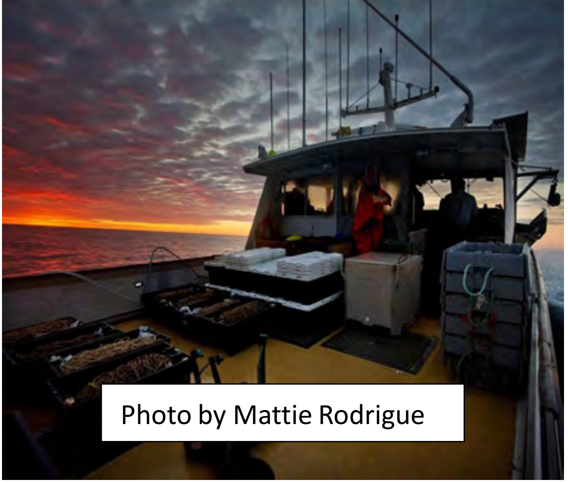

Photo by Mattie Rodrigue

Challenge and Opportunity for Fisheries Stock Assessment in Changing Environments

Yong CHEN
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Editor-in-Chief, CJFAS
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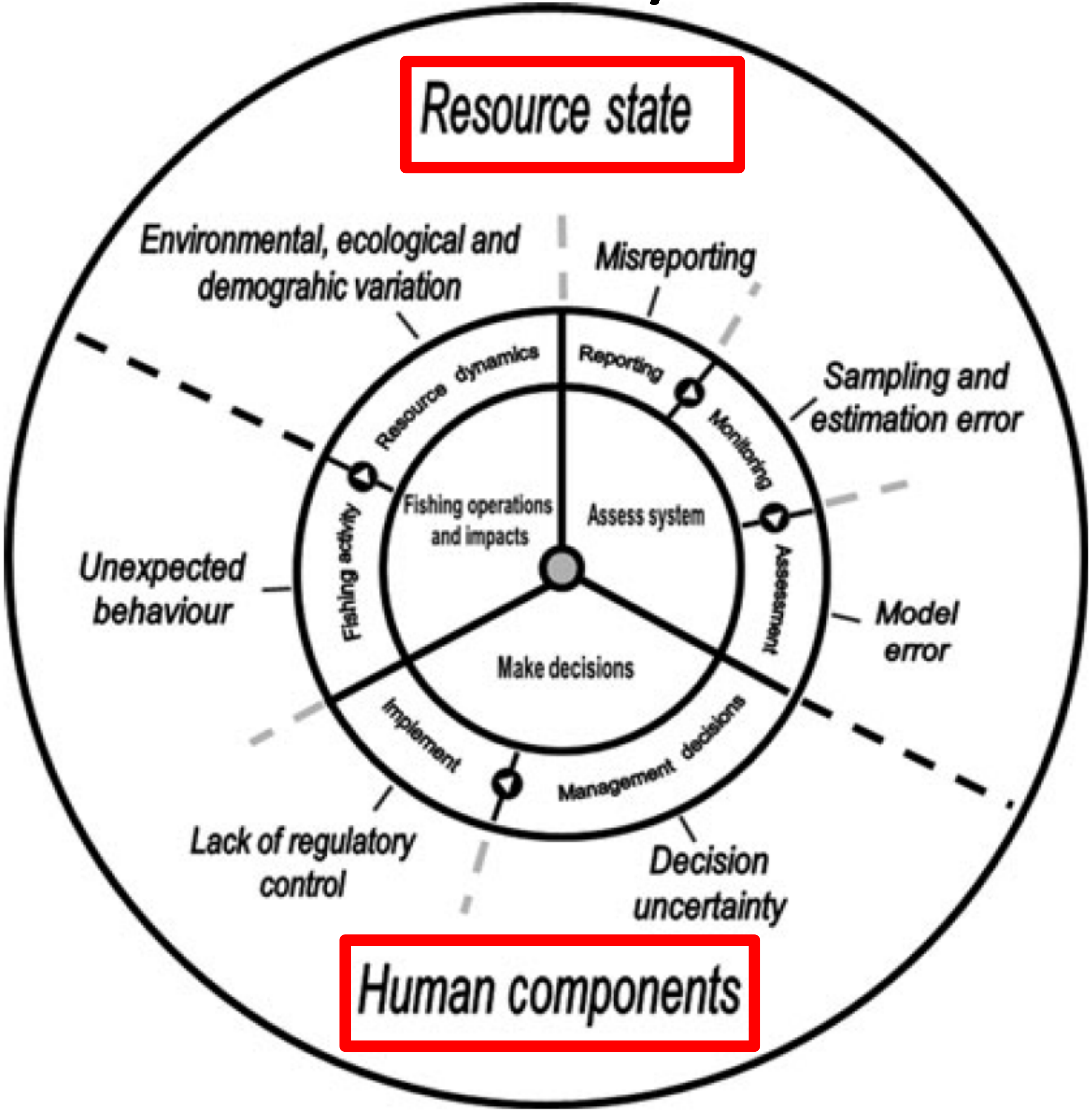
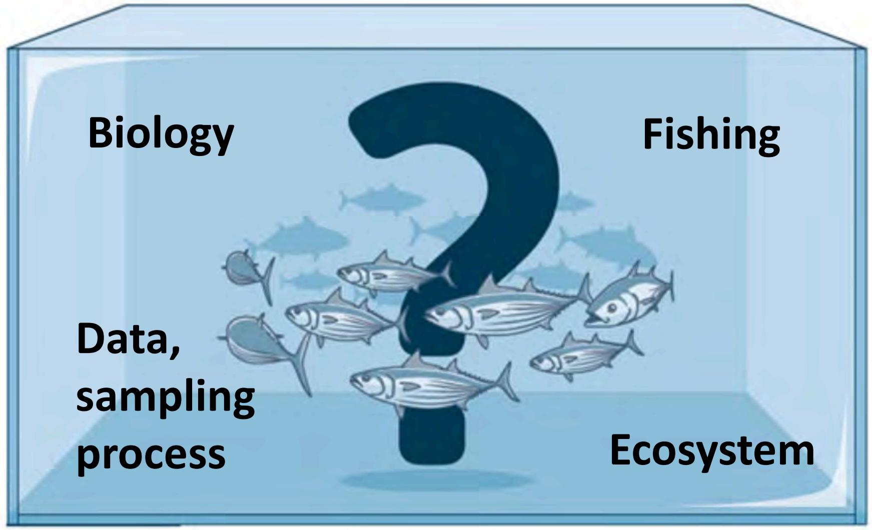
1865 THE UNIVERSITY OF MAINE
School of Marine Sciences

Fisheries Management System and Sources of Error /Variation

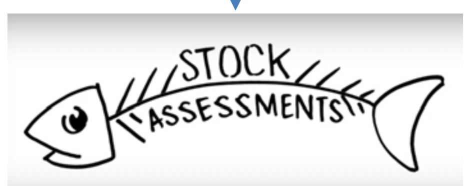


Fulton et al. 2011. Fish and Fisheries 12 2-17

Large Uncertainties in Stock Assessment
Lack of understanding



- Climate changes
- Regime shift
- Changes in management



problematic perception of stock status?

Poor management

Objectives of Fisheries Management

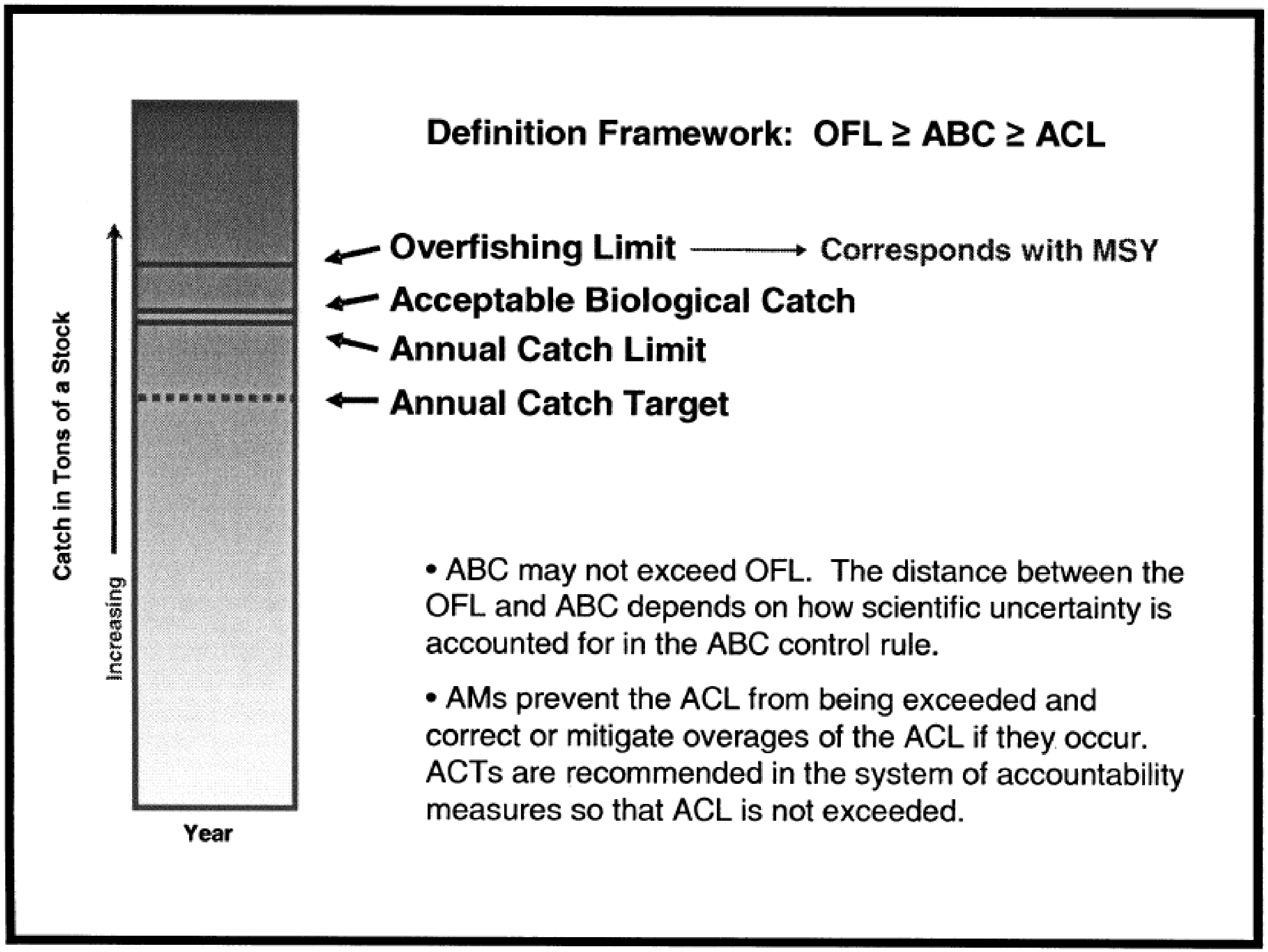
- ✓ Make management decision based on best available information and science
- ✓ Precautionary approach


