A KEYSTONE ISSUE:
MANAGING FORAGE FISHES IN A CHANGING CLIMATE

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INTRODUCTION

With the goal to address questions regarding forage fish in a changing climate, we established an international and interdisciplinary working group stemmed from the symposium, *Forage Fish and Climate Adaptation: Updates on Science and Management*, at the 2020 annual meeting of the American Fisheries Society (AFS). The group is comprised of 26 members, representing 21 non-governmental and private conservation, academic and federal organizations from 5 countries (USA, Canada, Mexico, Japan, and Australia). Members also span a diversity of taxonomic foci and research areas that include fisheries and wildlife management, ocean modeling, and climate adaptation.

DEVELOPMENT

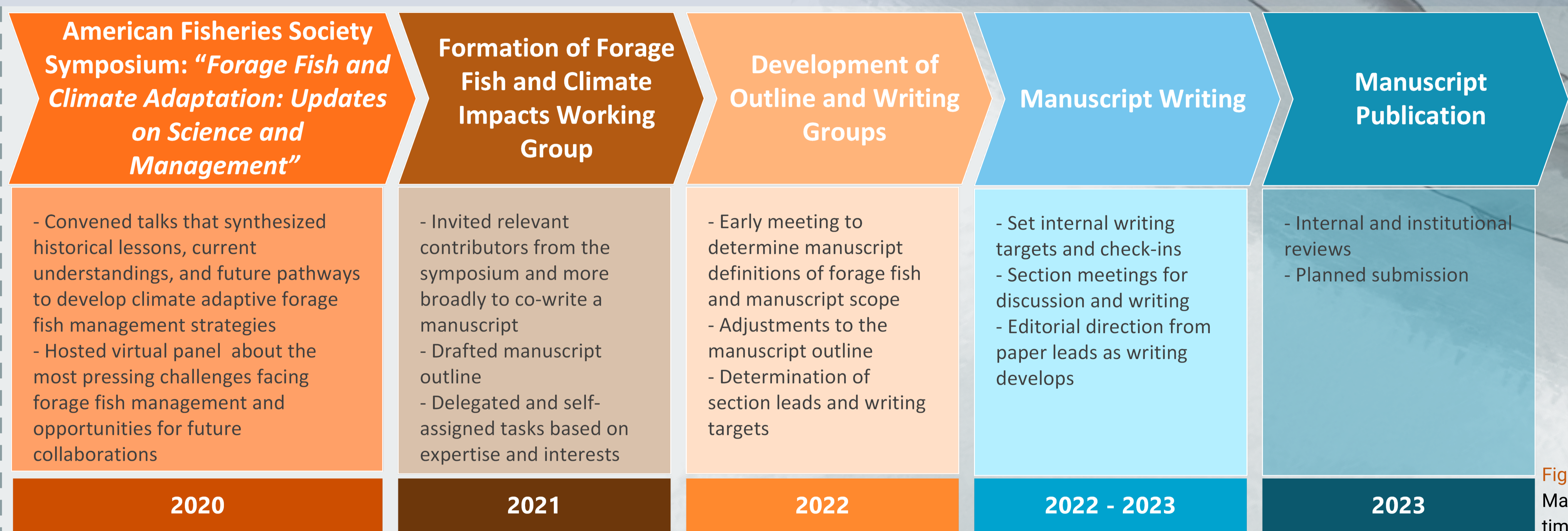| American Fisheries Society Symposium: "Forage Fish and Climate Adaptation: Updates on Science and Management"	Formation of Forage Fish and Climate Impacts Working Group	Development of Outline and Writing Groups	Manuscript Writing	Manuscript Publication
- Convened talks that synthesized historical lessons, current understandings, and future pathways to develop climate adaptive forage fish management strategies - Hosted virtual panel about the most pressing challenges facing forage fish management and opportunities for future collaborations	- Invited relevant contributors from the symposium and more broadly to co-write a manuscript - Drafted manuscript outline - Delegated and self-assigned tasks based on expertise and interests	- Early meeting to determine manuscript definitions of forage fish and manuscript scope - Adjustments to the manuscript outline - Determination of section leads and writing targets	- Set internal writing targets and check-ins - Section meetings for discussion and writing - Editorial direction from paper leads as writing develops	- Internal and institutional reviews - Planned submission
2020	2021	2022	2022 - 2023	2023

