Assessing Climate Risk and Building Resiliency in Fish Stocks: Tool & Perspectives

Inter-American Tropical Tuna Commission: 2nd Climate Change Workshop

Katie Schleit, MMA, Fisheries Director

Amy Irvine, MSc, Oceans and Climate Advisor

Wild Ocean Research vizzuality. AquaMaps 2.0 OCEANS NORTH FUTURE OF MARINE ECOSYSTEMS DALHOUSIE UNIVERSITY

Canada's fisheries science and management

OPEN ACCESS | Article

Leading or lagging: How well are climate change considerations being incorporated into Canadian fisheries management?

Authors: Daniel G. Boyce, Susanna Fuller, Chelsey Karbowski, Katie Schleit, and Boris Worm | AUTHORS INFO & AFFILIATIONS

Publication: Canadian Journal of Fisheries and Aquatic Sciences • 14 July 2021 • https://doi.org/10.1139/cjfas-2020-0394

ORIGINAL ARTICLE

Incorporating knowledge of changes in climatic, oceanographic and ecological conditions in Canadian stock assessments

Pierre Pepin, Jacquelyne King, Carrie Holt, Helen Gurney-Smith, Nancy Shackell, Kevin Hedges, Alida Bundy

First published: 25 June 2022 | https://doi.org/10.1111/faf.12692 | Citations: 1

Climate Risk Index for Biodiversity (CRIB)

nature climate change

ARTICLES

https://doi.org/10.1038/s41558-022-01437-y

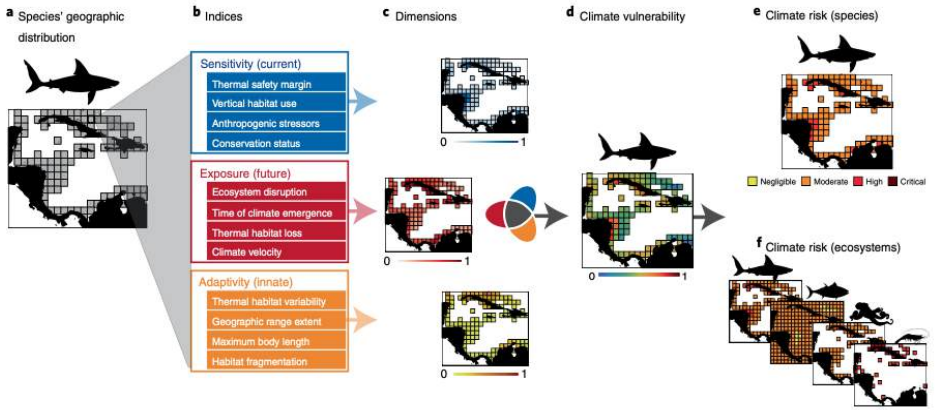
Check for updates

A climate risk index for marine life

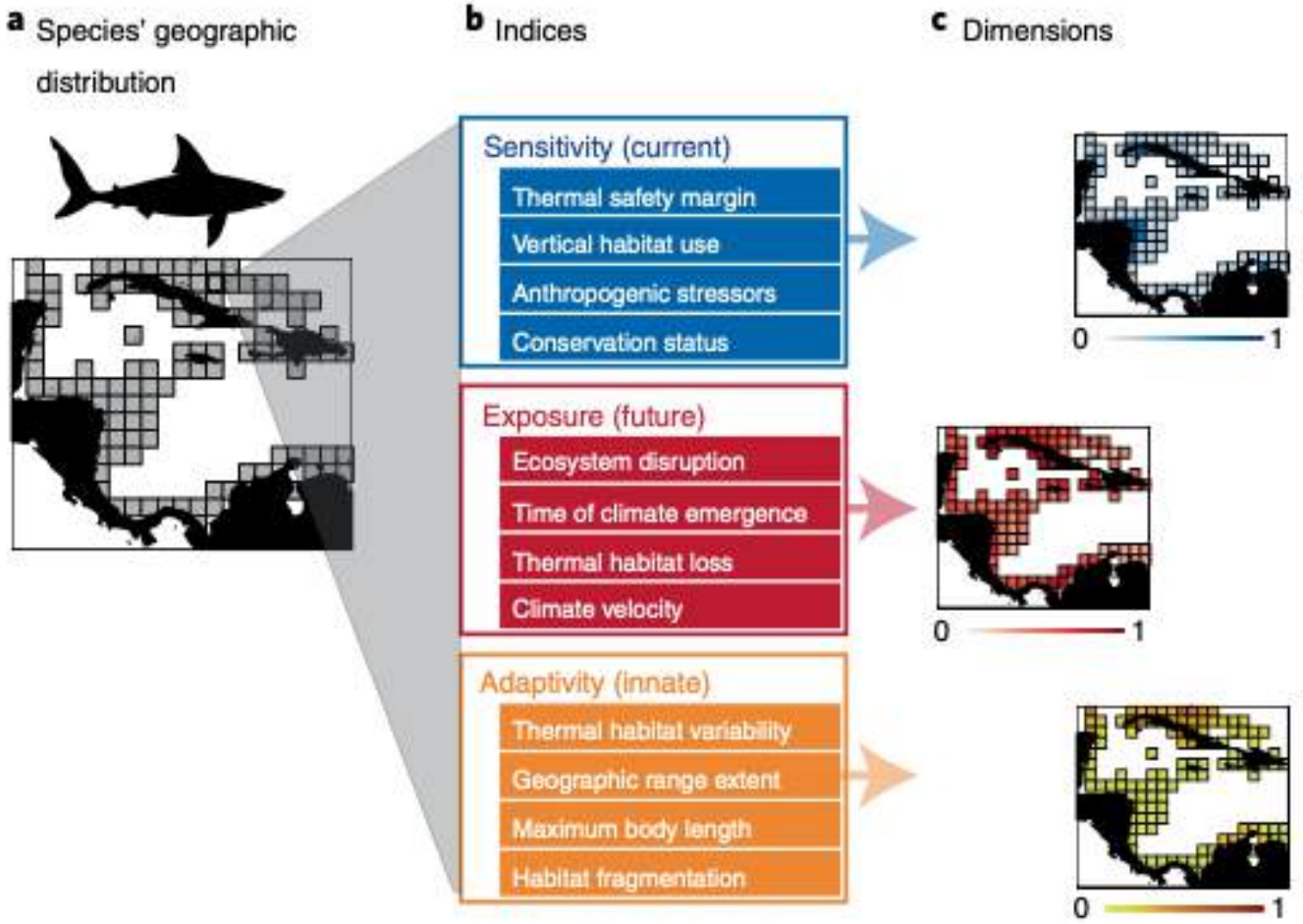
Daniel G. Boyce[1,2]✉, Derek P. Tittensor[1,3], Cristina Garilao[4], Stephanie Henson[5], Kristin Kaschner[6], Kathleen Kesner-Reyes[7], Alex Pigot[8], Rodolfo B. Reyes Jr.[7], Gabriel Reygondeau[9], Kathryn E. Schleit[10], Nancy L. Shackell[2], Patricia Sorongon-Yap[7] and Boris Worm[1]

Climate change is impacting virtually all marine life. Adaptation strategies will require a robust understanding of the risks to species and ecosystems and how those propagate to human societies. We develop a unified and spatially explicit index to comprehensively evaluate the climate risks to marine life. Under high emissions (SSP5-8.5), almost 90% of ~25,000 species are at high or critical risk, with species at risk across 85% of their native distributions. One tenth of the ocean contains ecosystems where the aggregated climate risk, endemism and extinction threat of their constituent species are high. Climate change poses the greatest risk for exploited species in low-income countries with a high dependence on fisheries. Mitigating emissions (SSP1-2.6) reduces the risk for virtually all species (98.2%), enhances ecosystem stability and disproportionately benefits food-insecure populations in low-income countries. Our climate risk assessment can help prioritize vulnerable species and ecosystems for climate-adapted marine conservation and fisheries management efforts.