en.wikipedia.org


by Obed Joshua

✓ Best Available Science
✓ Precautionary Approach

Figure 2: Relationship between OFL, ABC, ACL and ACT



Federal Register

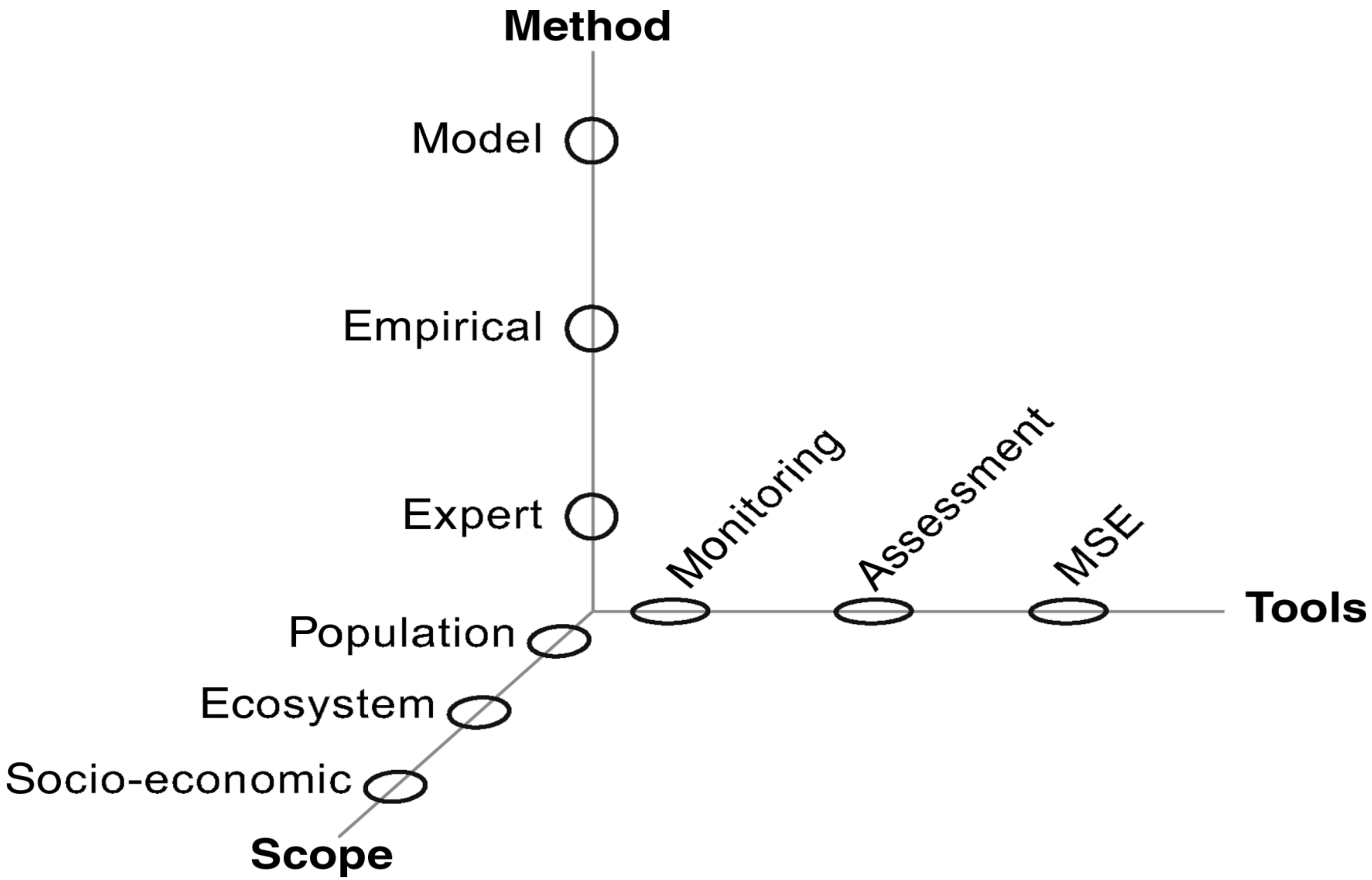
Friday,
January 16, 2009

Part III

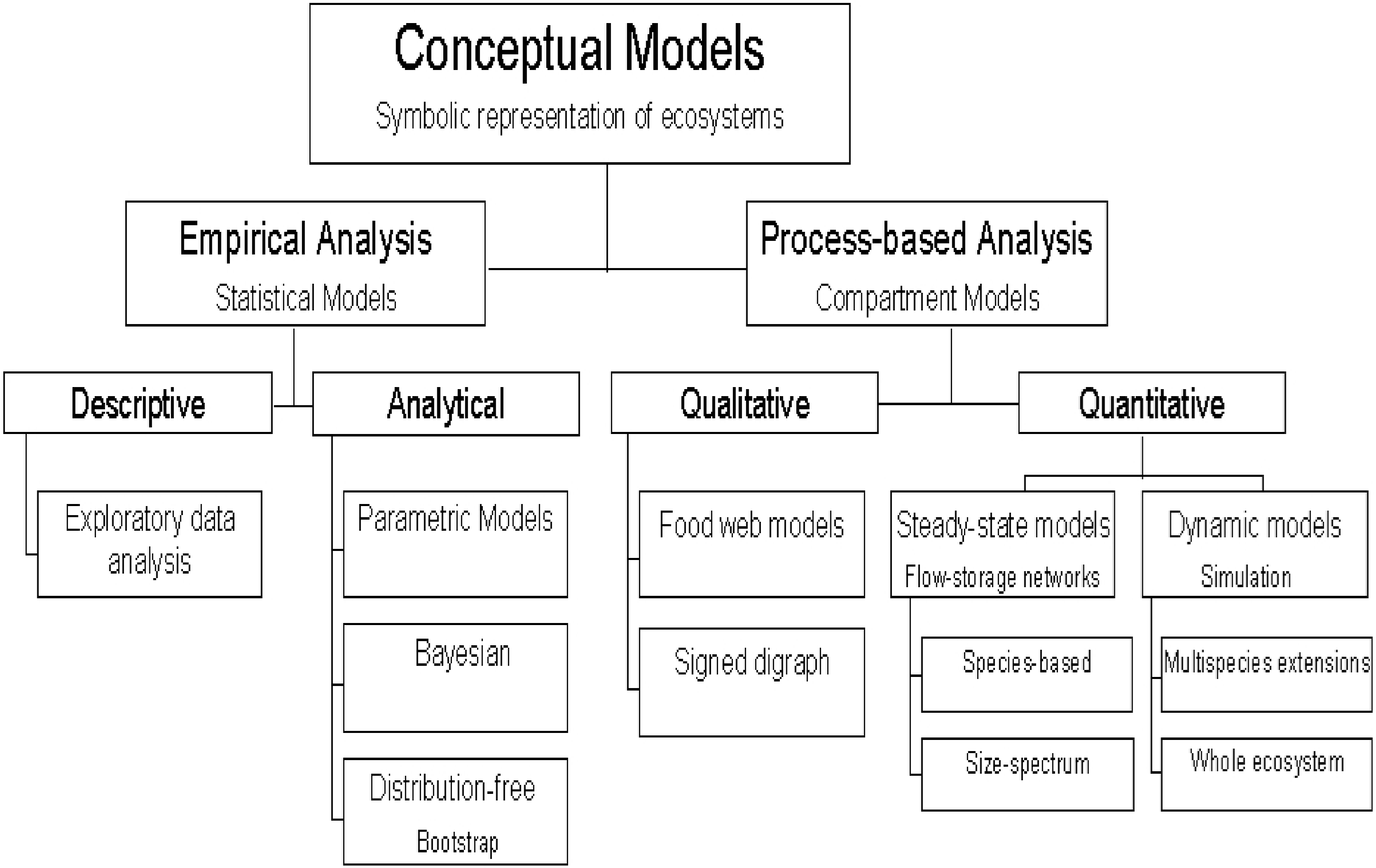
Department of Commerce

National Oceanic and Atmospheric Administration

50 CFR Part 600
Magnuson-Stevens Act Provisions; Annual Catch Limits; National Standard Guidelines; Final Rule



A general framework of developing tools for ecosystem-based fisheries management (cited from Smith et al. 2007)



Model classification of the types of multispecies ecological models (cited from Whipple et al. 2000).

Integrated Model

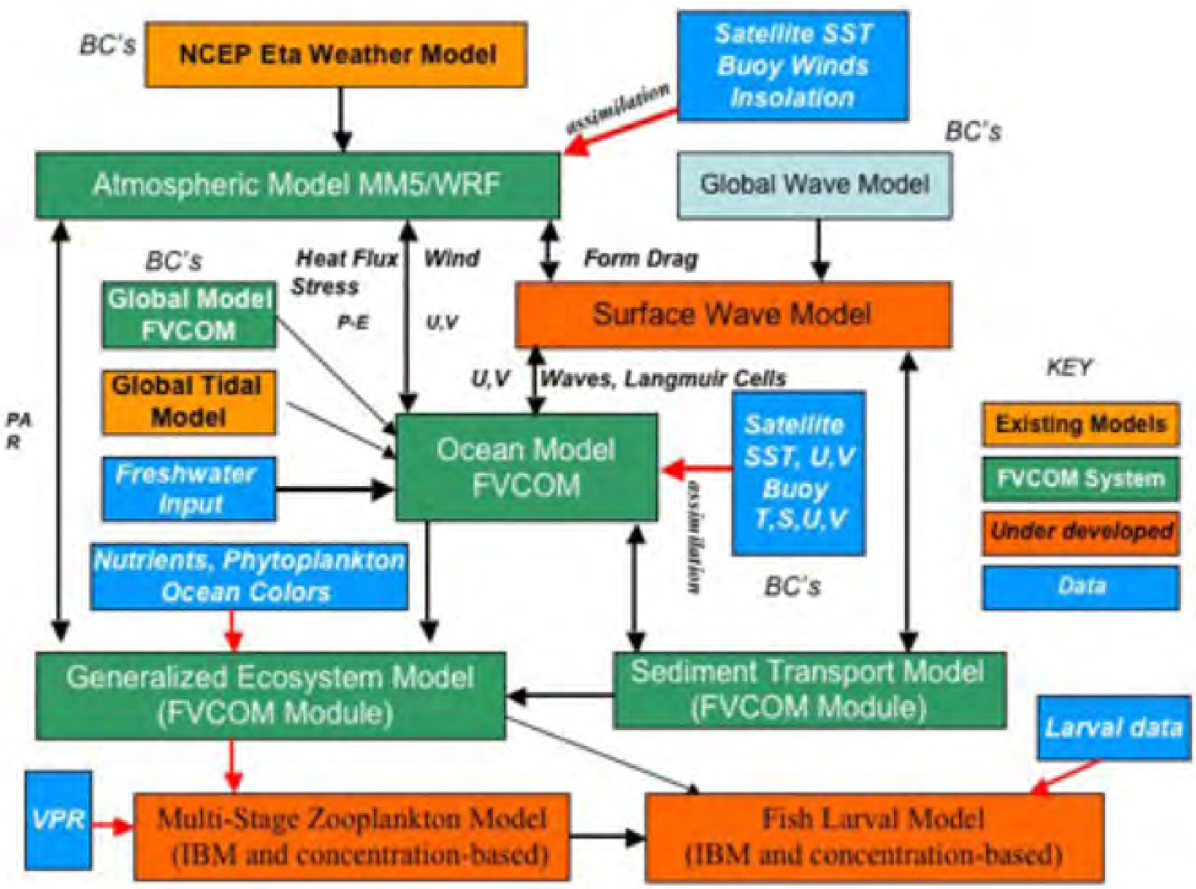
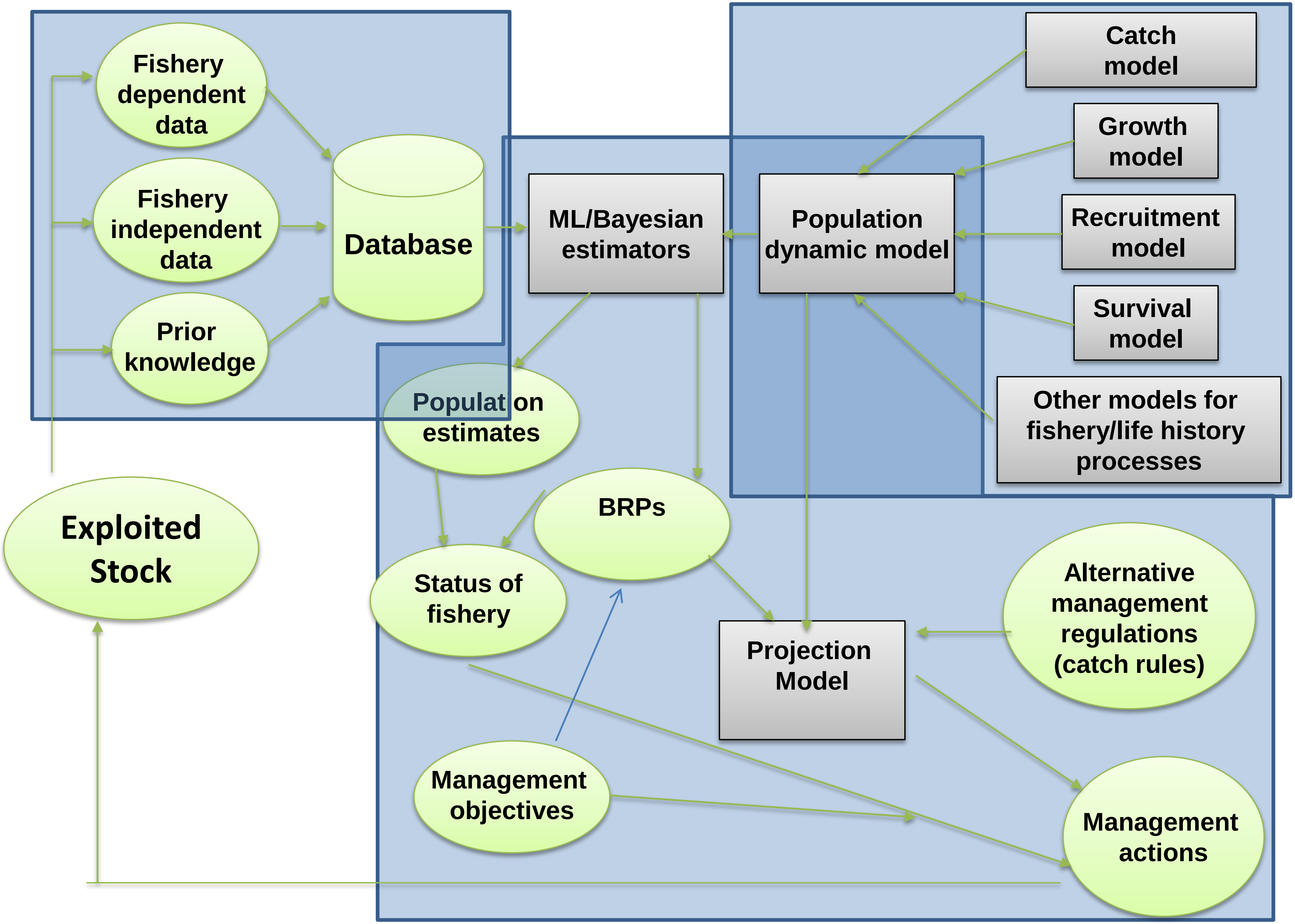
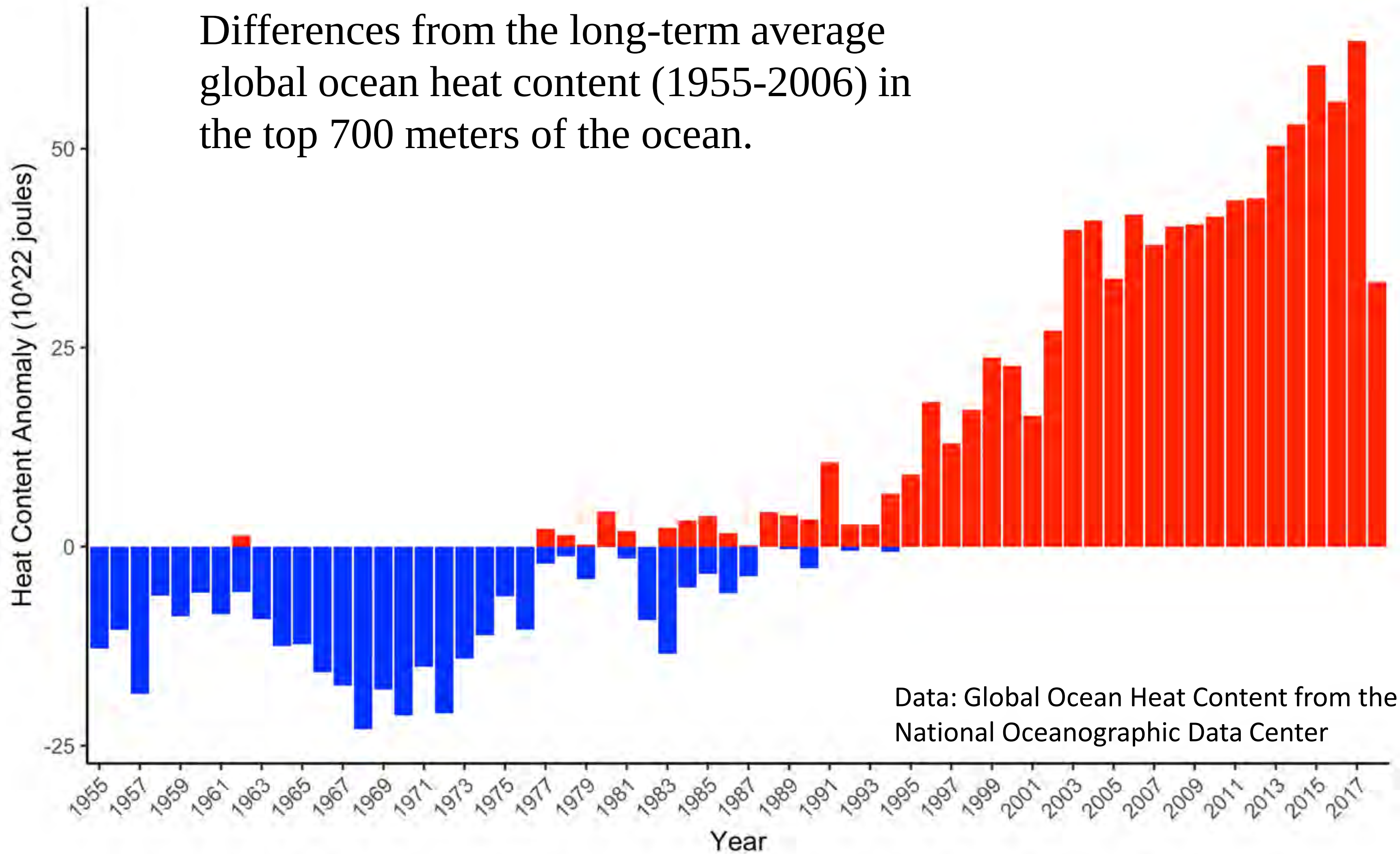