Fig. 1 Manuscript timeline

GOALS

- **Synthesize** current knowledge of historical & projected biological responses & vulnerabilities of forage fish to climate change;
- **Evaluate** the ecological consequences and management challenges for forage fish and fisheries to climate change;
- **Highlight** opportunities, tools, emerging technologies, and case studies that can support sustainable forage fish management and climate adaptation strategies across broad spatial scales.
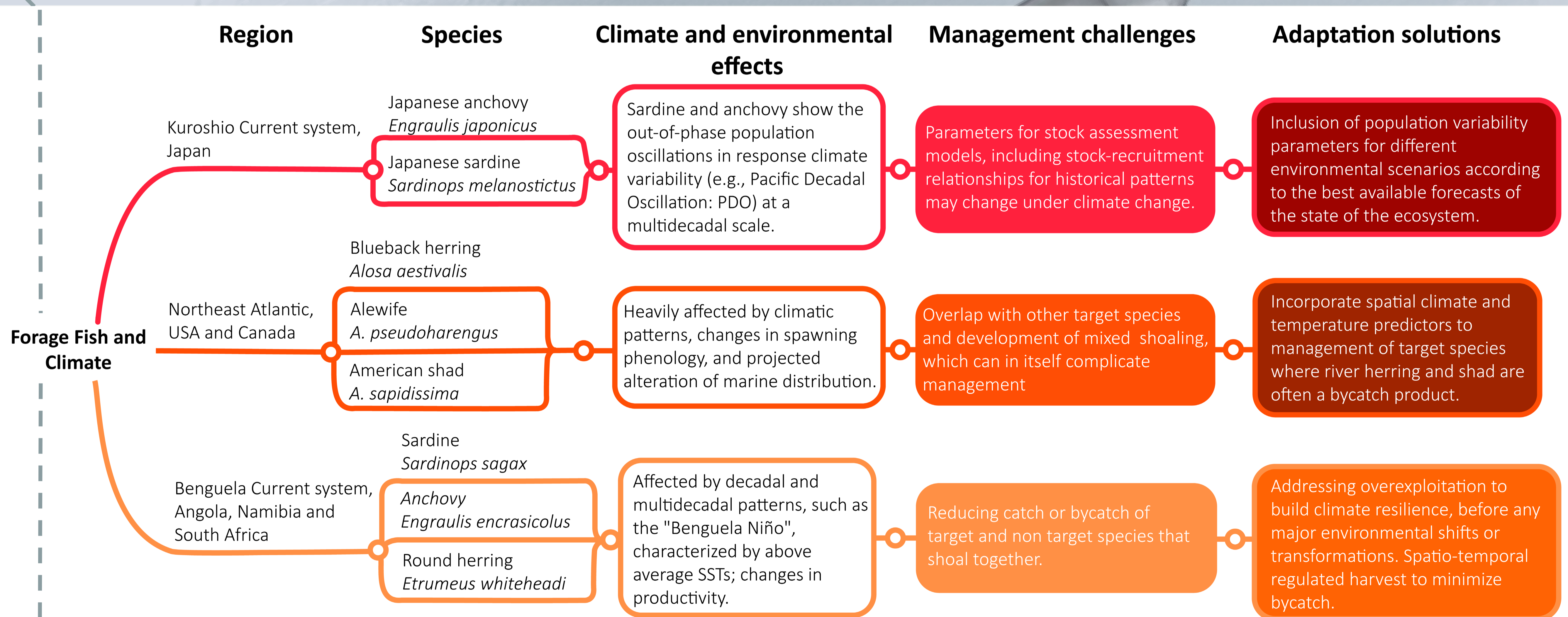
EXAMPLES

Fig. 2 Examples outlined during the paper draft process. Key species, the environmental and climate effects, management challenges and adaptation solutions and opportunities were identified for distinct regions

Forage Fish and Climate

Region	Species	Climate and environmental effects	Management challenges	Adaptation solutions
Kuroshio Current system, Japan	Japanese anchovy *Engraulis japonicus* / Japanese sardine *Sardinops melanostictus*	Sardine and anchovy show the out-of-phase population oscillations in response climate variability (e.g., Pacific Decadal Oscillation: PDO) at a multidecadal scale.	Parameters for stock assessment models, including stock-recruitment relationships for historical patterns may change under climate change.	Inclusion of population variability parameters for different environmental scenarios according to the best available forecasts of the state of the ecosystem.
Northeast Atlantic, USA and Canada	Blueback herring *Alosa aestivalis* / Alewife *A. pseudoharengus* / American shad *A. sapidissima*	Heavily affected by climatic patterns, changes in spawning phenology, and projected alteration of marine distribution.	Overlap with other target species and development of mixed shoaling, which can in itself complicate management	Incorporate spatial climate and temperature predictors to management of target species where river herring and shad are often a bycatch product.
Benguela Current system, Angola, Namibia and South Africa	Sardine *Sardinops sagax* / Anchovy *Engraulis encrasicolus* / Round herring *Etrumeus whiteheadi*	Affected by decadal and multidecadal patterns, such as the "Benguela Niño", characterized by above average SSTs; changes in productivity.	Reducing catch or bycatch of target and non target species that shoal together.	Addressing overexploitation to build climate resilience, before any major environmental shifts or transformations. Spatio-temporal regulated harvest to minimize bycatch.

EXPERT GROUP

Mayumi Arimitsu[1], Rebecca Asch[2], Laura Blamey[3], Jennifer Boldt[4], Jaclyn Cleary[4], Qihong Dai[5], Alex De Robertis, Chandra Goetsch[6], Amanda Hart[7], Joel Llopiz[8], Salvador Lluch-Cota[9], Ben Marcek[10], David McGowan[11], Hassan Moustahfid[12], John Piatt[1], Ryan Rykaczewski[13], Dylan Sinnickson[14], Margaret Siple[15], Justin Stevens[16], Joshua Stone[17], Justin Suca[18], Akinori Takasuka[19], Troy Tuckey[20].

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USGS science for a changing world

NECASC Northeast Climate Adaptation Science Center