The CRIB is a new climate **scorecard** for marine fish species that allows us to understand spatial dynamics: where, when, and how fish will be affected by climate change



“Risk for any species, anywhere in the ocean”.



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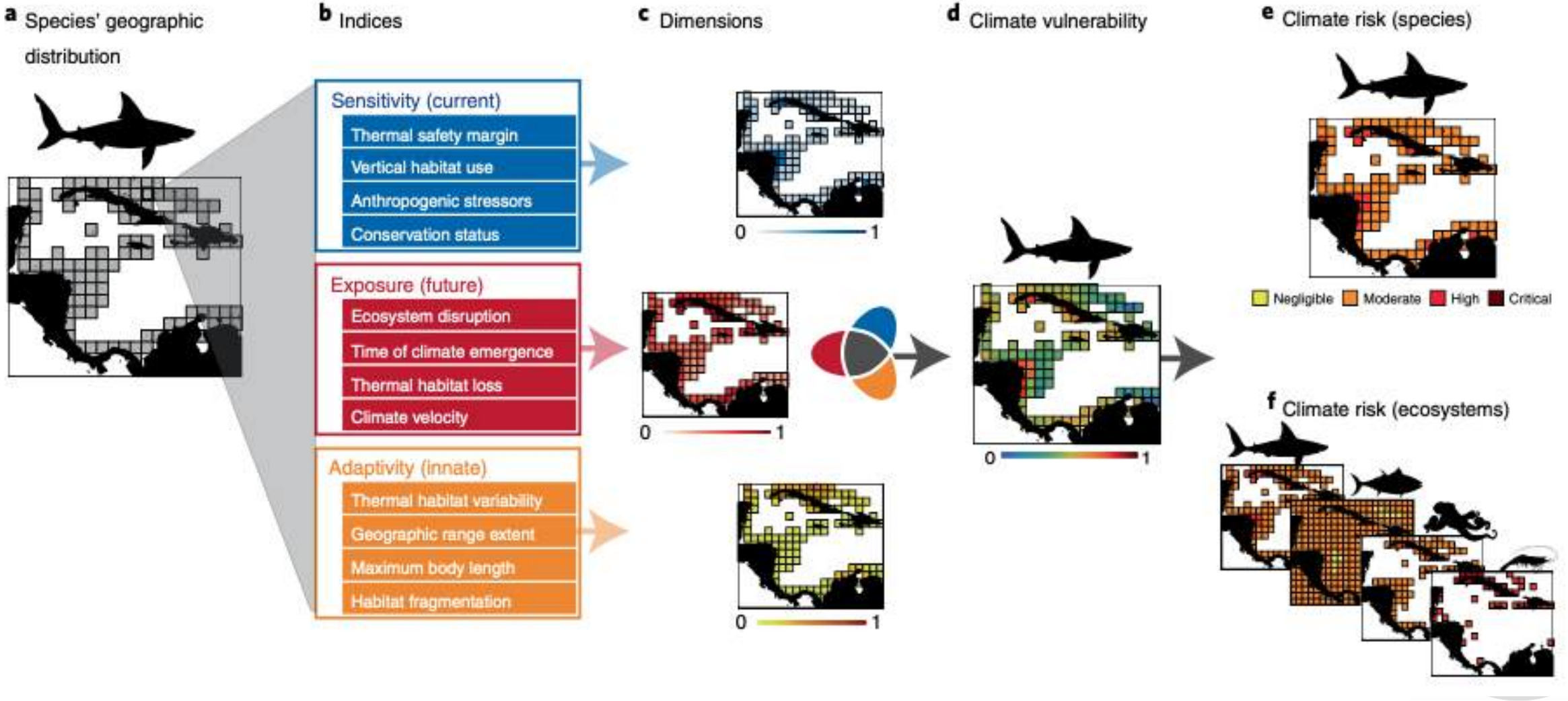


Climate Vulnerability Analyses (CVAs) vs Stock Assessments

Regulatory use: Planning, spatial management, and conservation prioritization

Regulatory use: Setting total allowable catch, fisheries closures

Units: Dimensionless — **Units:** Biomass, abundance

Input data: Varied — **Input data:** Catch, surveys

Output: Scores, rankings, maps — **Output:** Allowable catch (TAC)

Life stages: No — **Life stages:** Yes

Temporal scale: Long-term — **Temporal scale:** Short-term

Methods: Varied — **Methods:** Population models

CRIB Applications

CRIB in the Northwest Atlantic

nature > npj ocean sustainability > articles > article

Article | Open access | Published: 24 June 2024

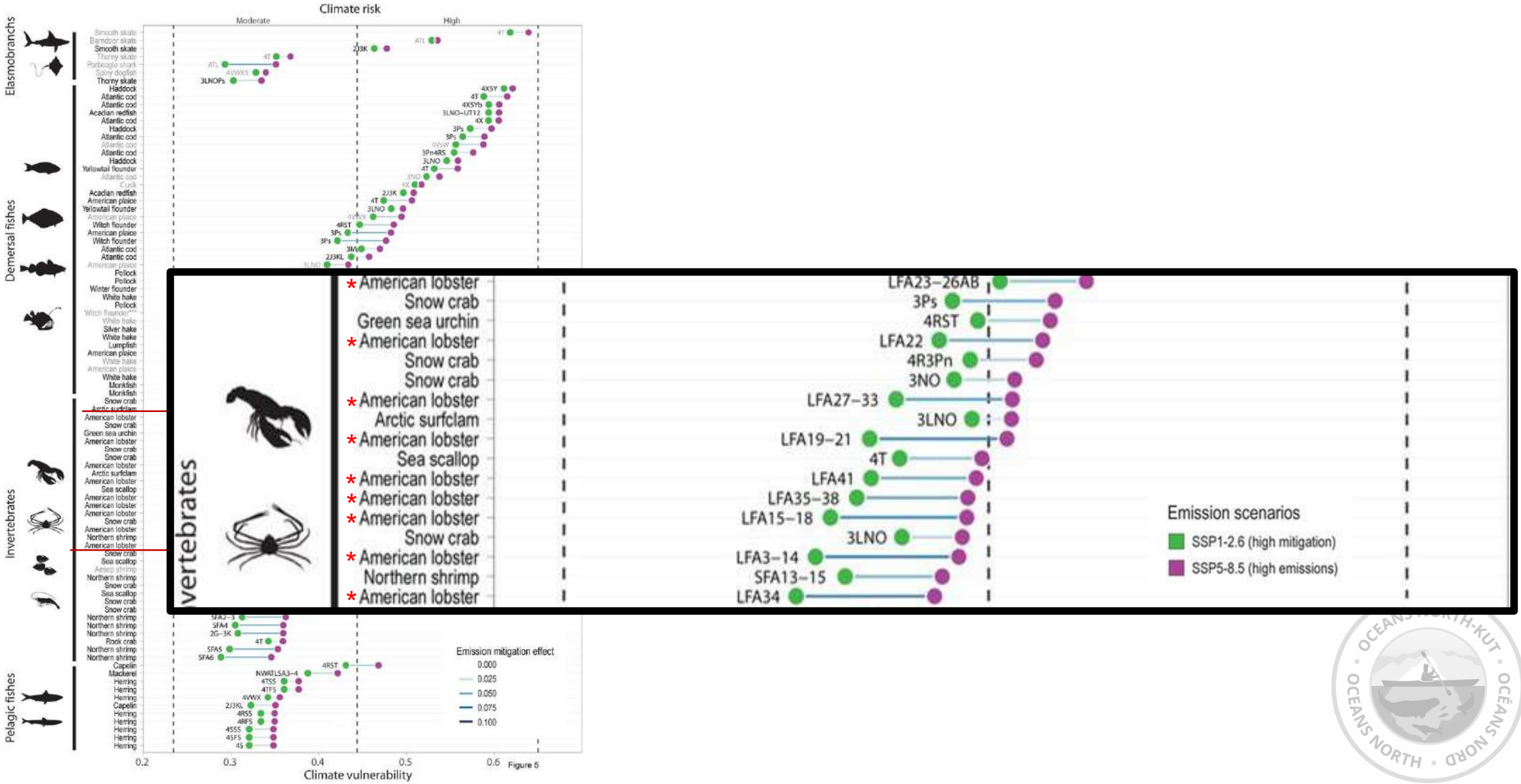
Operationalizing climate risk in a global warming hotspot