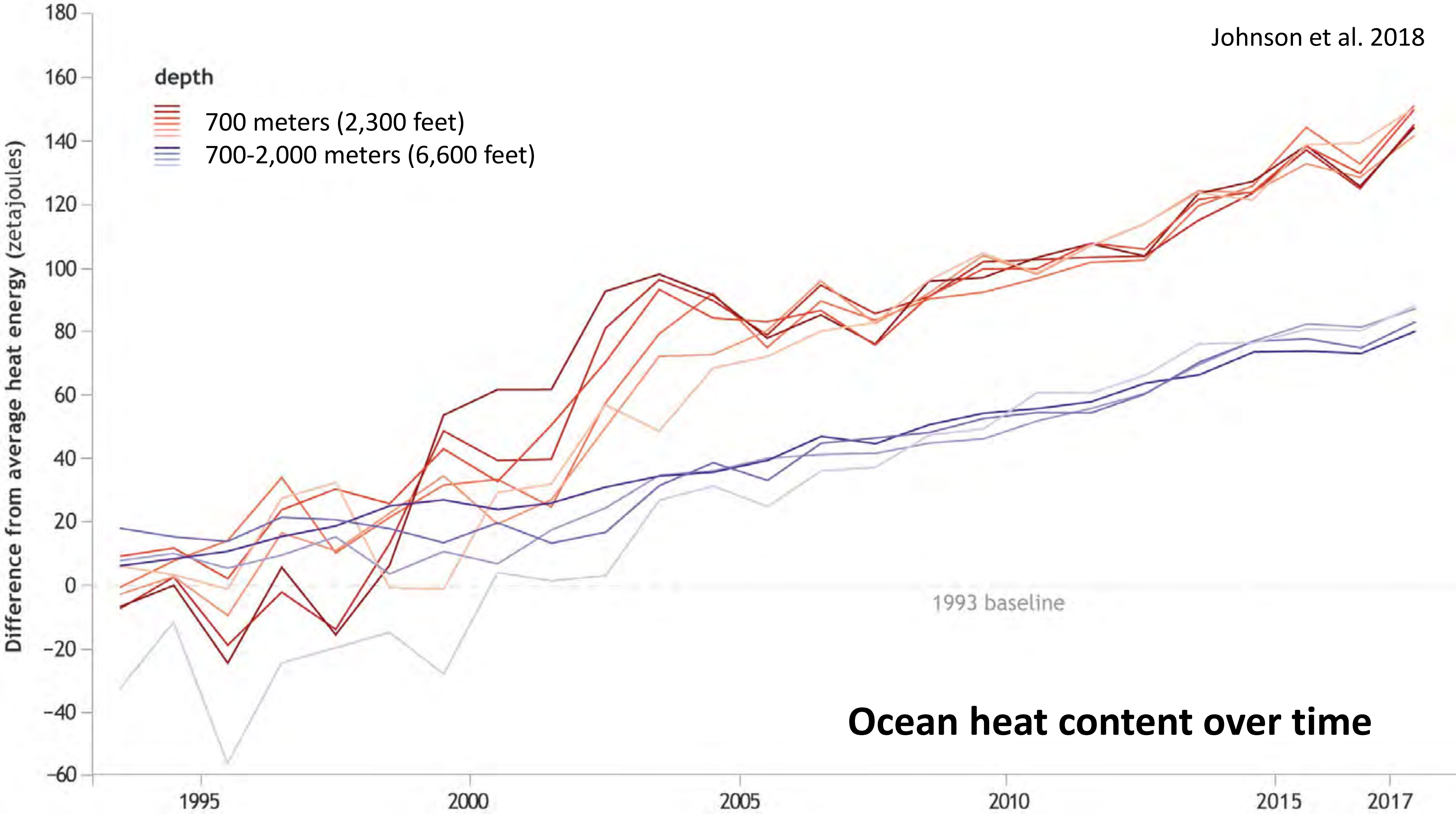
Fig. 1: Schematic of the integrated GoM/GB model system

Developed by Dr. Changshen Chen in SMAST UMASSD

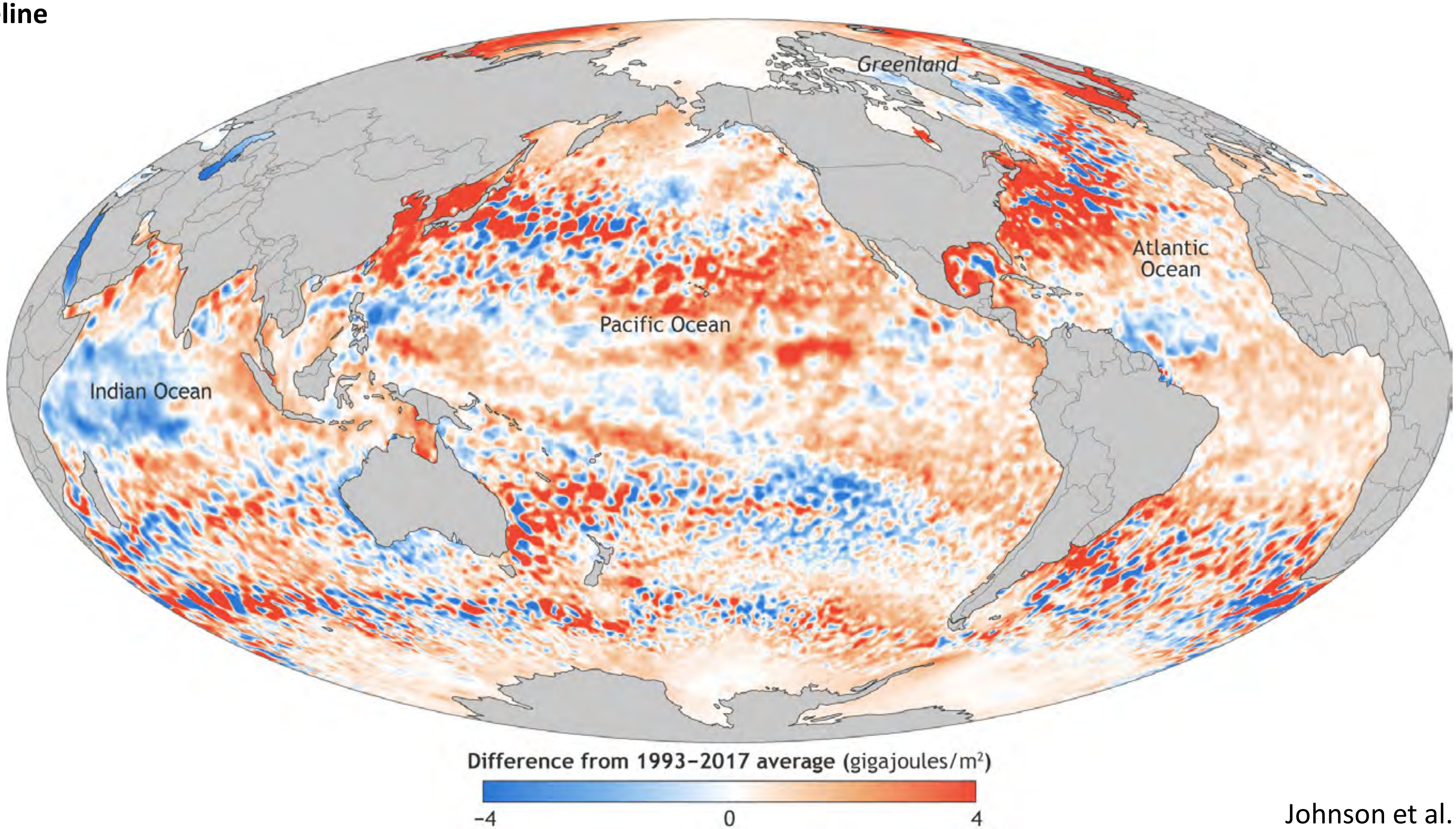


Flowchart of stock assessment framework

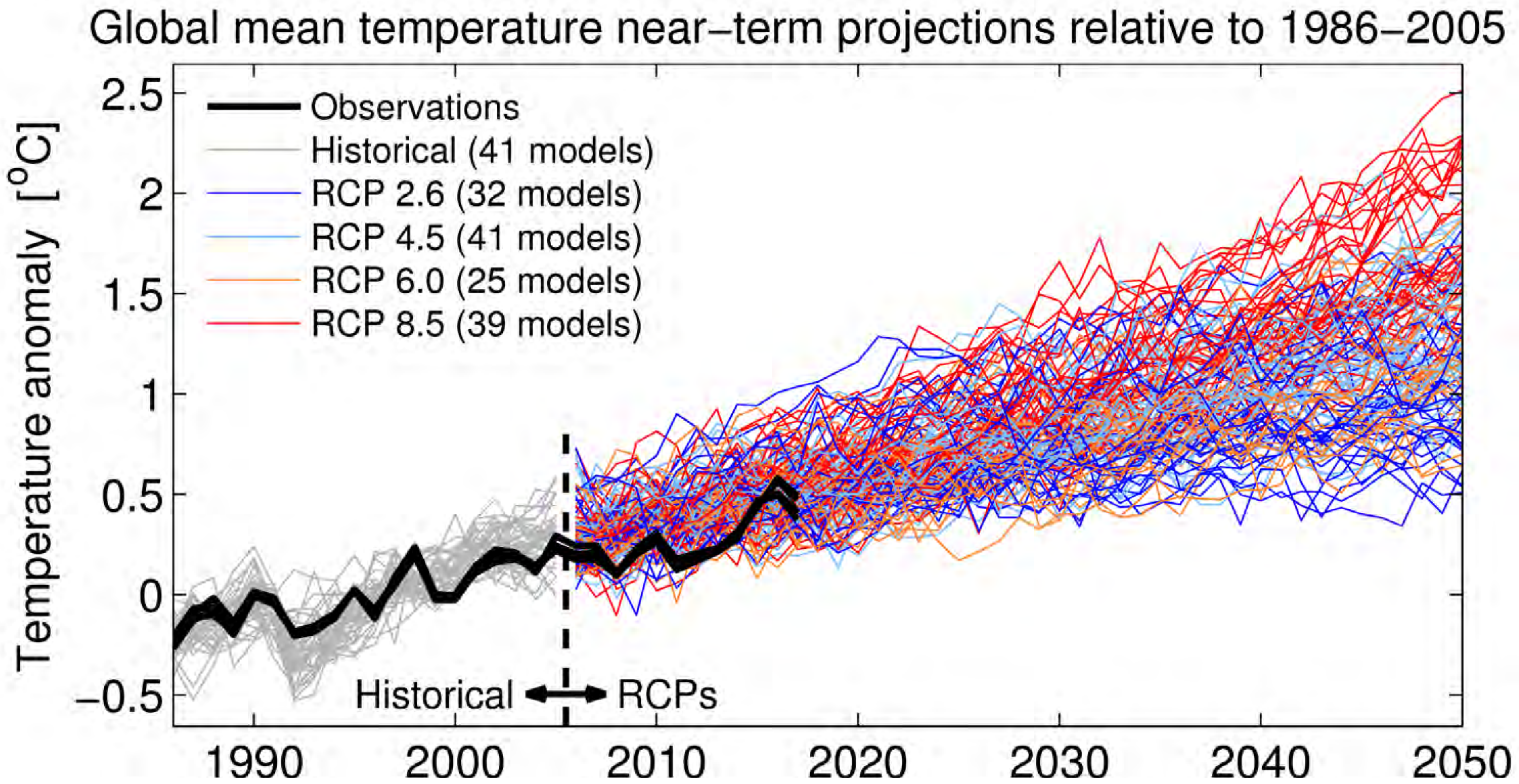

Differences from the long-term average global ocean heat content (1955-2006) in the top 700 meters of the ocean.
Heat Content Anomaly (10^22 joules)
50
25
0
-25
1955
1957
1959
1961
1963
1965
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
Year
Data: Global Ocean Heat Content from the National Oceanographic Data Center


Johnson et al. 2018
depth
700 meters (2,300 feet)
700-2,000 meters (6,600 feet)
Difference from average heat energy (zetajoules)
180
160
140
120
100
80
60
40
20
0
-20
-40
-60
1993 baseline
1995
2000
2005
2010
2015
2017
Ocean heat content over time

Ocean heat content in the upper ocean (from the sea surface to a depth of 700 meters) for 2017 relative to the 1993–2017 baseline



Johnson et al. 2018

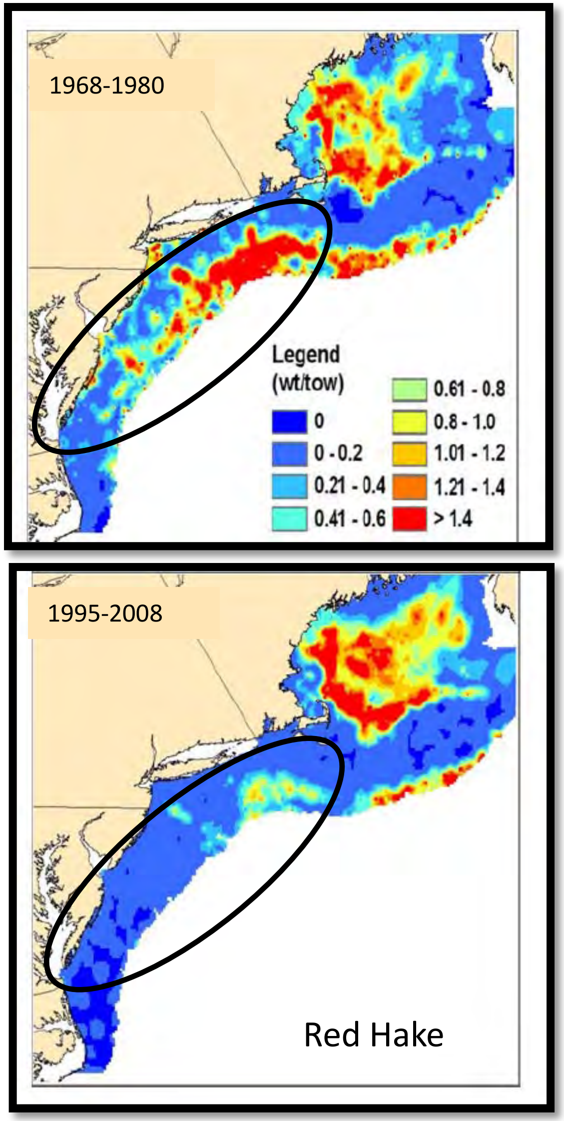

Global mean temperature near−term projections relative to 1986−2005
Temperature anomaly [°C]
2.5
2
1.5
1
0.5
0
−0.5
Observations
Historical (41 models)
RCP 2.6 (32 models)
RCP 4.5 (41 models)
RCP 6.0 (25 models)
RCP 8.5 (39 models)
Historical
RCPs
1990
2000
2010
2020
2030
2040
2050

Shifting Fish Distributions with Warming Ocean Temperatures

Cyr et al. 2012

Over past 40 yrs:

- **60% major fish stocks have shifted** distributions poleward (1 mile yr^{-1}) and/or deeper (0.8 ft yr^{-1}).
- **Species shifting at different rates** (25-200 miles poleward)
- **Also changes in** abundance, phenology, species assemblages
- **Implications to stock monitoring & assessment?**



Source: Nye JA et al. (2009), Hare et al. (2010)

Stock assessment in changing environments

Challenges

- More dynamic ecosystems
- Unknown adaptation and changes in fish life history
- Possible changes in movement, distribution, and fishing fleet dynamics
- Changes in prey-predator dynamics
- Unknown monitoring program performance
- Questionable data, assumptions, and models
- INCREASED UNCERTAINTIES

Opportunities

- Evaluate existing monitoring programs
- Develop new modeling tools for evaluating spatio-temporal dynamics of fish populations
- Include environmental/ecological drivers in stock assessment
- better understand dynamics of coupled human-natural system
- Improve quantification of the uncertainty
- Develop ecosystem-based fisheries monitoring and assessment

HMS Stock assessment in changing environments

Challenges

- Changes in migration, distribution and species composition (and bycatch)
- Changes in overlapping t-RFMOs and national jurisdictions
- t-RFMOs decision-making difficult in the face of increased uncertainty
- Increased complexity in stock assessment
- Increased difficulty to communicate science to stakeholders
- Reduced assessment effectiveness

Opportunities

- Develop new technology to better monitor spatio-temporal dynamics of HMS
- Include environmental/ecological drivers to reduce uncertainties in HMS stock assessment
- Operationalize ecosystem-based fisheries monitoring and assessment
- Improve science-management dialogues
- Establish a sustained dialogue across t-RFMOs and national experts for collaborative stock assessment

FISH and FISHERIES

FISH and FISHERIES, 2016, 17, 165–175

Ecosystem processes are rarely included in tactical fisheries management

Mette Skern-Mauritzen[1], *Geir Ottersen*[1,2], *Nils Olav Handegard*[1], *Geir Huse*[1], *Gjert E Dingsør*[1], *Nils C Stenseth*[2,3,4] *& Olav S Kjesbu*[1]

[1]Institute of Marine Research and Hjort Centre for Marine Ecosystem Dynamics, P.O. Box 1870 Nordnes, NO-5817, Bergen, Norway; [2]Centre for Ecological and Evolutionary Synthesis, Department of Biosciences, University of Oslo, P.O. Box 1066 Blindern, NO-0316, Oslo, Norway; [3]Institute of Marine Research, P.O. Box 1870 Nordnes, NO-5817, Bergen, Norway; [4]University of Agder, PO Box 422, NO-4604, Kristiansand, Norway

Ecosystem drivers were only considered for 24 of the 1200 marine fish stocks examined.

Abstract

Fish stock
(e.g. ocea
tion) proc
cesses and
fisheries r
the impac
tem appro
adopted w
drivers of fish stock productivity are actually implemented in fisheries management. Based on worldwide review of more than 1200 marine fish stocks, we found that such ecosystem drivers were implemented in the tactical management of only 24 stocks. Most of these cases were in the North Atlantic and north-east Pacific, where the scientific support is strong. However, the diversity of ecosystem drivers imple-

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E-mail: mettem@imr.no

Received 23 Jun

The current assessment of fish stocks focuses on harvest rates and spawning stock biomass and often do not incorporate environmental variability.

