) survey

What is the point?

At low population levels without meaningful recruitment, additional fishery removals can have a measurable negative impact on the population

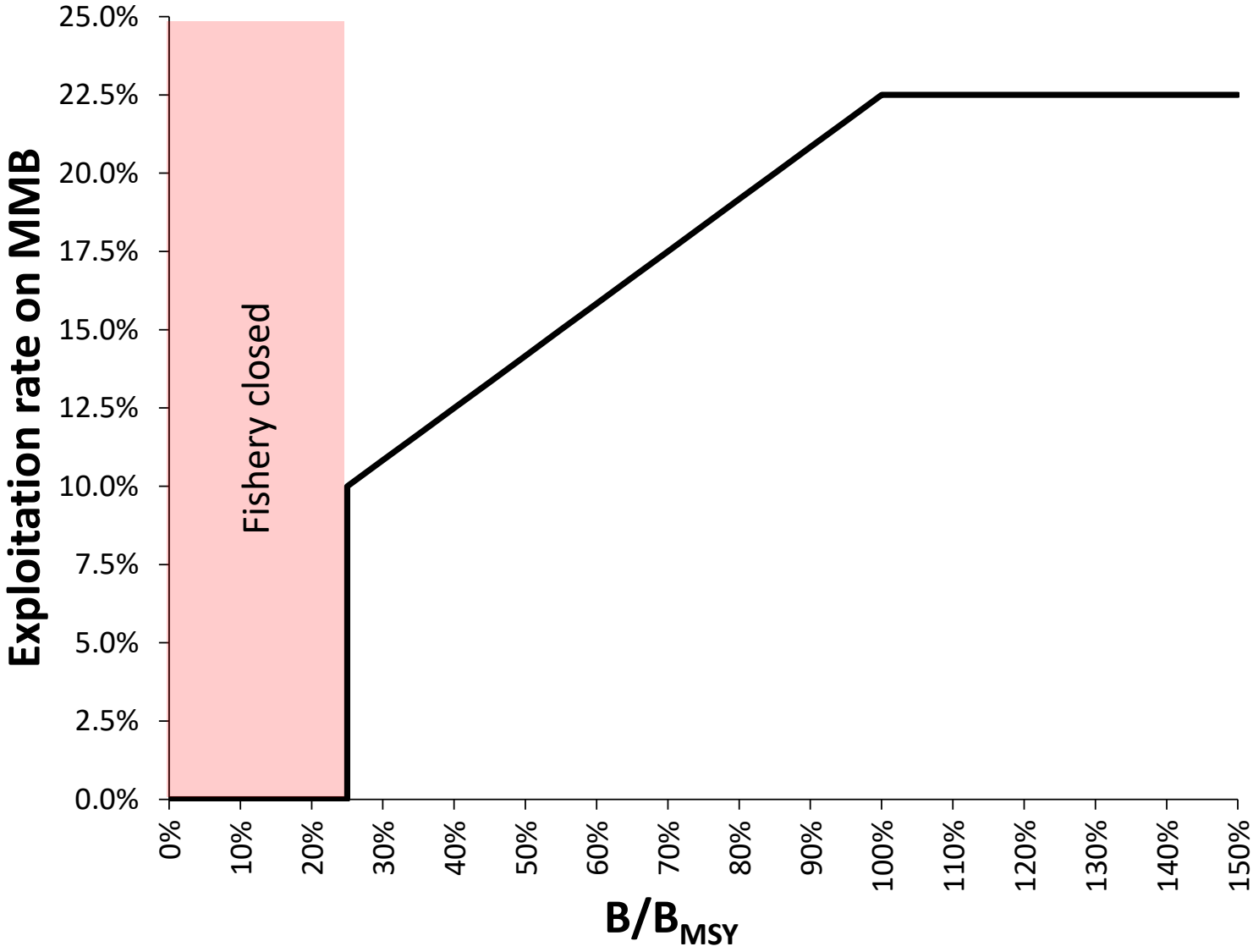
- Fishery targets clean 4 inch males
  - **Highest reproductive value**: competitively dominant, highest sperm output, still have 3 years reproduction before senescence

Troubling signal

Is this an early sign of recruitment failure?

NOAA survey area-swept data

State Harvest Strategy



Harvest Strategy Inputs: 4 sets

1. **"Area Swept" estimates**…….raw area-swept, defining male maturity at ≥ 95 mm CW and female maturity as morphometric (abdomen shape)

2. **"Model observed" estimates**…….model estimates of area-swept, defining male and female maturity within the model using maturity ogives informed by morphometric data using historic chela height data and female abdomen shape

3. **"Model survey" estimates**……the fitted line that interprets what the model observed estimates "should have been", attempting to correct for survey sampling error

4. **"Model population" estimates**……the fitted line that applies a survey selectivity curve by sex and size, attempting to correct for trawl efficiency (Q) …….estimates of the underlying population….. "the population estimate if all crabs in the line of the survey trawl net were caught"
    - Q = proportion of animals in trawl path captured
    - Q <1 in 2010−2022 stock assessment models
    - Big drop in Q in 2022 assessment

State Harvest Strategy

	Raw area-swept (MM GE95)		Survey Observed (Model Maturity Status)		Survey (Model Predicted)		Population (Model Estimated)	
	TMB	MMB	TMB	MMB	TMB	MMB	TMB	MMB
1983-2021 Average (millions lb)	**428.0**	217.2	**594.3**	374.4	**552.8**	385.2	**1,559.8**	784.9
2022 Estimate (millions lb)	**91.1**	**45.0**	**132.1**	**82.7**	**130.3**	**90.5**	**361.3**	**171.0**
(2022 Est)/(1983-2021 Avg)	**21%**	21%	**22%**	22%	**24%**	23%	**23%**	22%
F_{MSY} =		**0.3**		**0.3**		**0.3**		**0.3**
Exploitation Rate on MMB		**0.000**		**0.000**		**0.000**		**0.000**
Computed TAC = Exp Rate X MMB (mill lb)		0.00		0.00		0.00		0.00
Max TAC (58% cap on ELM (mill lb)		~~15.71~~		~~15.26~~		~~24.94~~		~~47.02~~
TAC		**0.000**		**0.000**		**0.000**		**0.00**

- All sets of population estimates (raw survey + model) result in a fishery closure because stock status is below the 25% (the closure threshold)
- This is consistent with the stock assessment model estimate of **current stock status** (23%)

Federal vs state process

Why does the assessment model yield a 23 million lb OFL but the state closed the fishery?

- The application of the federal control rule has the same closure threshold (25%) BUT applies **projected stock status** (30%)

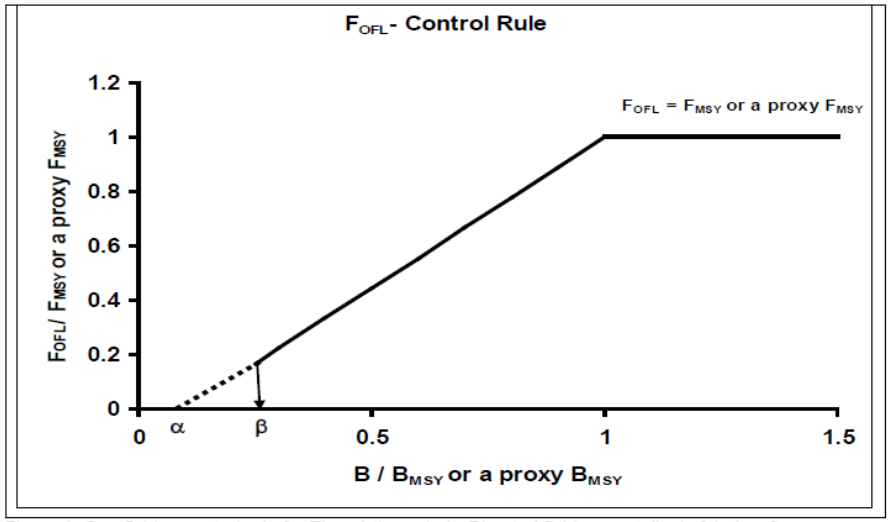


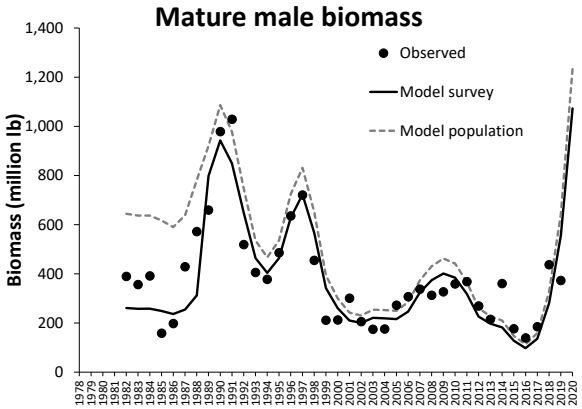
Figure 1. Overfishing control rule for Tiers 1 through 4. Directed fishing mortality is 0 below β.

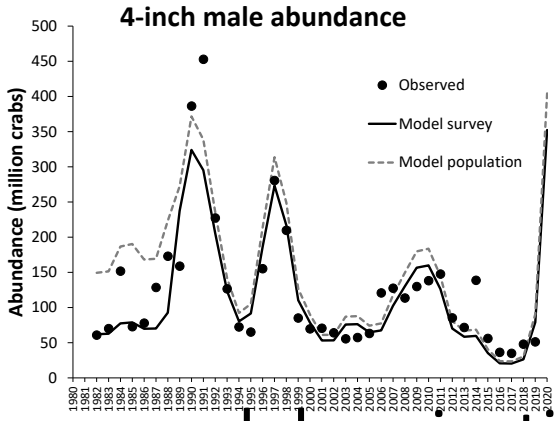
Federal vs state process

Model projections must be interpreted with caution

- **2021** assessment **projected** (Feb 15, 2022) stock status estimated was **33%**, but **2022** assessment estimated **current** (Feb 15, 2022) stock status at **23%**
- No 2020 survey, thus at the time, only model projections were available

2020 assessment estimates

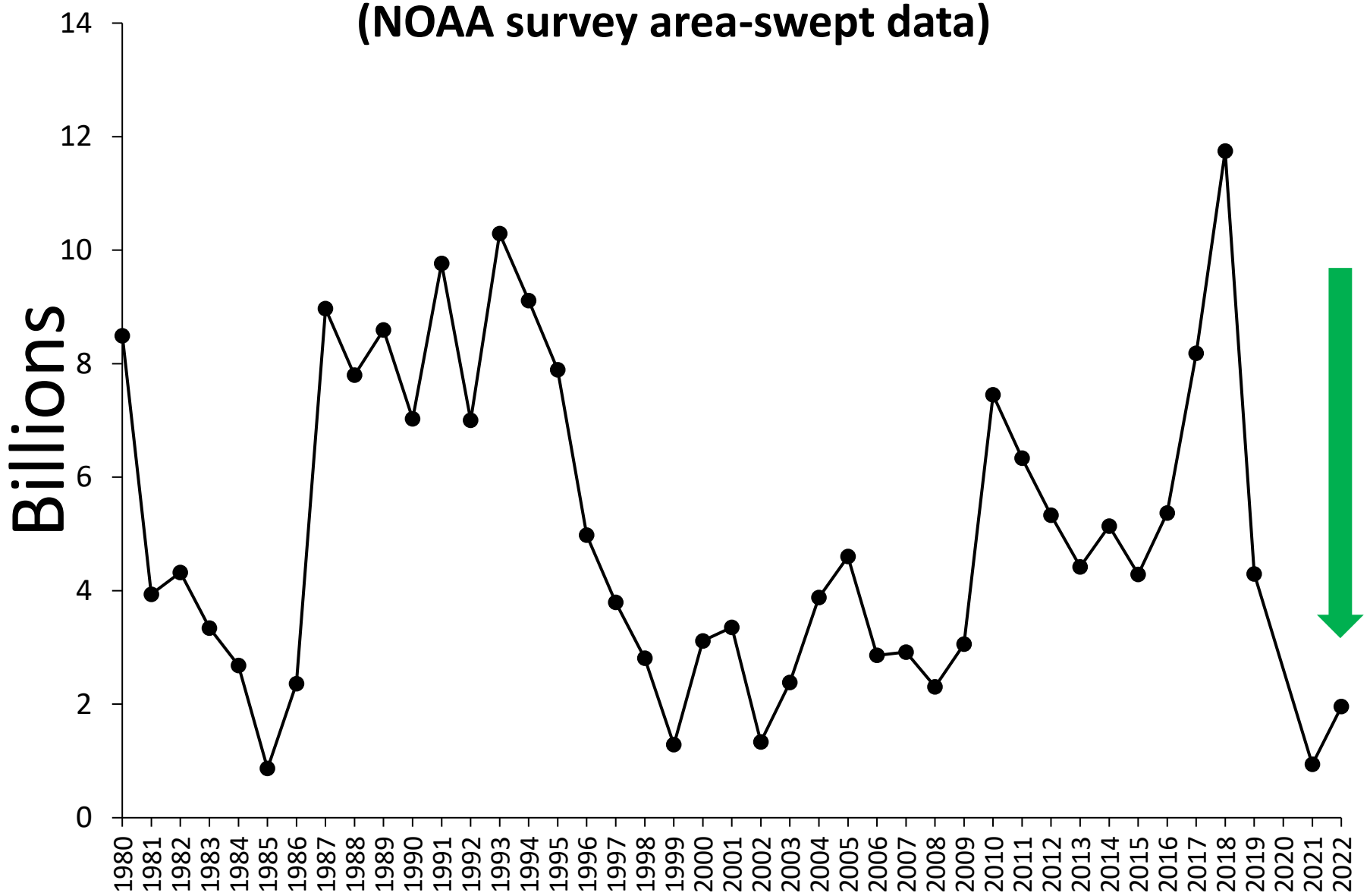




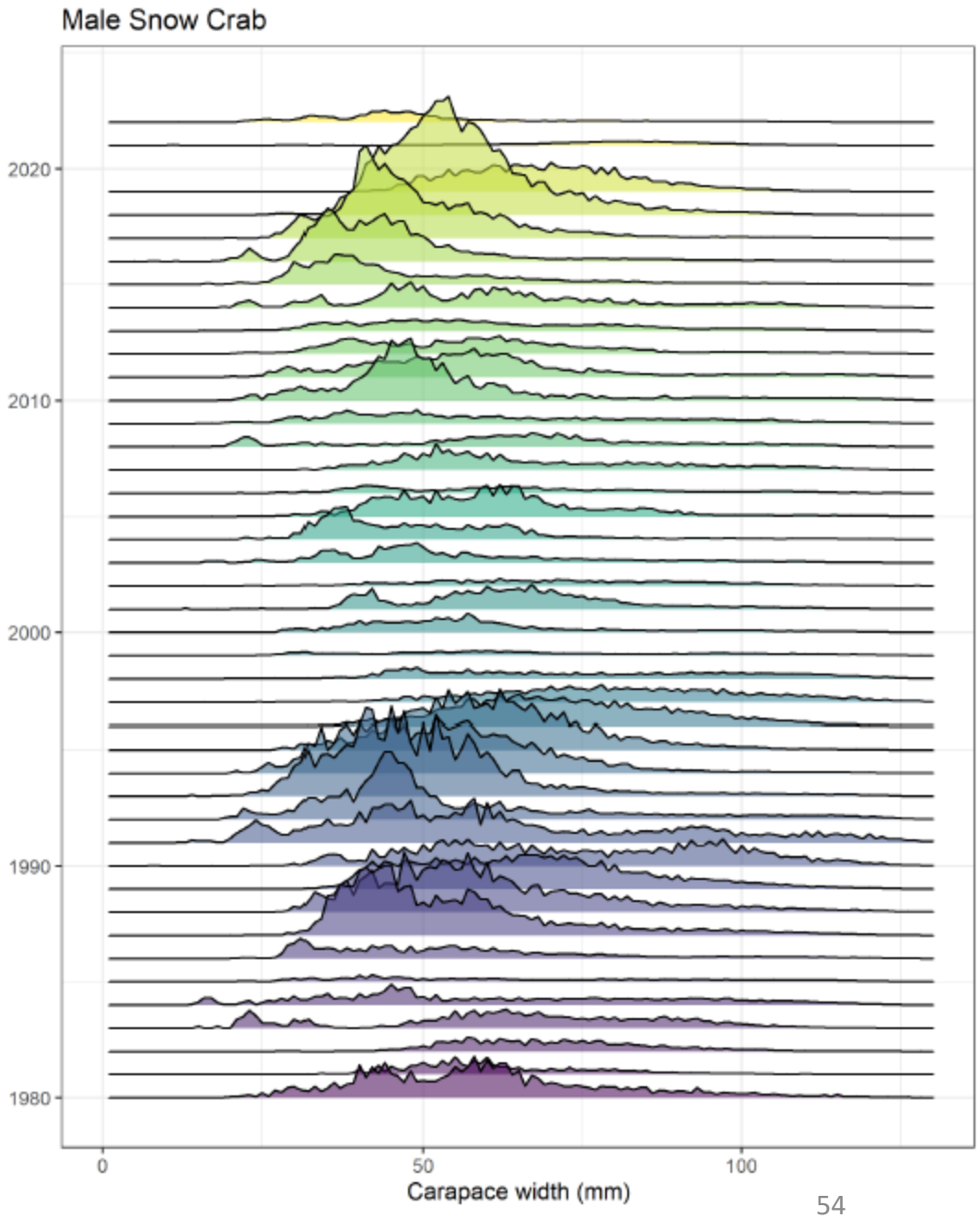
- We now know that those model projections were inconsistent with the population collapse

LOOKING AHEAD

Snow crab abundance (both sexes, all sizes)
(NOAA survey area-swept data)



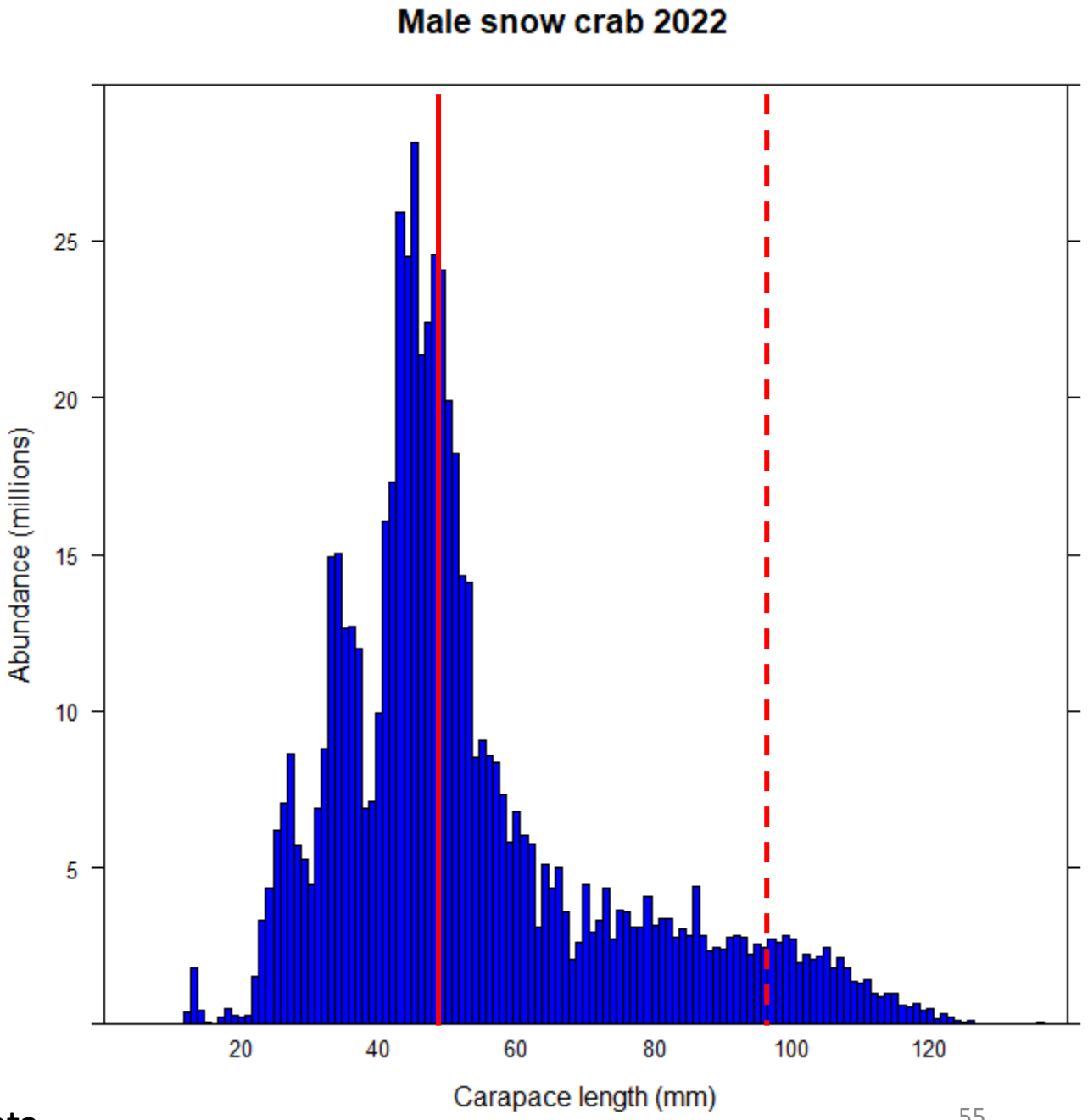
Recruitment signal <50 mm



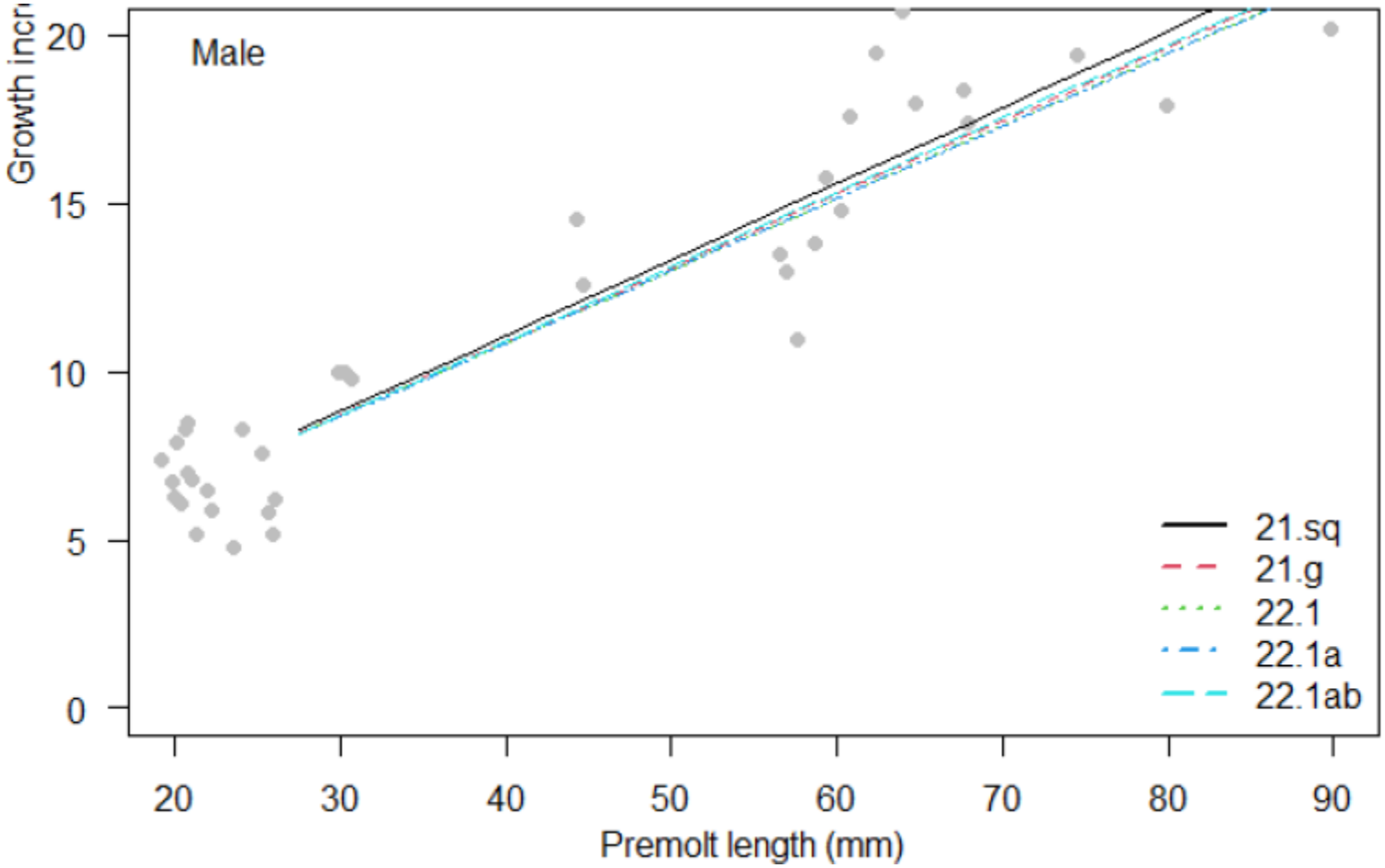
NOAA 2022 Tech Memo figure 80

2022 data

- 45 mill lb MMB (≥ 95mm CW)
- How long until ~50 mm juvenile cohort reaches 95 mm?



NOAA survey area-swept data



- ~15 mm increase per molt
- ~4 molts to grow from 50 mm to 95 mm CW
- How many molts per year at those sizes?.....1
- >4-ish years from 50 mm cohort to reach ~95mm

Figure from Szuwalski presentation to CPT, Sept 2022

Summary

Lots of uncertainty related to cause of recent decline

- mortality vs movement
- fishing behavior
- Russian border issues
- model convergence issues

- Likely see further declines in MMB in 2023 survey given size composition of population
  - MMB and 4-inch male numbers likely get worse before they get better
- MMB + MFB in water now likely the spawning stock for next ~4 yrs
- **Efforts must focus on protecting what is left in the population**

Looking ahead at research

3 main categories in the short-medium term:

1. Crab distributions with changing environmental conditions
2. Bycatch reduction
3. Benefits of closure areas

Satellite Tagging

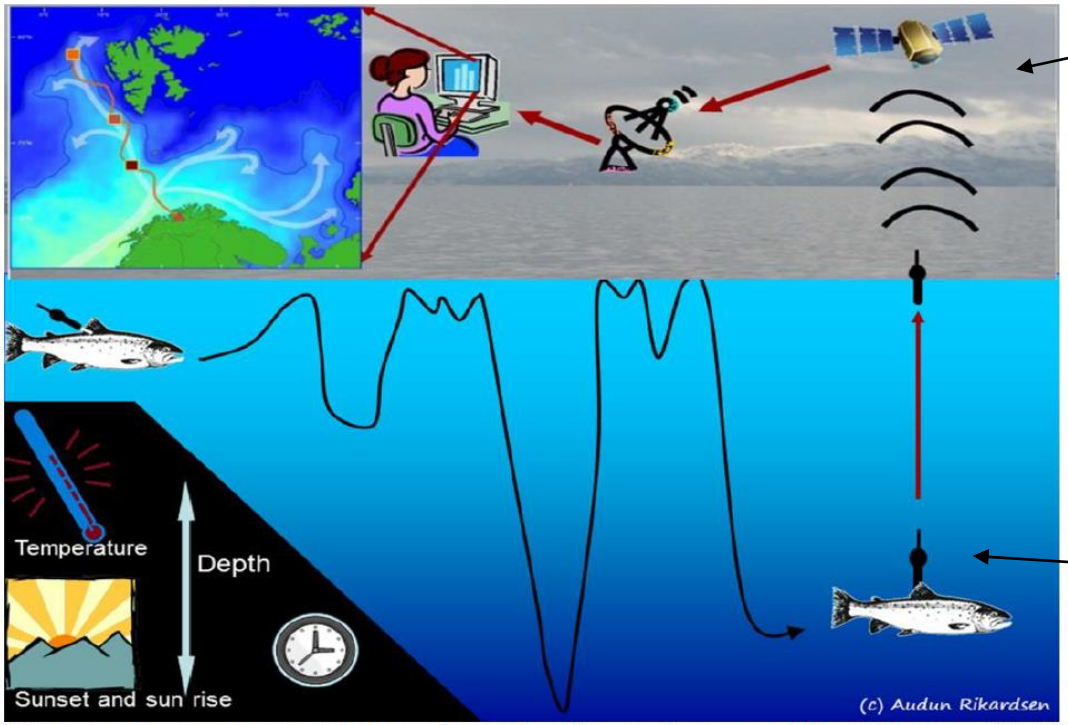


Figure 3. Illustration showing the principle by tracking fish with use of pop-up satellite archival tags (PSAT). The tag collects and stores data on depth, water temperature and light intensity as the fish migrates in the ocean. When the transmitter pops up to the surface, the position is recorded and stored data transferred to ARGOS satellites. Based on the stored data, migration routes of the fish can be calculated in retrospect.

Argos satellite-based system:

collects, processes, and disseminates environmental and other scientific data

Gather positional, behavioral, and environmental data which are archived in onboard memory.