Daniel G. Boyce, Derek P. Tittensor, Susanna Fuller, Stephanie Henson, Kristin Kaschner, Gabriel Reygondeau, Kathryn E. Schleit, Vincent Saba, Nancy Shackell, Ryan R. E. Stanley & Boris Worm

- Applied the CRIB to the Atlantic ecoregion
- 41% of 90 fish stocks evaluated at high climate risk
  - ➢ Decreased to 25% under low emissions / high mitigation scenario
- Species in NW Atlantic at high or critical risk across ~31% of their native distribution

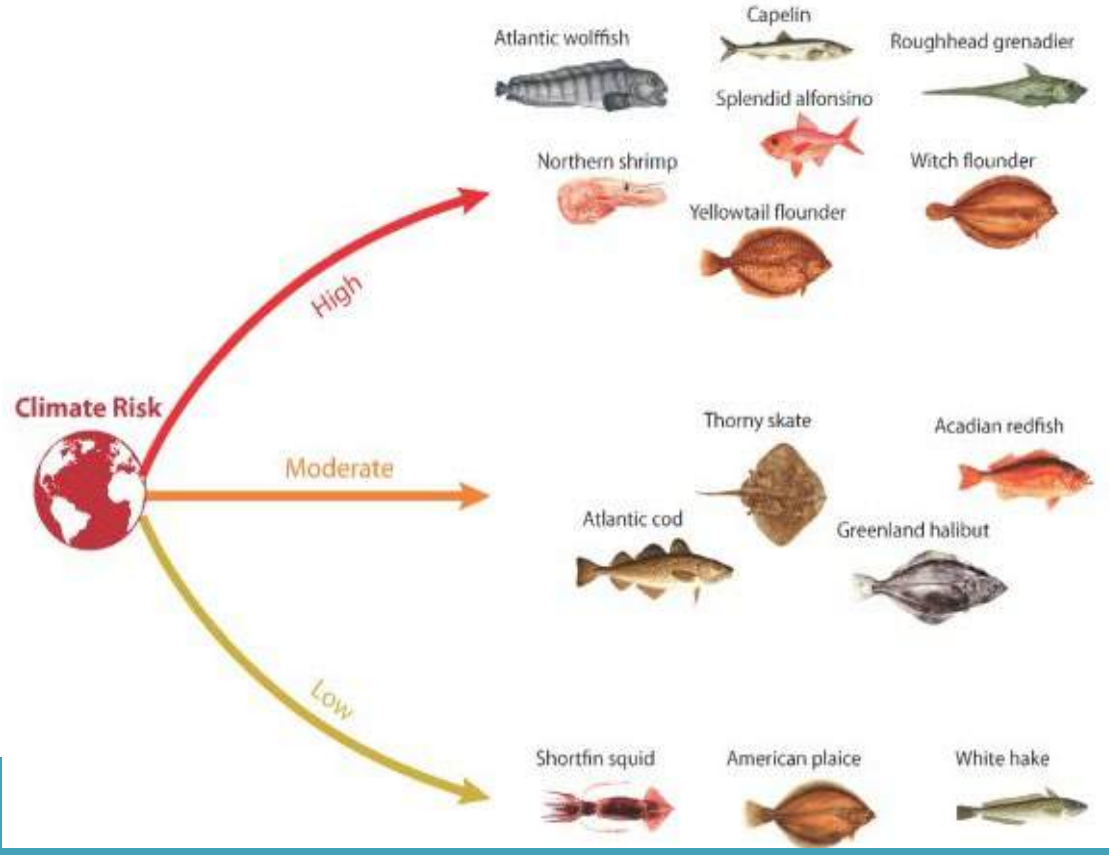
Research Highlights

- Harvested species had higher climate sensitivity and exposure
- Proportion of species with high or critical climate risk were higher near coastlines
- Lowering emissions most benefited species in nearshore and high-latitude environments


Climate risk
Moderate
High
Elasmobranchs
Demersal fishes
Invertebrates
Pelagic fishes
Smooth skate
Barndoor skate
Smooth skate
Thorny skate
Porbeagle shark
Spiny dogfish
Thorny skate
Haddock
Atlantic cod
Atlantic cod
Acadian redfish
Atlantic cod
Haddock
Atlantic cod
Atlantic cod
Atlantic cod
Haddock
Yellowtail flounder
Atlantic cod
Cusk
Acadian redfish
American plaice
Yellowtail flounder
American plaice
Witch flounder
American plaice
Witch flounder
Atlantic cod
Atlantic cod
American plaice
Pollock
Pollock
Winter flounder
White hake
Pollock
Witch flounder***
White hake
Silver hake
White hake
Lumpfish
American plaice
White hake
American plaice
White hake
Monkfish
Monkfish
Snow crab
Arctic surfclam
American lobster
Snow crab
Green sea urchin
American lobster
Snow crab
Snow crab
American lobster
Arctic surfclam
American lobster
Sea scallop
American lobster
American lobster
American lobster
Snow crab
American lobster
Northern shrimp
American lobster
Snow crab
Sea scallop
Aesop shrimp
Northern shrimp
Snow crab
Sea scallop
Snow crab
Snow crab
Northern shrimp
Northern shrimp
Northern shrimp
Rock crab
Northern shrimp
Northern shrimp
Capelin
Mackerel
Herring
Herring
Herring
Capelin
Herring
Herring
Herring
Herring
Herring
Herring
Emission mitigation effect
0.000
0.025
0.050
0.075
0.100
0.2
0.3
0.4
0.5
0.6
Climate vulnerability
Figure 5
vertebrates
* American lobster
Snow crab
Green sea urchin
* American lobster
Snow crab
Snow crab
* American lobster
Arctic surfclam
* American lobster
Sea scallop
* American lobster
* American lobster
* American lobster
Snow crab
* American lobster
Northern shrimp
* American lobster
LFA23–26AB
3Ps
4RST
LFA22
4R3Pn
3NO
LFA27–33
3LNO
LFA19–21
4T
LFA41
LFA35–38
LFA15–18
3LNO
LFA3–14
SFA13–15
LFA34
Emission scenarios
SSP1-2.6 (high mitigation)
SSP5-8.5 (high emissions)