Approaches used to incorporate environmental drivers in stock assessment:

- Use environmental variables to standardize CPUE
- Link environmental variable(s) to key life history processes (e.g., movement, recruitment, and/or growth)
- Use time-period-specific and/or area-specific life history parameters in stock assessment (time/space blocks)

Use environmental variables to standardize CPUE

- Widely used in HMS stock assessment (Erisman et al. 2011).

- Changes in fisheries spatial dynamics
  - ✓ Hyperstability: overfishing to go undetected
  - ✓ Hyperdepletion: foregone yields (van der Lee 2012)

Critical to understand gear dynamics and environmental influences for analyzing CPUE data.

Biased estimates of relative abundance if important environmental covariates are excluded in CPUE standardization (Bigelow and Maunder 2007)

Link environmental variable(s) to key life history processes (e.g., movement, recruitment, and/or growth)

$$N_{t+1} = GSN_t + R_t$$

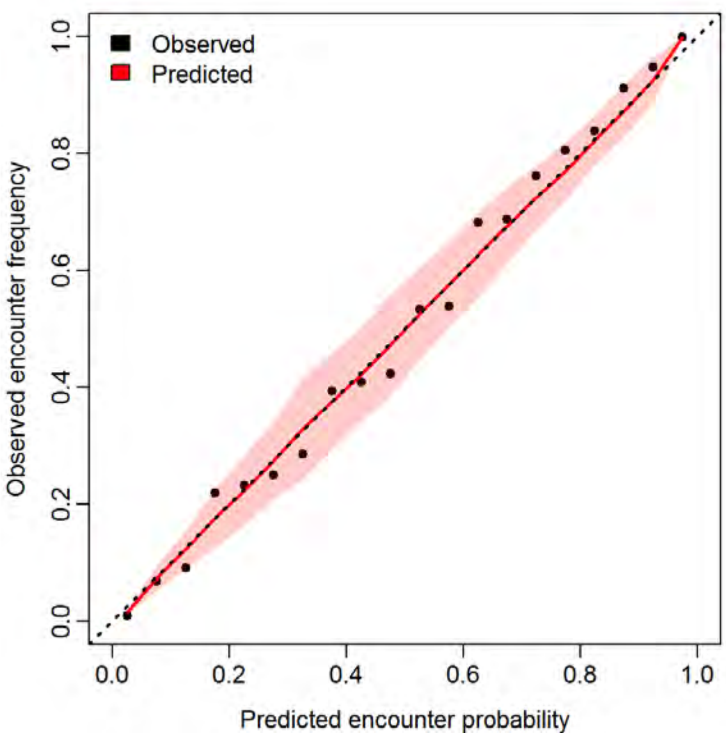
climate-driven recruitment models

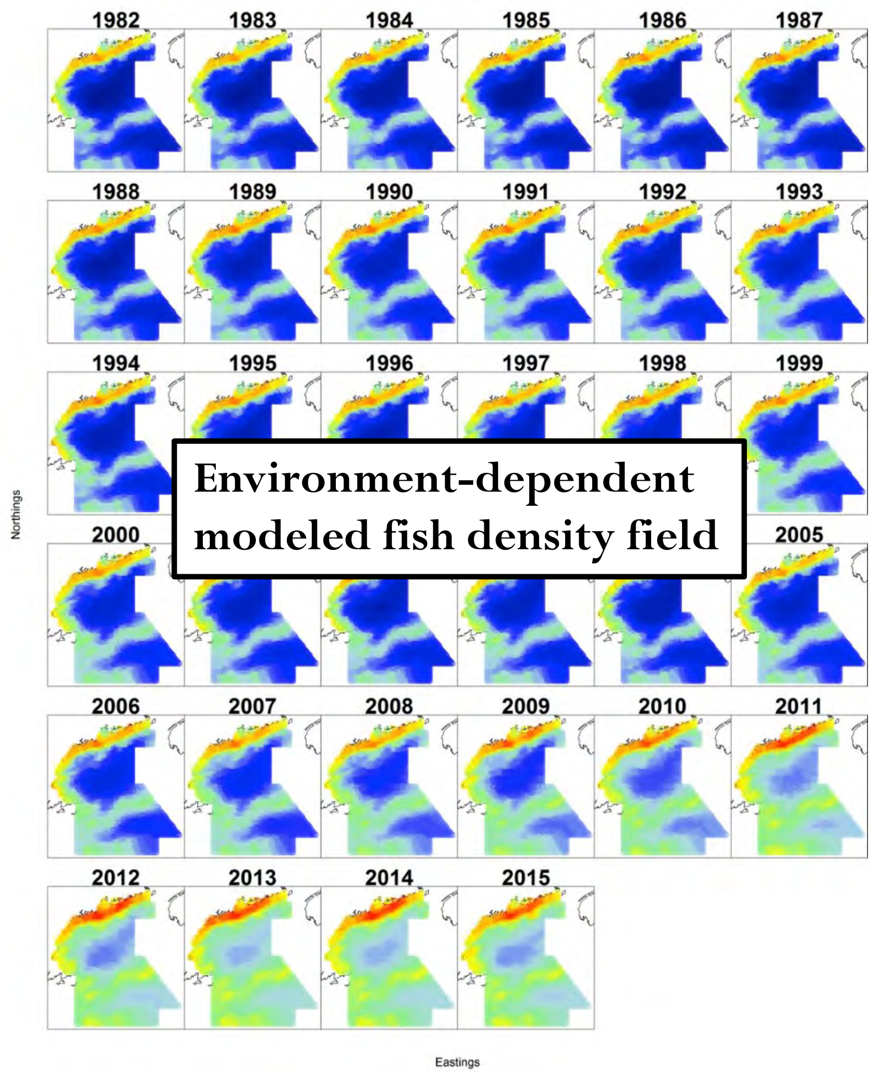
$$R_t = \frac{\alpha SSB_t}{\beta + SSB_t} e^{\sum_i \theta_i E_{i,t}} e^{Rdev_t}$$

Tanaka et al. In revision

$$N_{t+1} = GS\textcolor{red}{N_t} + R_t$$

Model-based approach to complement survey-based abundance index.





Tanaka et al. In revision

$$N_{t+1} = GSN_t + R_t$$

Growth transition matrices accounting for changing phenology.

Rev Fish Biol Fisheries (2017) 27:411–424
DOI 10.1007/s11160-017-9487-9

CrossMark

RESEARCH PAPER

Effects of spring onset and summer duration on fish species distribution and biomass along the Northeast United States continental shelf

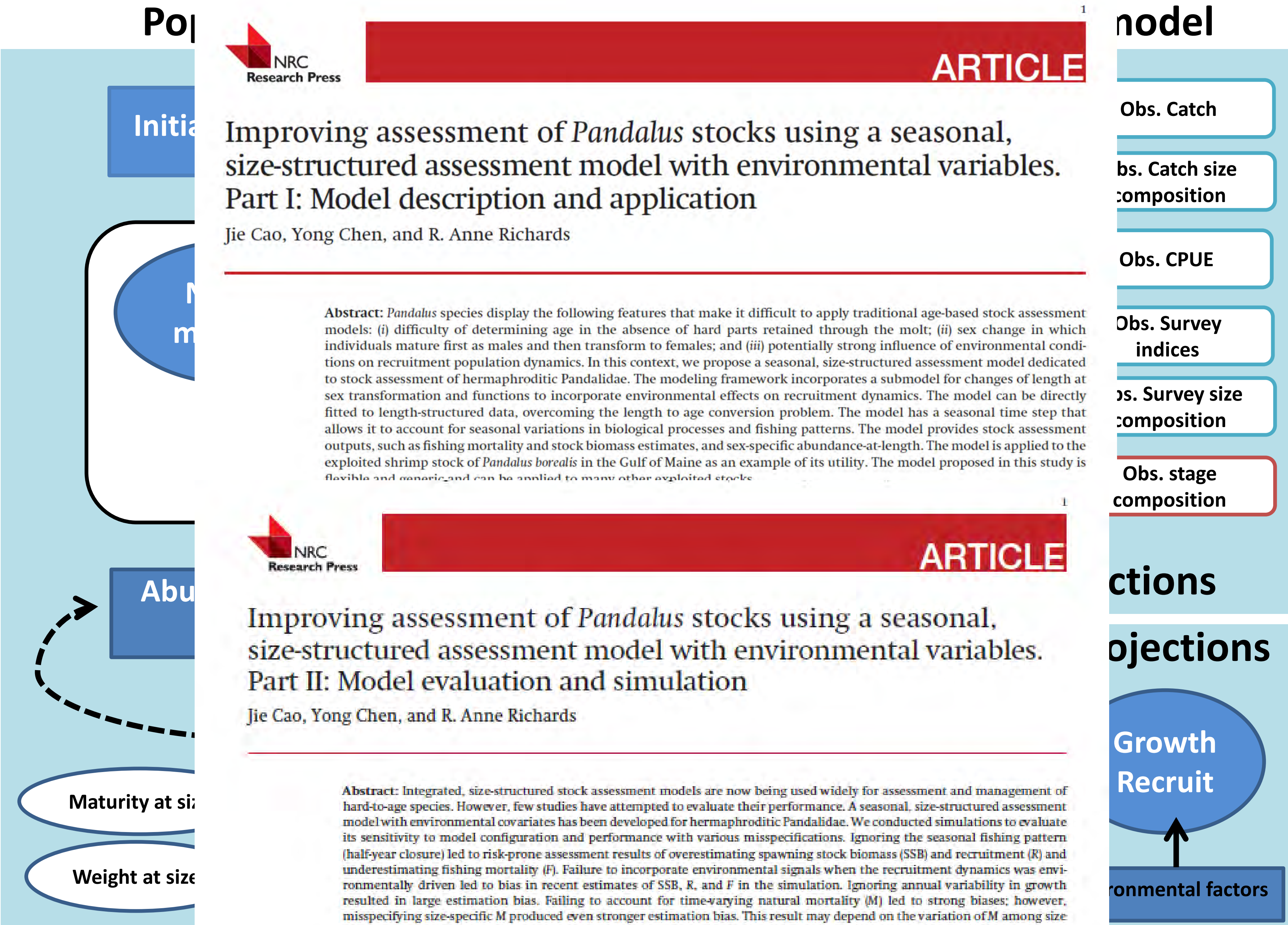
M. Elisabeth Henderson · Katherine E. Mills · Andrew C. Thomas · Andrew J. Pershing · Janet A. Nye

Winter & Spring

1.0	0.0	0.0	0.0	0.0
0.0	1.0	0.0	0.0	0.0
0.0	0.0	1.0	0.0	0.0
0.0	0.0	0.0	1.0	0.0
0.0	0.0	0.0	0.0	1.0

Summer & Fall

0.1	0.5	0.4	0.0	0.0
0.0	0.0	0.4	0.5	0.1
0.0	0.0	0.0	0.2	0.6
0.0	0.0	0.0	0.1	0.1
0.0	0.0	0.0	0.0	0.1



NRC Research Press
1
ARTICLE

Improving assessment of *Pandalus* stocks using a seasonal, size-structured assessment model with environmental variables. Part I: Model description and application

Jie Cao, Yong Chen, and R. Anne Richards

Abstract: *Pandalus* species display the following features that make it difficult to apply traditional age-based stock assessment models: (*i*) difficulty of determining age in the absence of hard parts retained through the molt; (*ii*) sex change in which individuals mature first as males and then transform to females; and (*iii*) potentially strong influence of environmental conditions on recruitment population dynamics. In this context, we propose a seasonal, size-structured assessment model dedicated to stock assessment of hermaphroditic Pandalidae. The modeling framework incorporates a submodel for changes of length at sex transformation and functions to incorporate environmental effects on recruitment dynamics. The model can be directly fitted to length-structured data, overcoming the length to age conversion problem. The model has a seasonal time step that allows it to account for seasonal variations in biological processes and fishing patterns. The model provides stock assessment outputs, such as fishing mortality and stock biomass estimates, and sex-specific abundance-at-length. The model is applied to the exploited shrimp stock of *Pandalus borealis* in the Gulf of Maine as an example of its utility. The model proposed in this study is flexible and generic and can be applied to many other exploited stocks.

1
NRC Research Press
ARTICLE

Improving assessment of *Pandalus* stocks using a seasonal, size-structured assessment model with environmental variables. Part II: Model evaluation and simulation

Jie Cao, Yong Chen, and R. Anne Richards

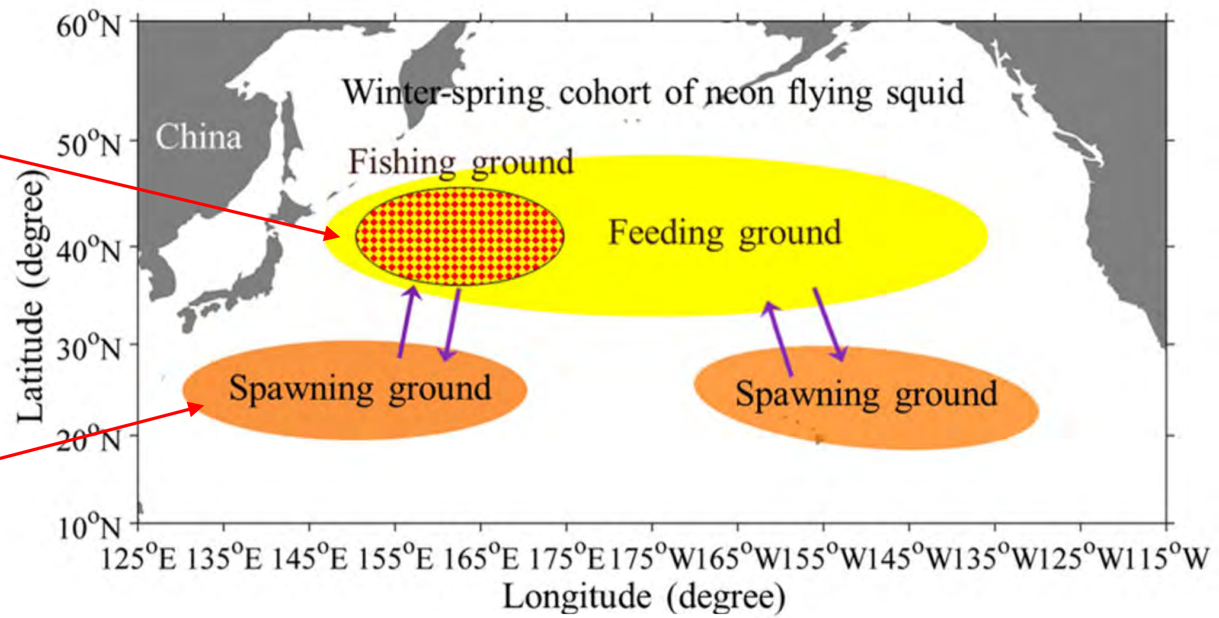
Abstract: Integrated, size-structured stock assessment models are now being used widely for assessment and management of hard-to-age species. However, few studies have attempted to evaluate their performance. A seasonal, size-structured assessment model with environmental covariates has been developed for hermaphroditic Pandalidae. We conducted simulations to evaluate its sensitivity to model configuration and performance with various misspecifications. Ignoring the seasonal fishing pattern (half-year closure) led to risk-prone assessment results of overestimating spawning stock biomass (SSB) and recruitment (*R*) and underestimating fishing mortality (*F*). Failure to incorporate environmental signals when the recruitment dynamics was environmentally driven led to bias in recent estimates of SSB, *R*, and *F* in the simulation. Ignoring annual variability in growth resulted in large estimation bias. Failing to account for time-varying natural mortality (*M*) led to strong biases; however, misspecifying size-specific *M* produced even stronger estimation bias. This result may depend on the variation of *M* among size classes. Under no model misspecifications, an unbiased estimate of *M* could be obtained by taking advantage of the seasonal fishery closure. Annual growth parameters were also estimable, but the large number of parameters with annual growth made it difficult for the model to converge.