Thorstad, E.B., A.H. Rikardsen, A. Alp, F. Okland. 2013. The use of electronic tags in fish research – An overview of fish telemetry methods. Turk. J Fish. Aquat. Sci. 13: 881-896.

Satellite Tags: Wildlife Computers

Argos satellite telemetry is one of the most widely used methods to relay data and track the movements of marine animals

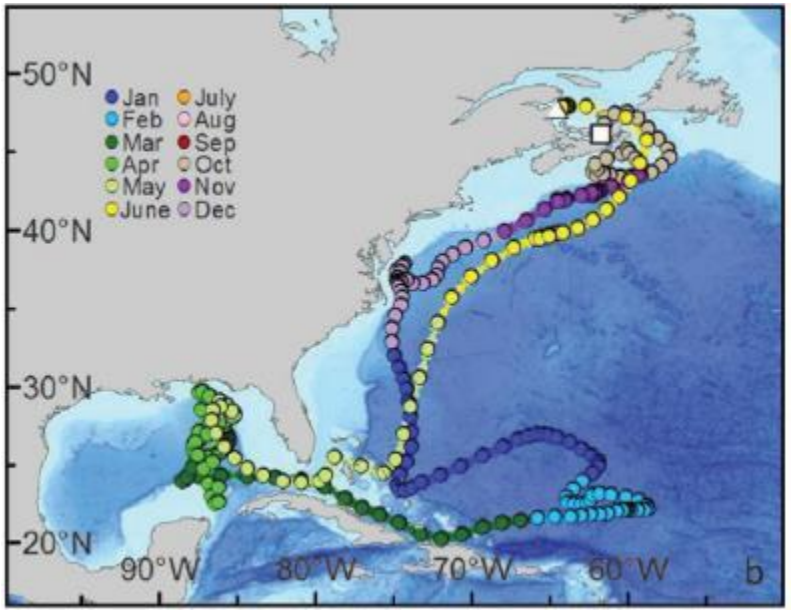
Pop-up Archival tag

- Record data (temperature, depth, light) while on host animal
- Surface on pre-set date and transmit data (including surface location) via ARGOS

WILDLIFE COMPUTERS

Usually used on large pelagic marine animals with broad-scale movement: sharks, whales, rays, tuna, turtles, porpoises, etc

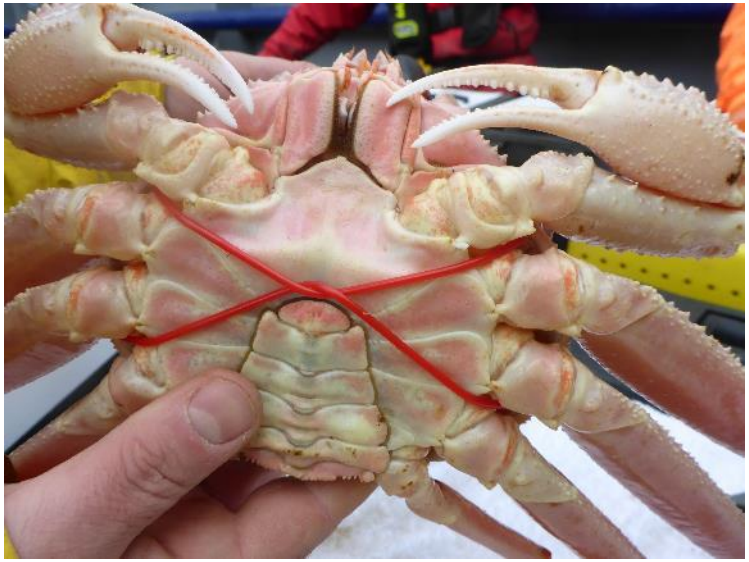
Photo credit: Kim Birnie-Gauvin



Wilson, et al. 2015. Tracking the fidelity of Atlantic bluefin tuna releases in Canadian waters to the Gulf of Mexico spawning grounds. CJFAS, 72:1-18.

Seasonal movement: satellite tagging

- Past ADFG Tanner crab research had good success
- Several deployments in Bering Sea + Kodiak waters
- Lab observational studies
- No indication tags impact crab behavior



- Will satellite tags work with snow crab?
- Unknown impacts on crab behavior (smaller body size)

Recent snow crab satellite tagging efforts

UAF pilot study: Concepcion Melovidov, Leah Zacher, Andrew Seitz

- 30 tags deployed April/May 2022 via commercial fishery, popped July 2022
  - Good success, crab generally moved north 32 miles, (0.4 miles per day)

- 18 tags deployed July 2022 via NOAA survey, programmed to pop up December 2022

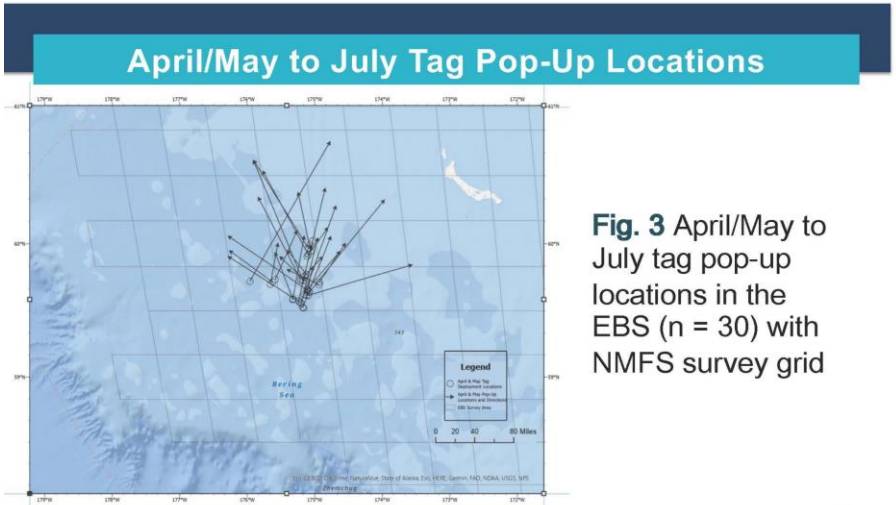


Fig. 3 April/May to July tag pop-up locations in the EBS (n = 30) with NMFS survey grid

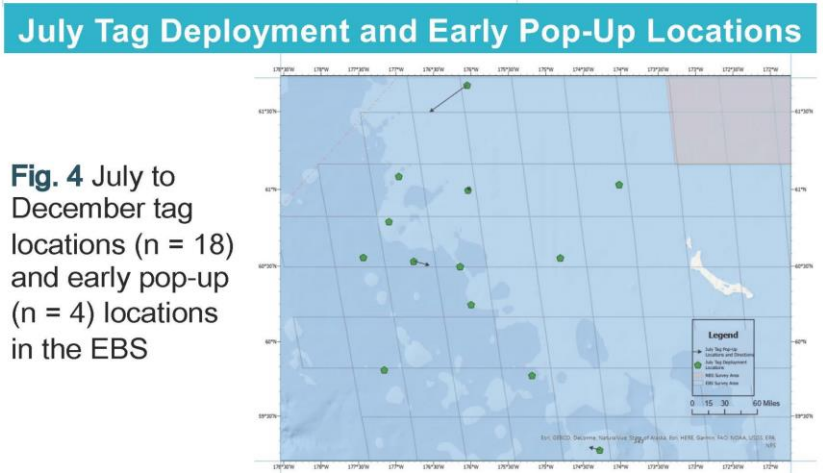


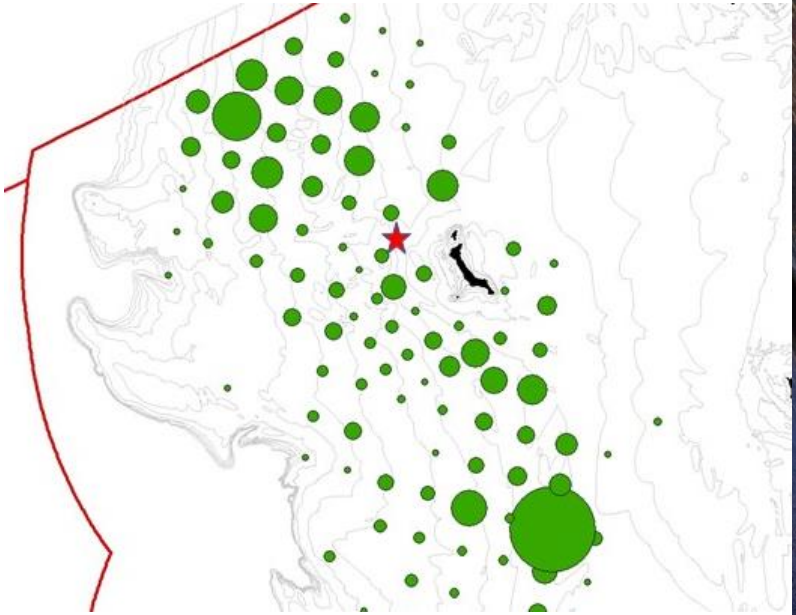
Fig. 4 July to December tag locations (n = 18) and early pop-up (n = 4) locations in the EBS

Figures courtesy of Melovidov et al AISES poster

Recent snow crab satellite tagging efforts

ADFG pilot study: Vicki Vanek, Andrew Nault

- Testing "*micro*PAT" prototype tag (smallest tag to date, less-drag design)
- Deployed on 6 legal male snow crab in Sept 2022, programmed to pop-up in Dec 2022 and June 2023



Future snow crab sat tagging

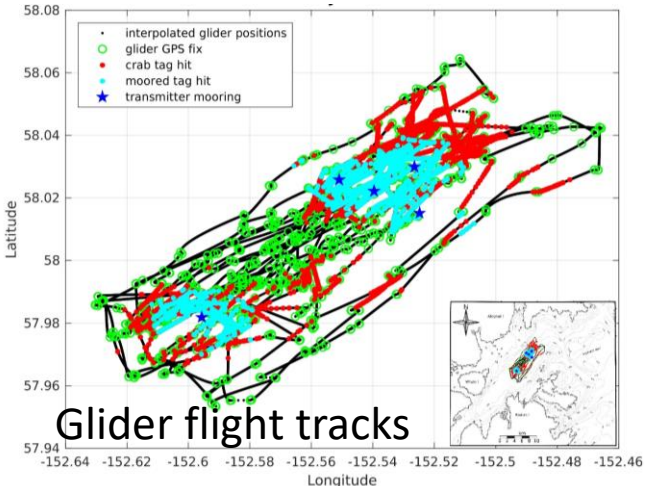
- No specific project secured
- Topic of interest: Movement around the slope and Russian border
  - No existing information on transboundary movement
  - Challenges with sea ice: impacts when crab can be deployed and when they can pop to surface
- Cost: $1,500–$4,200 per tag depending on model

Other recent movement research: AUV Glider feasibility

ADF&G-UAF pilot study: Jared Weems, Andrew Nault, Hank Statscewich, Seth Danielson

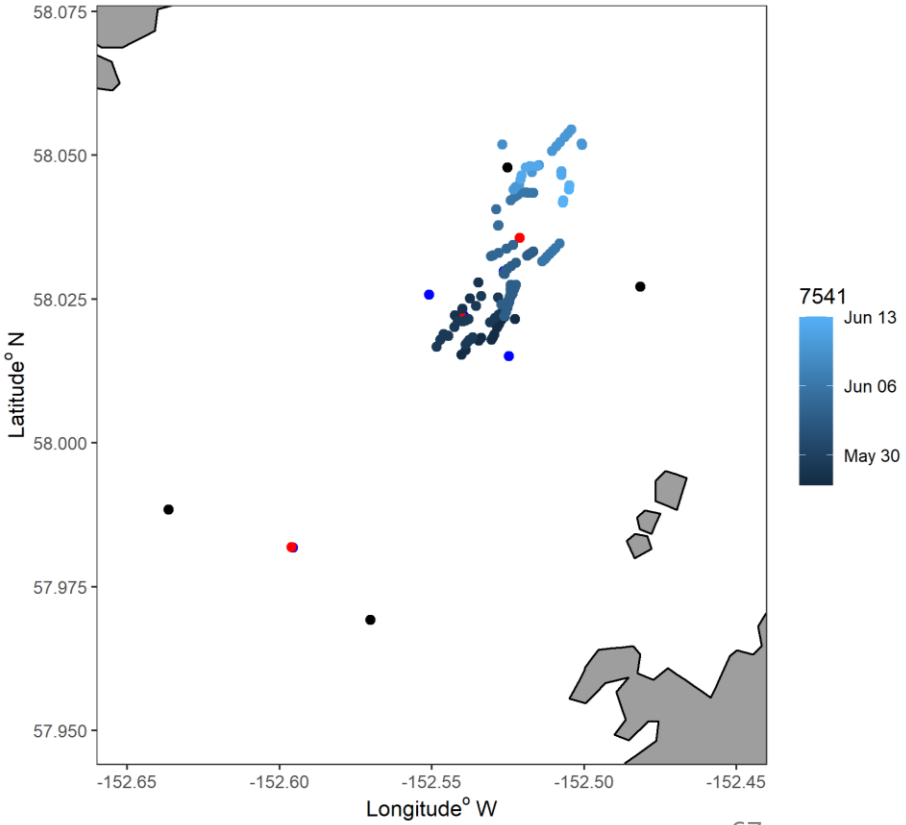
- Tested feasibility of using autonomous underwater vehicles (AUV glider) to track Tanner crab movement near Kodiak
- Acoustic tags smaller and cheaper than satellite tags
- Acoustic tags can be detected multiple times by various receiver platforms
- Preliminary results extremely positive
  - Detection of all tagged Tanner crab
  - Movement estimates
  - Bodes well for future use in Bering Sea

Other recent movement research: AUV Glider feasibility



Glider flight tracks

Individual crab movement trajectory by date



Other research needs to facilitate recovery

- Distribution and abundance on the Bering Sea slope
  - Explore survey methods/gear: long-lined pots, single pots, trawl
- Bycatch reduction: soak time, mesh size, pot mods
- Juvenile dynamics: better assess distribution to ensure maximum protection
- Habitat concerns
  - Efficacy of closure areas: habitat assessment in vs out of closure areas
  - Consistent juvenile “nursery” hotspots?

Ongoing + developing research

- Disease monitoring + assessment:
  - bitter crab (NOAA Kodiak)
  - black eye syndrome (BES) (Bigelow Lab, USGS, VIMS, ADFG Kodiak)
- Ocean acidification effects (NOAA-Kodiak)
- Borealization and species distribution work (NOAA-Kodiak, Litzow et al)

Tanner crab

2022 Assessment: scenario 22.03

- SSC + Council adopted CPT recommendations
- Stock status
  - Current: 178% of B_{MSY}
  - Projected: 137% of B_{MSY}

- OFL: 72.34 million lbs
- ABC: 54.25 million lbs
  - including bycatch mortality of males and females in all fisheries
  - based on a 20% buffer on OFL

20% ABC Buffer: status quo

- Recruits not propagating to large sizes
- Poor fit to terminal year biomass
- Poor fit for large crab

Sept 2022 CPT minutes: "The author suggested increasing the buffer used in calculating the ABC to 25% based on concerns around estimated **recruitments that have not been propagating to larger size classes**. Furthermore, the **fits of the model to the terminal years of survey MMB were diverging from the survey trend** and missed the confidence intervals of the data. The CPT recommended using the same buffer as last year (20%) because these were **not new problems** and were listed as justification for the buffer last year."

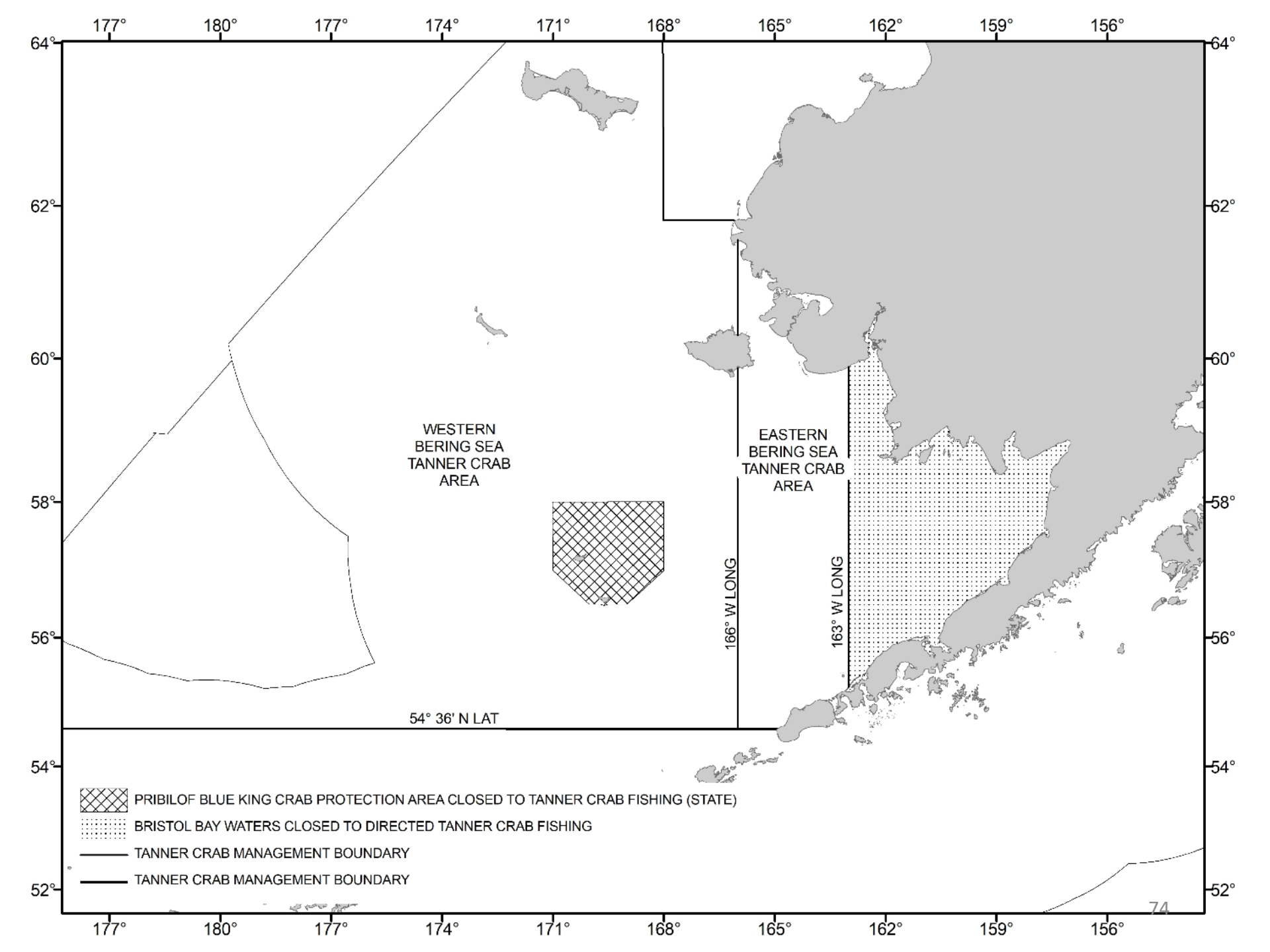
Tanner TAC setting

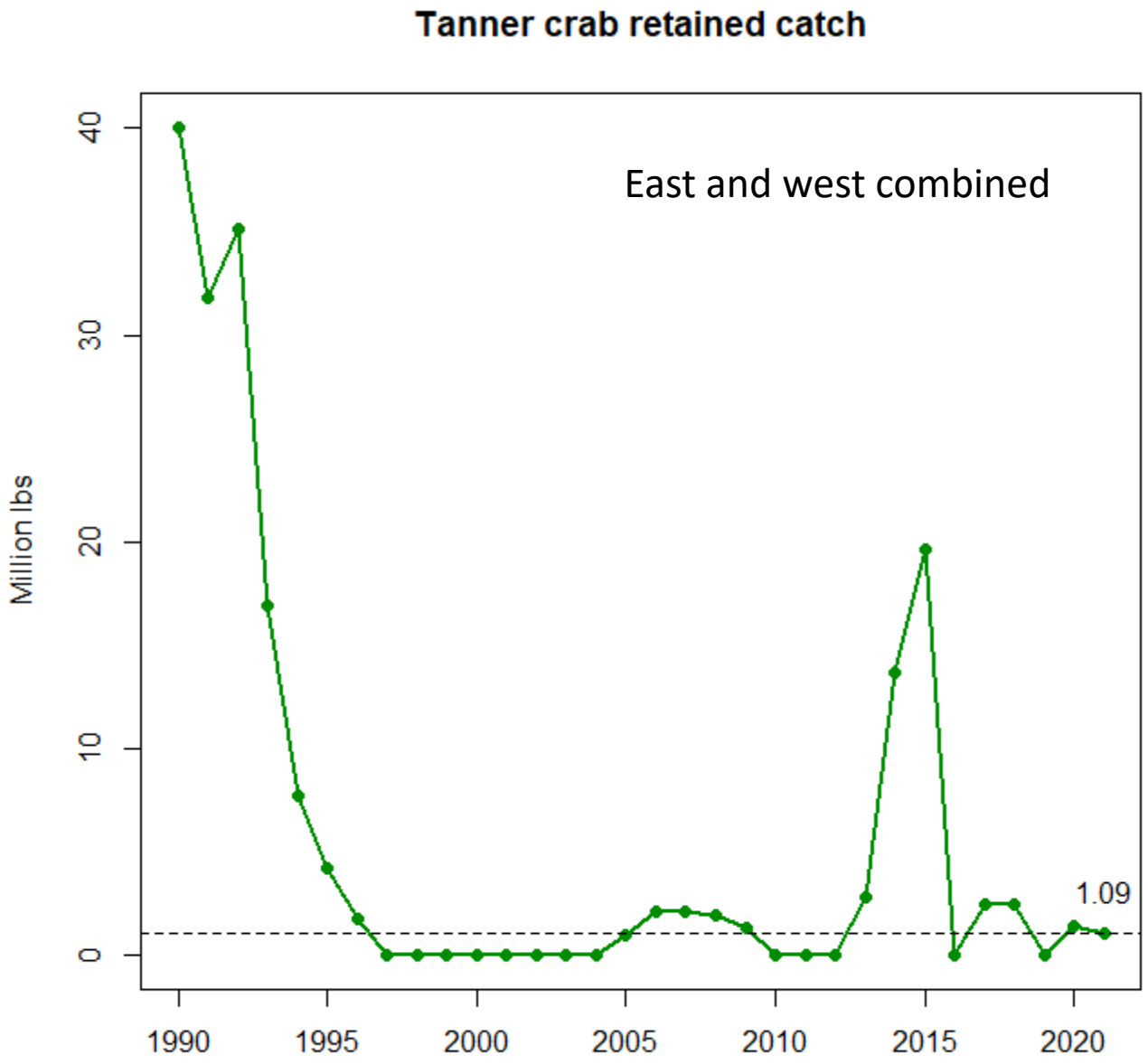
Harvest strategy: 2 control rules

- 1. Exploitation on MMB via “female dimmer” control rule
- 2. 50% ELM CAP

Model challenges

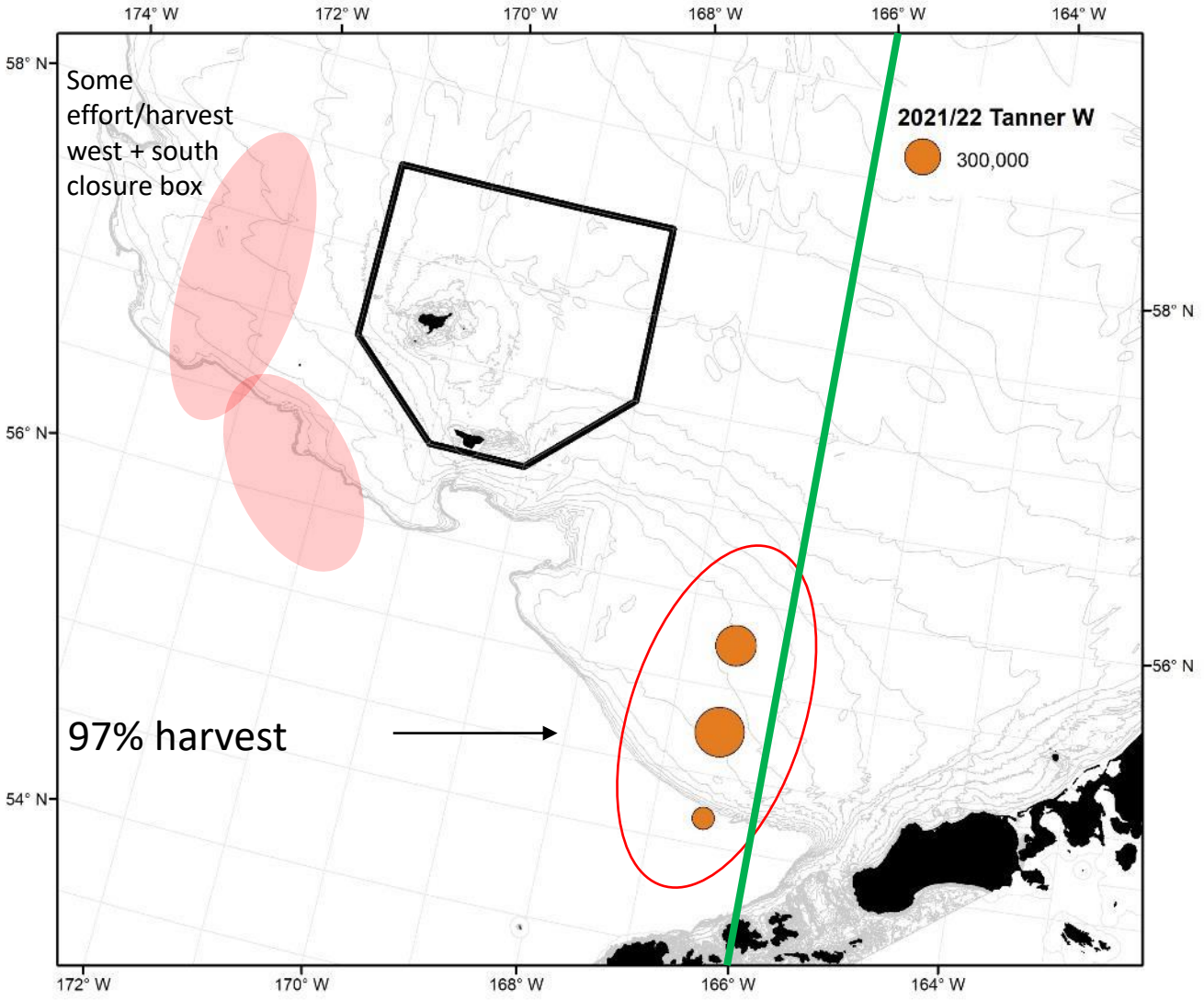
- Outputs are for entire EBS, not E/W 166° W
- Tendency to overestimate large crab


177°
180°
177°
174°
171°
168°
165°
162°
159°
156°
64°
62°
60°
58°
56°
54°
52°
WESTERN
BERING SEA
TANNER CRAB
AREA
EASTERN
BERING SEA
TANNER CRAB
AREA
166° W LONG
163° W LONG
54° 36' N LAT
PRIBILOF BLUE KING CRAB PROTECTION AREA CLOSED TO TANNER CRAB FISHING (STATE)
BRISTOL BAY WATERS CLOSED TO DIRECTED TANNER CRAB FISHING
TANNER CRAB MANAGEMENT BOUNDARY
TANNER CRAB MANAGEMENT BOUNDARY