Northwest Atlantic Fisheries Organization (NAFO) Application

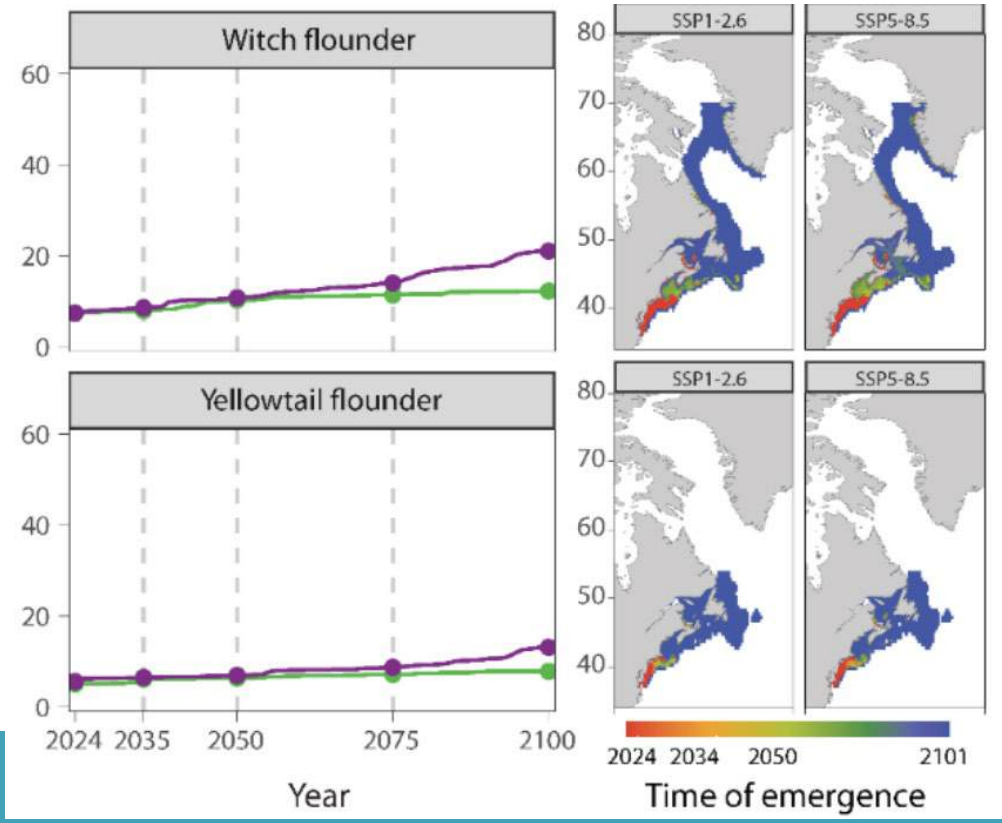
- Assessed 14 species at Northwest Atlantic Fisheries Organization (NAFO) under contract



Boyce, D.G., Cyr, F. Fuller, S., Schleit, K and Rideout, R.M. *In press*. Exploring the impacts of climate change on fisheries resources within the NAFO Convention Area. *Journal of Northwest Atlantic Fisheries Science.*

Northwest Atlantic Fisheries Organization (NAFO) Application

- Assessed 14 species at Northwest Atlantic Fisheries Organization (NAFO) under contract
- Presented to NAFO Science Council and provided to Commission



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New Zealand Fisheries Application

Phase 1: Literature Review

- Reviewed 75 studies to understand how scientists assess climate change risks to fisheries, and best approach for New Zealand
  - Highlighted five case studies
  - Best approaches considered fish biology, fishing infrastructure, and community resilience
  - CVAs help to prioritize resources, inform adaptive strategies, enhance resilience

Boyce, D.G., Tittensor, D.P., Schleit, K.E., & Fuller, S. (2025). Climate vulnerability and risk assessments in marine ecosystems, with a special focus on fisheries in Aotearoa (New Zealand). *New Zealand Aquatic Environment and Biodiversity Report No. 367.* 50 p. https://fs.fish.govt.nz/Page.aspx?pk=113&dk=26140.

New Zealand Fisheries Application

Phase 2: CRIB feedback for domestic stocks

- Consultation with government and stakeholder group – Fisheries Science Working Group on Biodiversity Research (BRAG)

Feedback and modification:

- Customized to New Zealand - 9 of 11 initial data layers were modified
- Focus on deep-dwelling species
- High spatial resolution
- “Middle of the road” emission scenario

Canada Application & Perspectives

National-scale:

- Integrating the CRIB into the Climate Adaptation Framework for Fisheries
- Evaluated climate risk across Canadian ecosystems

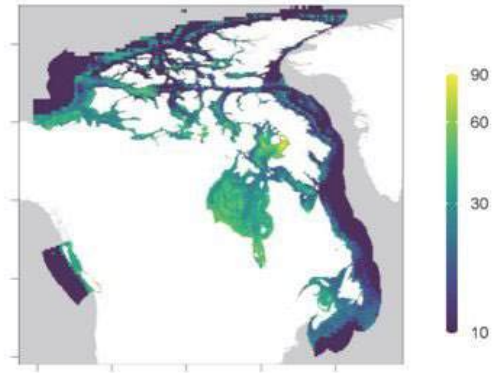


Figure 13 | Geographic patterns of ecosystem climate risk.
The percent of species at high or critical climate risk across the Canadian marine territ
under the SSP5-8.5 emission scenario.

Regional-scale:

- Applying CRIB to harvested species in Atlantic Canada small craft fishing harbours, supporting the Coastal Infrastructure Vulnerability Index (CIVI)
- Adapting the CRIB for lobster and snow crab in the Gulf of St. Lawrence.

Canada Application & Perspectives

Formed an ongoing advisory committee with Canadian federal-level government officials including:

- Fisheries and Conservation Managers
- Policy Managers
- Regional Directors
- Fisheries Research Scientists
- Science Advisors

CRIB:
Fisheries Prototype

Climate Risk of fish stocks in Canada

Lorem ipsum dolor sit amet consectetur. Egestas sed ante nibh gravida sem sit. Eu ut viverra mauris placerat venenatis urna.