Use time-period-specific and/or area-specific life history parameters in stock assessment (time/space blocks)

- ✓ **Need to identify time blocks/areas within which fish productivity/life history is more or less stable**

North Pacific Neon Flying Squid Fishery

15-19 C in August
14-18 C in September
10-13 C in October
12-15 C in November



21-25° C from January to May

Bower and Ichii 2005
Chen and Tian 2005

Acta Oceanol. Sin., 2018, Vol. 37, No. 2, P. 94–101
DOI: 10.1007/s13131-017-1131-y
http://www.hyxb.org.cn
E-mail: hyxbe@263.net

A stock assessment for *Illex argentinus* in Southwest Atlantic using an environmentally dependent surplus production model

WANG Jintao[1, 5, 4], CHEN Xinjun[1, 2, 3, 5*], Kevin W. Staples[4], CHEN Yong[4, 1]
[1] College of Marine Sciences, Shanghai Ocean University, Shanghai 201306, China
[2] National Distant-water Fisheries Engineering Research Center, Shanghai Ocean University, Shanghai 201306, China
[3] Key Laboratory of Sustainable Exploitation of Oceanic Fisheries Resources of Ministry of Education, Shanghai Ocean University, Shanghai 201306, China
[4] School of Marine Sciences, University of Maine, Orono, Maine 04469, USA
[5] Collaborative Innovation Center for National Distant-water Fisheries, Shanghai 201306, China

Received 25 June 2016; accepted 14 February 2017

Four surplus production models were proposed:

Assume SSTs have no effects on K and r

$$\log\left(B_{t=1}\right)\big|K,\sigma^2 = \log(K) + u_t$$
$$\log(B_t)\big|B_{t-1},K,r,\sigma^2 =$$
$$= \log\left\{B_{t-1} + rB_{t-1}\left(1 - \frac{B_{t-1}}{K}\right) - C_{t-1}\right\} + u_t \qquad (3)$$

Assume SSTs on the spawning grounds have effects on parameter K

$$\log\left(B_{t=1}\right)\big|K,\sigma^2 = \log(K) + u_t$$
$$\log(B_t)\big|B_{t-1},K,r,\sigma^2 =$$
$$= \log\left\{B_{t-1} + rB_{t-1}\left(1 - \frac{B_{t-1}}{Ps_{t-1}K}\right) - C_{t-1}\right\} + u_t \qquad (4)$$

Assume SSTs on the feeding grounds have effects on parameter r

$$\log\left(B_{t=1}\right)\big|K,\sigma^2 = \log(K) + u_t$$
$$\log(B_t)\big|B_{t-1},K,r,\sigma^2 =$$
$$= \log\left\{B_{t-1} + Pf_{t-1}rB_{t-1}\left(1 - \frac{B_{t-1}}{K}\right) - C_{t-1}\right\} + u_t \qquad (5)$$

Assume SSTs on the spawning grounds have effects on K and SSTs on the feeding grounds have effects on r

$$\log\left(B_{t=1}\right)\big|K,\sigma^2 = \log(K) + u_t$$
$$\log(B_t)\big|B_{t-1},K,r,\sigma^2 =$$
$$= \log\left\{B_{t-1} + Pf_{t-1}rB_{t-1}\left(1 - \frac{B_{t-1}}{Ps_{t-1}K}\right) - C_{t-1}\right\} + u_t \qquad (6)$$

Wang et al., 2017

Table 4. – Summary of the estimates of parameters with the bootstrapped ML method from 1500 runs of bootstrap simulation for CPUE and catch data observed from 2003 to 2013 for *O. bartramii*. For each bootstrap run, mean square error (MSE) was calculated.

Models	Statistic	r	K	q	MSE	AIC
SP	Median	0.455	106	0.03	0.45	30.26
	Mean	0.665	116	0.04	0.53	32.26
	CV	104%	45%	96%	35%	33%
	5th%	0.22	42	0.01	0.38	25.38
	95th%	2.707	224	0.09	0.96	38.74
Ps-EDSP	Median	0.443	125	0.027	0.43	25.32
	Mean	0.492	138	0.031	0.49	27.47
	CV	52%	38%	64%	30%	29%
	5th%	0.214	70	0.01	0.38	23.12
	95th%	0.882	247	0.069	0.90	32.43%
Pf-EDSP	Median	0.56	108	0.03	0.45	34.53
	Mean	0.624	122	0.036	0.51	36.07
	CV	52%	45%	71%	33%	31%
	5th%	0.23	54	0.008	0.39	29.86
	95th%	1.237	241	0.087	0.95	39.45
Ps-Pf-EDSP	Median	0.558	126	0.026	0.45	34.47
	Mean	0.627	138	0.032	0.50	36.04
	CV	56%	42%	68%	32%	32%
	5th%	0.245	62	0.01	0.38	29.38
	95th%	1.226	261	0.076	0.93	39.93

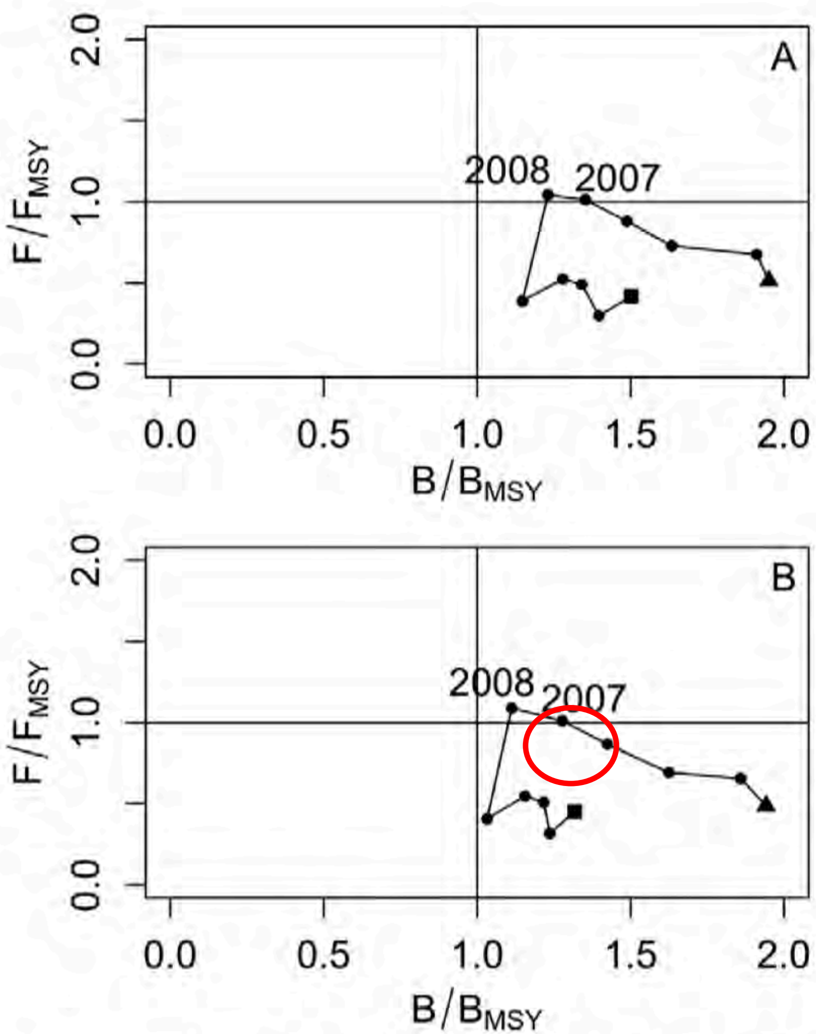


Fig. 6. – Development of the *O. bartramii* fishery from 2003 to 2013. A, based on the PS model; B, based on the Ps-EDSP model. Triangle represents the biomass status of the first year (2003) of study; square represents the biomass status of the last year (2013).

Develop a framework to incorporate environmental variability into assessment

Qualitative modeling approach

Statistical modeling approach

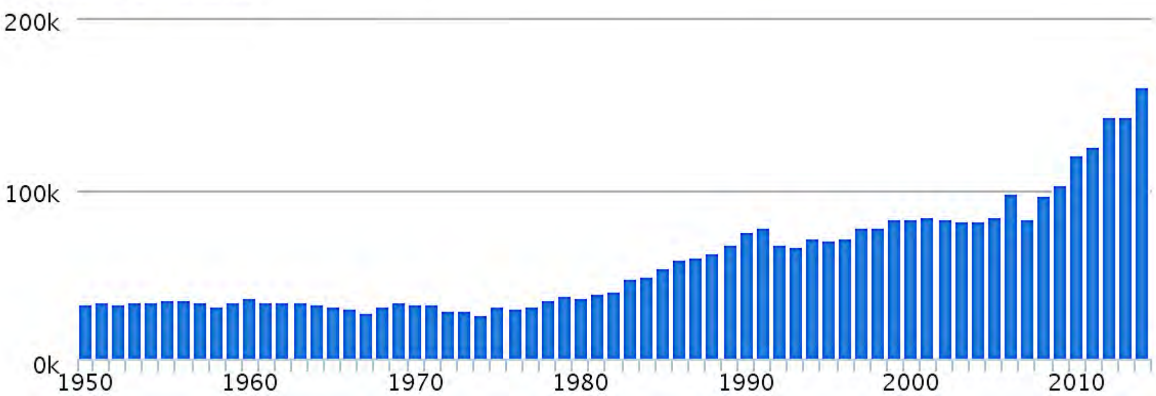
Population modeling approach

American lobster fishery

American lobster supports the most valuable fishery in the United States worth over 666 million USD in 2016. Gulf of Maine/Georges Bank accounted for ~97 % of total landings (ACCSP 2017).

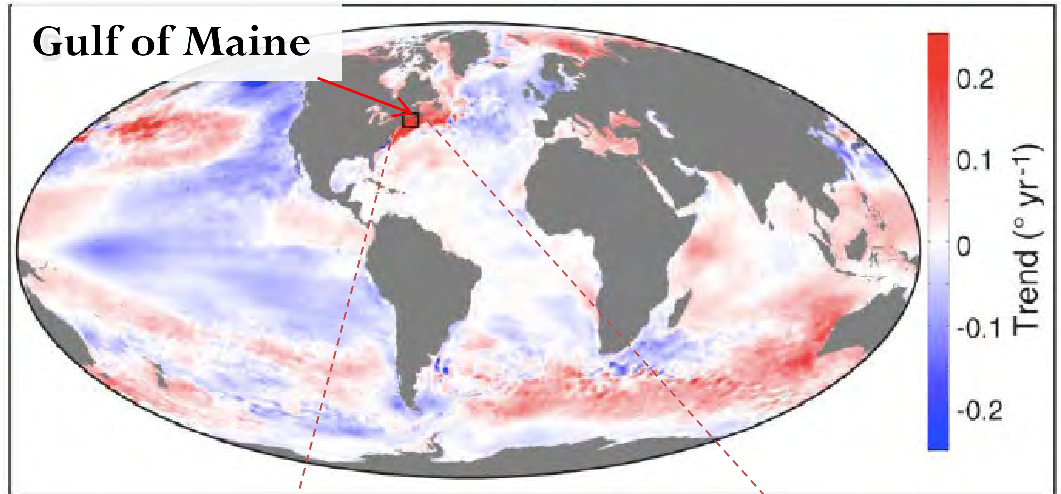
Global Capture Production for species (tonnes)

Source: FAO FishStat

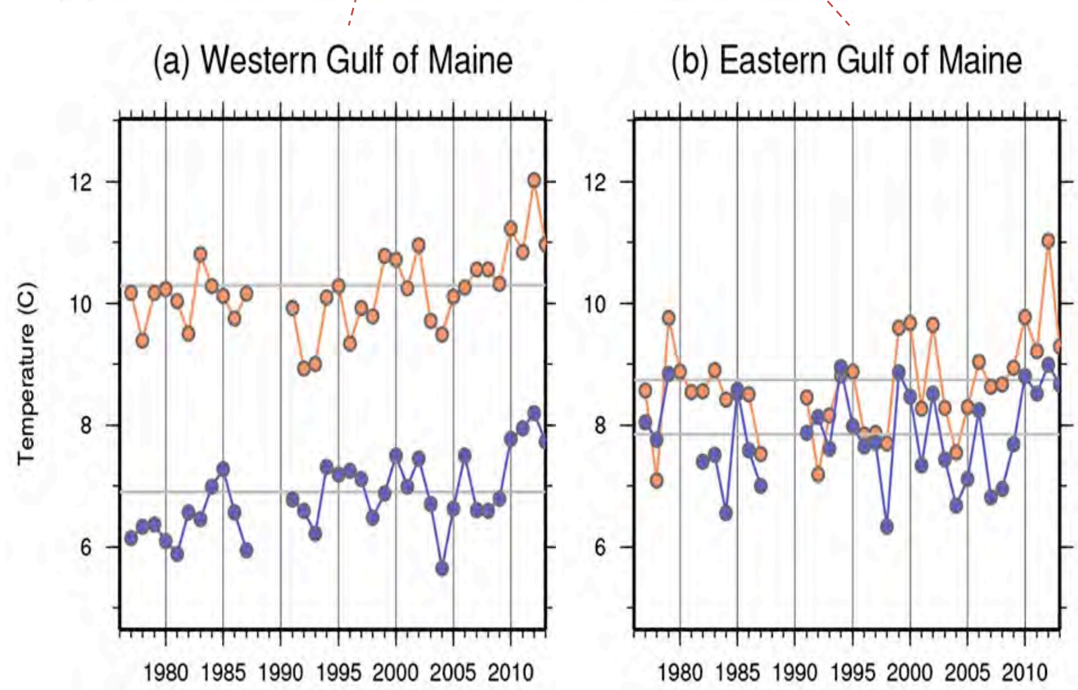


Changing environment

Global sea surface temperature trends (° yr^{-1}) over the period 2004-2013. (Pershing et al. 2015)



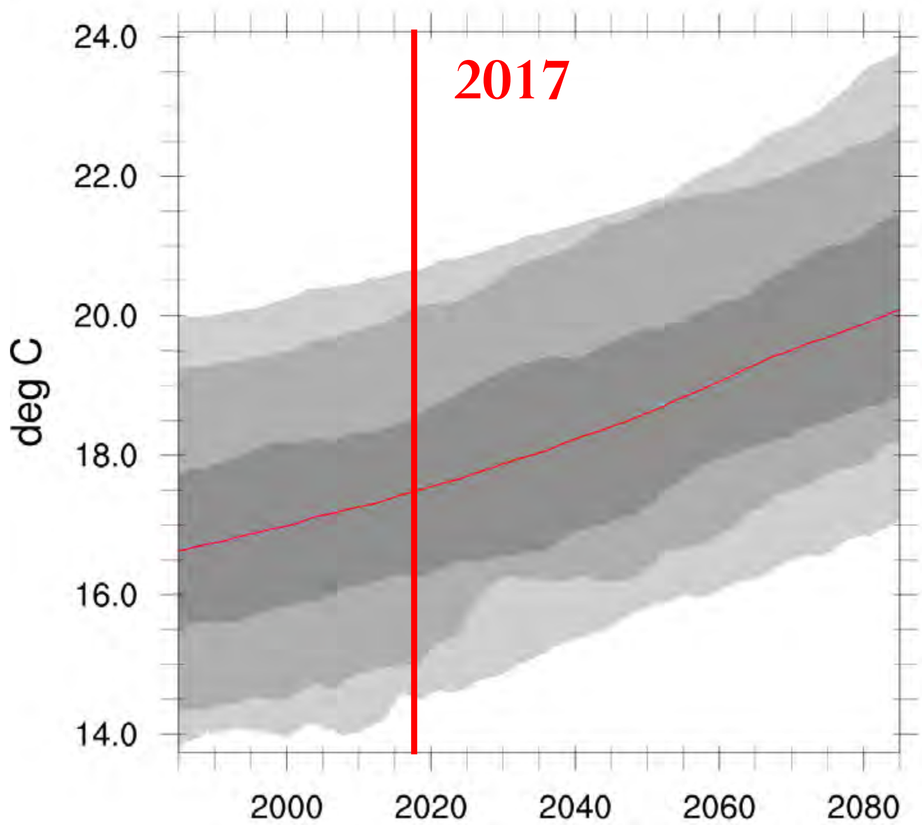
Time series of bottom temperature (blue) and surface temperature (orange) within Gulf of Maine. (Kleisner et al. 2016)