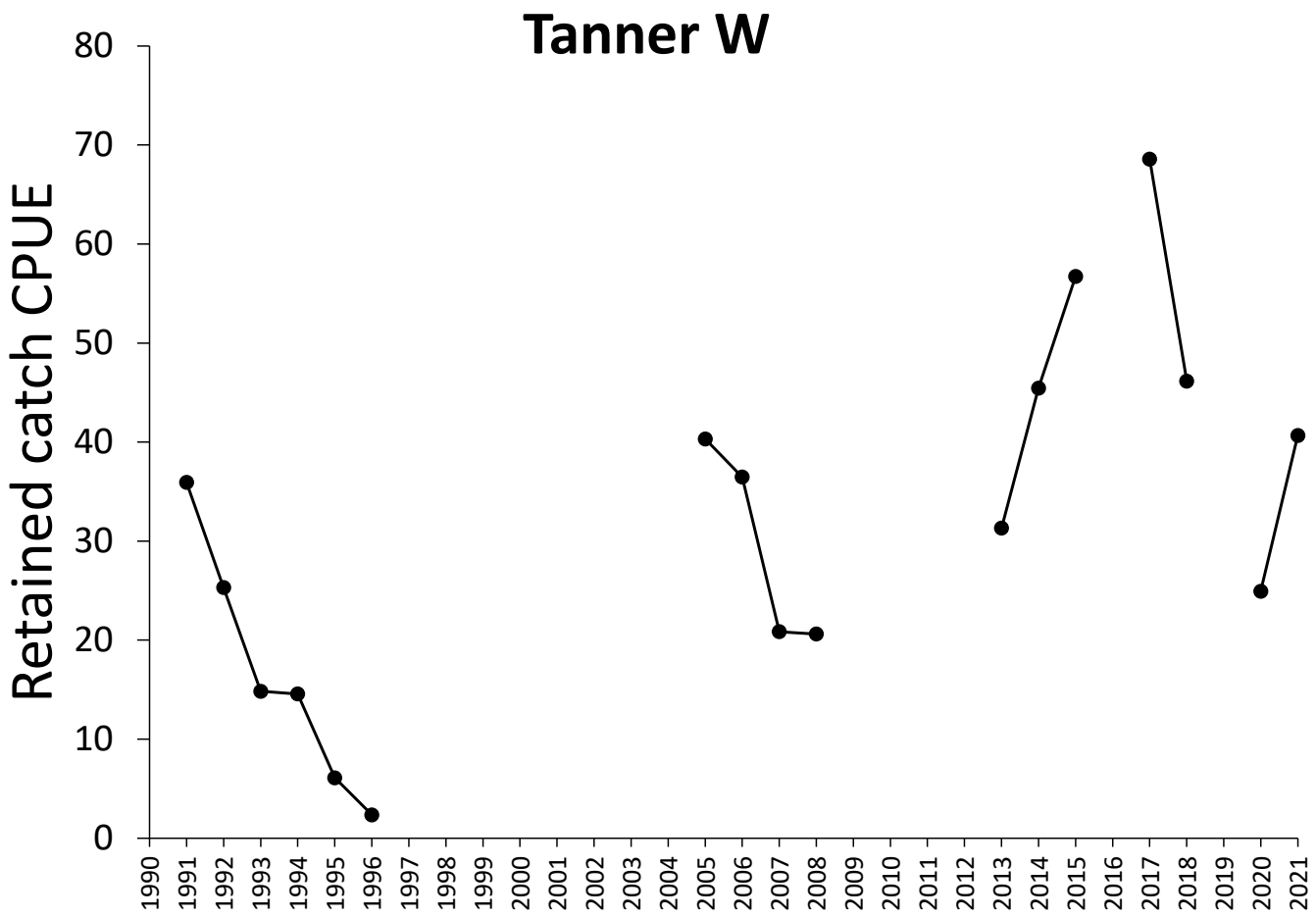
2021/22 TAC East=0, **West=1.1** mill lb

2021/22 Tanner crab retained catch



* Excludes stat areas with <3 vessels

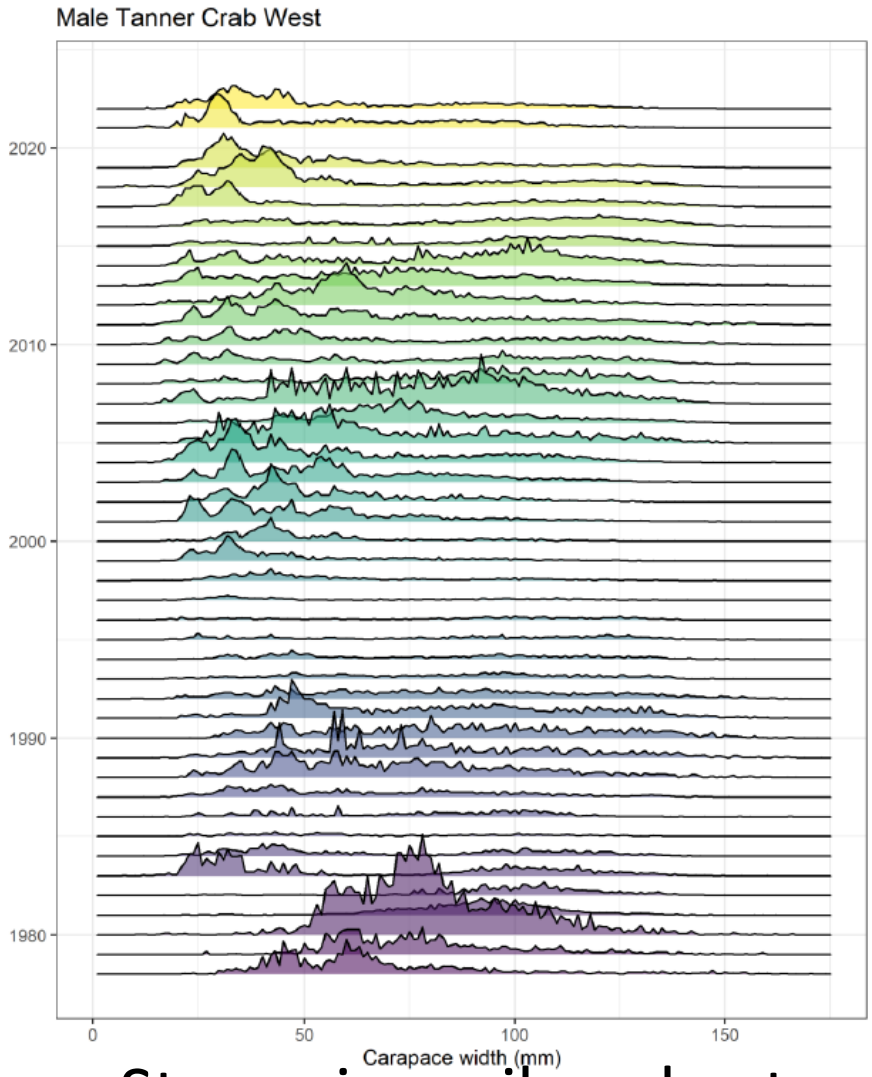
Retained catch CPUE

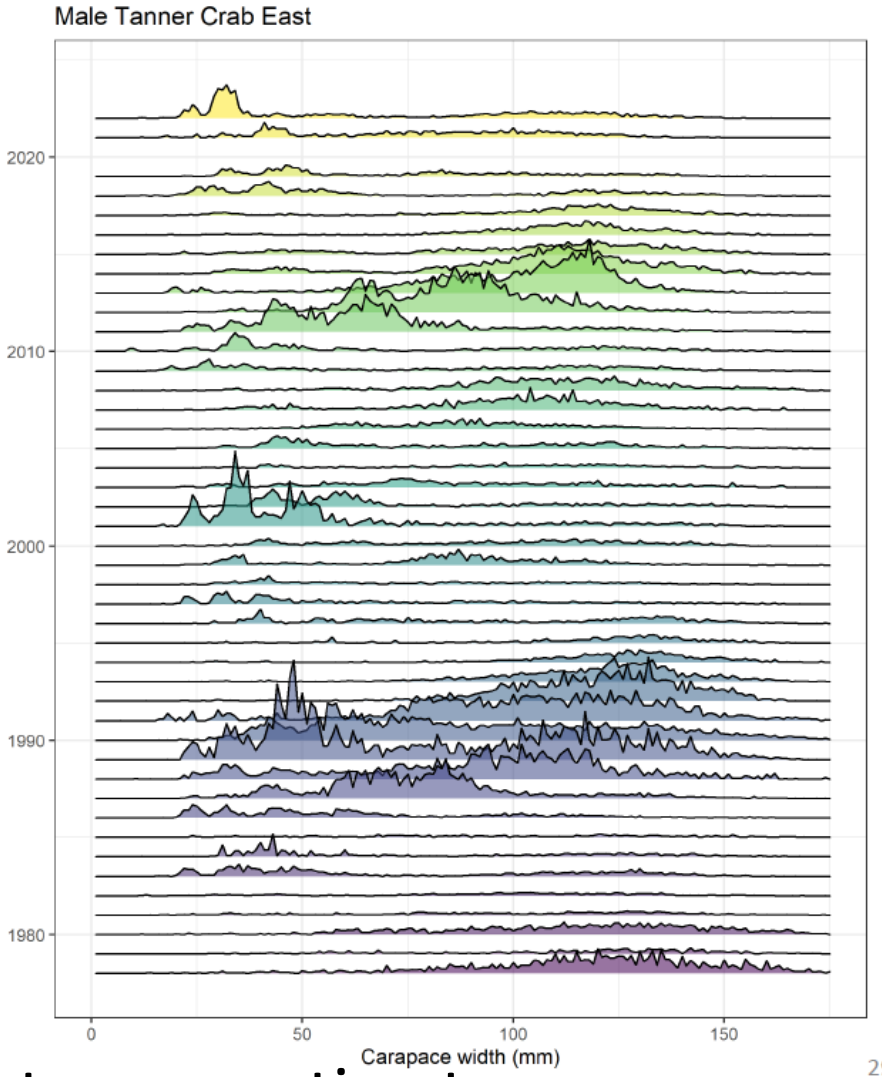


2021/22 CPUE approximated rationalized timeseries average, 40 crab/pot

Survey Data

Survey size comps



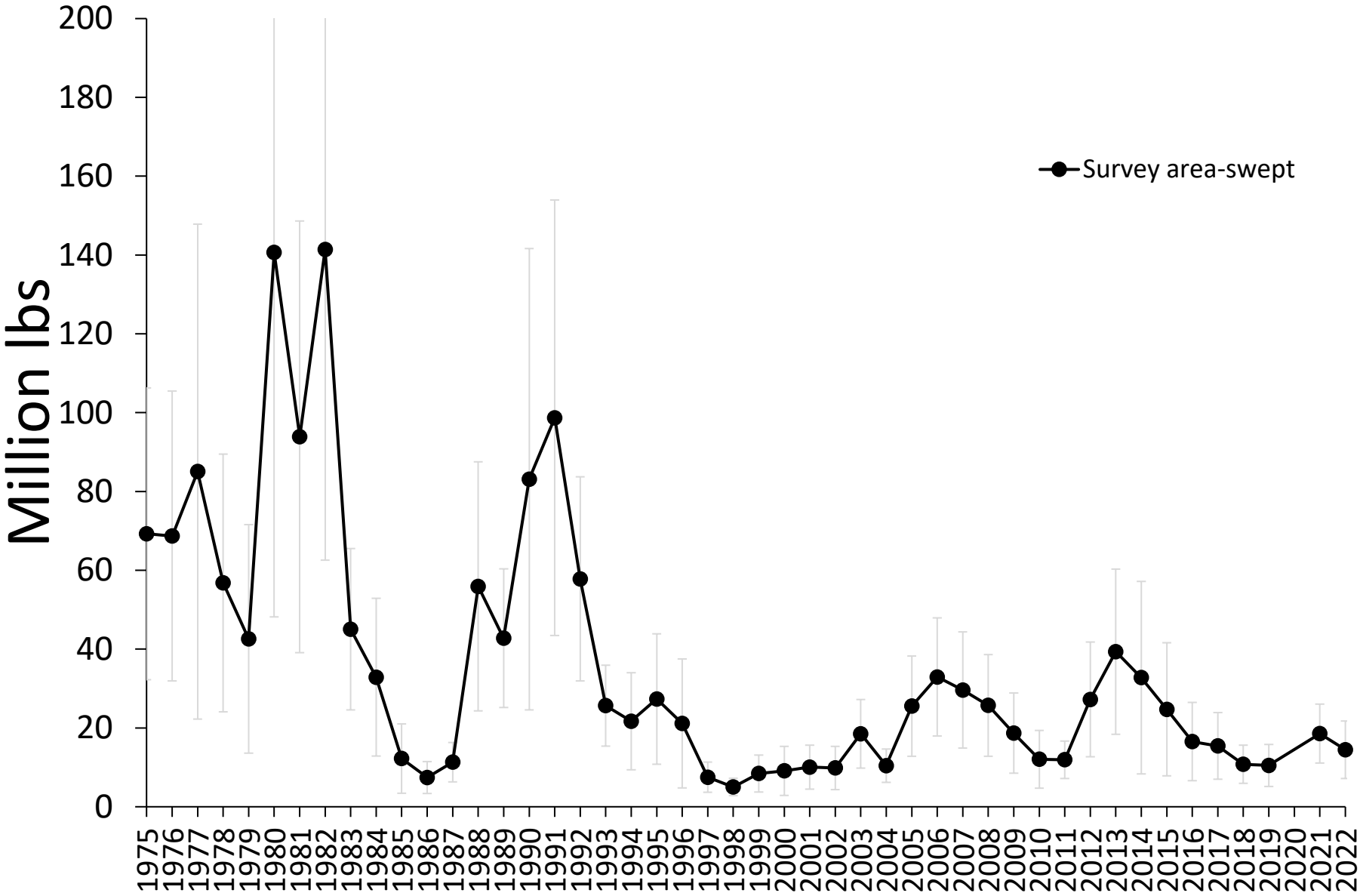


Strong juvenile cohorts not propagating to industry preferred size in recent years

Litzow presentation to CPT Sept 2022

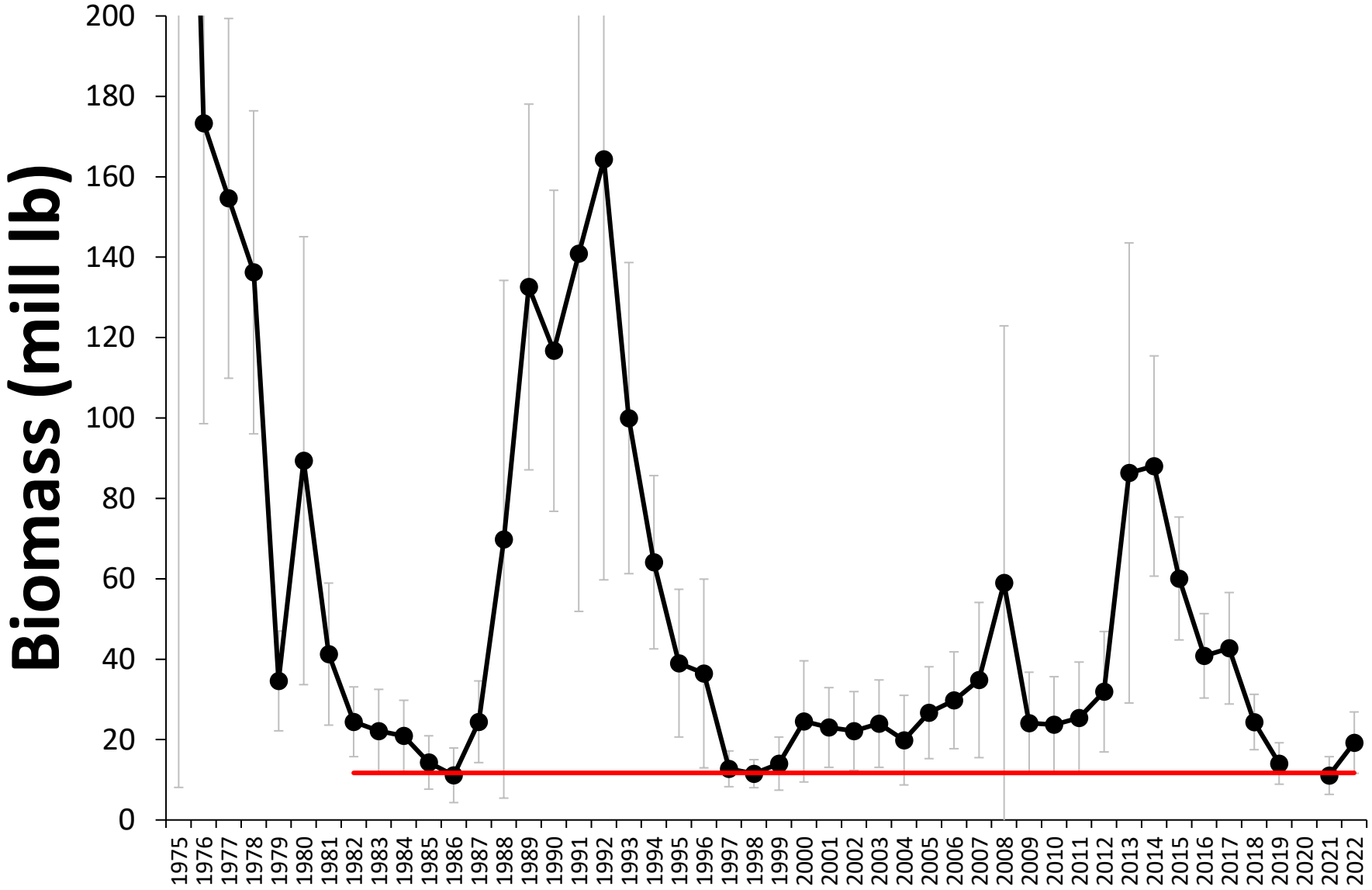
NOAA survey data

Mature female biomass



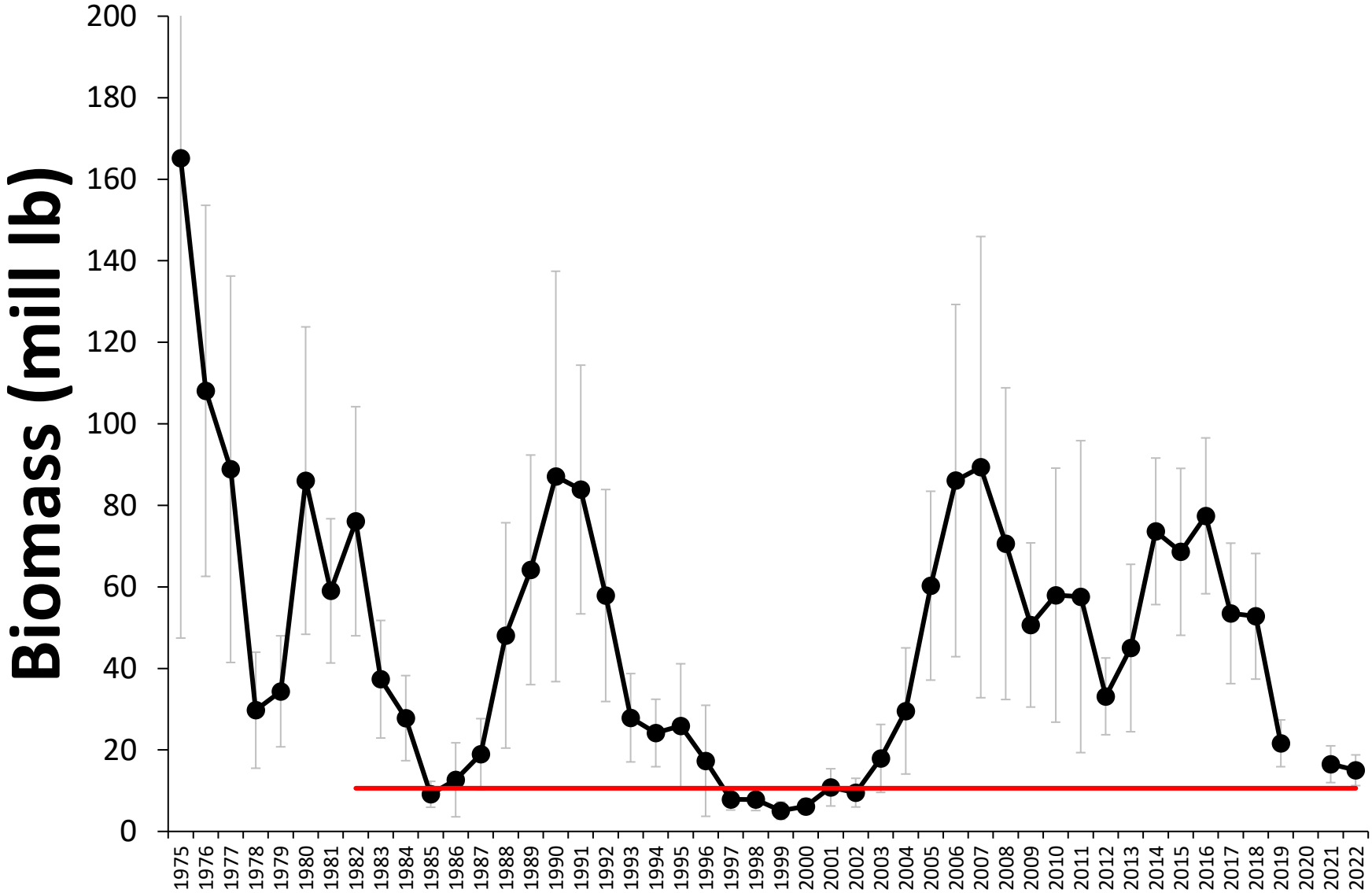
NOAA survey data

Mature males EAST of 166 W



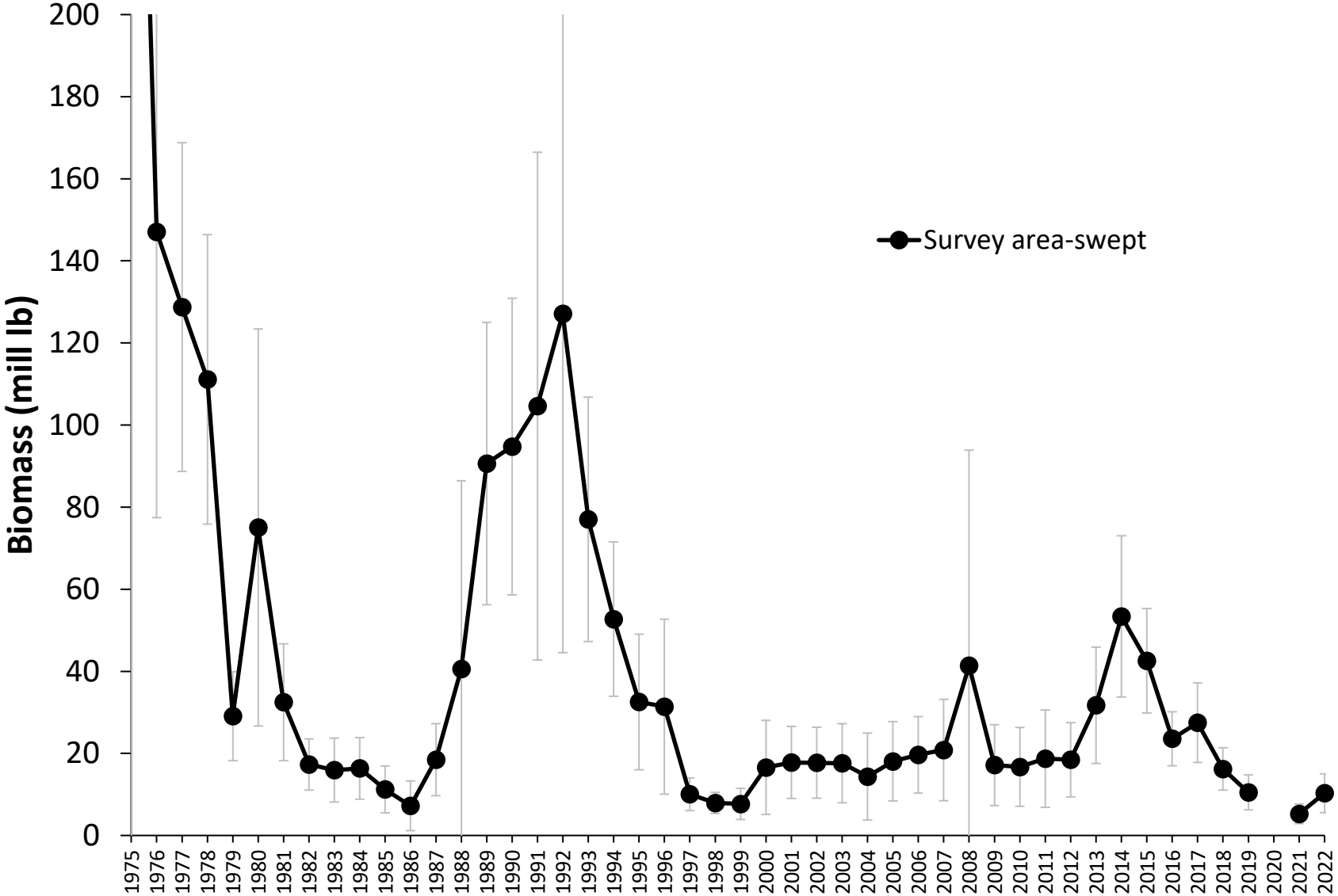
NOAA survey data

Mature males WEST of 166 W



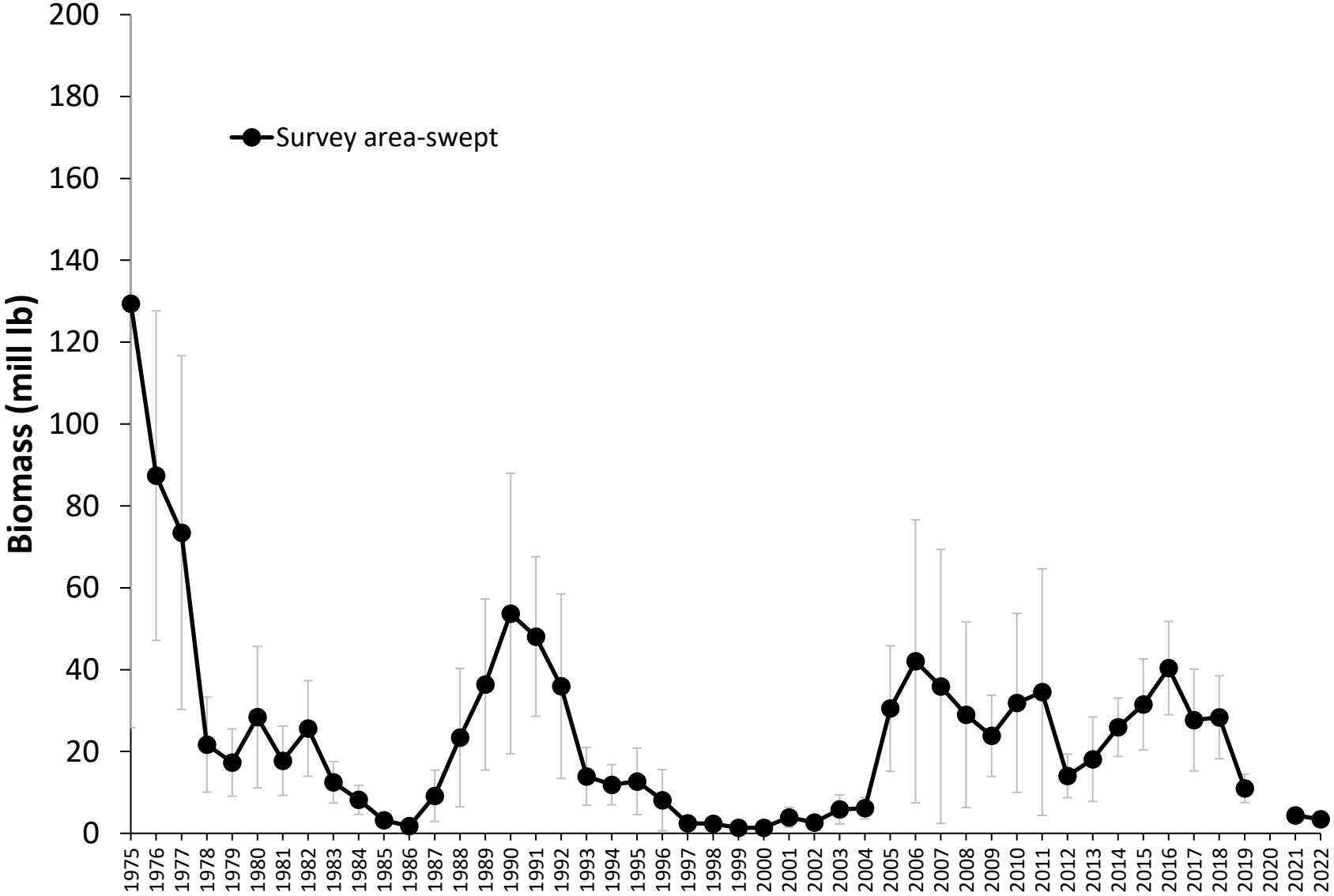
NOAA survey data

5 inch males EAST of 166 W



NOAA survey data

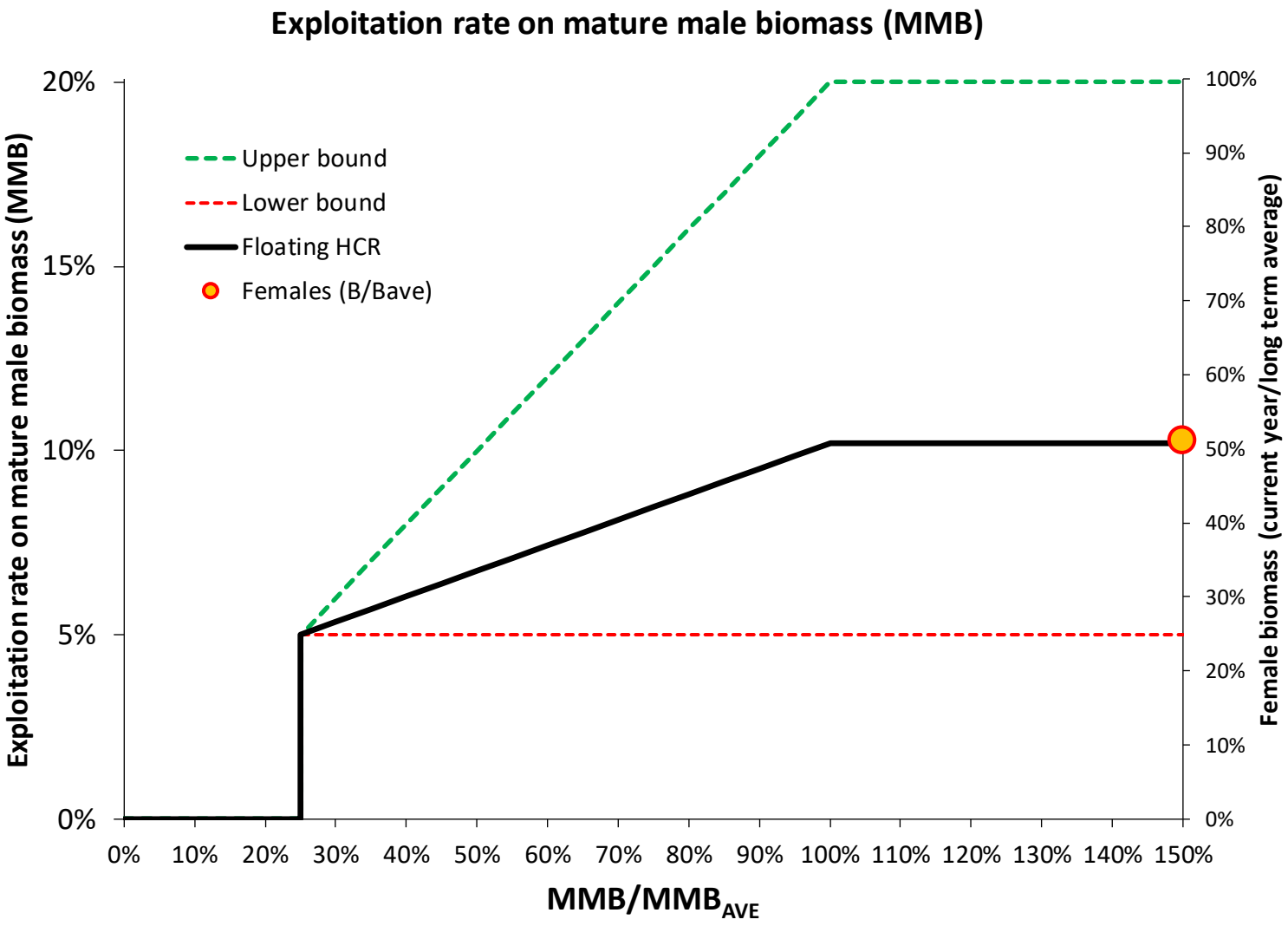
5 inch males WEST of 166 W



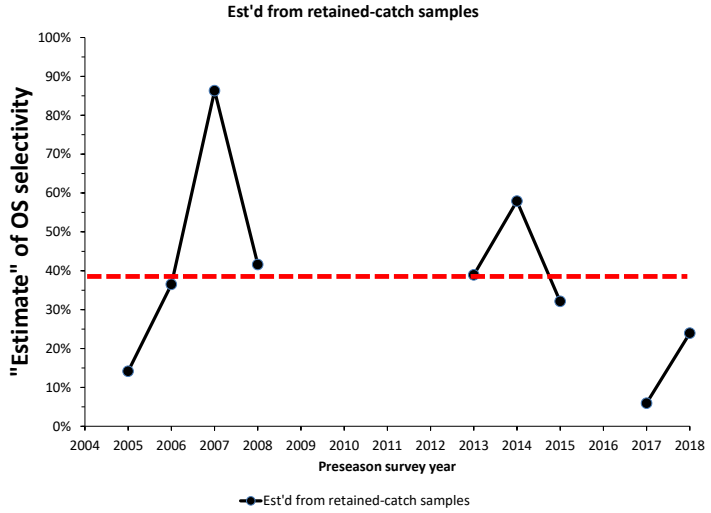
NOAA survey data

Harvest Strategy

“Female dimmer”