Search stocks by name or region

Filters

Total of 140 stocks

Sort by Name

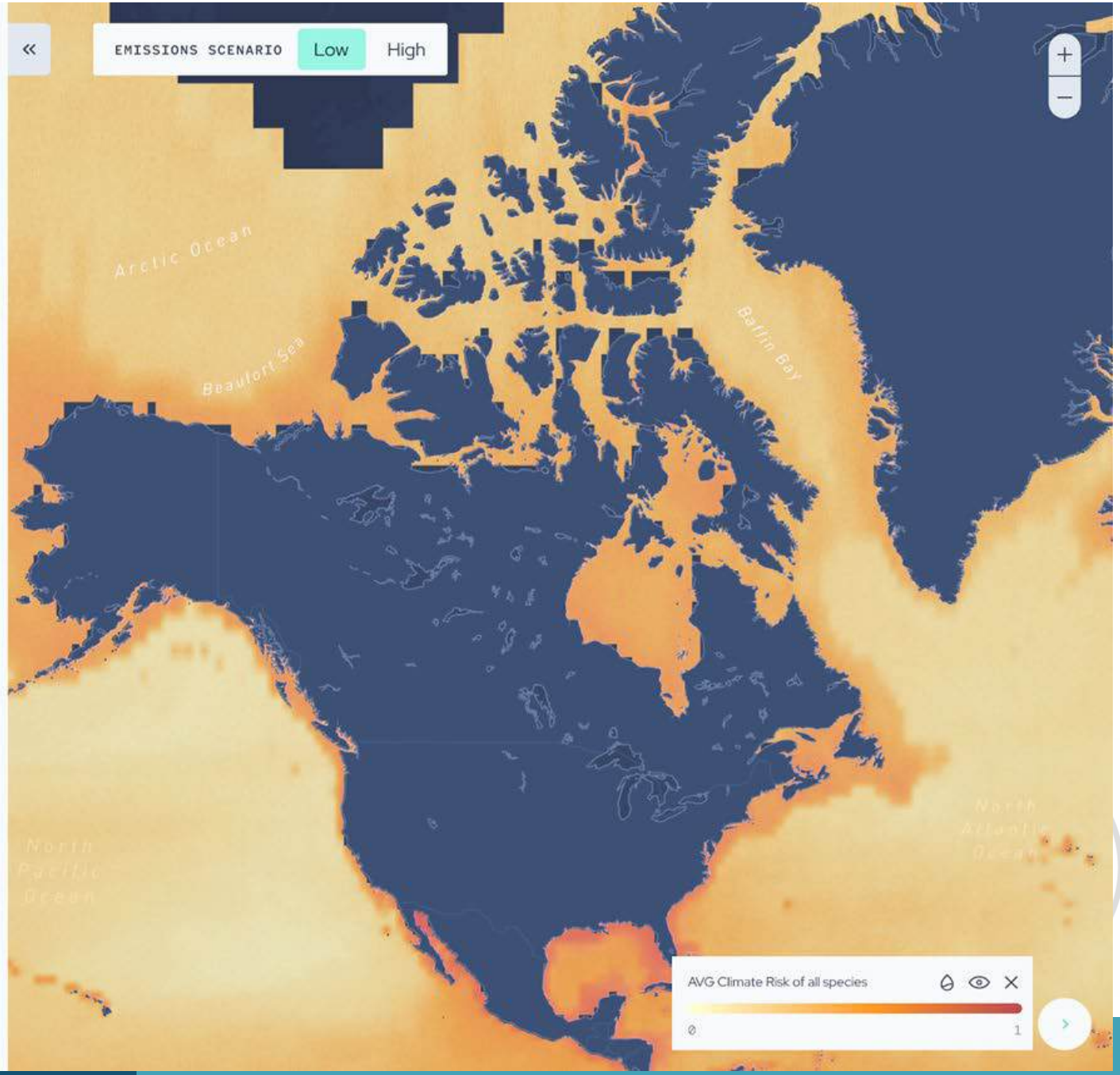
Stock name	Overall climate risk	Stock status
Albacore Tuna - North…		CAUTIOUS
American Lobster - LFA…		HEALTHY
American Plaice - Sout…		CRITICAL
Arctic Char - Cumberla…		CRITICAL
Atlantic Canada Dogfis…		HEALTHY
Atlantic Cod - 2J3KL		CAUTIOUS
Atlantic Cod - 3Ps		CAUTIOUS
Atlantic Cod - 4X5Y		HEALTHY
Atlantic Cod - 5Zjm		CRITICAL
Atlantic Halibut - 3NO…		HEALTHY
Atlantic Halibut - 4RST		CRITICAL
Atlantic Salmon - Gulf		CRITICAL
Beluga - Cumberland So…		HEALTHY
Beluga - Northern Queb…		CRITICAL
Bluefin Tuna - Western…		HEALTHY
Bocaccio		CRITICAL

RISK — Negligible, Moderate, High, Critical

Fish Stocks

Layers

Info



CRIB

Fish Stocks

Layers

Info

Climate Risk of fish stocks in Canada

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Beluga - Cumberland So…		HEALTHY
Beluga - Northern Queb…		CRITICAL
Bluefin Tuna - Western…		HEALTHY
Bocaccio		CRITICAL