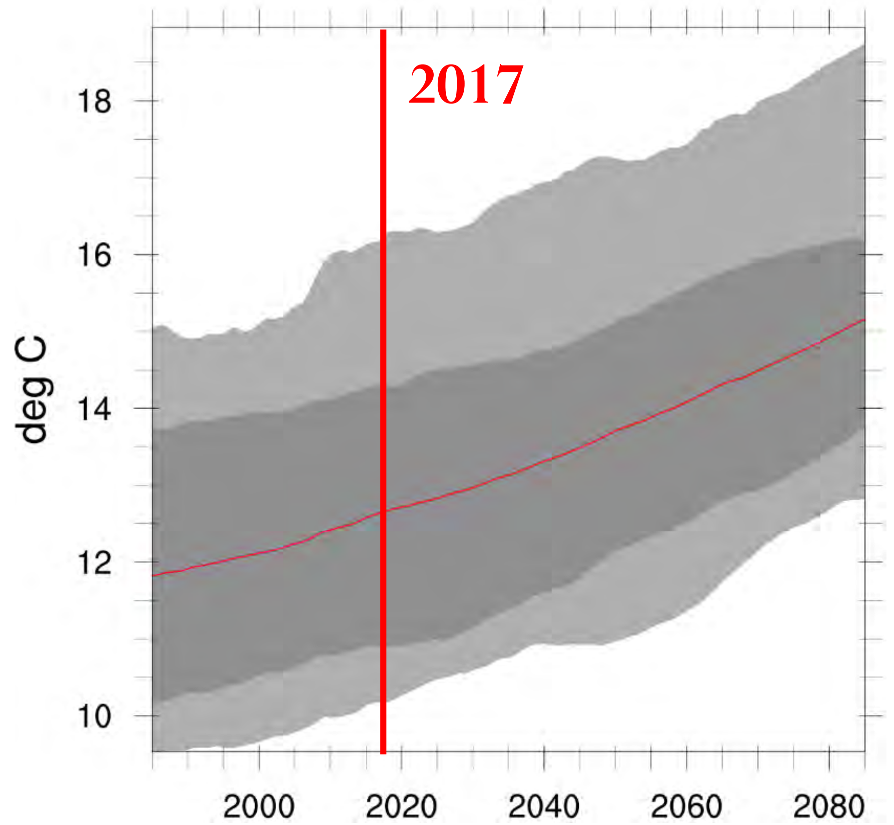
Changing environment

IPCC 5th assessment ensemble model projections in Northeast Continental Shelf under RCP 8.5

Surface temperature



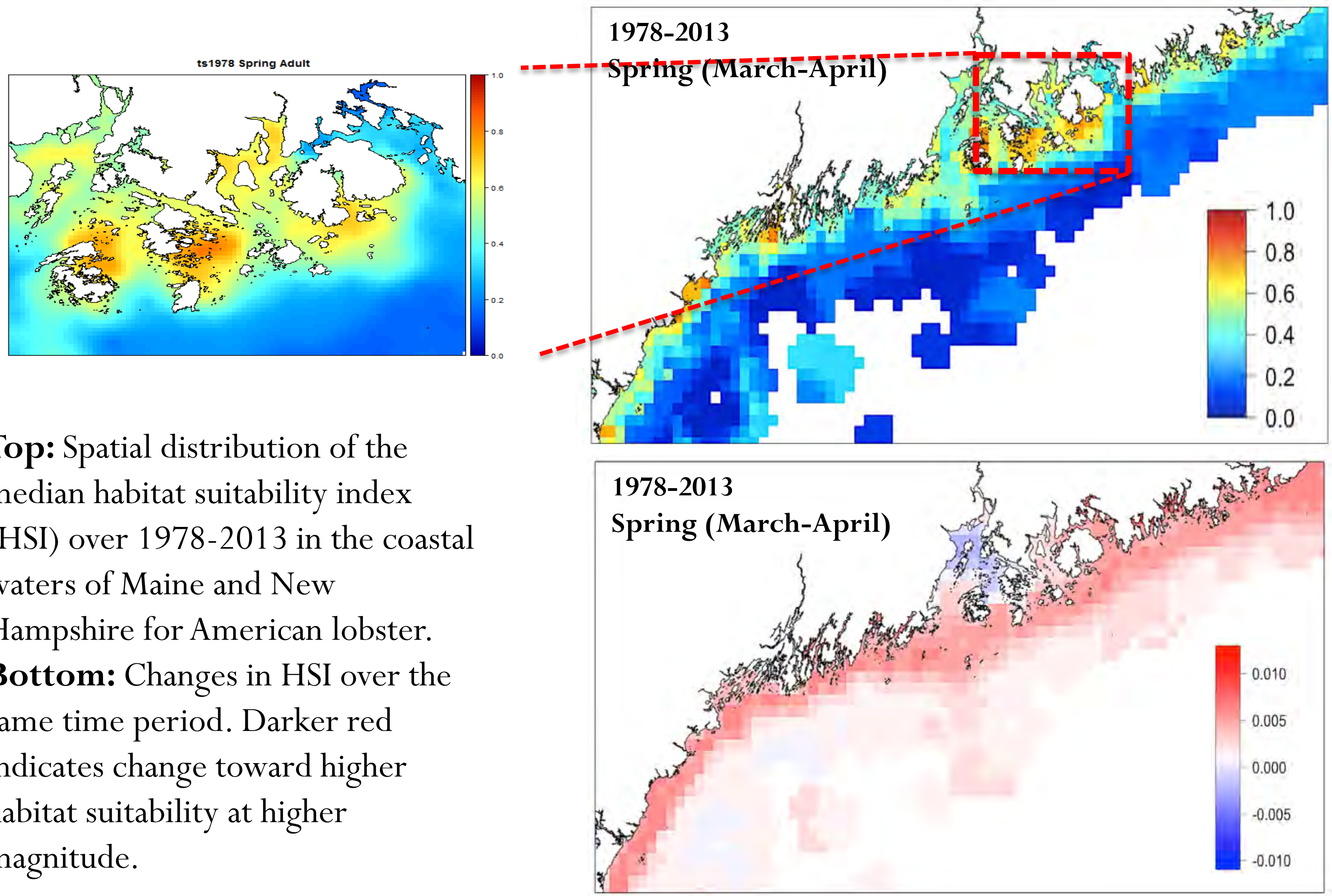
Bottom temperature



NOAA ESRL 2016

Qualitative modeling approach

Evaluate the impact of climate variability on lobster habitat quality.

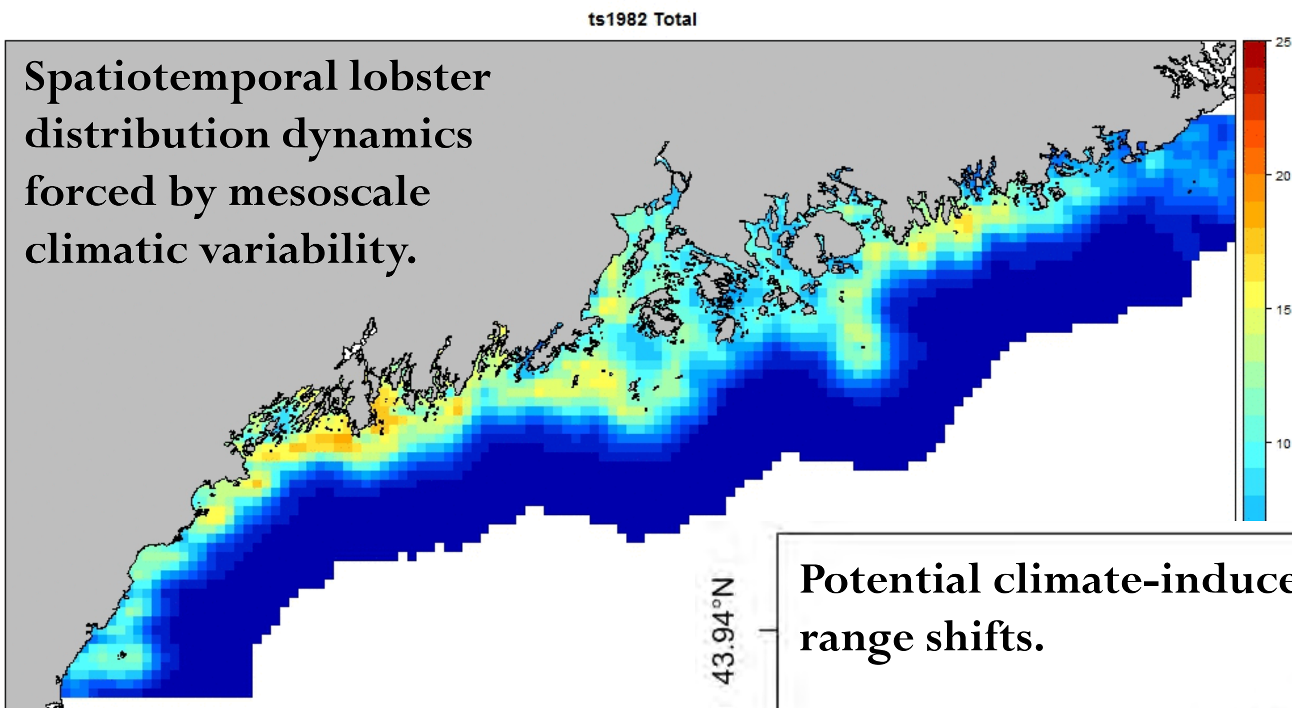


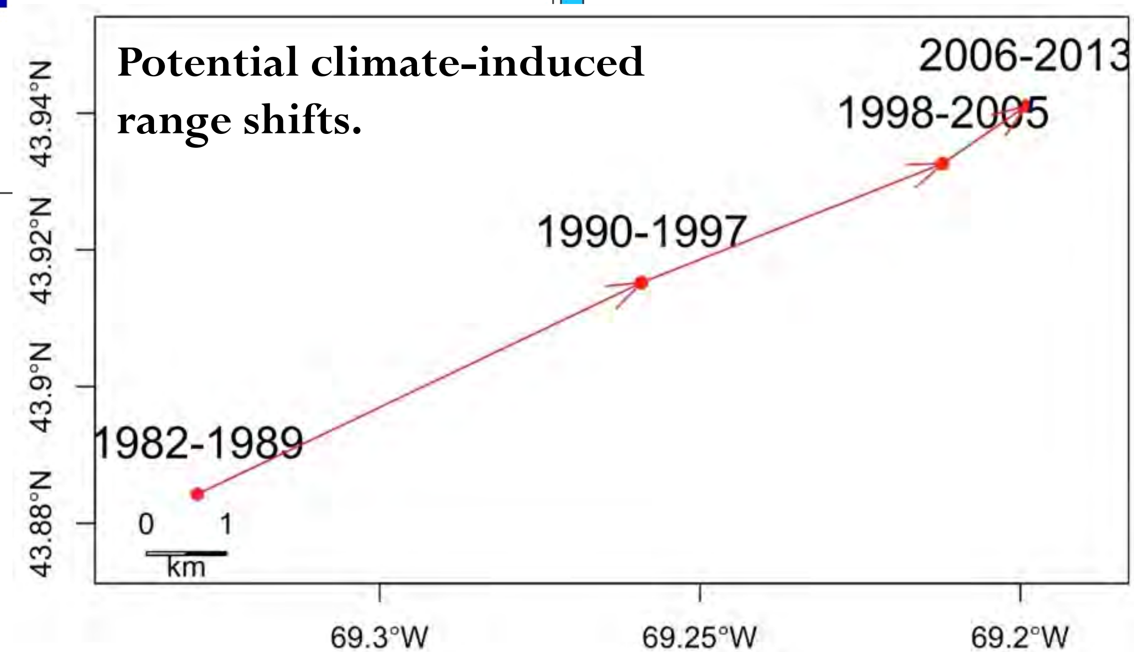
Top: Spatial distribution of the median habitat suitability index (HSI) over 1978-2013 in the coastal waters of Maine and New Hampshire for American lobster. **Bottom:** Changes in HSI over the same time period. Darker red indicates change toward higher habitat suitability at higher magnitude.