50% ELM Cap

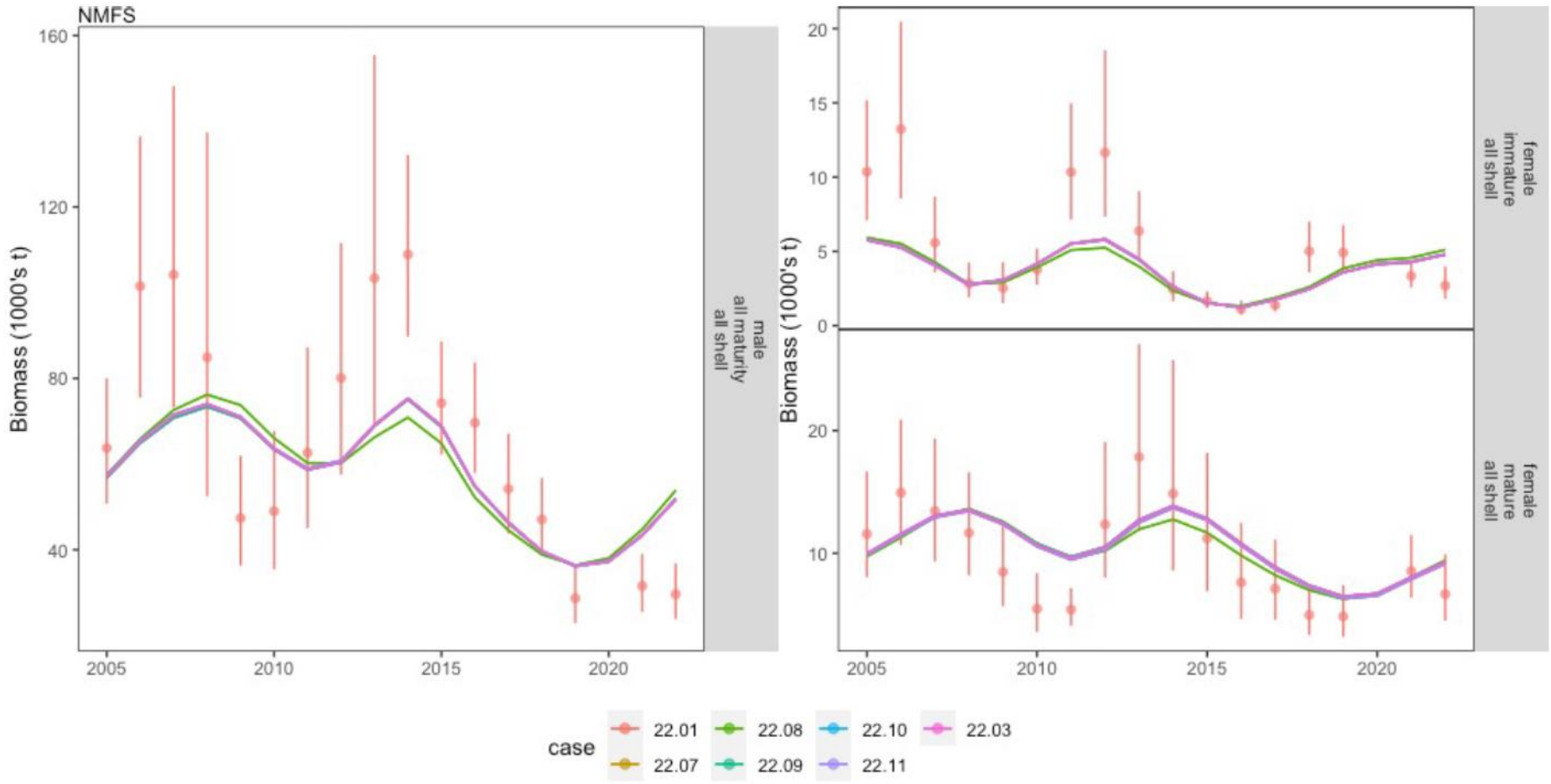


ELM= “exploitable legal males”

- 5 inch males: 100% newshell + 40% oldshell
- Considers selectivity of oldshell crabs: industry generally prefers “clean” crab (i.e., mostly newshell)
- Mean OS selectivity = ~40%

- Sensitive to industry preferred size
- TAC capped at 50% of ELM: **0.5 * ELM * ave wt**

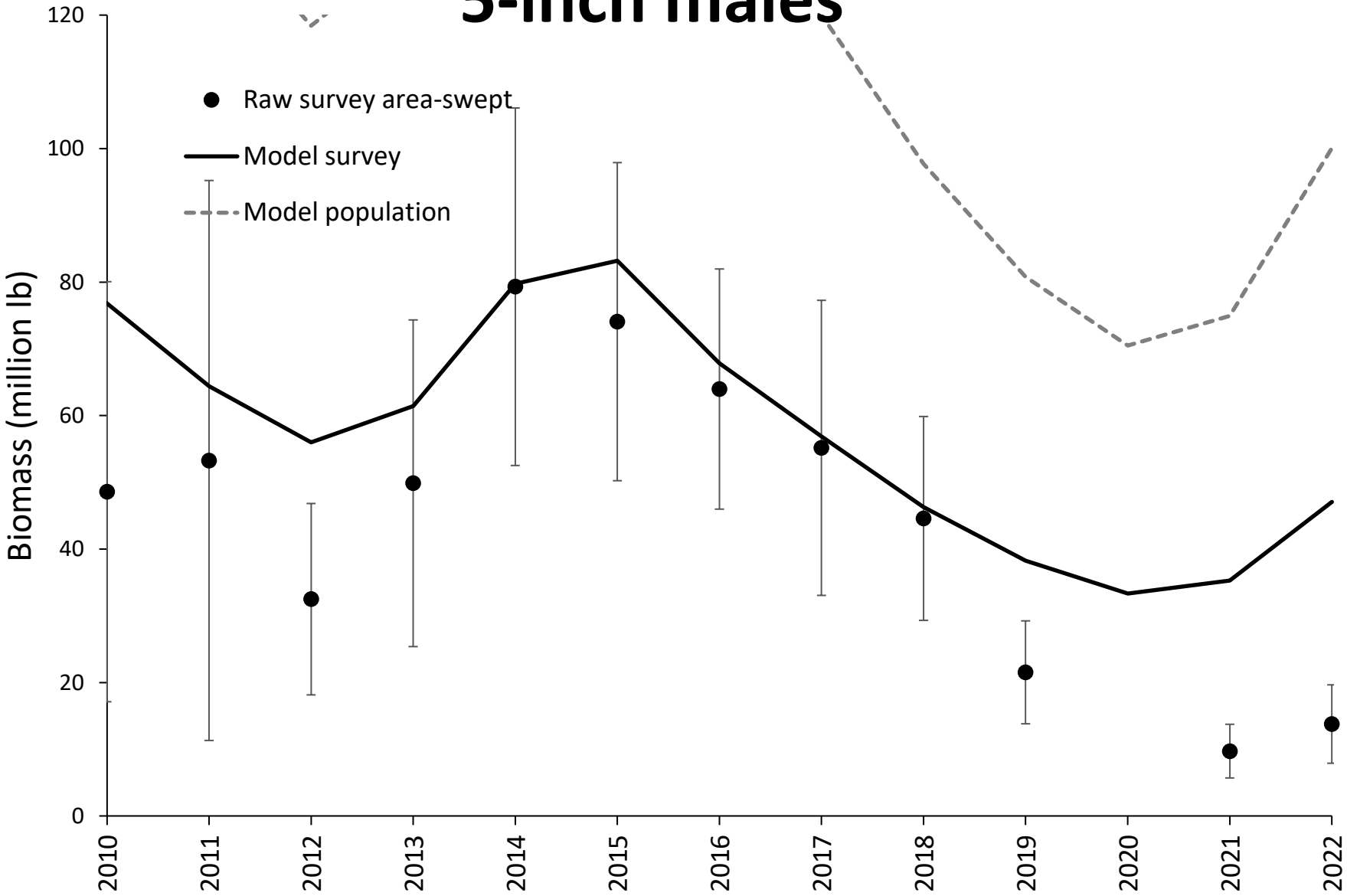
Model estimates

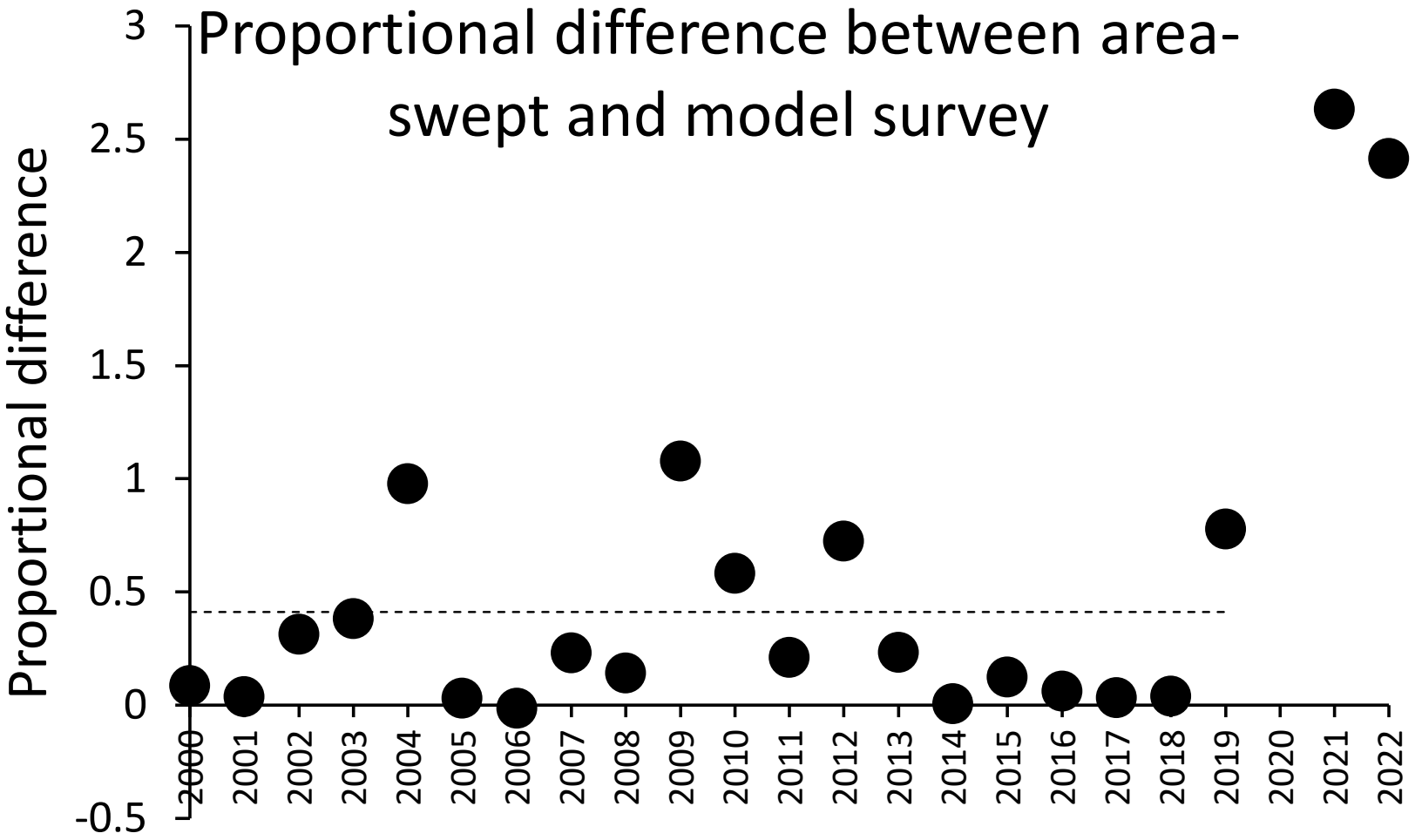


Challenges for setting TAC

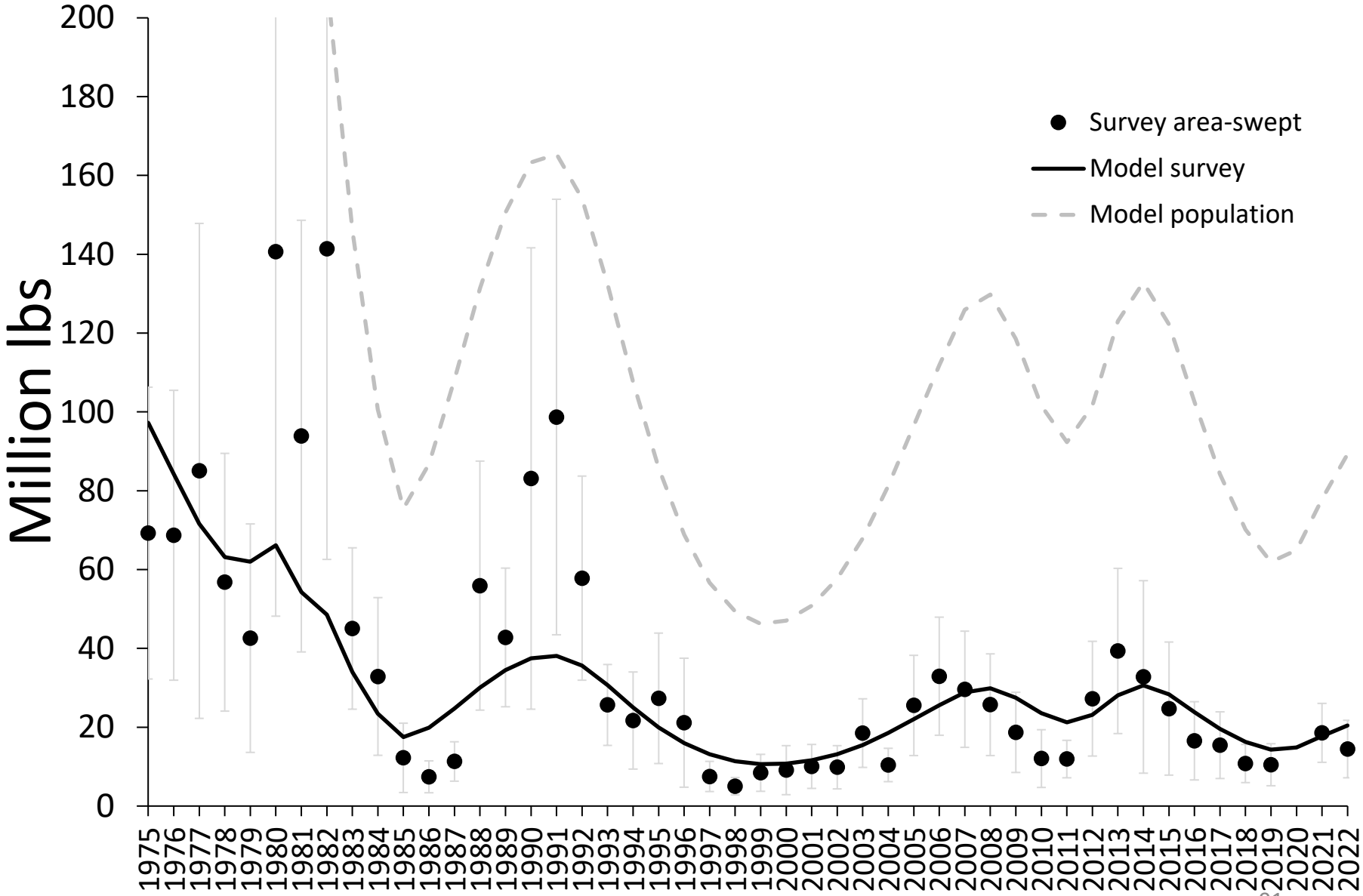
- EBS wide
- 2022 estimates

5-inch males

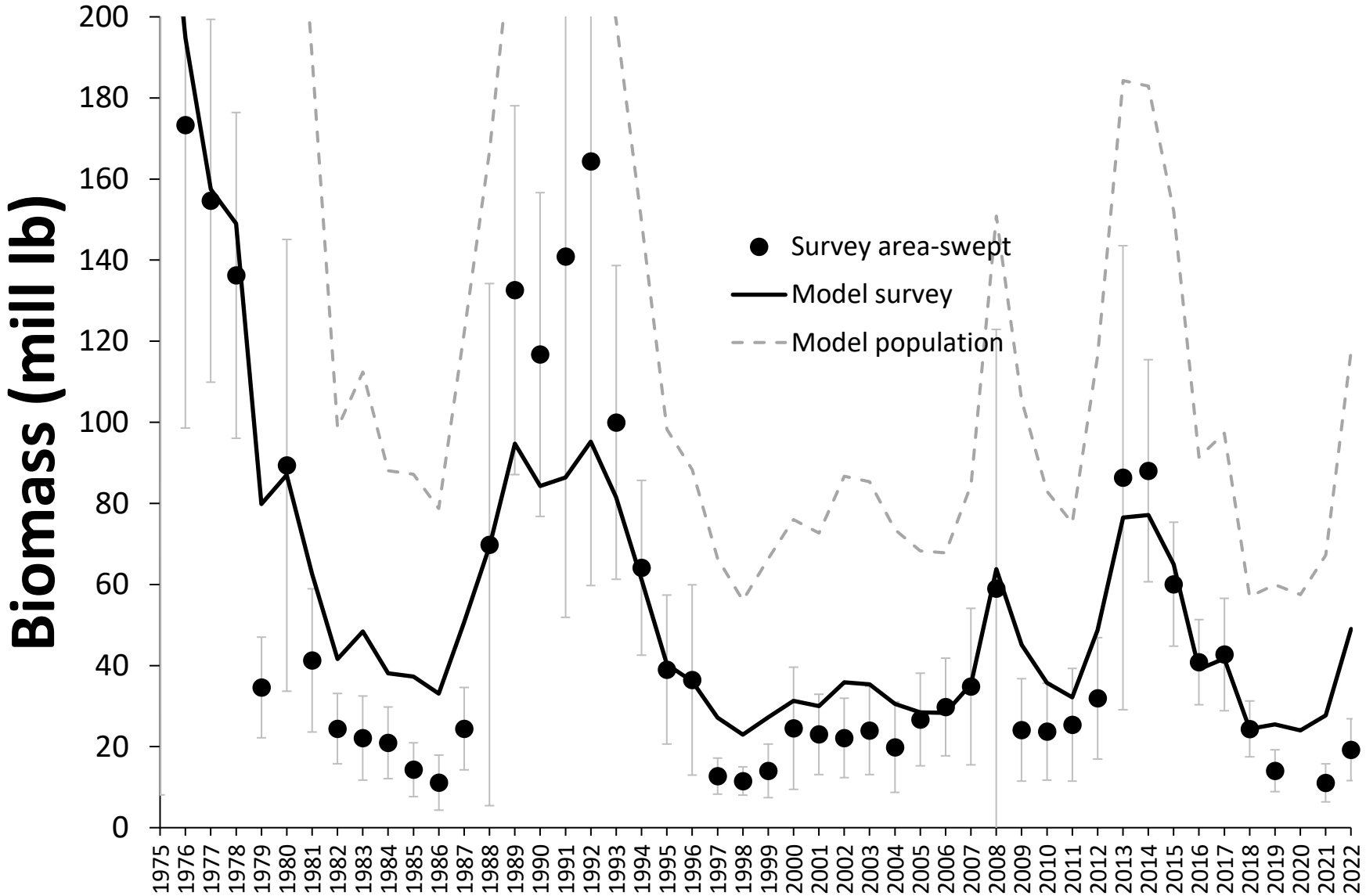

Raw survey area-swept
Model survey
Model population
Biomass (million lb)
120
100
80
60
40
20
0
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022


Proportional difference between area-swept and model survey
Proportional difference
3
2.5
2
1.5
1
0.5
0
-0.5
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022