RISK Negligible Moderate High Critical

EMISSIONS SCENARIO Low High

Arctic Ocean

Beaufort Sea

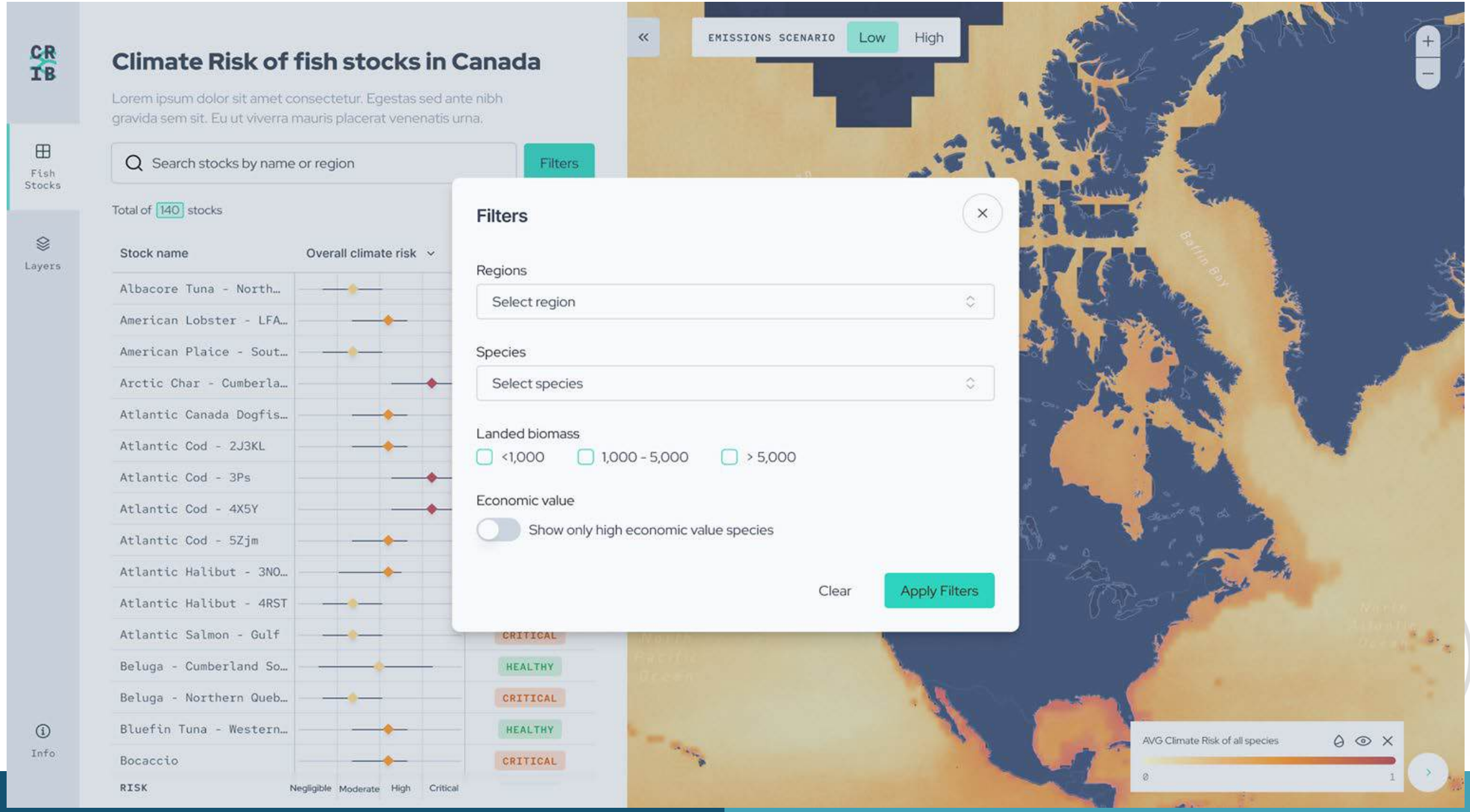
Baffin Bay

North Pacific Ocean

North Atlantic Ocean

AVG Climate Risk of all species

0 1


CRIB
Climate Risk of fish stocks in Canada
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Search stocks by name or region
Filters
Total of 140 stocks
Fish Stocks
Layers
Info
Stock name
Overall climate risk
Albacore Tuna - North…
American Lobster - LFA…
American Plaice - Sout…
Arctic Char - Cumberla…
Atlantic Canada Dogfis…
Atlantic Cod - 2J3KL
Atlantic Cod - 3Ps
Atlantic Cod - 4X5Y
Atlantic Cod - 5Zjm
Atlantic Halibut - 3NO…
Atlantic Halibut - 4RST
Atlantic Salmon - Gulf
Beluga - Cumberland So…
Beluga - Northern Queb…
Bluefin Tuna - Western…
Bocaccio
CRITICAL
HEALTHY
CRITICAL
HEALTHY
CRITICAL
RISK
Negligible
Moderate
High
Critical
Filters
Regions
Select region
Species
Select species
Landed biomass
<1,000
1,000 - 5,000
> 5,000
Economic value
Show only high economic value species
Clear
Apply Filters
EMISSIONS SCENARIO
Low
High
Baffin Bay
AVG Climate Risk of all species
0
1

Climate Risk of fish stocks in Canada

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Search stocks by name or region

Filters

Newfoundland and Labrador

Total of 5 stocks

Sort by Name

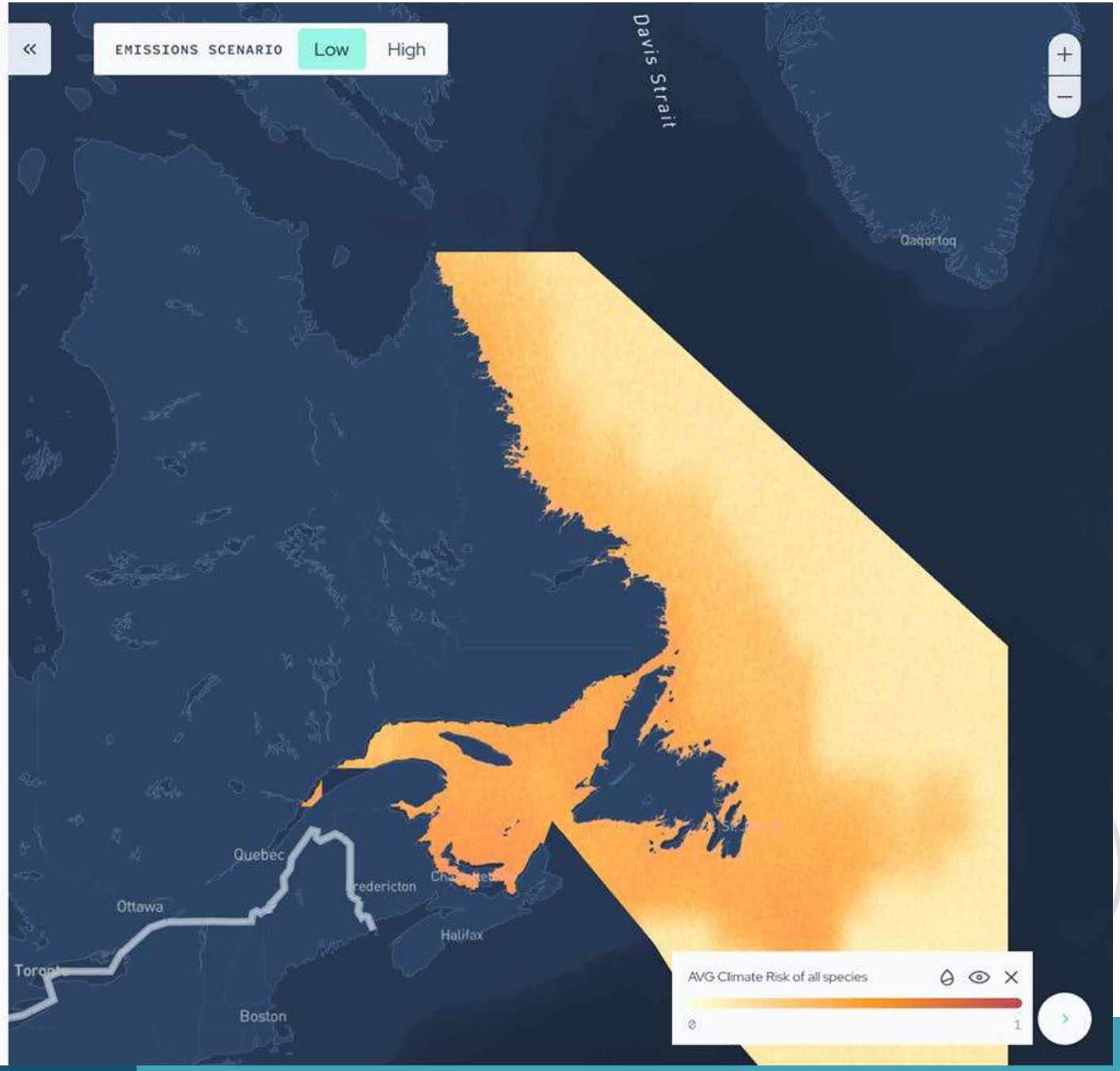
Stock name	Overall climate risk	Stock status
American Lobster - LFA…		HEALTHY
Atlantic Cod - 2J3KL		CAUTIOUS
Capelin - 4RST		UNCERTAIN
Capelin - SA2+3KLPs		UNCERTAIN
Greenland Halibut - Cu…		CRITICAL

RISK — Negligible, Moderate, High, Critical

Fish Stocks

Layers

Info



CRIB

Fish Stocks

Layers

Info

Stocks > *Atlantic Cod - 2J3KL*

Atlantic Cod - 2J3KL

Atlantic Cod

Gadus Morhua

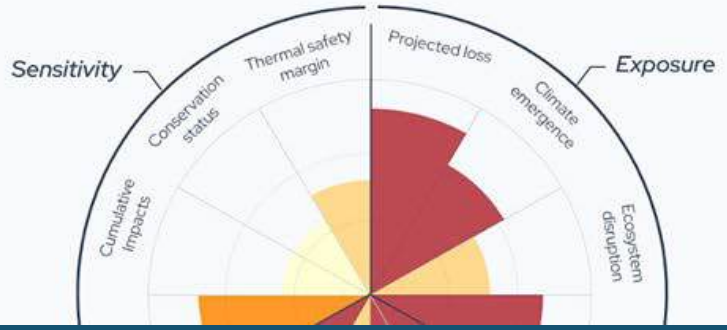
The Atlantic cod is a fish of the family Gadidae, widely consumed by humans. It is also commercially known as cod or codling.