Tanaka & Chen 2016

Statistical modeling approach

Evaluate the impacts of climatic variability on lobster distribution



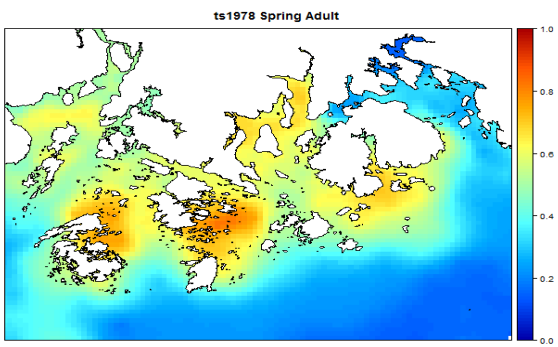


Tanaka et al. In press

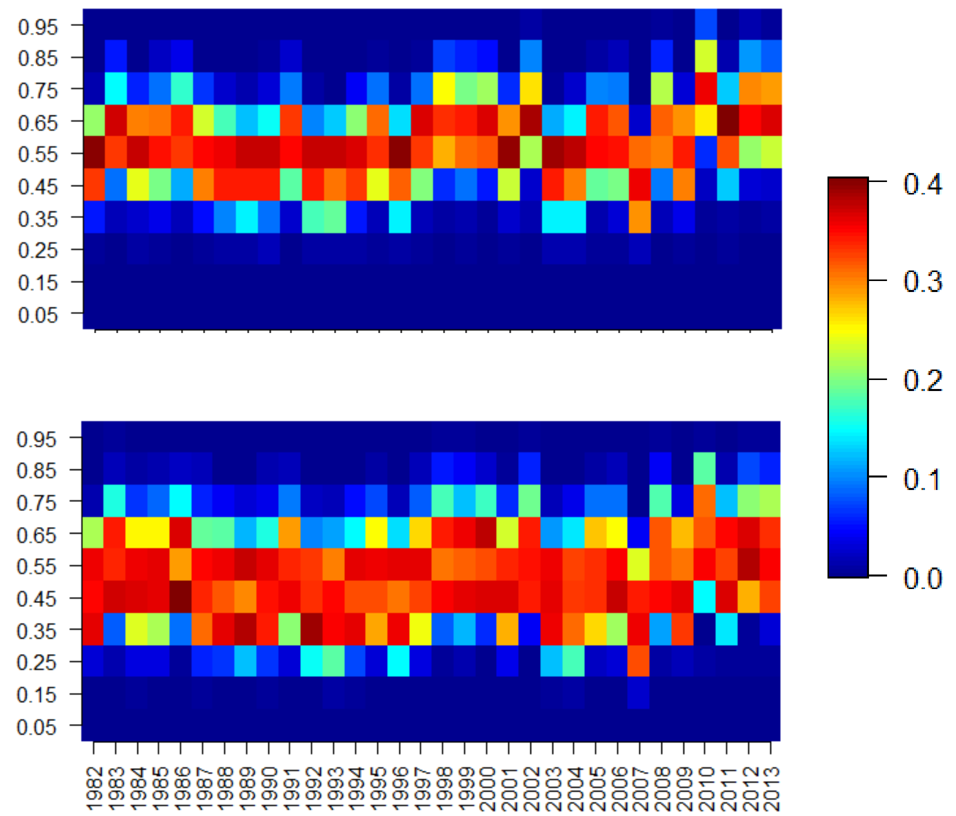
$$N_{t+1} = GSN_t + R_t$$

Climate-driven recruitment models

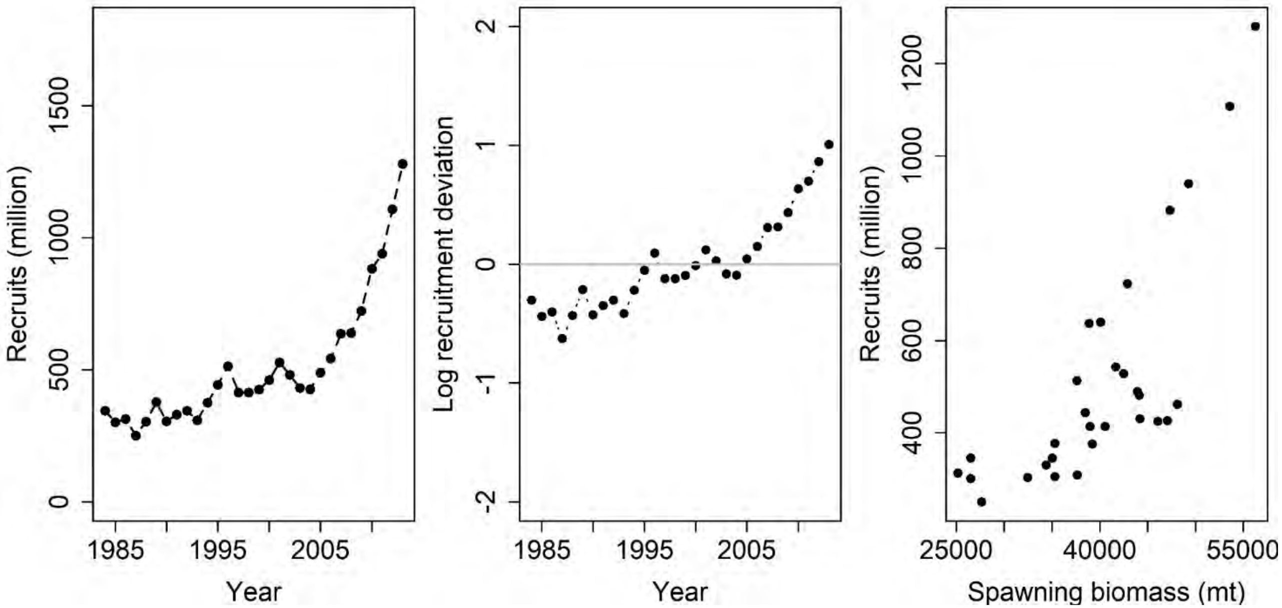
$$R_t = \frac{\alpha SSB_t}{\beta + SSB_t} e^{\sum_i \theta_i E_{i,t}} e^{Rdev_t}$$



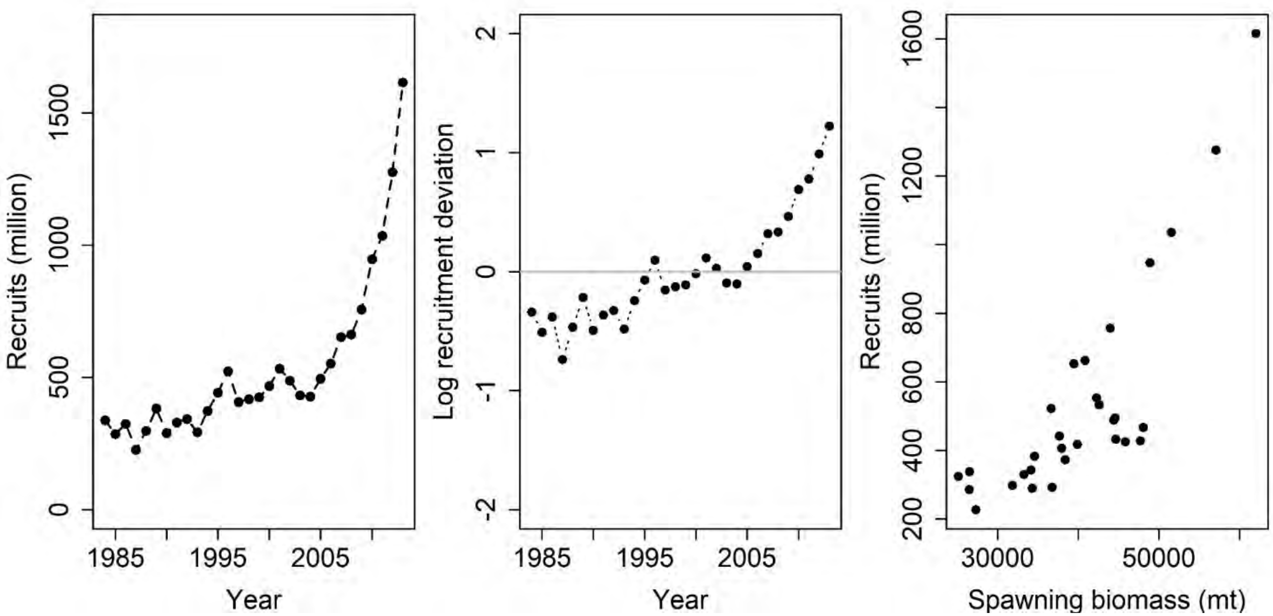
Tanaka et al. In Prep



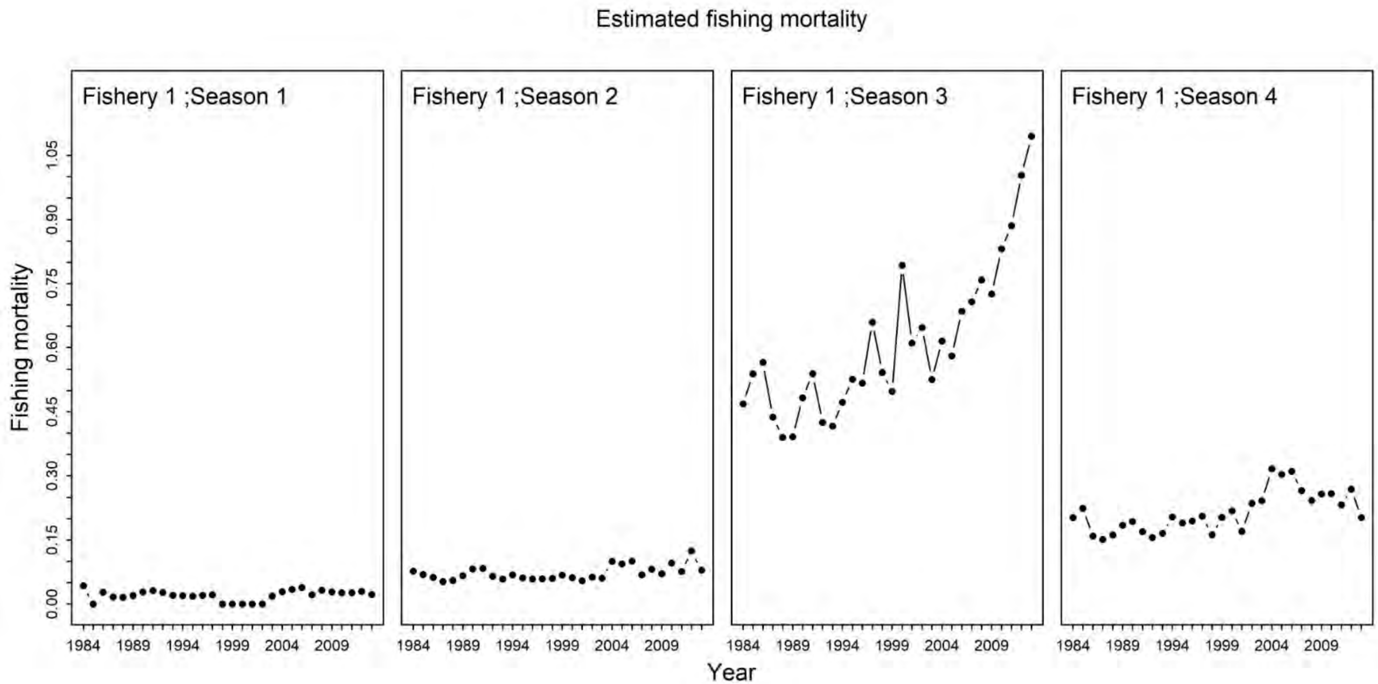
Temporal change in the proportion of the study area with suitable climate for lobster recruit (CL 53-63 mm; top) and spawning stock biomass (CL > 60 mm; bottom)



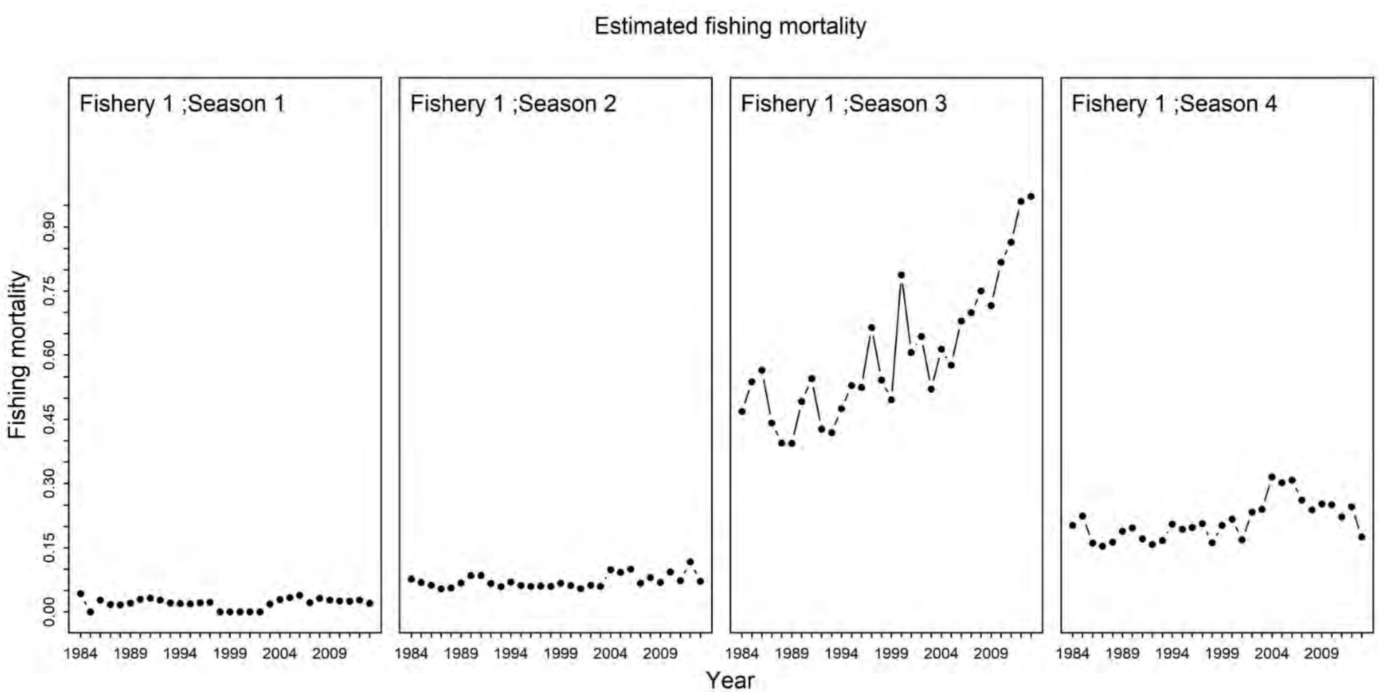
Changes in environment (HSI) not considered



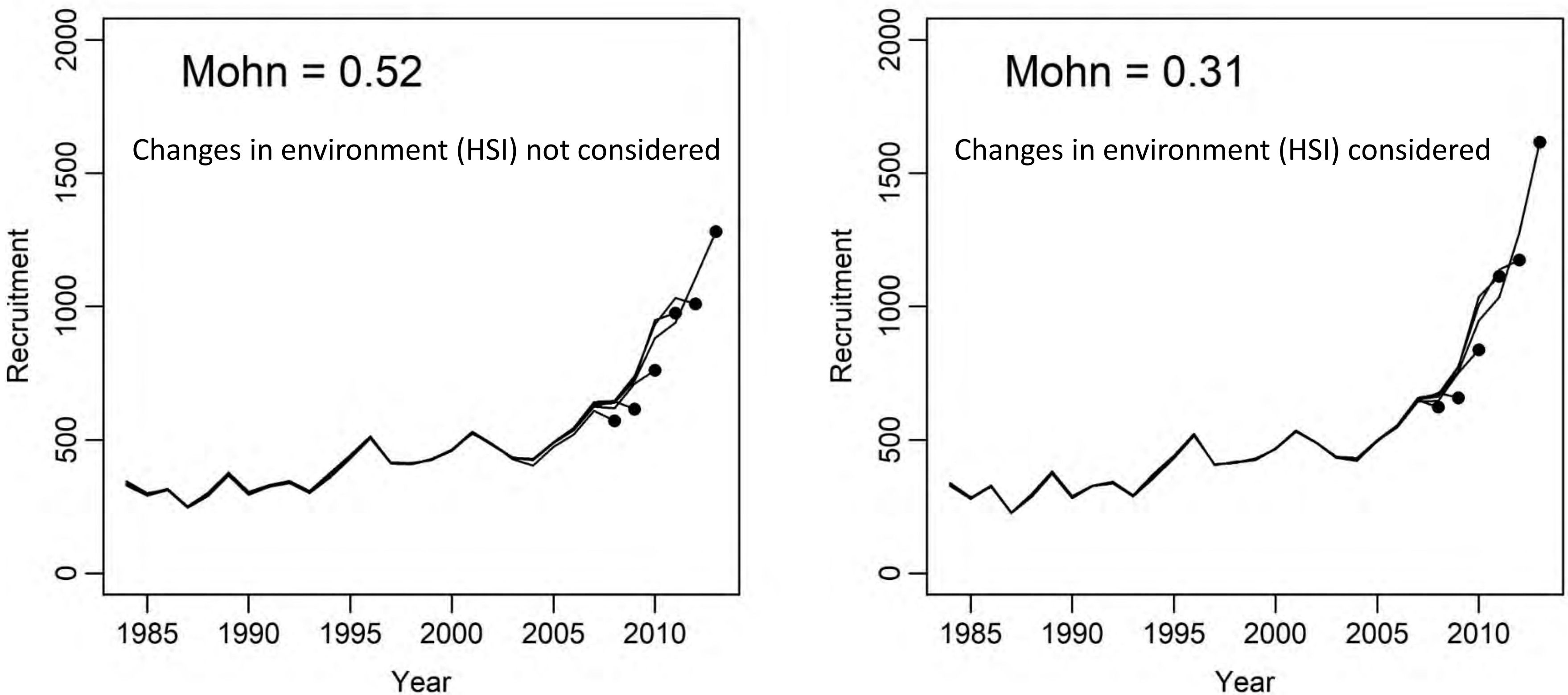
Changes in environment (HSI) considered



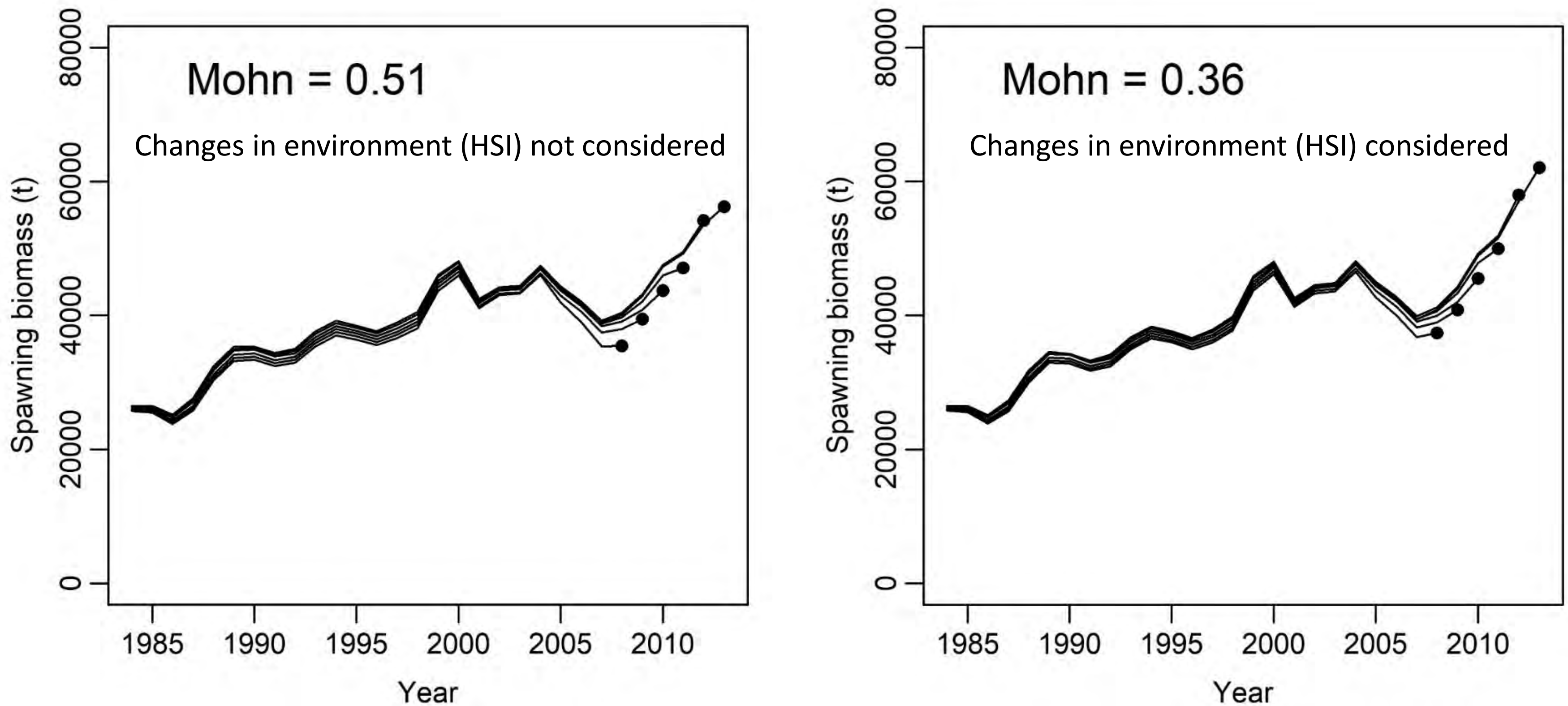
Changes in environment (HSI) not considered