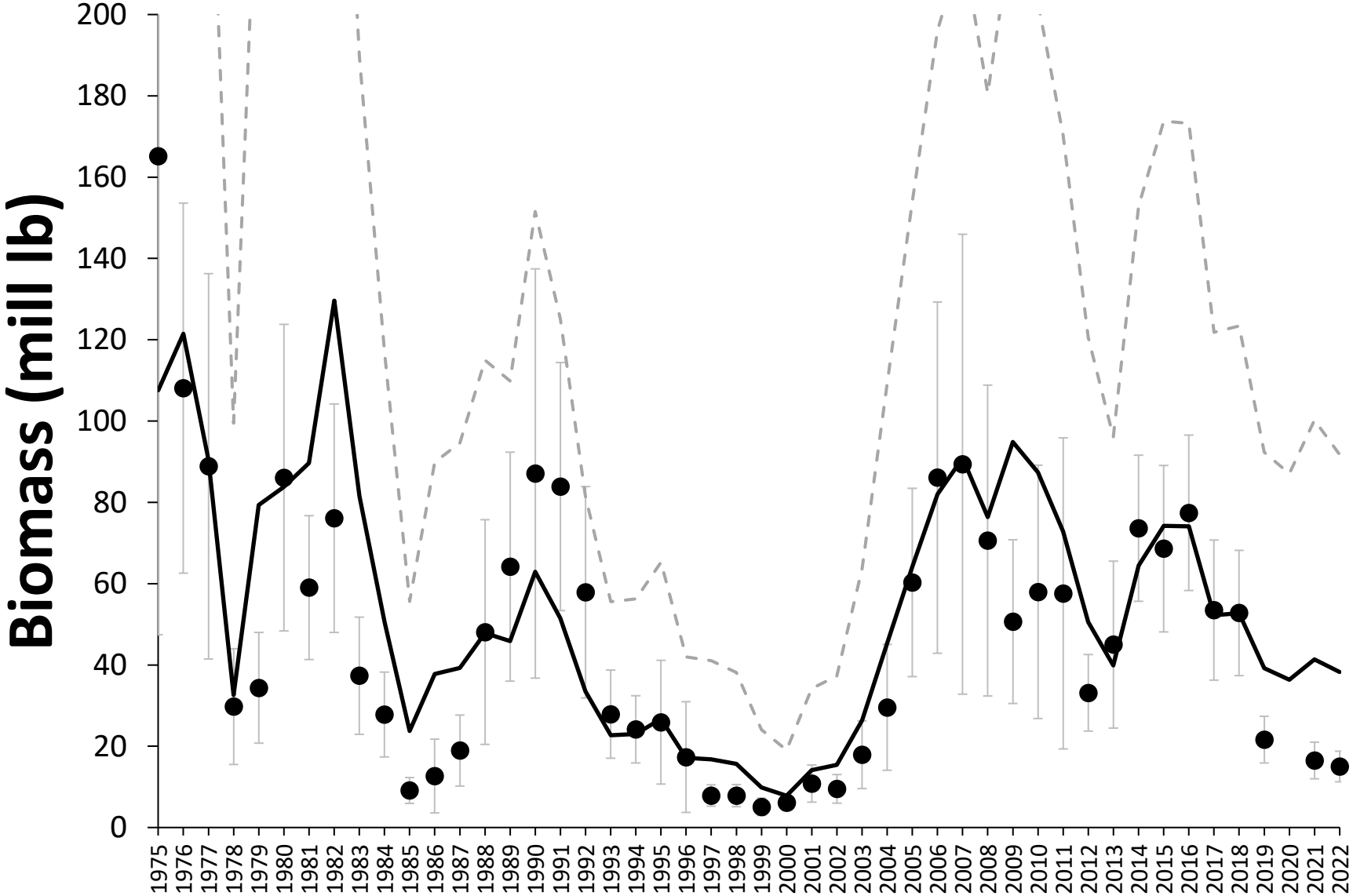
Mature female biomass Entire EBS



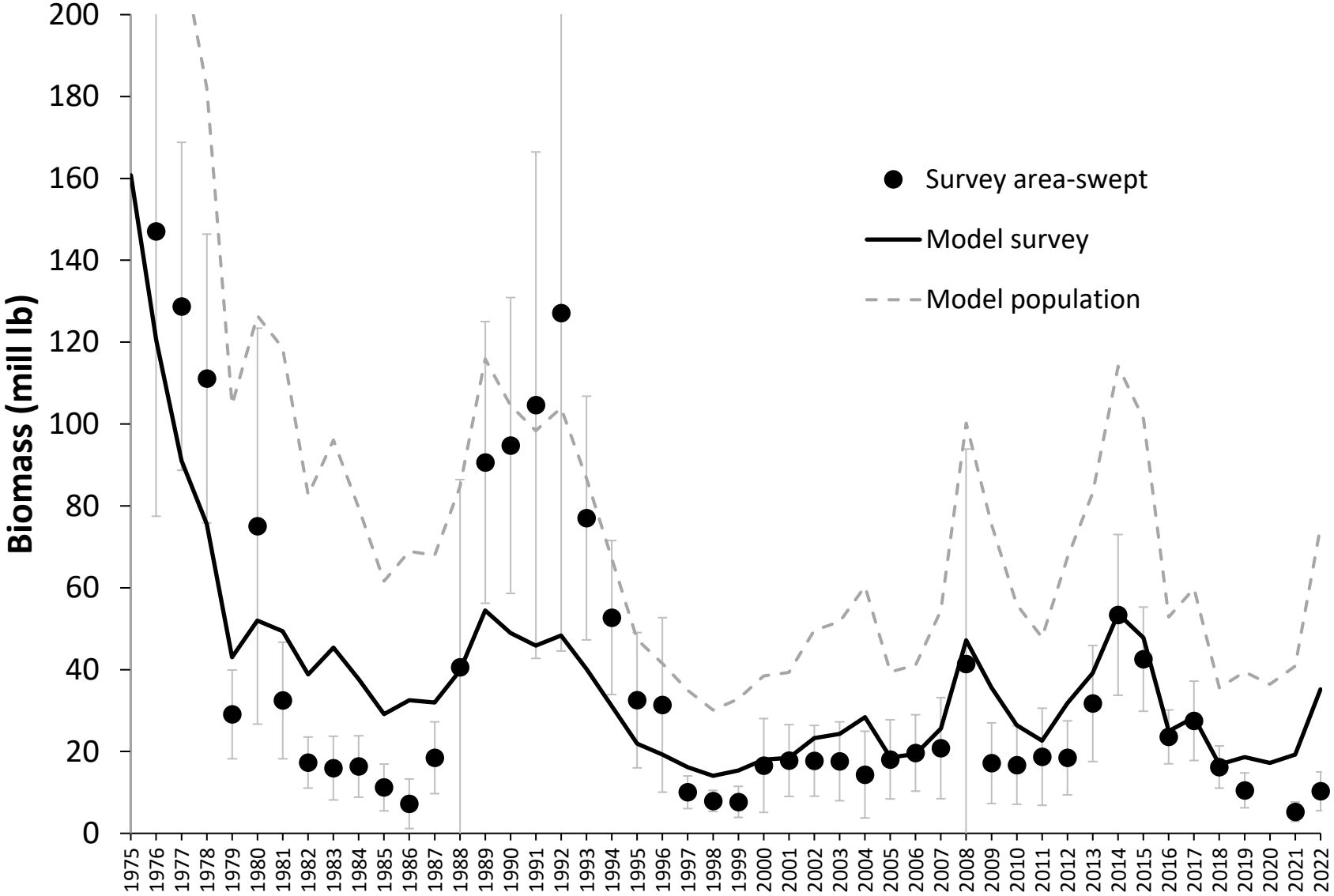
Mature males EAST of 166 W



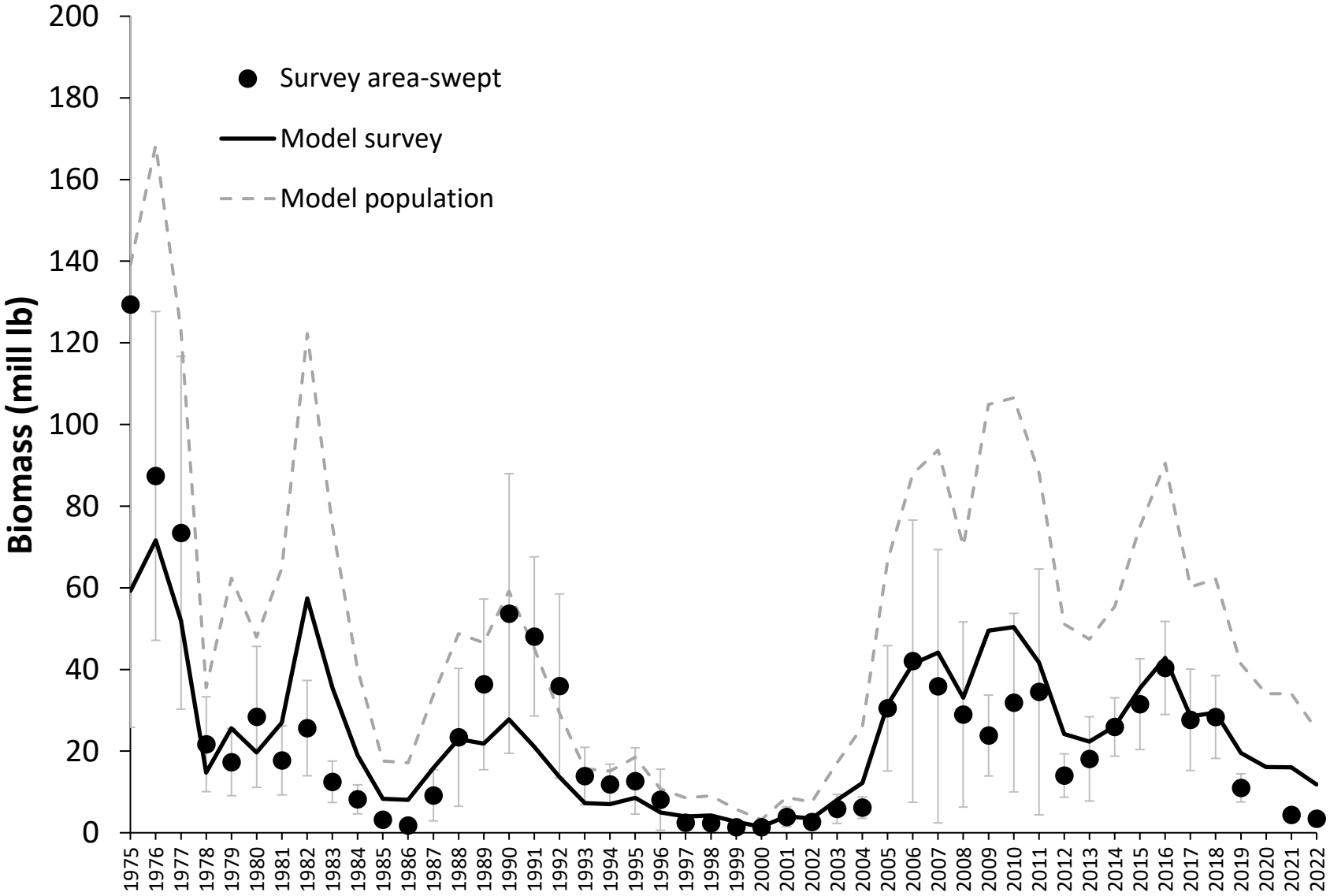
Mature males WEST of 166 W



5 inch males EAST of 166 W



5 inch males WEST of 166 W

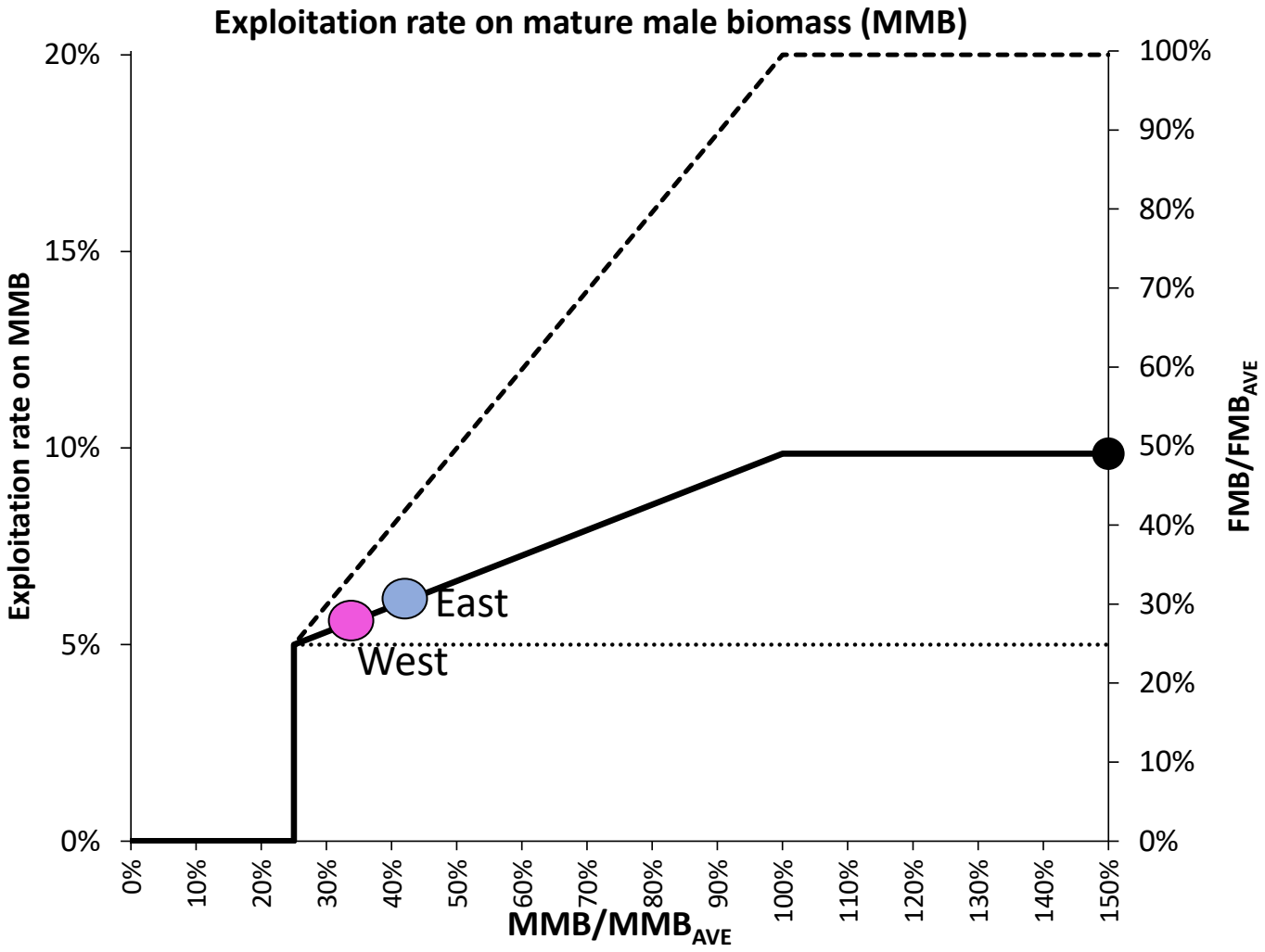


Application of State Harvest Strategy

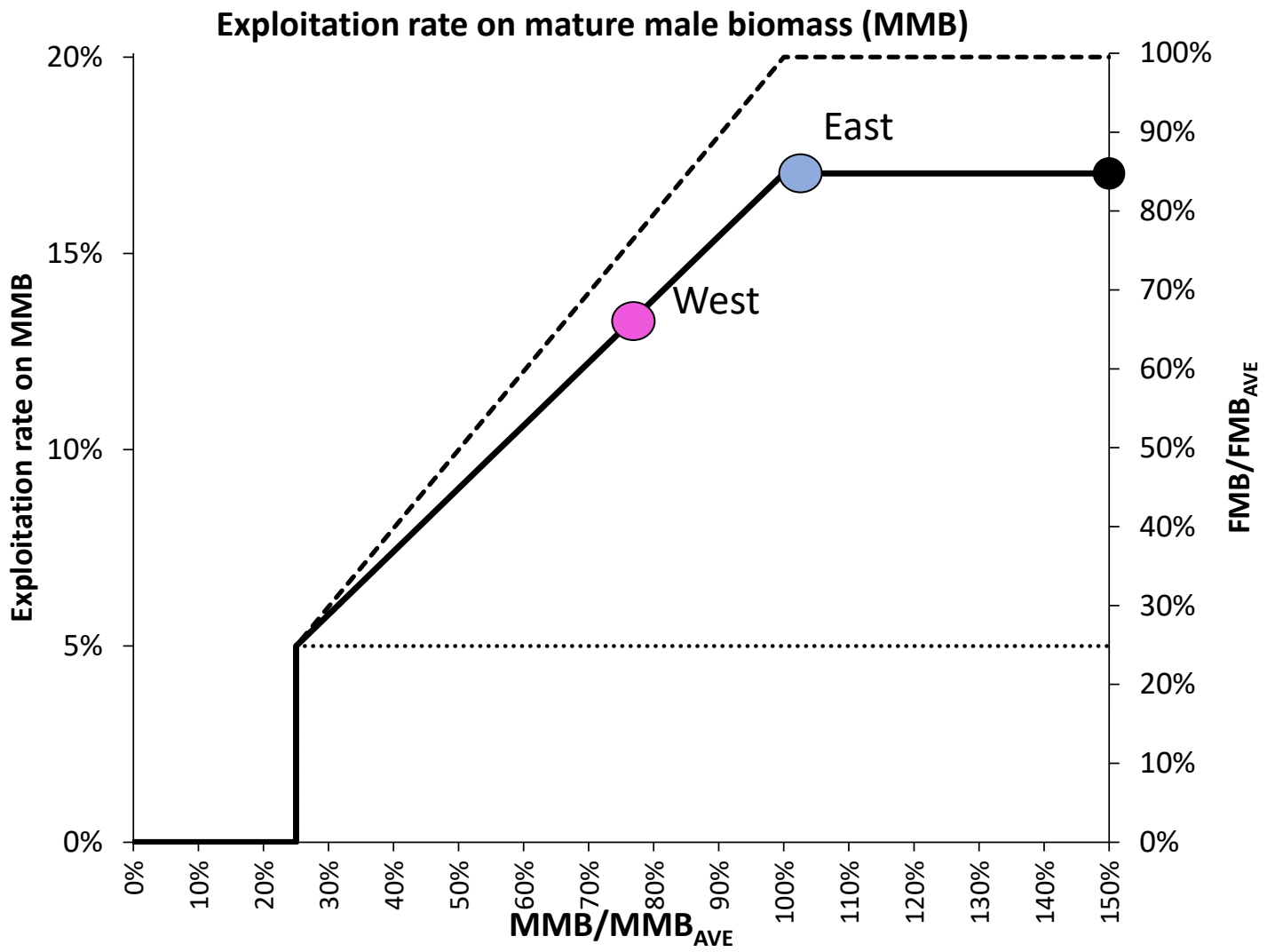
3 TAC calculations for comparison

1. **Survey area-swept** based TAC: raw area-swept, use size cut for male maturity
2. **Model survey** TAC: model estimates of survey, uses maturity ogive
3. **Model population** TAC: accounts for survey selectivity

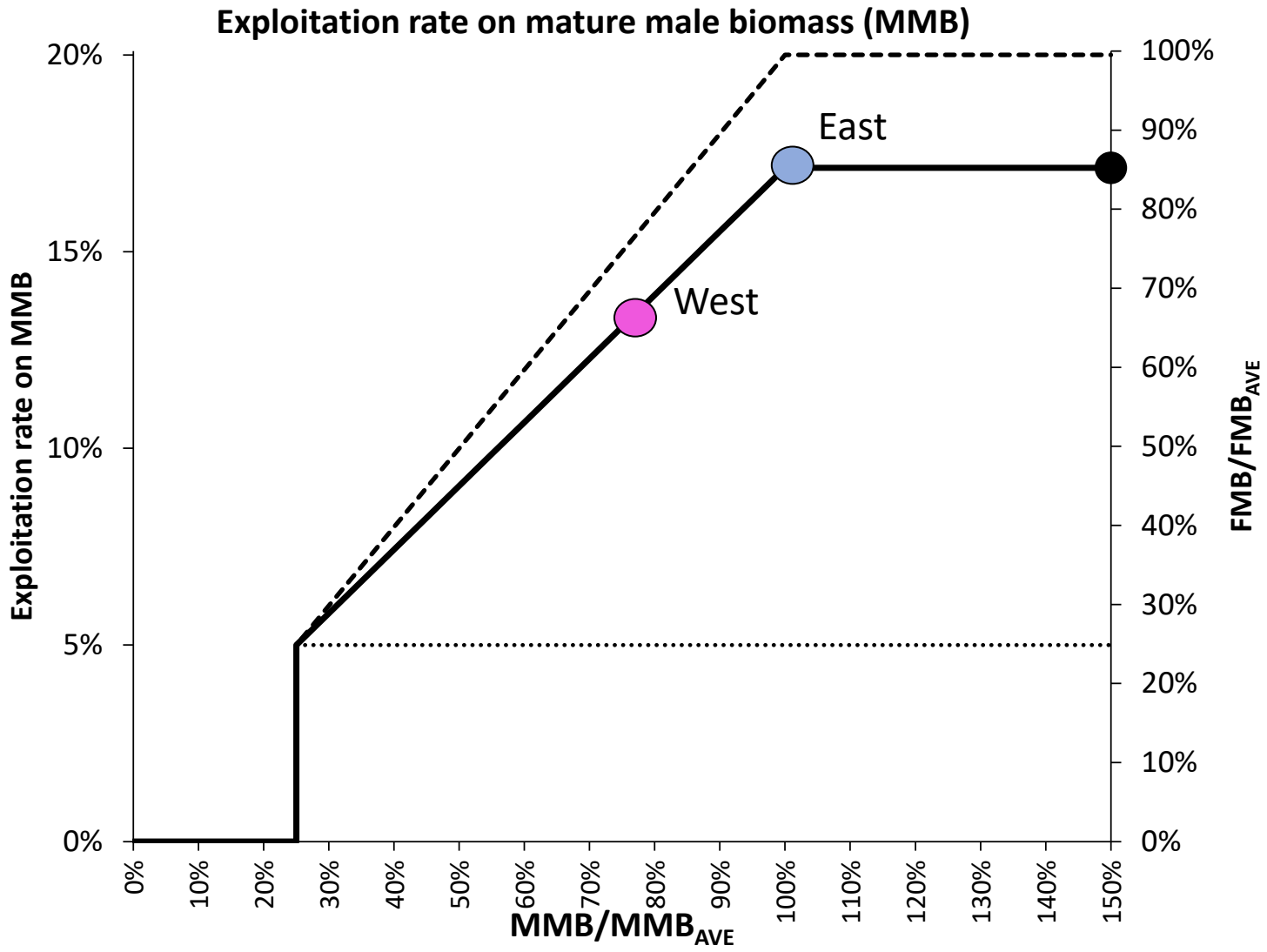
Survey


Exploitation rate on mature male biomass (MMB)
Exploitation rate on MMB
20%
15%
10%
5%
0%
FMB/FMB$_{AVE}$
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
East
West
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
110%
120%
130%
140%
150%
MMB/MMB$_{AVE}$

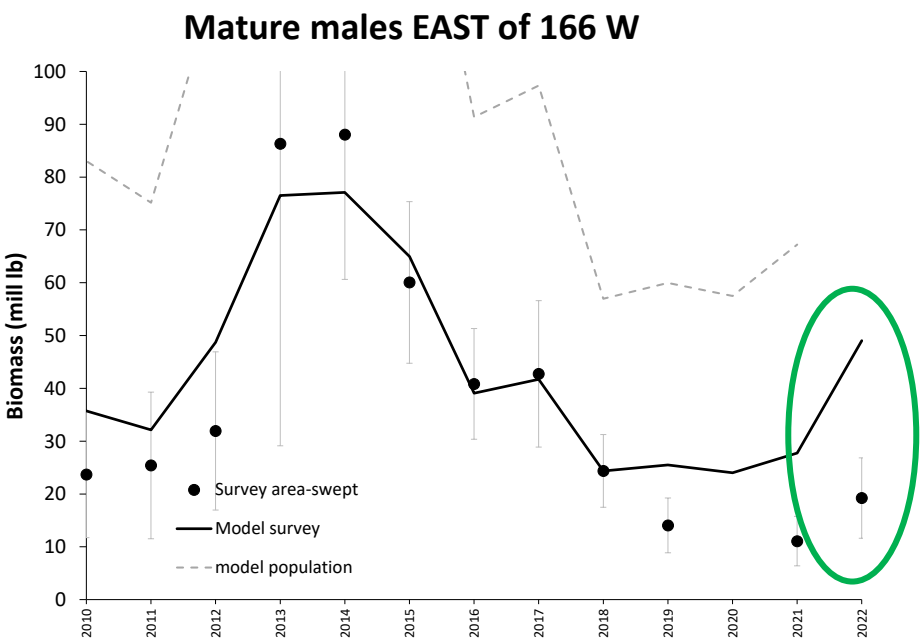
Model Survey

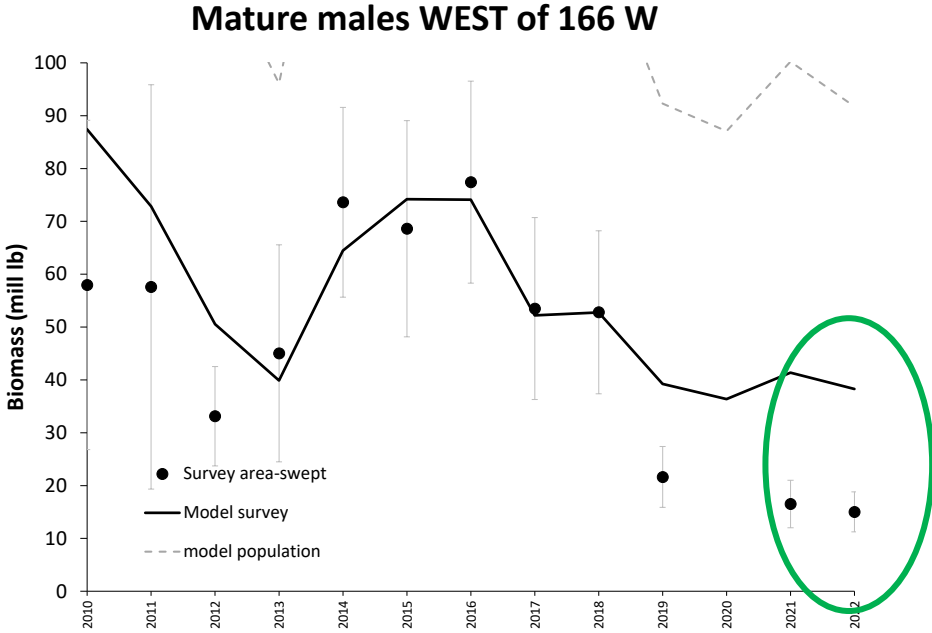


Model Population



2022 Model survey MMB ~2.5X survey estimate





General uncertainty about model estimates

EAST

Computed 2022/23 TACs: area-swept and Model estimates. Assumed old-shell fishery selectivity = 0.40 relative to new-shell.

	Raw area-swept (size cut)		Survey (Model Predicted)		Population (Model Estimated)	
	MFB	MMB	MFB	MMB	MFB	MMB
1982-2018 Average (millions lb)	**29.4**	46.8	**24.0**	48.1	**104.2**	115.1
2022 Estimate (millions lb)	**14.5**	**19.2**	**20.5**	**49.0**	**89.3**	**117.4**
(2022 Est)/(1982-2018 Avg)	**49%**	41%	**85%**	102%	**86%**	102%
Exploitation Rate on MMB		**0.060**		**0.170**		**0.171**
Computed TAC = Exp Rate X MMB (millions lb)		1.16		8.35		20.12
Max TAC (50% cap on exploited legal males (million lb)		4.50		13.55		29.17
TAC		**1.163**		**8.352**		**20.12**

	Area-swept (Raw NOAA values)	Survey (Model Predicted)	Population (Model Estimated)
Abundance of ♂♂ ≥ 5-in CW (millions)	6.3	18.9	40.6
Average wt (W; from survey; lb)	1.646	1.646	1.646
% old shell (from area-swept)	21%	21%	21%
Expected old shell selectivity	0.4	0.4	0.4
Exploited legal males ("ELM"; millions)	5.5	16.5	35.4
Max TAC (= 0.5xELMxW; millions lb)	**4.50**	**13.55**	**29.17**

WEST

Computed 2022/23 TACs: area-swept and Model estimates. Assumed old-shell fishery selectivity = 0.40 relative to new-shell.

	Raw area-swept (size cut)		Survey (Model Predicted)		Population (Model Estimated)	
	MFB	MMB	MFB	MMB	MFB	MMB
1982-2018 Average (millions lb)	**29.4**	43.0	**24.0**	49.3	**104.2**	117.0
2022 Estimate (millions lb)	**14.5**	**15.0**	**20.5**	**38.3**	**89.3**	**91.7**
(2022 Est)/(1982-2018 Avg)	**49%**	35%	**85%**	78%	**86%**	78%
Exploitation Rate on MMB		**0.056**		**0.135**		**0.136**
Computed TAC = Exp Rate X MMB (millions lb)		0.85		5.16		12.52
Max TAC (50% cap on exploited legal males (million lb)		1.18		3.55		7.65
TAC		**0.848**		**3.553**		**7.65**

	Area-swept (Raw NOAA values)	Survey (Model Predicted)	Population (Model Estimated)
Abundance of ♂♂ ≥ 5-in CW (millions)	2.3	6.9	14.8
Average wt (W; from survey; lb)	1.518	1.518	1.518
% old shell (from area-swept)	53%	53%	53%
Expected old shell selectivity	0.4	0.4	0.4
Exploited legal males ("ELM"; millions)	1.6	4.7	10.1
Max TAC (= 0.5xELMxW; millions lb)	**1.18**	**3.55**	**7.65**

EAST TAC Recommendation = 1.163 mill lbs

- Uncertainty with model 2022 estimates
  - Model MMB ~2.5x survey
  - Model 5 inch male ~4x survey
- Survey trends for MMB + 5 inch males increased from 2021
  - 5 inch male abundance doubled from 2021

WEST TAC Recommendation = 0.850 mill lb

- Recognizes reductions in survey biomass
- Survey trends for MMB + 5 inch continue downward trend
- Uncertainty with model 2022 estimates
  - Model MMB ~2.5x survey
  - Model 5 inch male ~4x survey

Tanner crab outlook

- Good signs of recruitment, but strong juvenile cohorts not propagating to larger sizes
- Unclear what is causing population bottleneck
- Warm conditions likely to become more frequent in future
  - Effects on Tanner crab unknown

BBRKC

2022 Assessment: scenario 21.1b

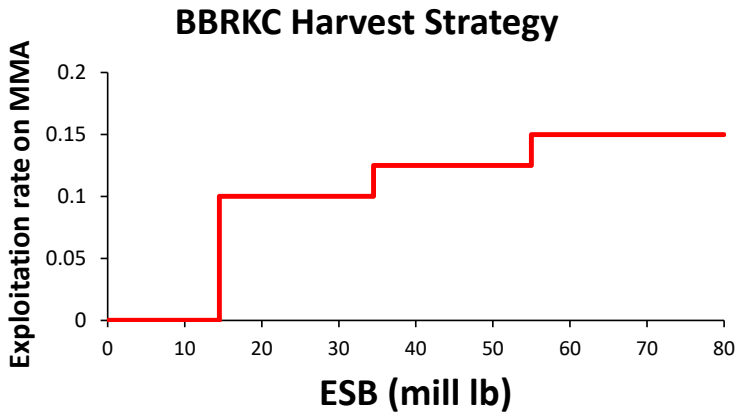
- SSC + Council adopted CPT recommendations
- Stock status:
  - Current: 69% of B_{MSY}
  - Projected: 71% of B_{MSY}

- OFL: 6.70 million lbs
- ABC: 5.35 million lbs
  - including bycatch mortality of males and females in all fisheries
  - based on a 20% buffer on OFL

BBRKC State Harvest Strategy

1. **Stock threshold for opening fishery:**
   - 8.4-million mature-sized females (≥ 90 mm CL), and
   - 14.5-mill lb of effective spawning biomass (ESB)

2. **Exploitation rate on mature-sized (≥120-mm CL) male abundance:**
   - 10%, when ESB <34.75-mill lb
   - 12.5%, when ESB is between 34.75-mill lb and 55.0-mill lb
   - 15%, when ESB ≥55.0-mill lb