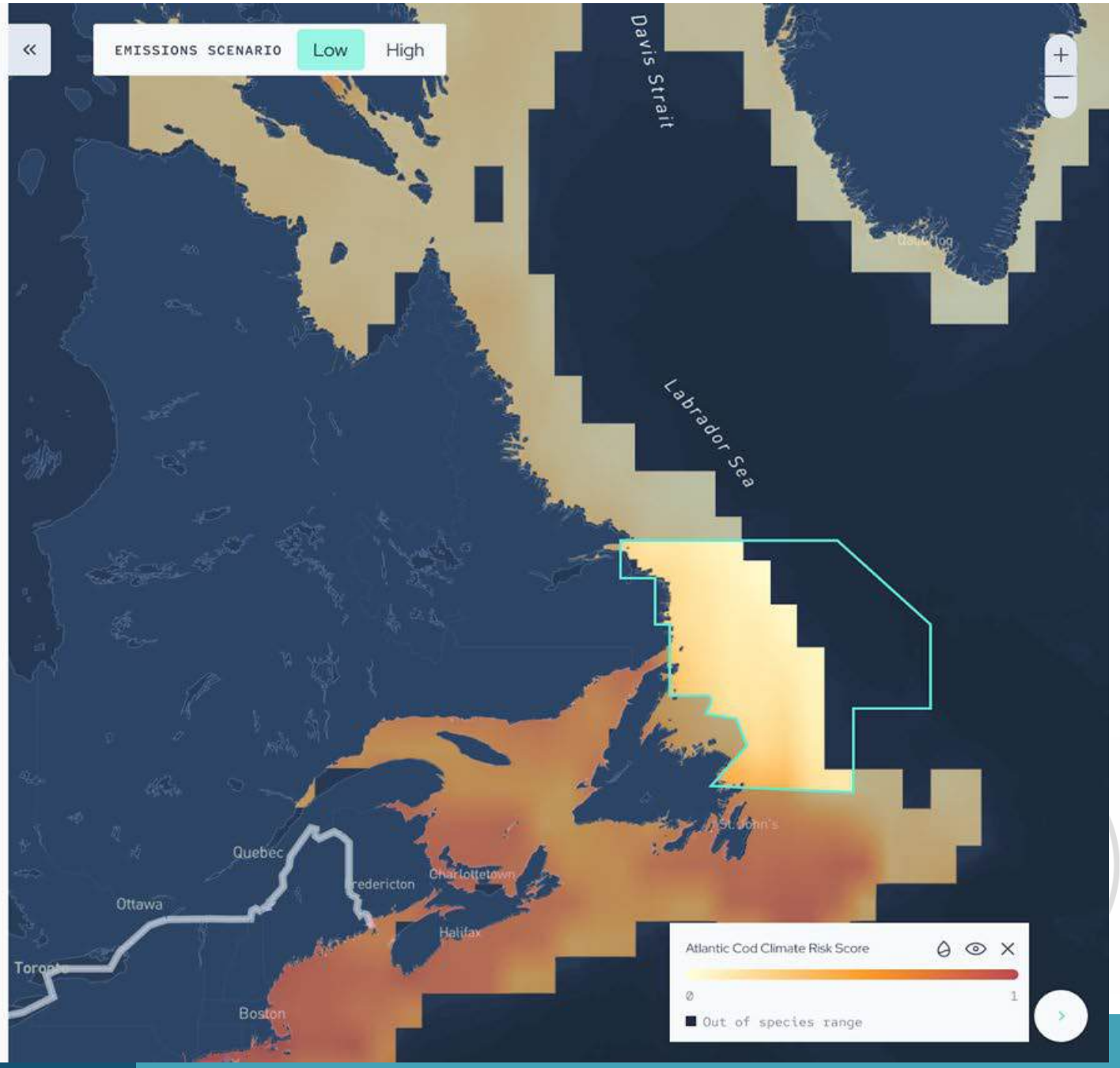
REGION	Newfoundland and Labrador
STOCK STATUS	CAUTIOUS
LANDED BIOMASS	12 170 t
ECONOMIC VALUE	17 423 000 CA$

Climate Risk

Climate Risk represented in the 3 dimensions of risk and the sub-dimensions.

RISK: Negligible Moderate High Critical





CRIB:
Marine Protected Area Prototype

CLIMATE RISK FOR THE ATLANTIC CANADA TERRITORY

Marine Protected Areas

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Search area by name or region

Filters

Total of 578 protected areas

Download content

Edit table

Marine protected area	Overall climate risk	IUCN category	Number Species
1. Western Jordan Basin		II	12
2. Georges Bank		III	6
3. LeHave Basin		III	8
4. Scotian Gulf		I	1
5. Central Scotian Slope Ri...		UNCLEAR	33
6. Inner Shelf Sea Pen		II	26
7. Canso Bank and Channe...		IV	1
8. Misaine Bank and Laure...		II	3
9. Logan Canyon		IV	8
10. St. Anns Bank Marine Pr...		II	6
11. Coin du Banc 18-18-06...		II	6
12. Cloridorme 18-10-01 Wat...		II	2
13. Bay of Fundy Horse Mus...		I	4
14. Gully Marine Protected...		III	11
15. Sable River Bird Sanctua...		II	7
16. Grand Manan Bird Sanct...		UNCLEAR	5
17. Cold Seeps		IV	5
18. Rive des Mornes Rouge...		I	2