Changes in environment (HSI) considered

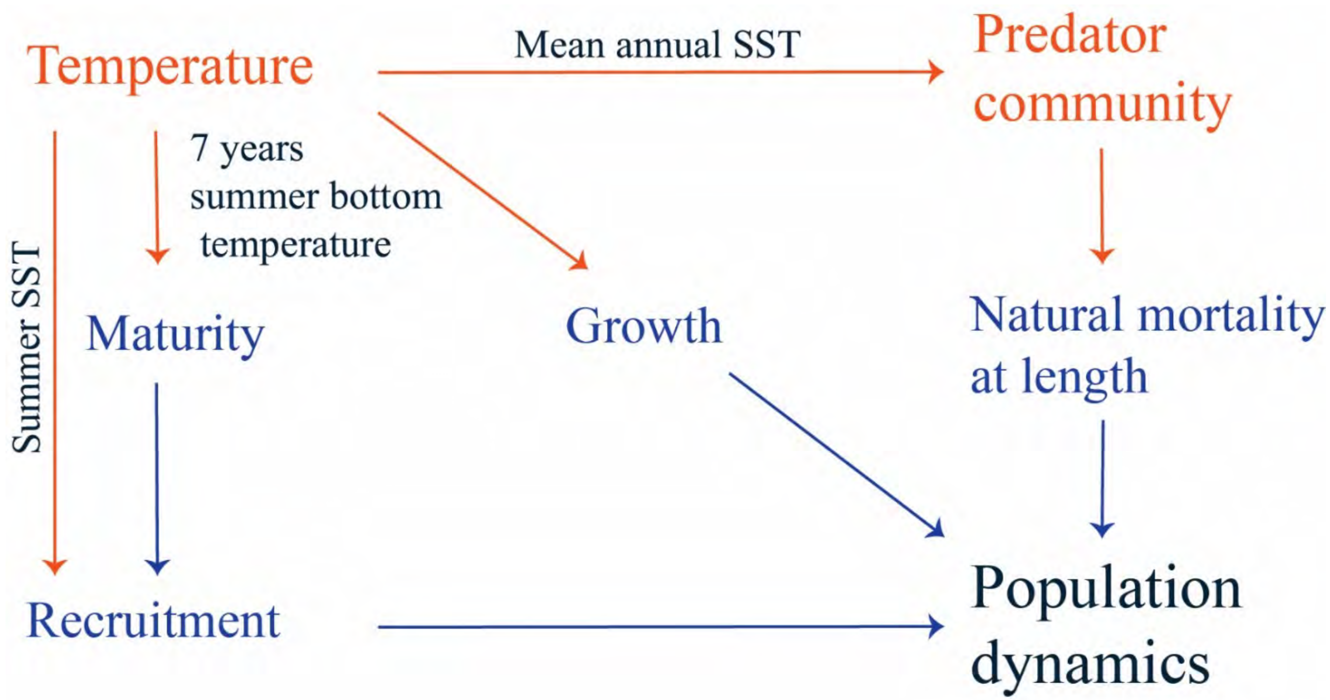


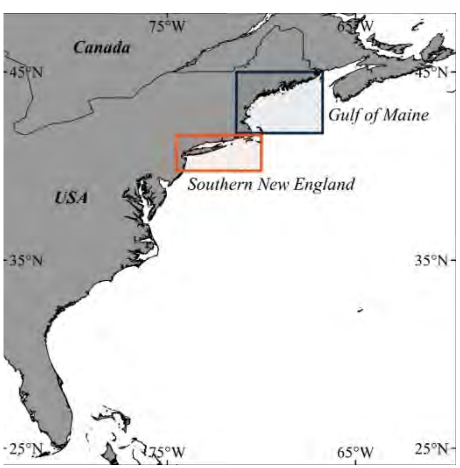
Mohn = 0.52
Changes in environment (HSI) not considered
Recruitment
Year
Mohn = 0.31
Changes in environment (HSI) considered
Recruitment
Year

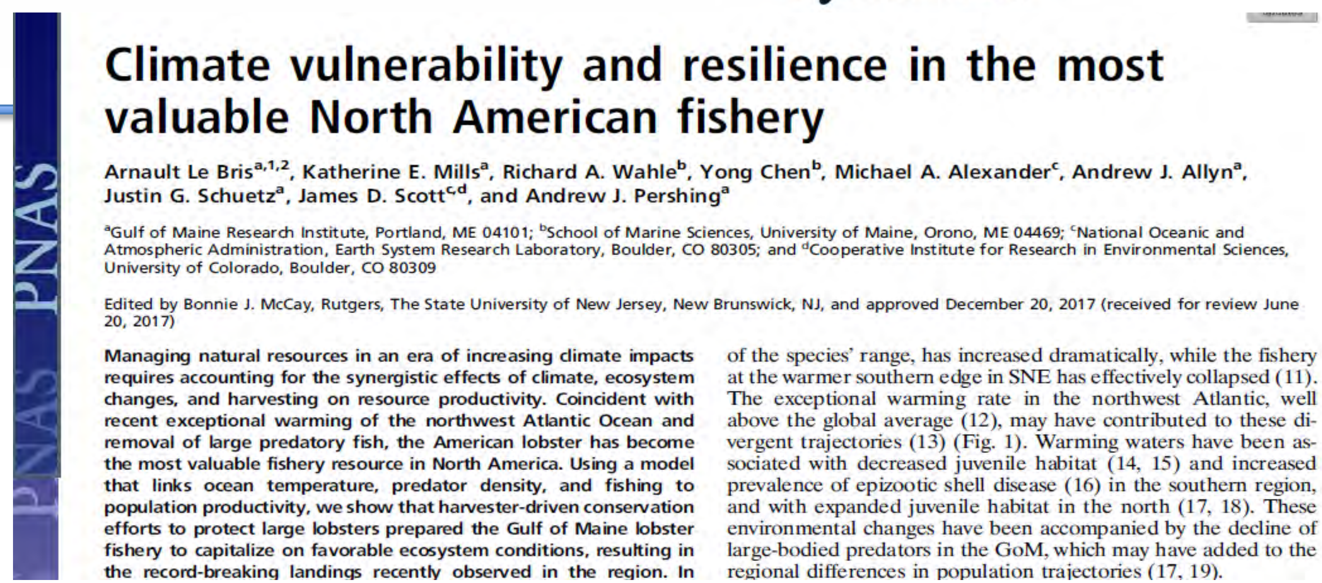


Mohn = 0.51
Changes in environment (HSI) not considered
Spawning biomass (t)
0
20000
40000
60000
80000
1985
1990
1995
2000
2005
2010
Year
Mohn = 0.36
Changes in environment (HSI) considered
Spawning biomass (t)
0
20000
40000
60000
80000
1985
1990
1995
2000
2005
2010
Year

Schema of temperature/predator dependent population dynamics model







Climate vulnerability and resilience in the most valuable North American fishery

Arnault Le Bris[a,1,2], Katherine E. Mills[a], Richard A. Wahle[b], Yong Chen[b], Michael A. Alexander[c], Andrew J. Allyn[a], Justin G. Schuetz[a], James D. Scott[c,d], and Andrew J. Pershing[a]

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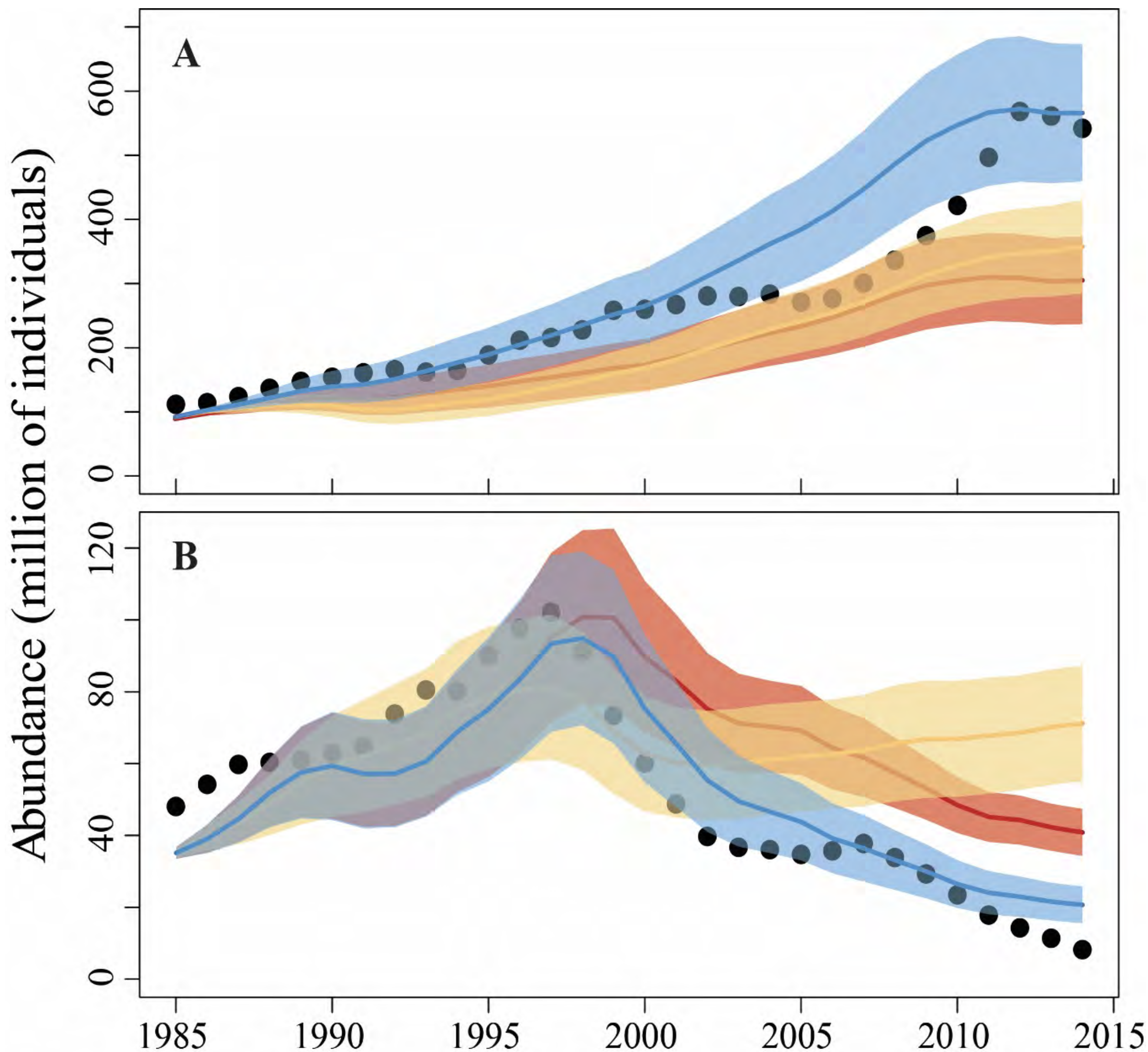
Managing natural resources in an era of increasing climate impacts requires accounting for the synergistic effects of climate, ecosystem changes, and harvesting on resource productivity. Coincident with recent exceptional warming of the northwest Atlantic Ocean and removal of large predatory fish, the American lobster has become the most valuable fishery resource in North America. Using a model that links ocean temperature, predator density, and fishing to population productivity, we show that harvester-driven conservation efforts to protect large lobsters prepared the Gulf of Maine lobster fishery to capitalize on favorable ecosystem conditions, resulting in the record-breaking landings recently observed in the region. In

of the species' range, has increased dramatically, while the fishery at the warmer southern edge in SNE has effectively collapsed (11). The exceptional warming rate in the northwest Atlantic, well above the global average (12), may have contributed to these divergent trajectories (13) (Fig. 1). Warming waters have been associated with decreased juvenile habitat (14, 15) and increased prevalence of epizootic shell disease (16) in the southern region, and with expanded juvenile habitat in the north (17, 18). These environmental changes have been accompanied by the decline of large-bodied predators in the GoM, which may have added to the regional differences in population trajectories (17, 19).

Hindcast of abundance of American lobster across three temperature and management scenarios (A) Gulf of Maine stock (B) Southern New England stock.



The blue lines show model hindcast with observed temperatures and actual management plans.

Yellow lines show model hindcast with constant temperature set at the average of the 1984-1999 time period (first half of temperature time series).

Red lines show model hindcast with observed temperatures but inversed management strategies between the two stocks.

Le Bris et al. 2018

Summary

In light of the great complexity of natural systems and large environmental variability, appropriate incorporation of environmental drivers in stock assessment can reduce the uncertainty and help develop assessment and management strategies more robust to the gradual and abrupt environmental changes.

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FISHERMEN'S VOICE

News and Comment for and by the Fishermen of Maine

New Model Accounts for Northern Shrimp's Sensitivity to Temperature

by Catherine Schmitt

Winter is not the same without shrimp. Since 1938, Maine fishermen have spent the cold months from December through March working the icy waters, hauling in nets filled with small, tender, dark pink shrimp: Pandalus borealis, northern shrimp. Fishing historically took place statewide by hundreds of boats. Maine

CONTENTS

Challenges and opportunities abound in fisheries assessment In a changing environment

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Kisei Tanaka (UM), Jie Cao (UM), Larry Jacobson (NOAA NEFSC), Burton Shank (NOAA NEFSC), Andy Pershing (GMRI), Arnault Le Bris (MUN), Rick Wahle (UM), Andy Thomas (UM), James Thorson (NOAA NWFSC), Anne Richards (NOAA NEFSC), Jui-han Chang (NOAA NEFSC), Carl Wilson (ME DMR), Kathleen Reardon (ME DMR), and Sam Truesdell (GMRI)

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ATLANTIC STATES MARINE FISHERIES COMMISSION

Sea Grant Maine

Three Boys in a Dory with Lobster Pots
Winslow Homer, 1875

Thanks! Question?