3. **Harvest capped at 50% of legal male abundance**

Thresholds for Opening the Fishery

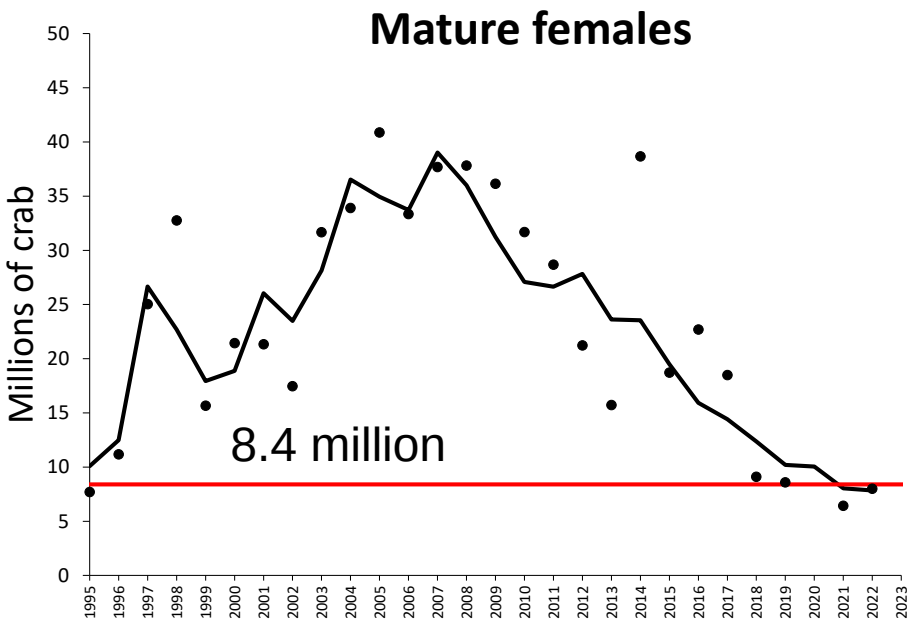
8.4-million mature females

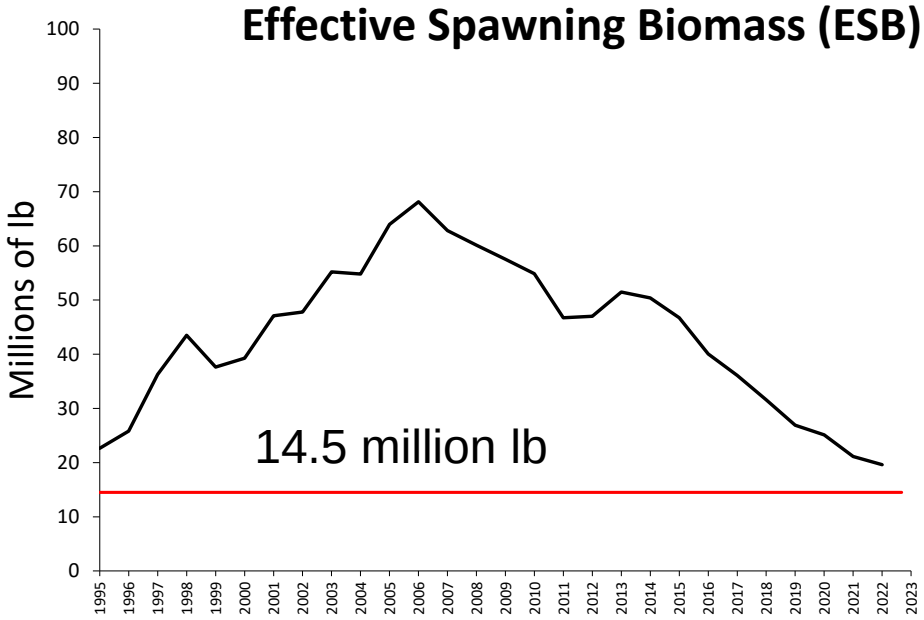
+

14.5-mill lb of effective spawning biomass (ESB)

Harvest Strategy Closure Thresholds

2 thresholds, both based on mature females

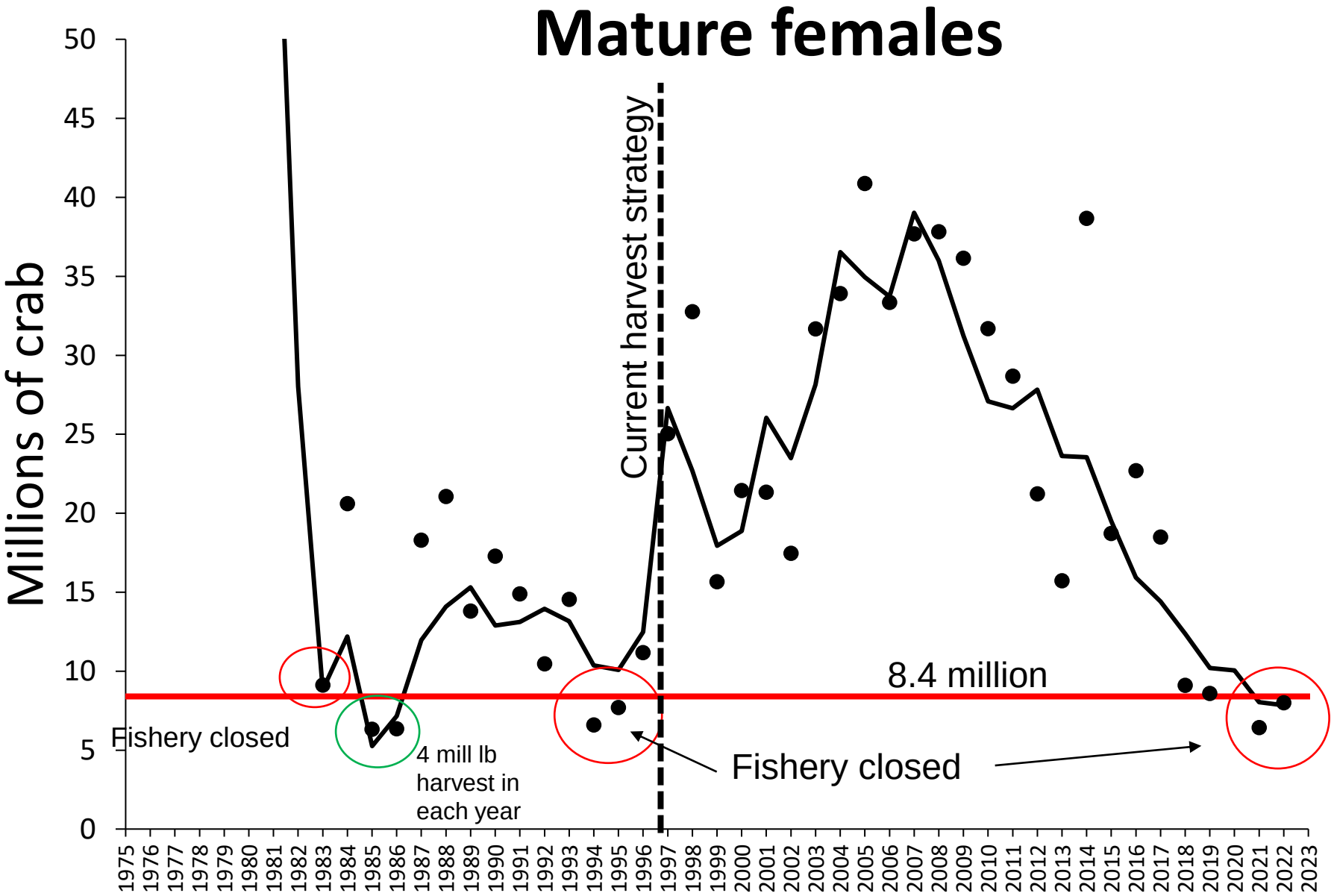




2022 area-swept: 8.0 million
2022 model: 7.8 million

2022 model: 19.6 million lb

Stock below threshold for opening fishery


Mature females
Millions of crab
50
45
40
35
30
25
20
15
10
5
0
Current harvest strategy
8.4 million
Fishery closed
4 mill lb
harvest in
each year
Fishery closed
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
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2021
2022
2023

Mature Female Abundance Threshold

- Blunt tool meant to avoid recruitment overfishing
- **8.4 million MFA threshold**: estimated at 20% of equilibrium level of fertilized females from Ricker stock-recruitment curve ("Thompsons rule", Thompson 1990)
  - Defined as the minimum mature female abundance "*that allows sufficient recruitment so that the stock can eventually reach a level that produces MSY*" (1989 BSAI Crab FMP)

Thompson G.G. 1990. A proposal for a threshold stock size and maximum fishing mortality rate. Chapter 3, Appendix I in Environmental assessment, regulatory impact review, and initial regulatory flexibility analysis for a mendment 21 to the Fishery Management Plan for groundfish of the Gulf of Alaska and Amendment 16 to the Fishery Management Plan for groundfish of the Bering Sea Aleutian Islands. North Pacific Fishery Management Council, Anchorage.

2021/22 BBRKC fishery closure

Analysis of harvest strategies for red king crab, *Paralithodes camtschaticus*, in Bristol Bay, Alaska

J. Zheng, M.C. Murphy, and G.H. Kruse

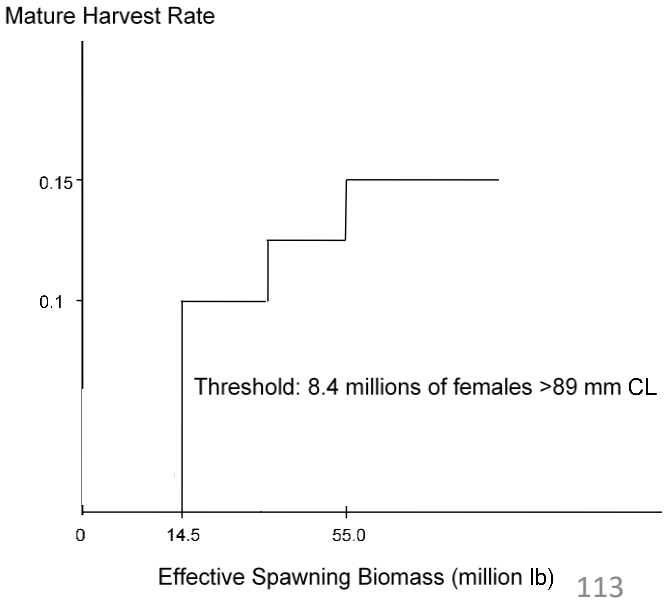
Abstract: A modifiable harvest rate constrained by a minimum spawning abundance (threshold) is currently used to set the annual harvest level for Bristol Bay red king crab, *Paralithodes camtschaticus*. A length-based simulation model was constructed to evaluate effects of recruitment, natural mortality, and handling mortality on this harvest strategy. Evaluation criteria included mean yield, stability of yield, harvest opportunity, and stability of spawning stock. Optimal mature male harvest rates were strongly negatively related to handling mortality. For any given harvest rate, handling mortality is a key factor influencing optimal thresholds. The current harvest strategy produces a high mean yield and low variability in yield under low handling mortality scenarios, but the population is at high risk of collapse with a high handling mortality. Given uncertainties of recruitment, natural mortality, and handling mortality estimates, we recommend reducing mature male harvest rate from 20 to 15% and maximum legal male harvest rate cap from 60 to 50%. If handling mortality rate is greater than 30%, then we recommend increasing the threshold from 6600 to 11 000 metric tons of effective spawning biomass. Our recommended harvest strategy produces a mean yield similar to the current harvest strategy and safeguards against recruitment overfishing.

A length-based population model and stock–recruitment relationships for red king crab, *Paralithodes camtschaticus*, in Bristol Bay, Alaska[1]

J. Zheng, M.C. Murphy, and G.H. Kruse

Abstract: A length-based population model was constructed for Bristol Bay red king crab, *Paralithodes camtschaticus*, incorporating stochastic growth, gradual recruitment over length, and a bowl-shaped pattern for instantaneous natural mortality as a function of length. A nonlinear least squares approach was used to estimate abundance, recruitment, and natural mortality. The model was applied to abundance and catch data from 1968 to 1993. The observed population abundances fit well with the model. Natural mortality was estimated to be three to six times higher in the early 1980s than during other periods. High natural mortality coupled with high harvest rates and followed by low spawning biomass may have contributed to the collapse of the population in the early 1980s and its continued lack of recovery. The stock–recruitment data estimated from the length-based model provided a good fit to both general and autocorrelated Ricker models. The general Ricker model is supported by strong recruitment associated with intermediate levels of spawning biomass and extremely low recruitment related to low spawning stock; the autocorrelated Ricker model fit the data slightly better and is supported by the fact that extremely strong and weak recruitment occurred successively over two separate periods.

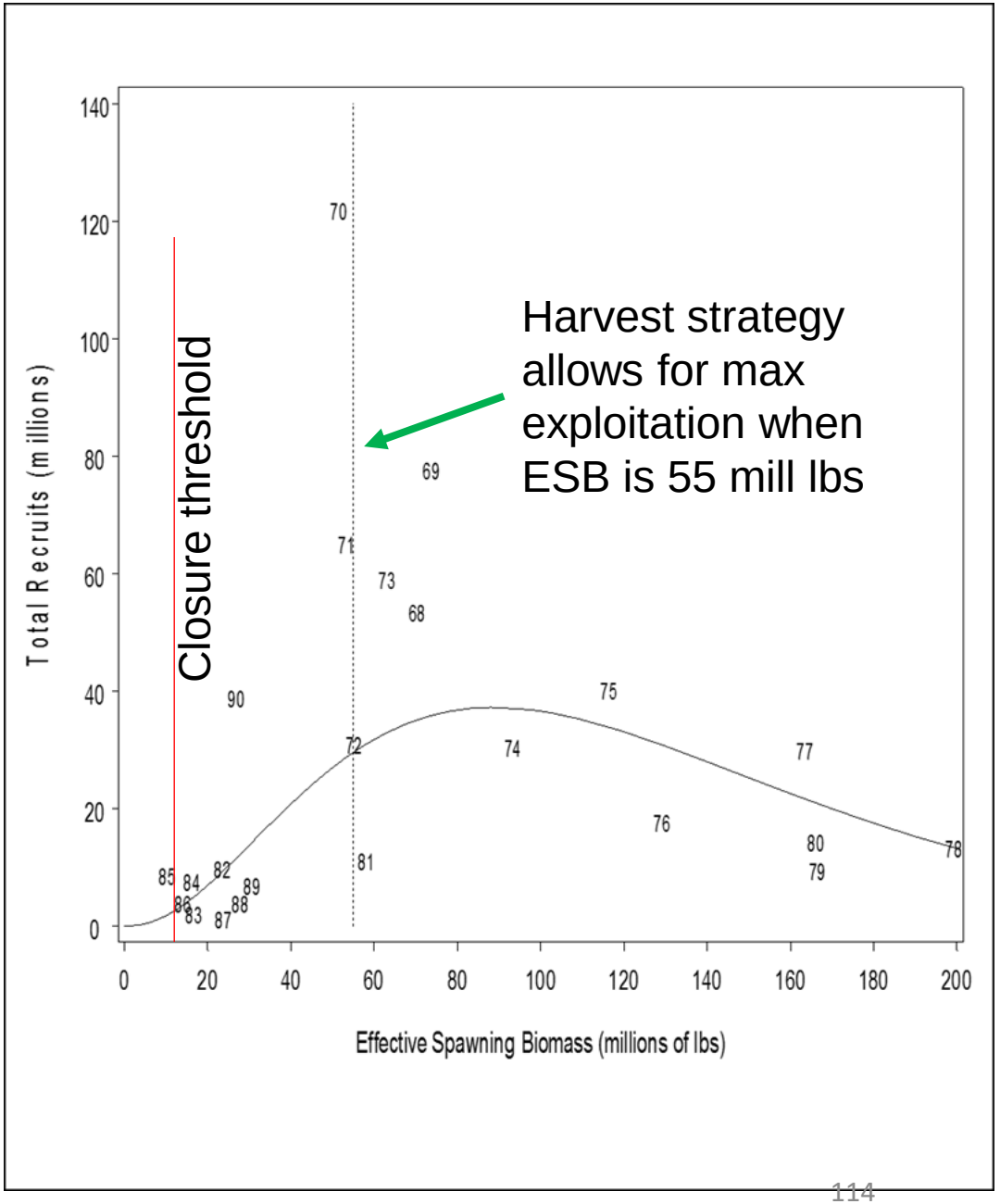
- Protecting females + maintaining adequate males for fertilization



BBRKC S-R

- Done in 1997 using data from the 70s + 80s when high recruitment occurred

- Fit is much worse with more recent data due to very low recruitment



Effective Spawning Biomass

- Max number of females that males in population can mate (male reproductive potential, MRP)
  - Assumes males can mate with multiple females in a season (mating pair lab studies, Kodiak field observations)

If MFA < MRP, then female spawning abundance = mature female abundance

If MFA > MRP, then male reproductive potential = female spawning abundance

Female spawning abundance then converted to biomass via LW relationship, and defined as effective spawning biomass (ESB)

Table 1. Average weight and assumed maximum number of female mates for male red king crab in Bristol Bay by length class.

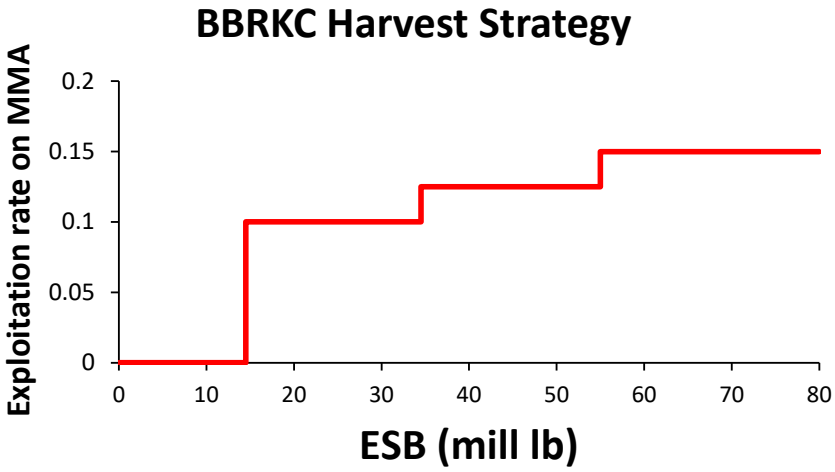
Male carapace length (mm)	Average male weight (kg)	Number of female mates
0–119		0.0
120–124	1.43	1.0
125–129	1.63	1.2
130–134	1.84	1.4
135–139	2.06	1.6
140–144	2.31	1.8
145–149	2.58	2.1
150–154	2.86	2.4
155–159	3.17	2.7
160+	3.50	3.0

Zheng et al., 1995

14.5 mill lb ESB Threshold

- 55 million lb rebuilding target: “intermediate level of biomass above which strong recruitment occurs with high frequency in the past” (Zheng et al 1997)
  - At or above this level allows for max exploitation rate of 15%

- 14.5 million lb is meant to approximate 8.4 million females
- 34.75 million lb stairstep was added on later, halfway between 55 and 14.5



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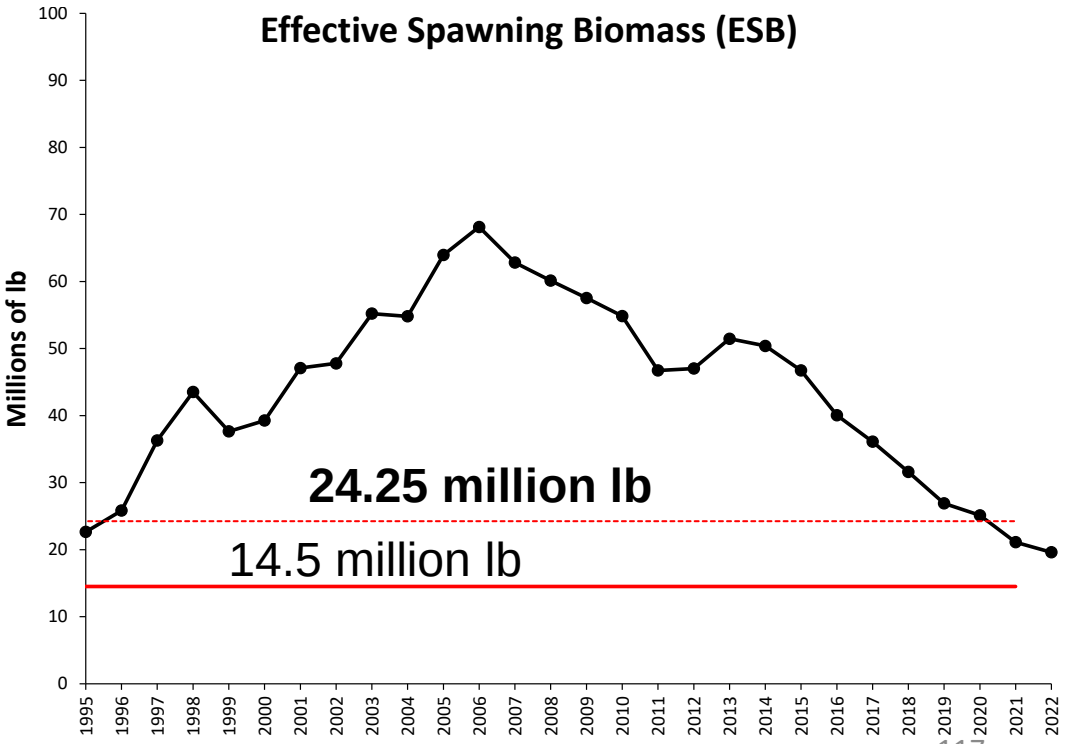
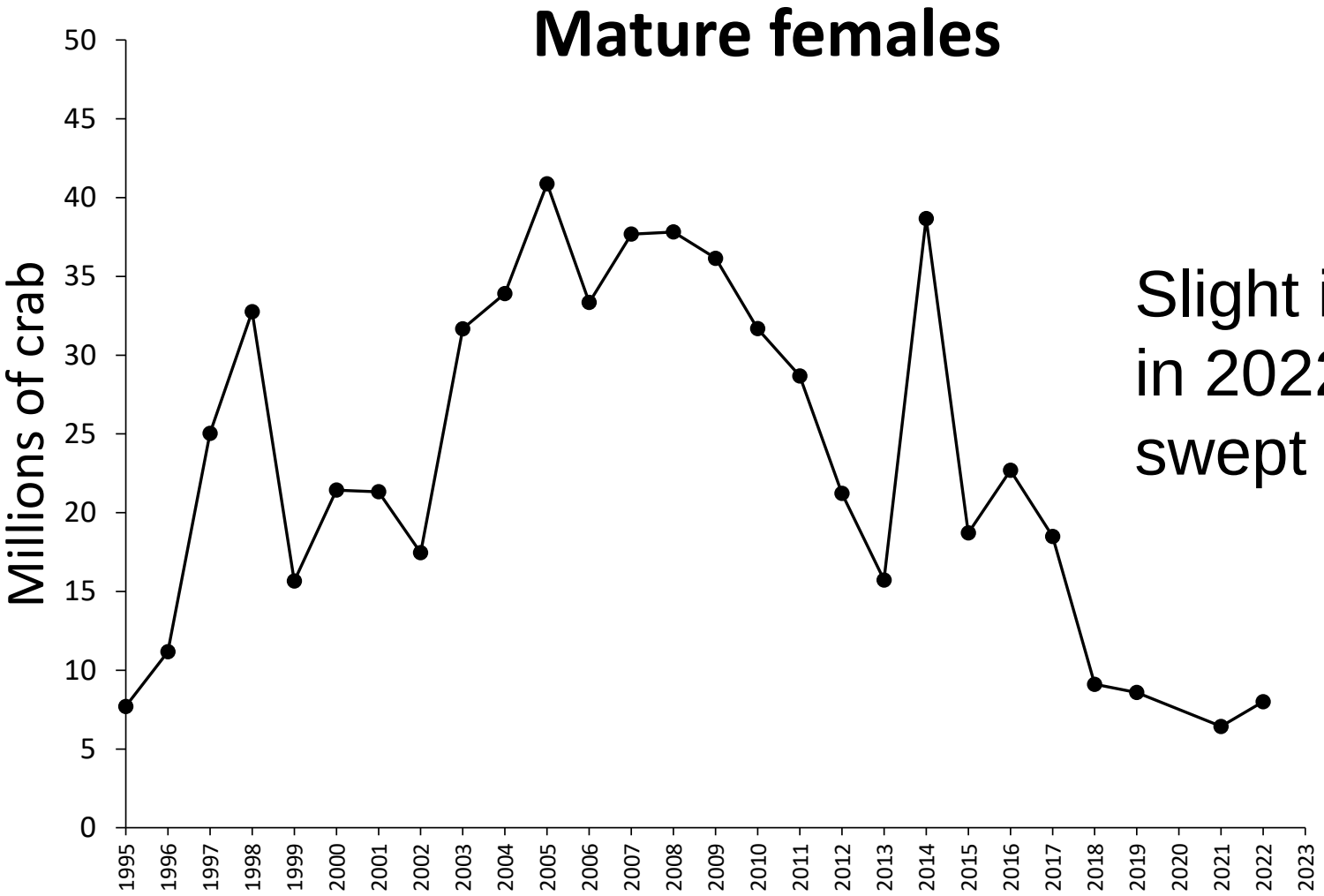
Early recommendation to increase threshold to 24.25 million lb ESB



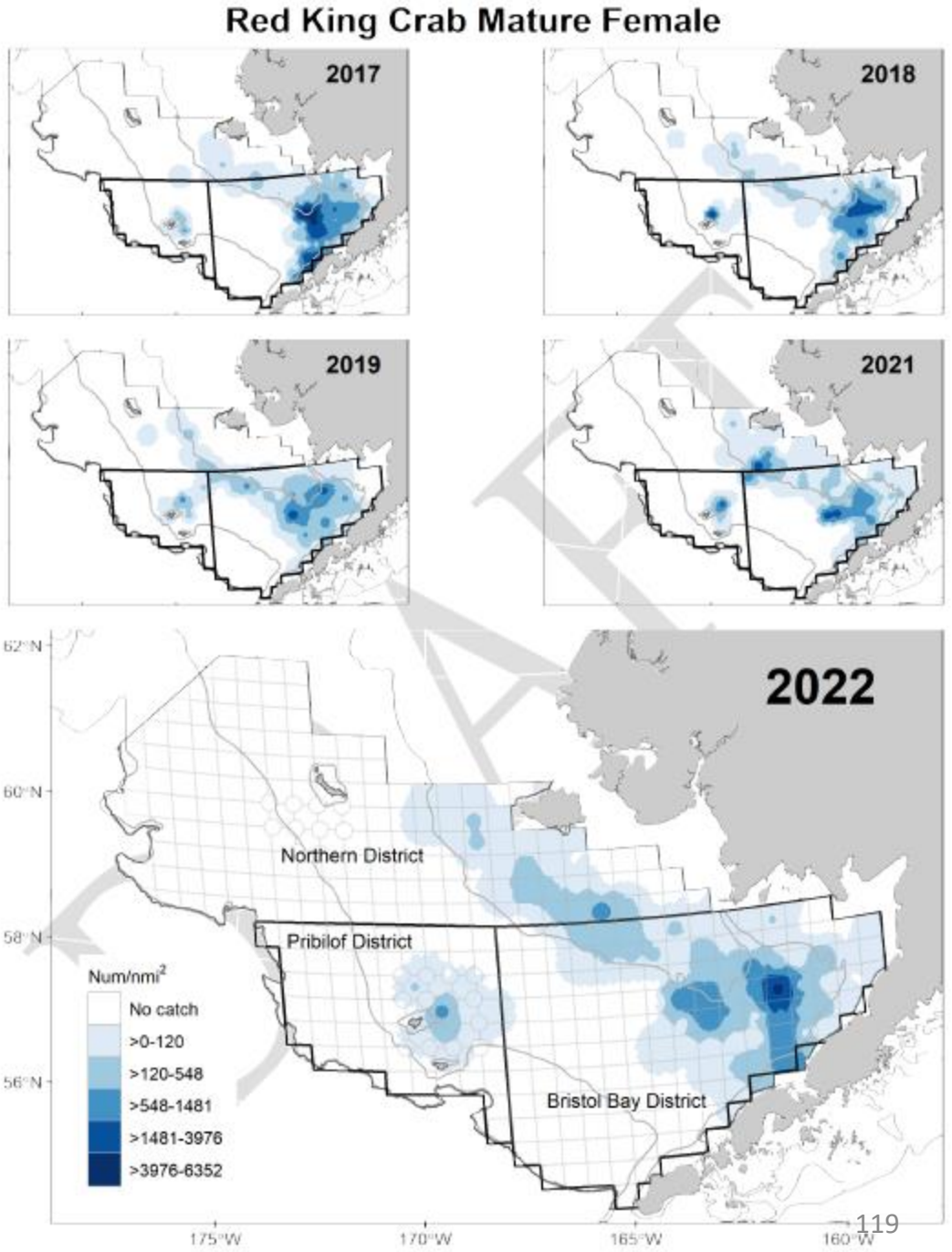
Mature females: survey data



Slight increase in 2022 area-swept

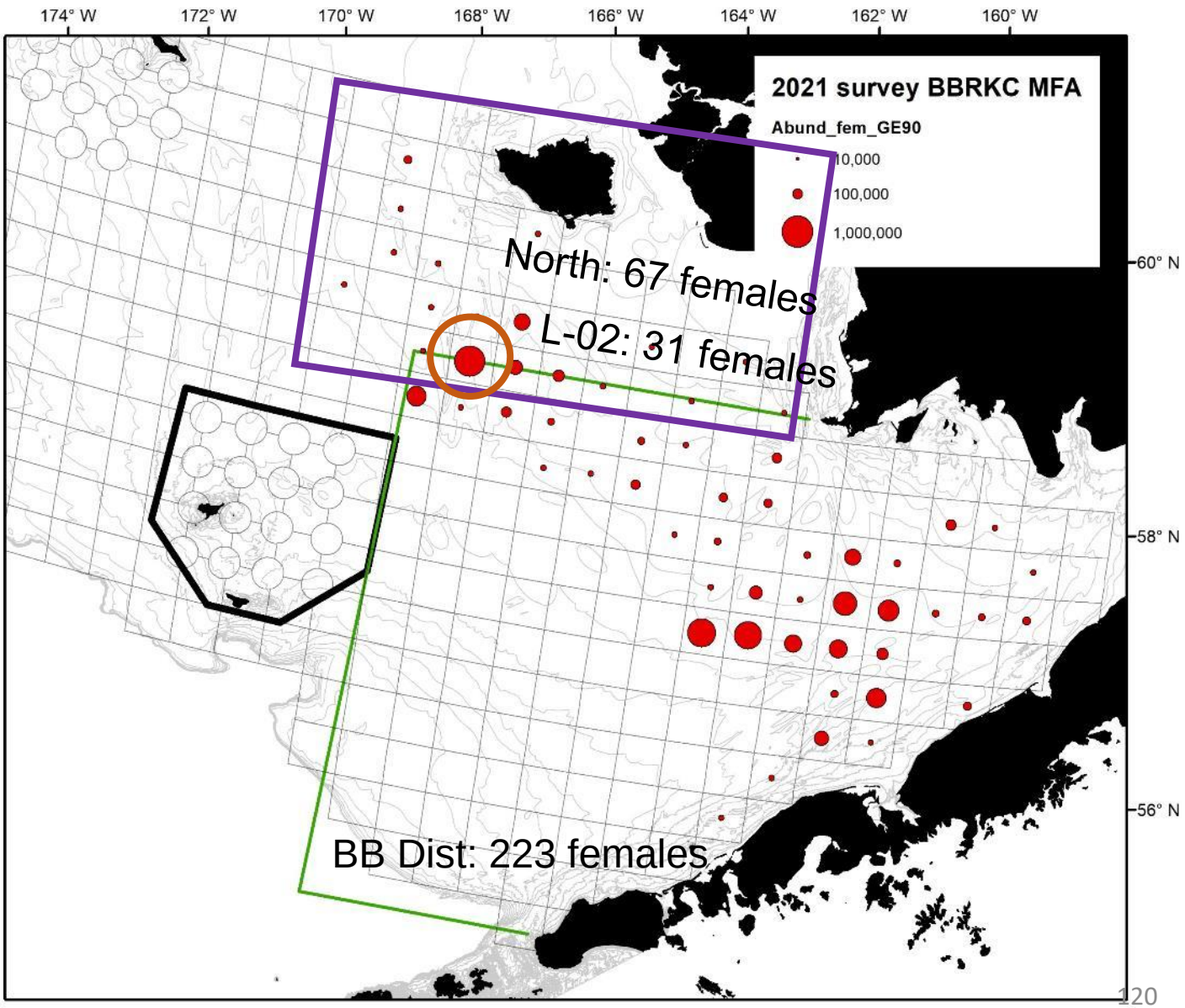
Mature female spatial dist

- RKC above northern border in all years
- 2021 had hot spot (station L-02)

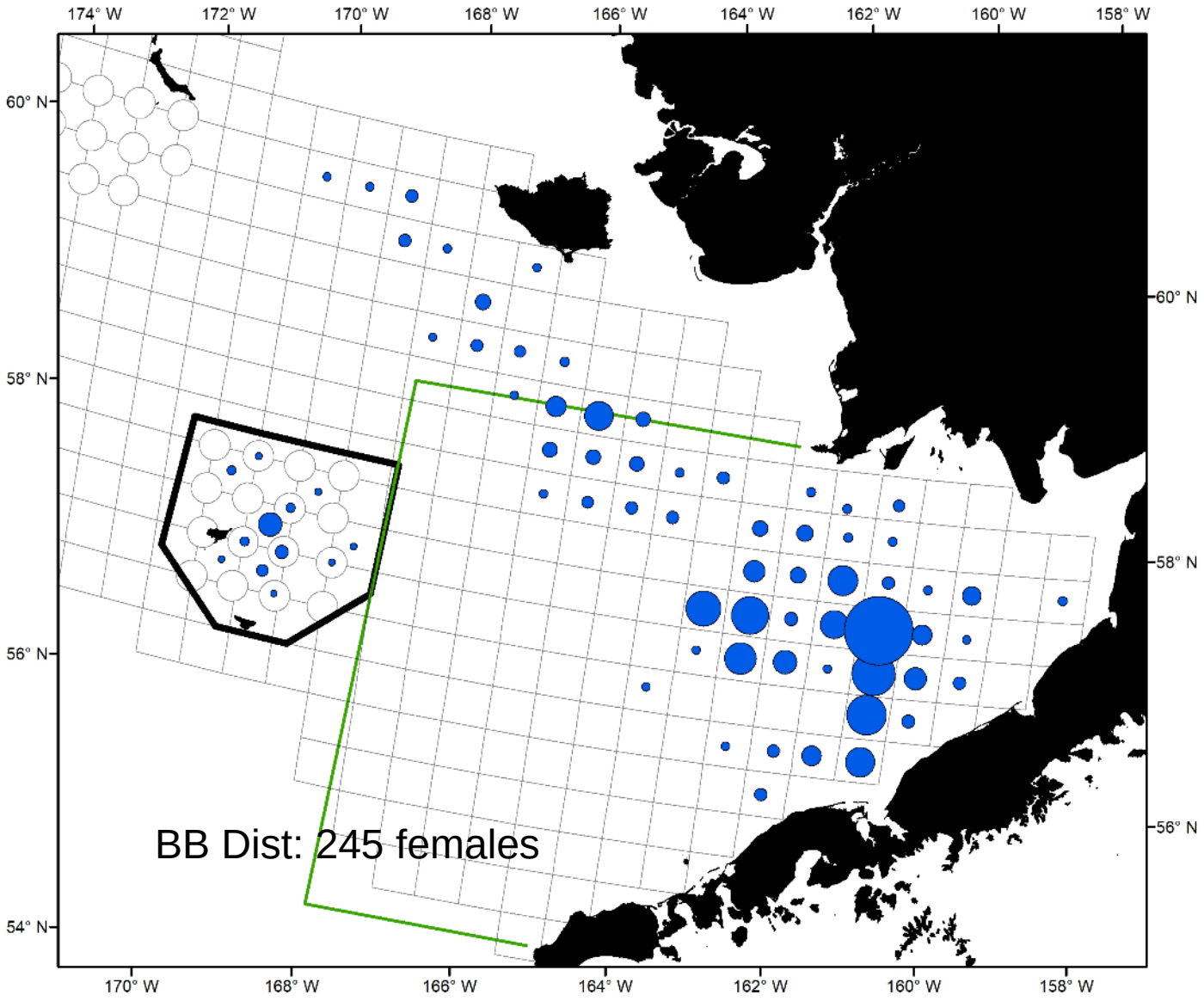


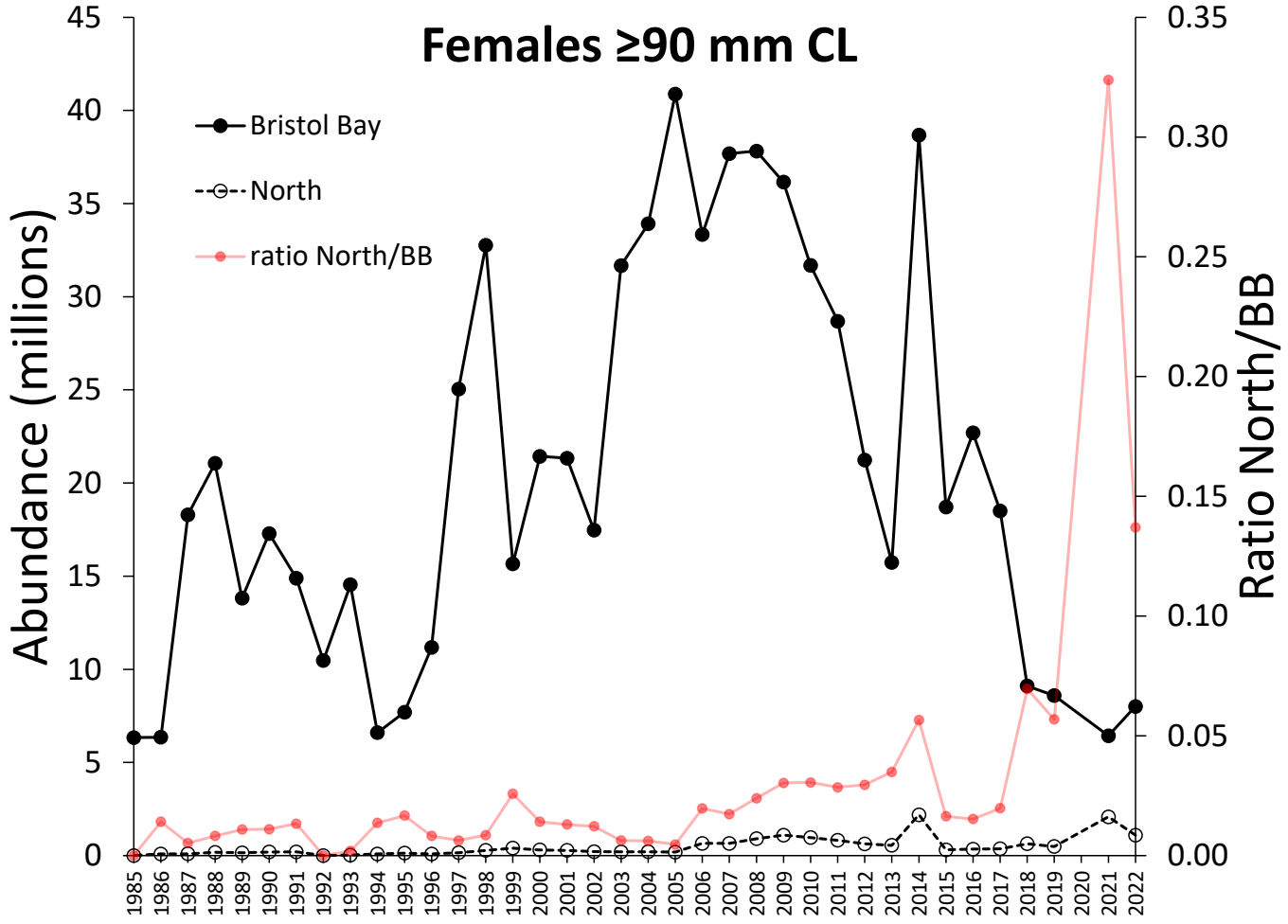
2022 NOAA Tech Memo

2021 Survey: Mature females



2022 Survey: Mature females



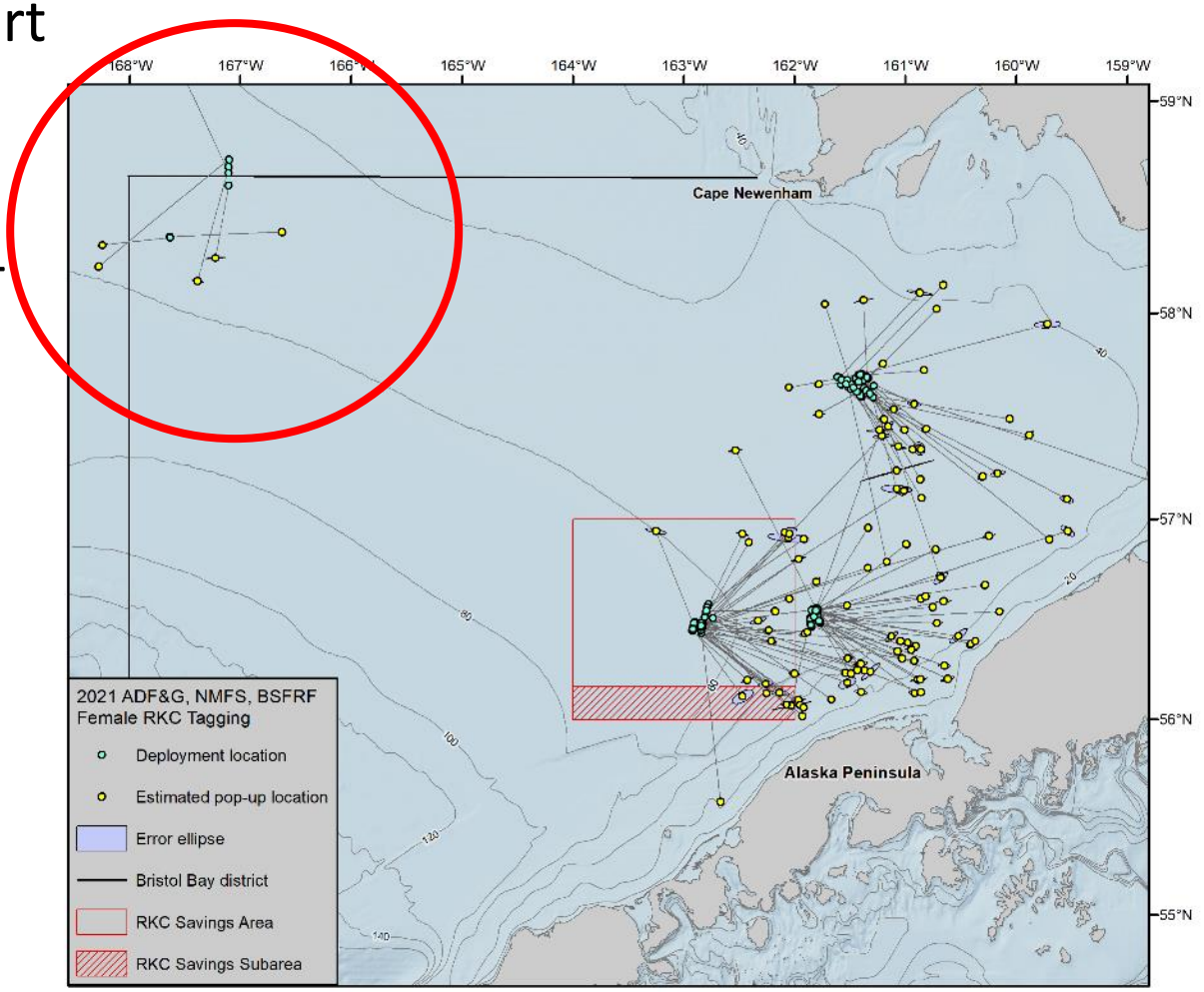


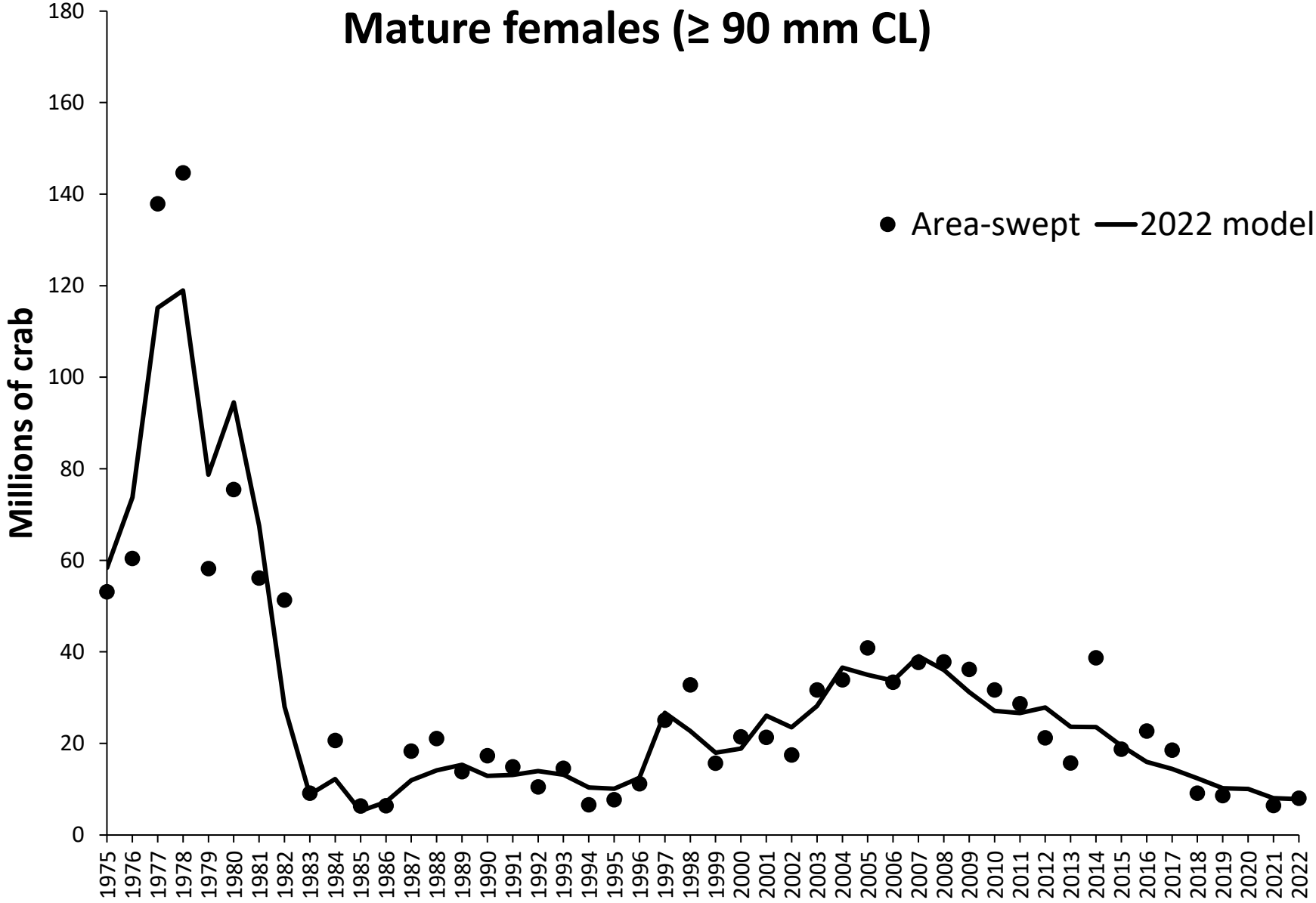
- Increase in BB female abundance
- Decrease in North female abundance
- Drop in proportion north
- Movement to the south?

Some evidence via 2021 tagging project (Nov 2021-May 2022) for movement to the south

- Large tagging effort in Nov 2021
- Very few female crab at L-02 (2021 survey hot spot)

- Small number of tagged crab provide some evidence for movement to south, but needs further work




Mature females (≥ 90 mm CL)
Millions of crab
Area-swept
2022 model
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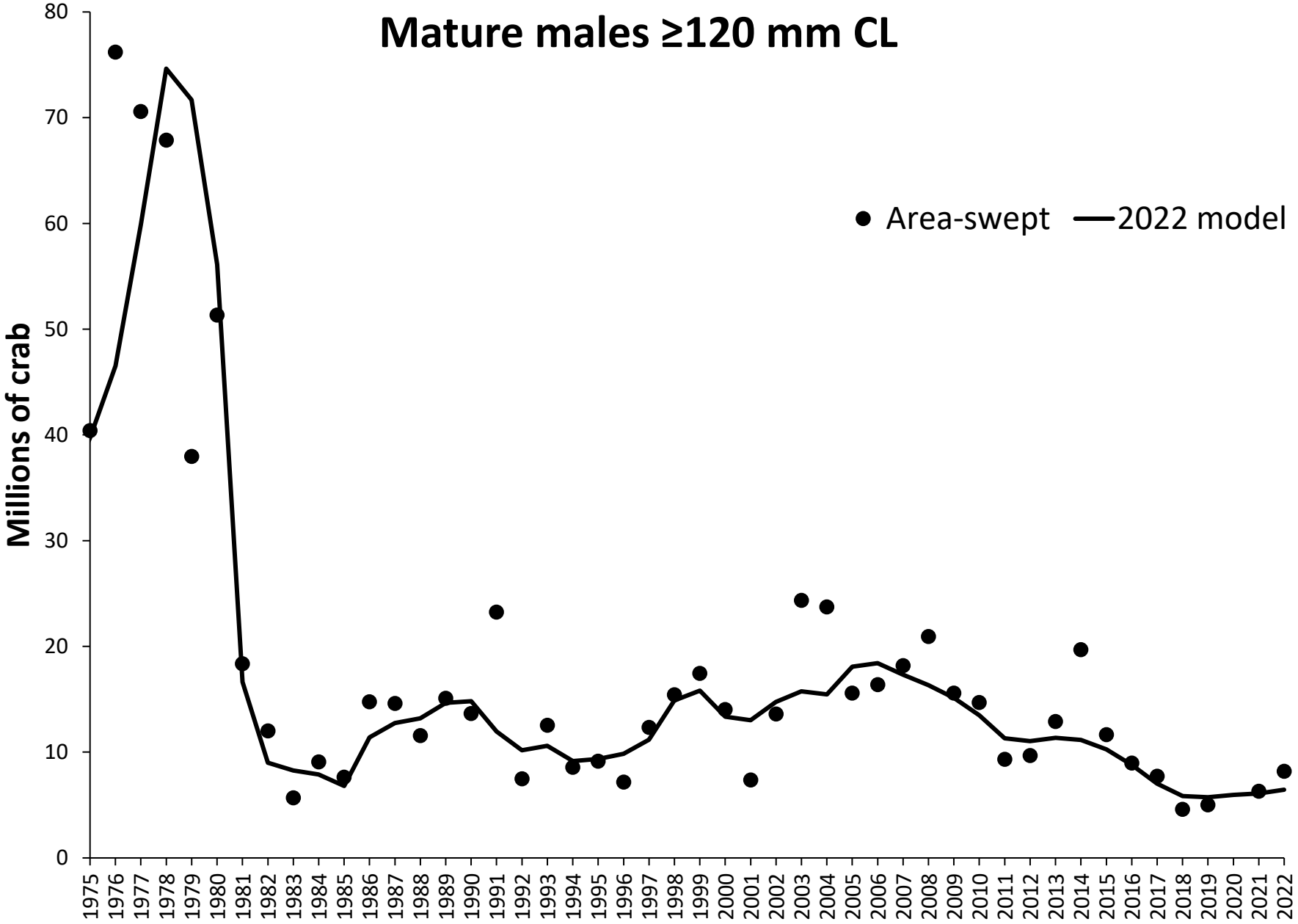
Mature males ≥120 mm CL
Millions of crab
Area-swept
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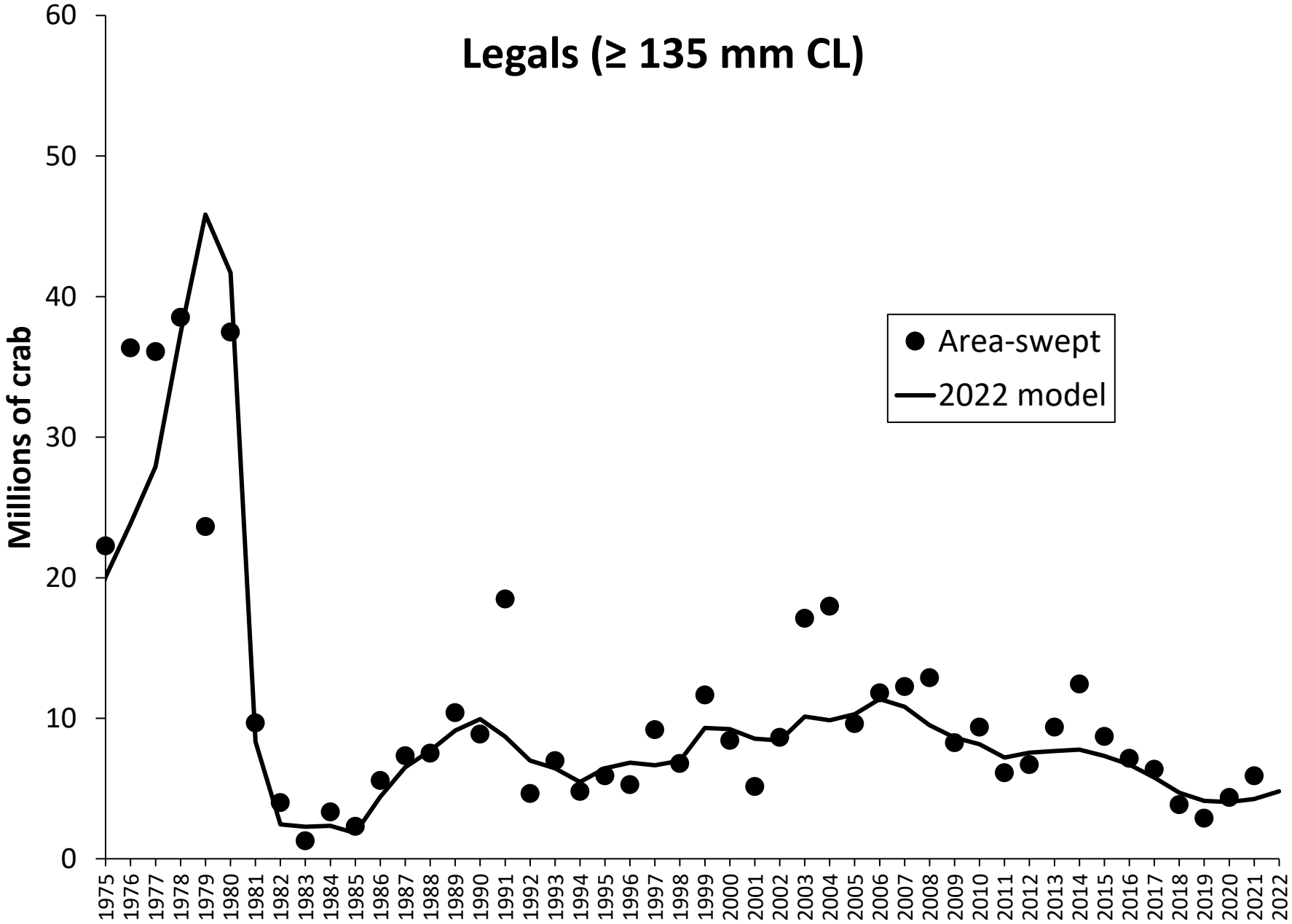
Legals (≥ 135 mm CL)
Millions of crab
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Area-swept
2022 model
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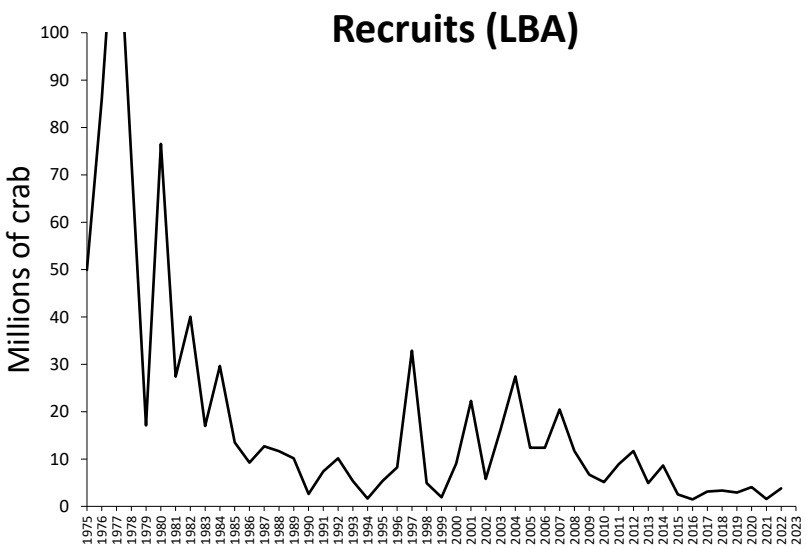
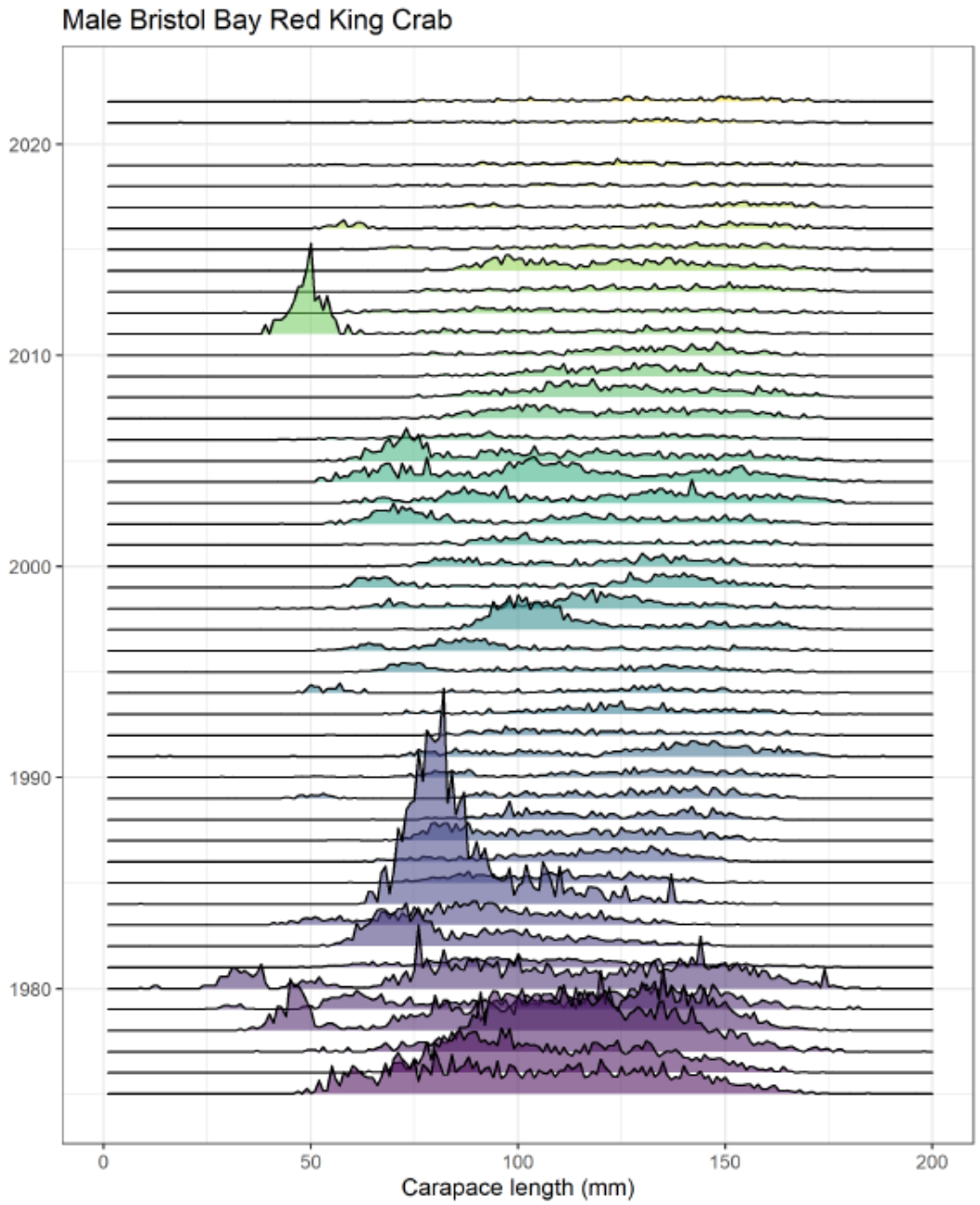
Low recruitment





- Not enough babies
- Females look to be mated, so where is the bottleneck?

Overall Outlook

- Abundance increases after prolonged decline
  - Males: increases 2 years in a row
  - Females: 2022 up from 2021 but still at very low level
- Females below harvest strategy closure threshold
- Low estimated recruitment
- Length frequencies discouraging, no strong pulses of small crabs in system
- Fluctuating environmental conditions
  - Impacts on BBRKC uncertain

What can we do?

1. Protect females
   - Minimize fishery mortality: bycatch reduction, closure areas
   - Habitat protection
2. Optimize mating opportunities
   - Maintain adequate males for fertilization
3. Understand critical spawning habitats
   - Where are females at during larval hatch?
     - Does this position facilitate advection towards favorable settlement habitats?
   - What are the critical larval source locations?
   - Make sure those locations are being protected

Recent, ongoing, + developing research

Seasonal movement: satellite tagging

- Spring spawning areas
- Winter distributions
- Inform area-protections

Recruitment limitation projects in development:

- Nursery habitat assessment: location, extent, impacts of trawling
- Larval supply: are larvae being delivered to nursery habitats?

Winter survey?

- Winter spatial distributions
- Are current area closures effective? Are changes needed?

BBRKC 2021 project: legal males

- Nov 2021 to Jan 2022

Generally supports location of RKCSA

Mean rate: 0.48 miles per day

Mean bearing: 128 degrees

BSFRF, NOAA, ADF&G collaborative effort

BBRKC 2021 project: mature females

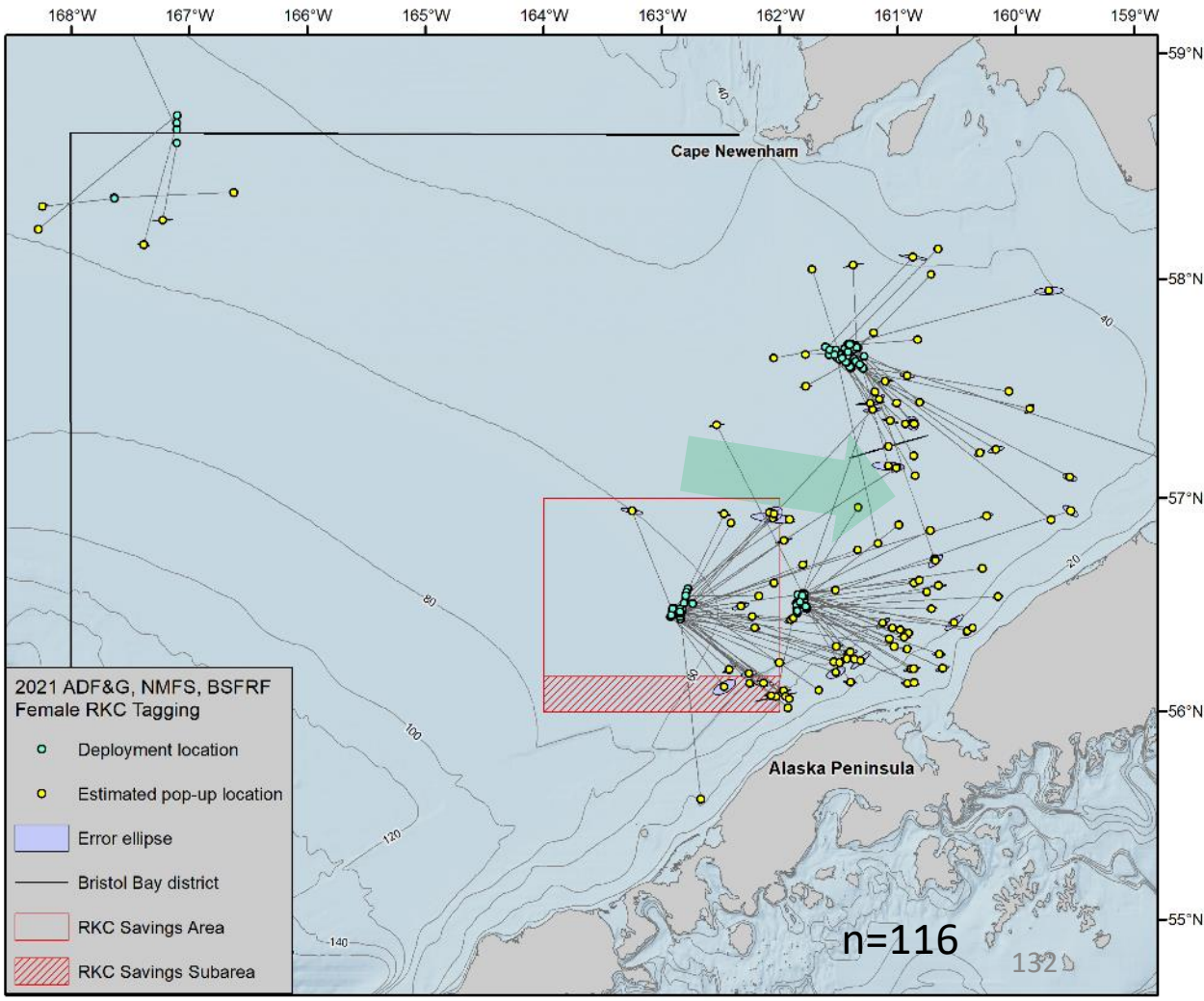
- Nov 2021 to April/May 2022

Generally supports location of RKCSA + nearshore trawl closure

Some nearshore spawning

Mean rate: 0.26 miles per day

Mean bearing: 116 degree



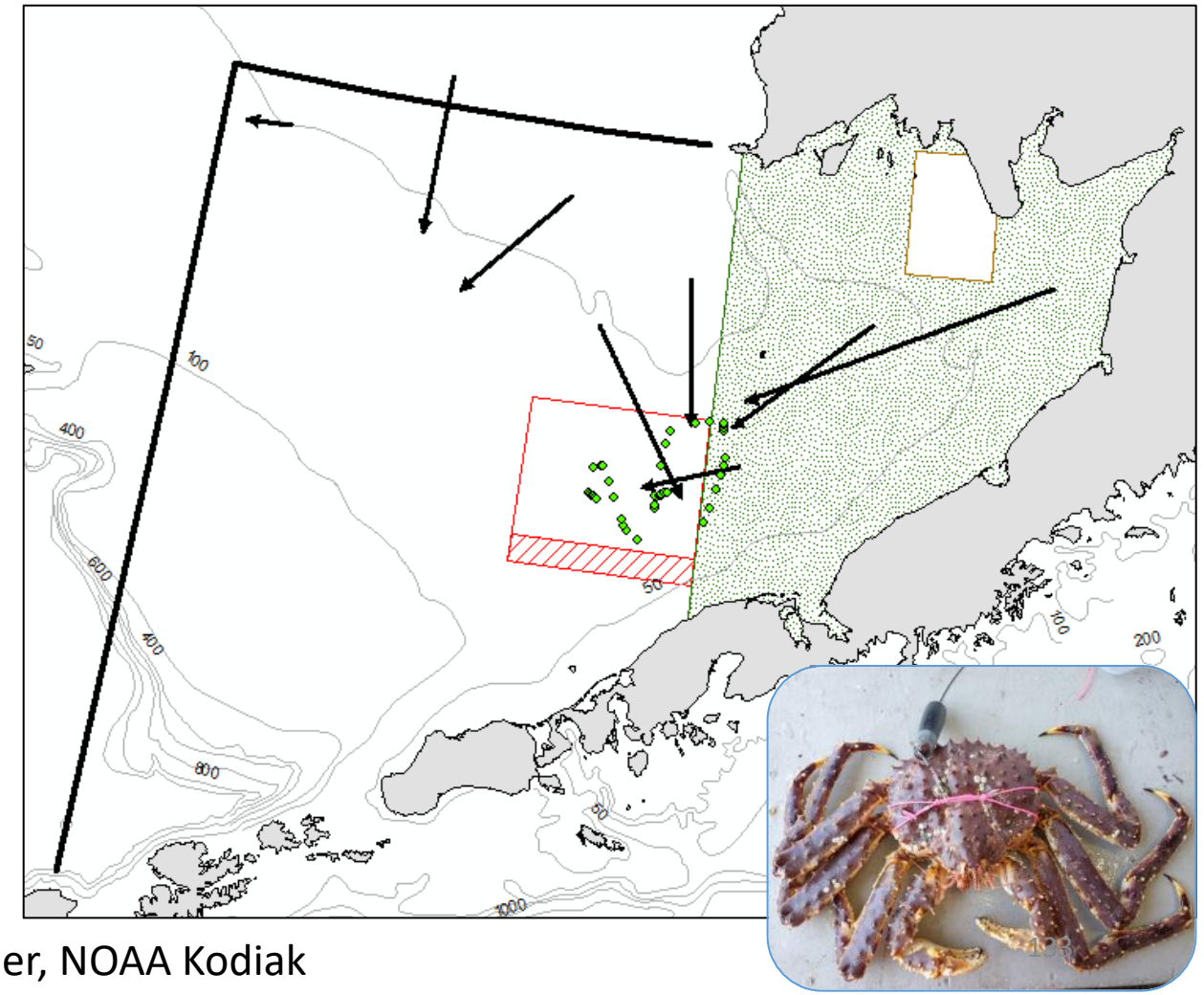
BSFRF, NOAA, ADF&G collaborative effort

2022 BBRKC Tagging Update

All Tags on Mature Males

- June to October movement
  - Tagged during NMFS survey released Oct. 12/13

- Tagging locations during cost recovery
  - Tags will release early January and early June

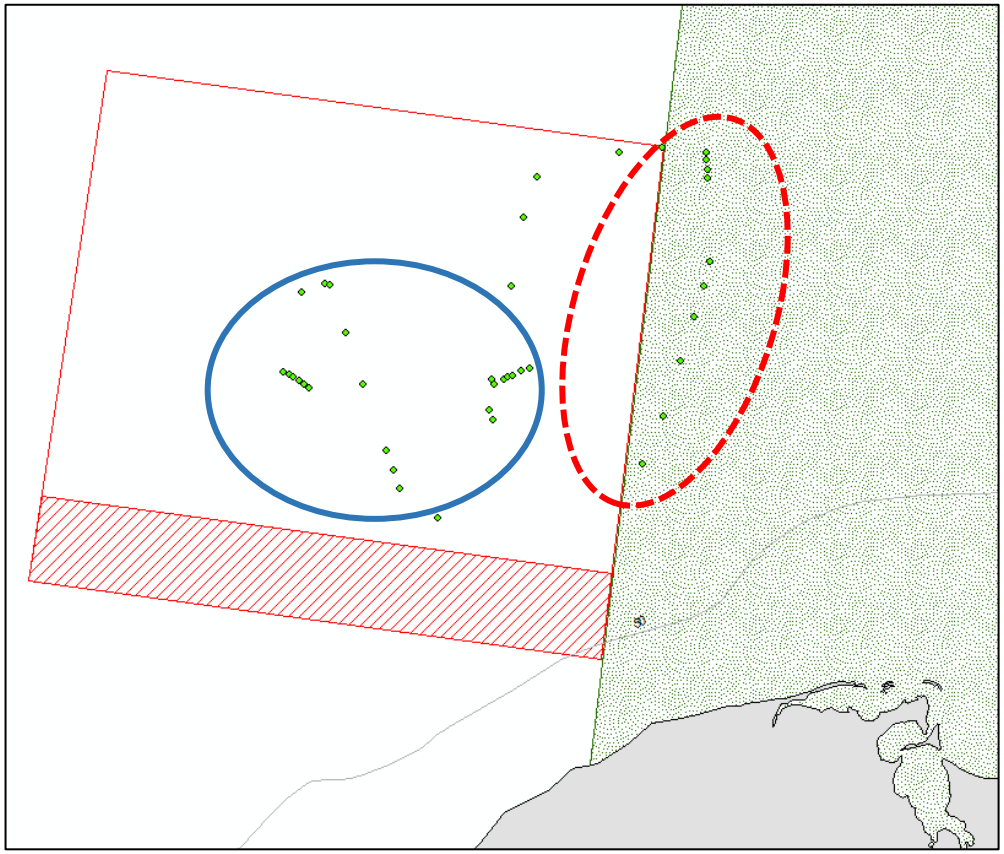


Slide courtesy of Leah Zacher, NOAA Kodiak

2022 cost recovery – how did it go?

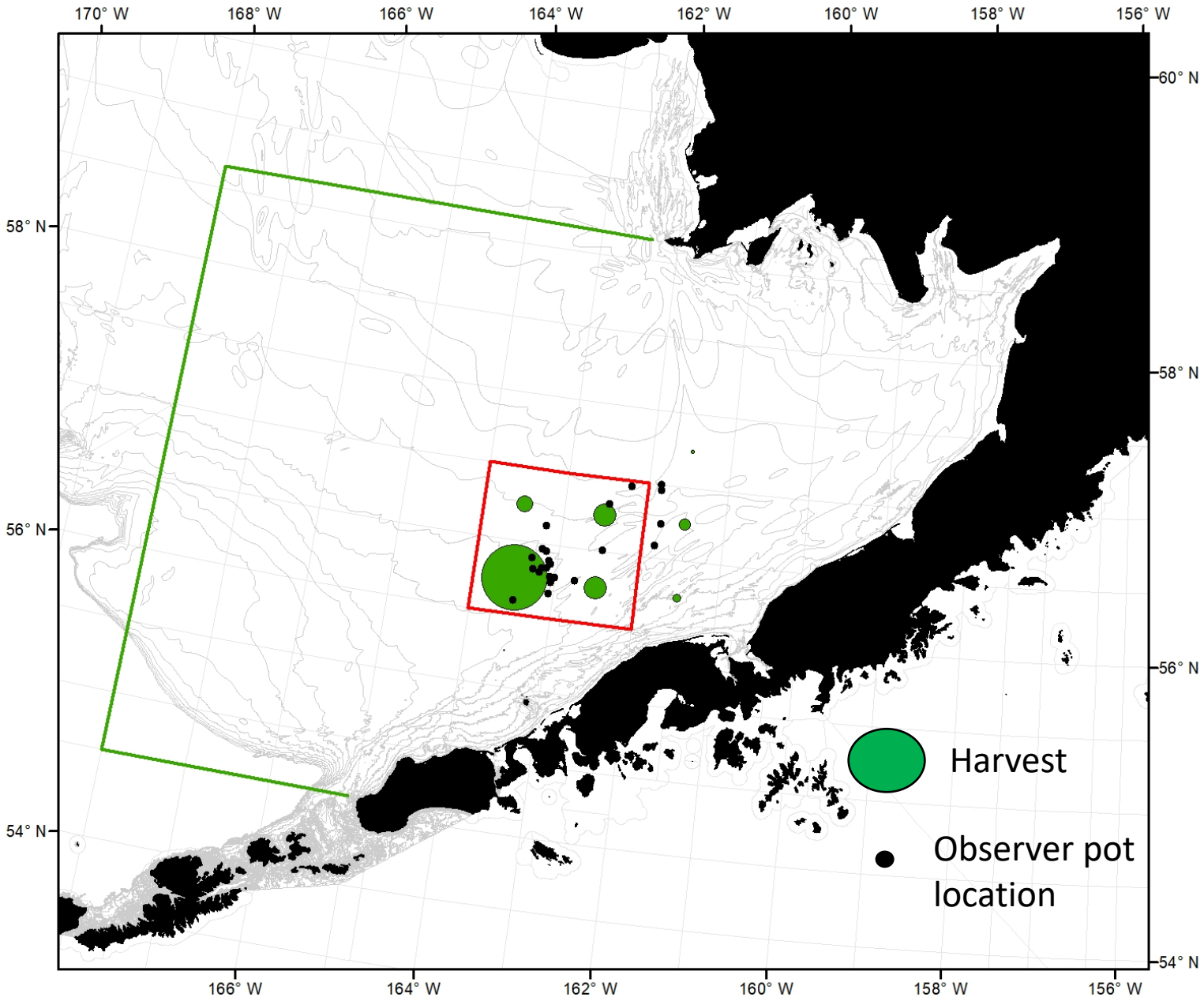
- Tagging Locations

- Best Fishing here
  - Mostly legal males
  - ~40 legals/pot (anecdotal, not exact)
- Poor fishing, many females

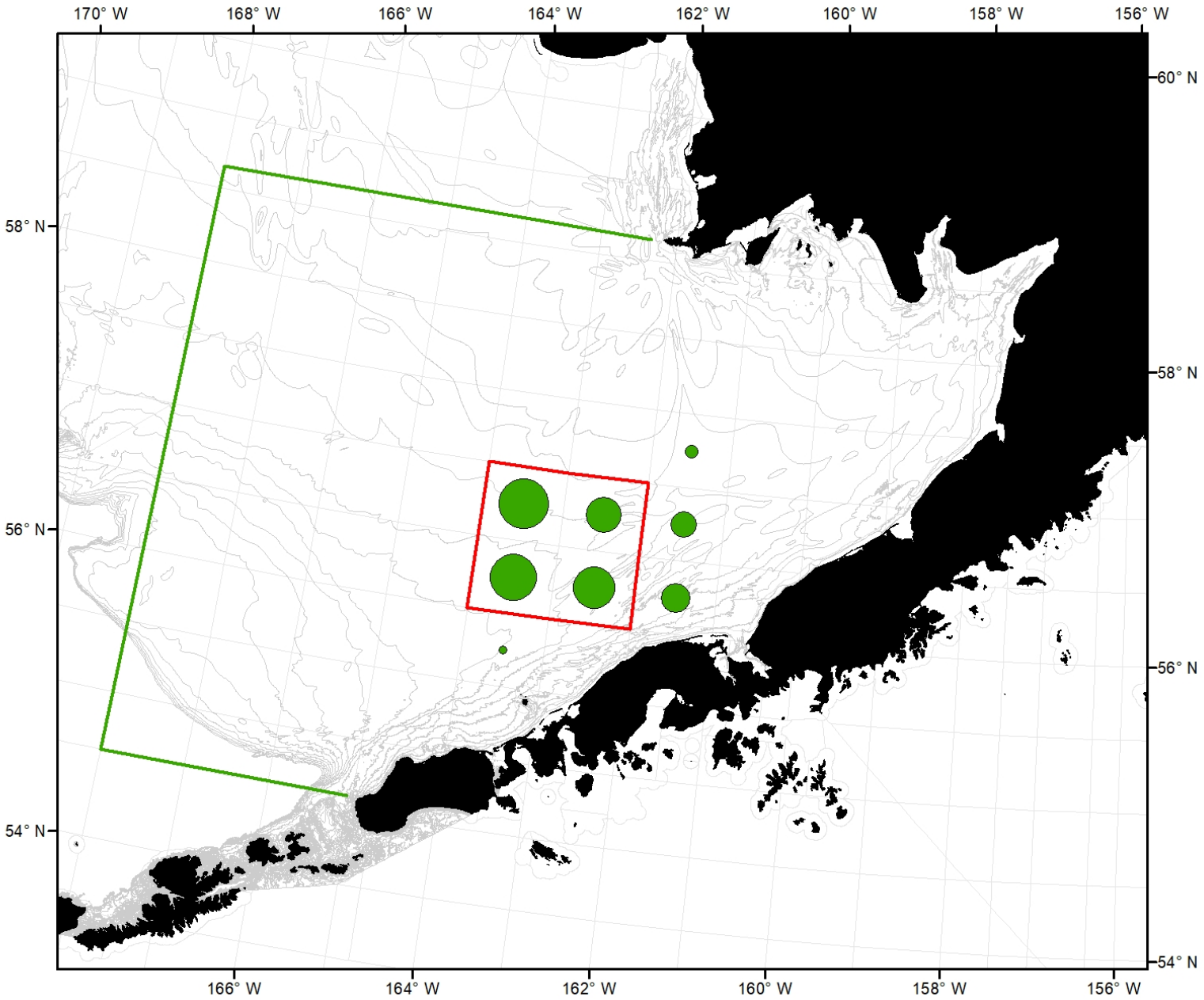


Slide courtesy of Leah Zacher, NOAA Kodiak

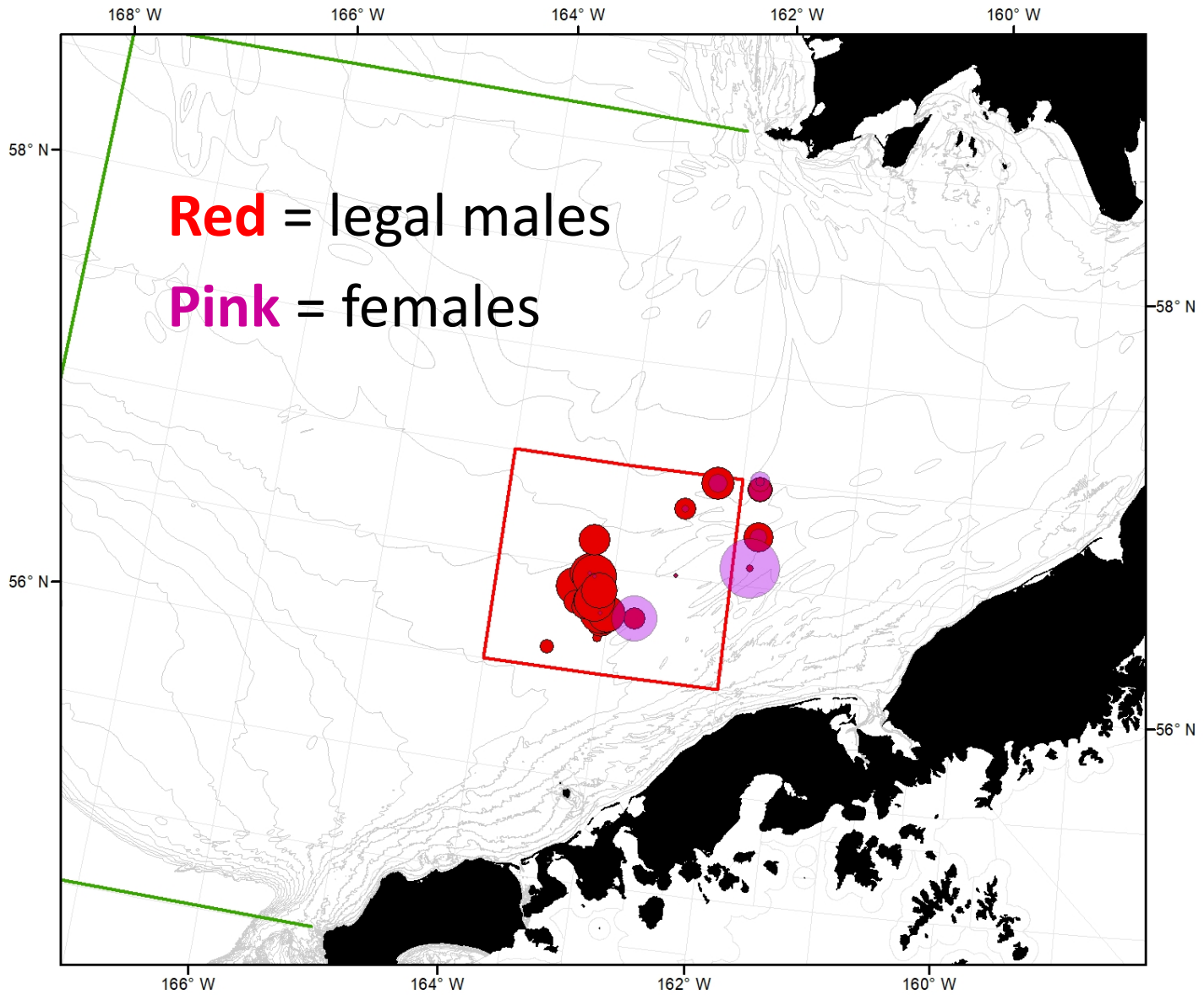
2022 BBRKC CR catch



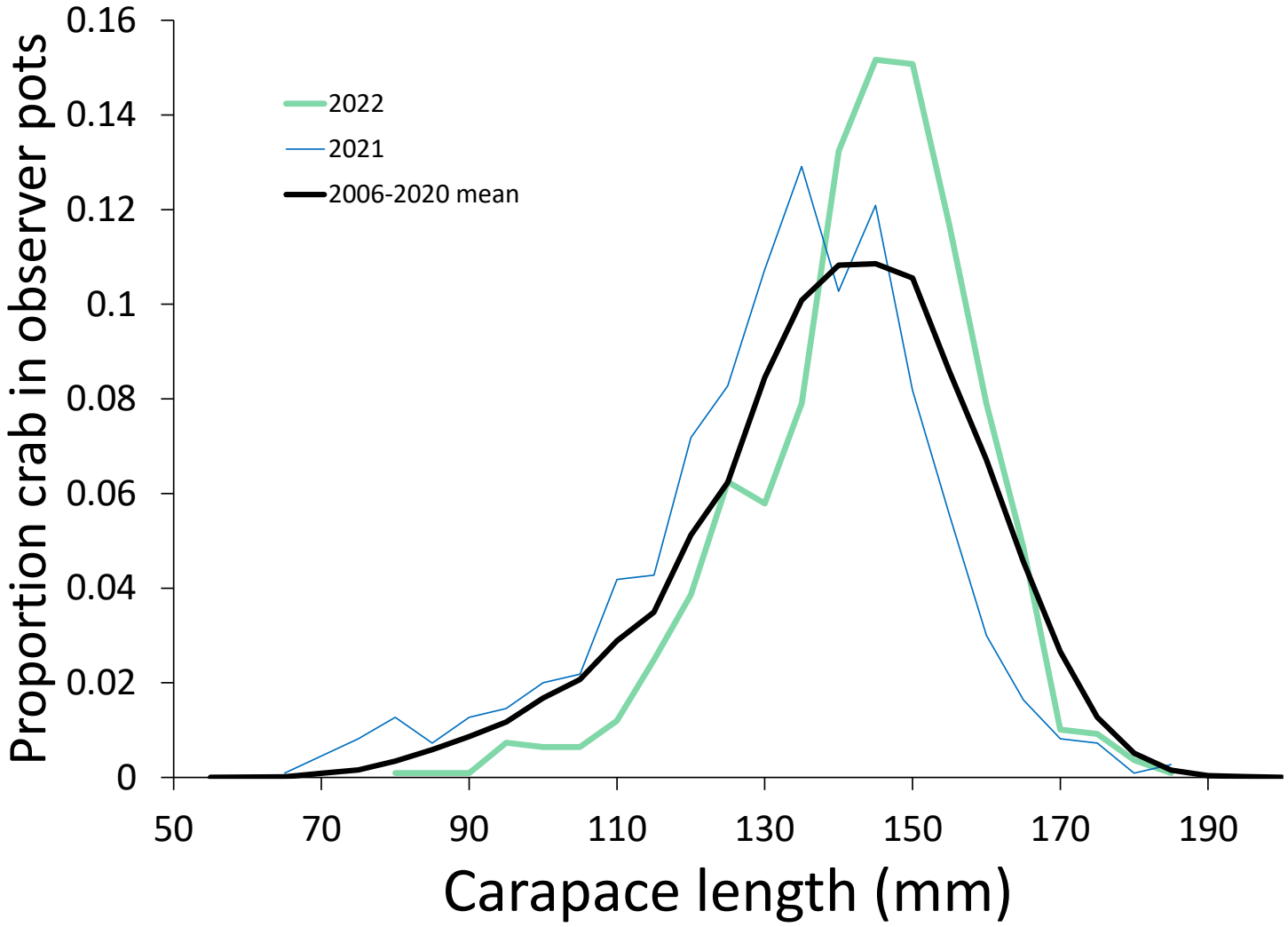
2022 BBRKC CR CPUE



2022 BBRKC CR observer data



BBRKC CR observer data



BBRKC retained catch CPUE