CLIMATE RISK INDEX Negl. Mod. High Critical

Protected Areas

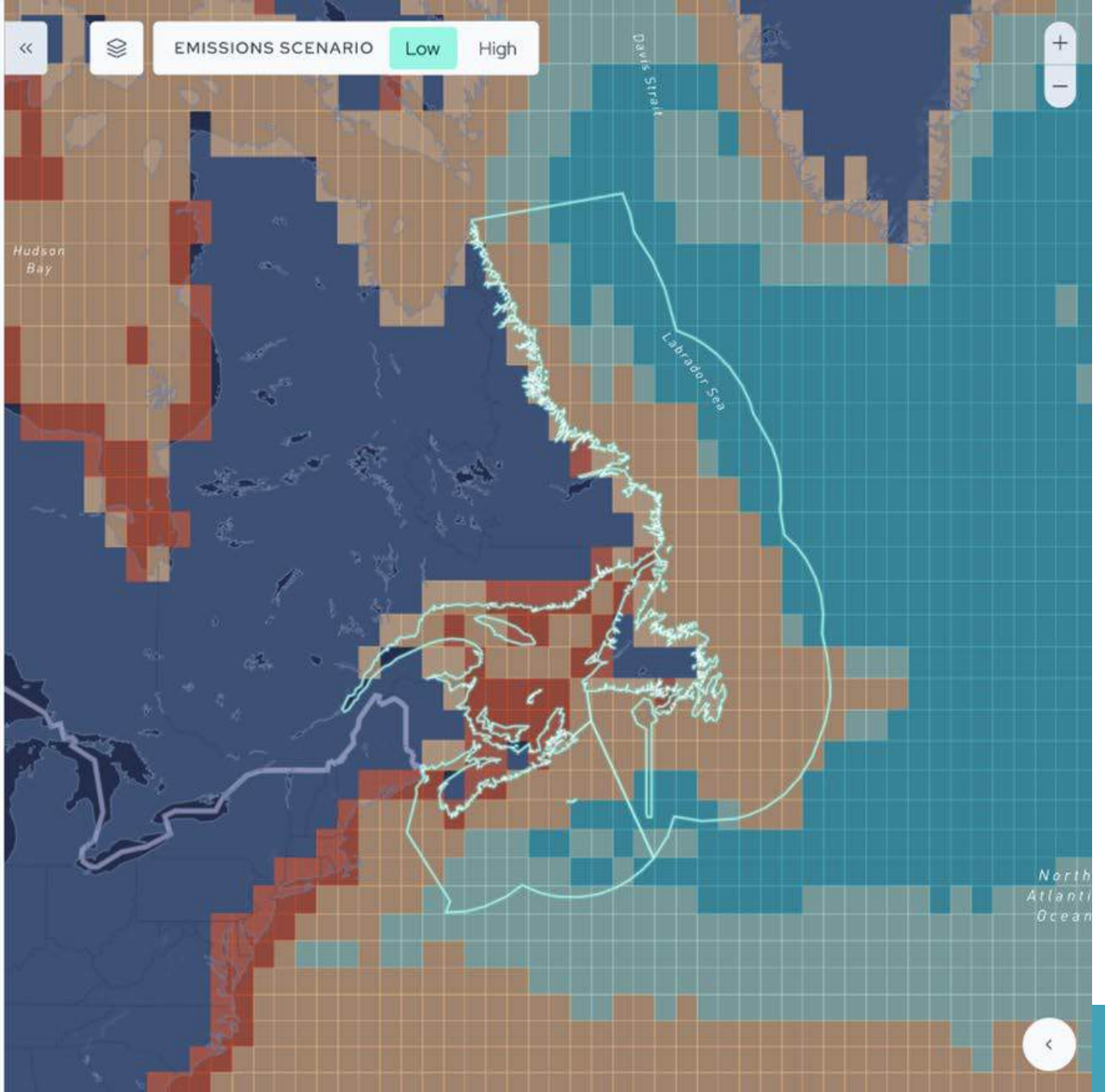
Marine Species

Analyse areas

EN

Info

EMISSIONS SCENARIO Low High



CLIMATE RISK FOR THE ATLANTIC CANADA TERRITORY

Marine Species

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Search specie by name or family

Filters

Total of 516 marine species

Download content

Edit table

Species name	Overall climate risk
1. Albacore Tuna	0.32
2. American Lobster	0.18
3. American Plaice	0.32
4. Arctic Char	0.85
5. Atlantic Canada Dogfish	0.18
6. Atlantic Cod	0.18
7. Atlantic Halibut	0.53
8. Atlantic Salmon	0.32
10. Beluga	0.32
11. Bluefin Tuna	0.18
12. Bocaccio	0.18
13. Bowheadand	0.53
14. Canary Rockfish	0.85
15. Capelin	0.53
16. Cod	0.32
17. Dogfish	0.18
18. Dungeness Crab	0.18
19. Geoduck	0.53

CLIMATE RISK INDEX

Negligible Moderate High Critical

Protected Areas

Marine Species

Analyse areas

EN

Info

EMISSIONS SCENARIO Low High

Hudson Bay

Davis Strait

Labrador Sea

North Atlantic Ocean

CRIB Feedback from a Canadian context

Application:

- Minimal climate change integration efforts exist in fisheries and conservation - CRIB helps start these analyses
- Important to consider risk scores in relation to identified objectives and for an ecosystem-based approach
- Consider what an ideal climate analysis would do and how the users will apply it

Data:

- Helpful to filter species based on their habitat
- “Most likely” emission scenarios better than only high or low emissions
- Must be able to download and integrate the data with own analyses
  - Interoperability important for use across other data sources by managers (i.e. stock assessment tools)

Thank you

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Amy Irvine
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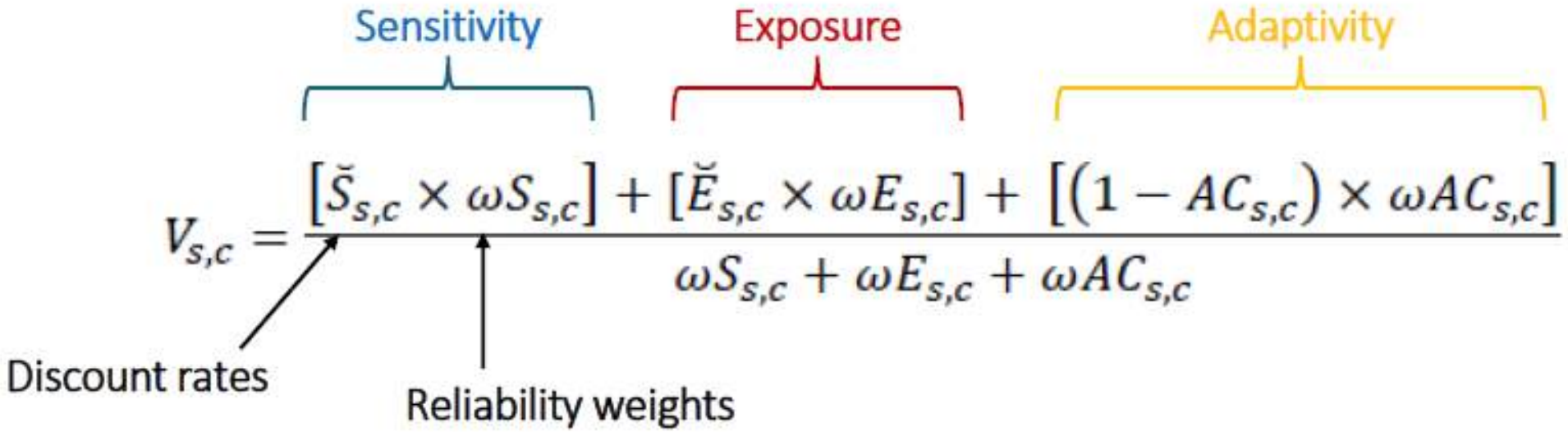
www.oceansnorth.ca

CRIB methods



$$\omega S_{s,c} = \left(\frac{\sigma S_{s,c}}{\mu S_{s,c}}\right)^{-1}$$

$V_{s,c}$: Vulnerability for species (s) and cell (c)
$\omega S_{s,c}$: Reliability weight for species (s) and cell (c)
$\check{S}_{s,c}$: Discount rate for species (s) and cell (c)

CRIB methods

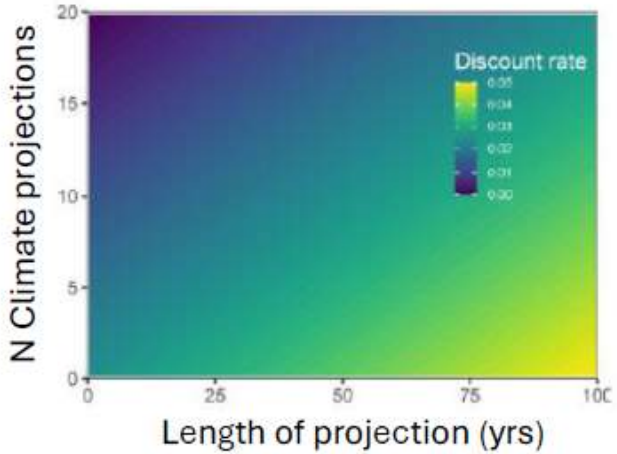
Future state uncertainty: Increases with increasing projection length and reduced ensembles (Wu et al. 2022, *Earth's Future*; Latif, 2011, *J. Geochem. Explor.*)

Timeseries length

Number of climate models

$$\partial = \frac{Years}{100\theta} + \frac{Models}{-20\theta} + \vartheta,$$

Theta, epsilon (scaling)



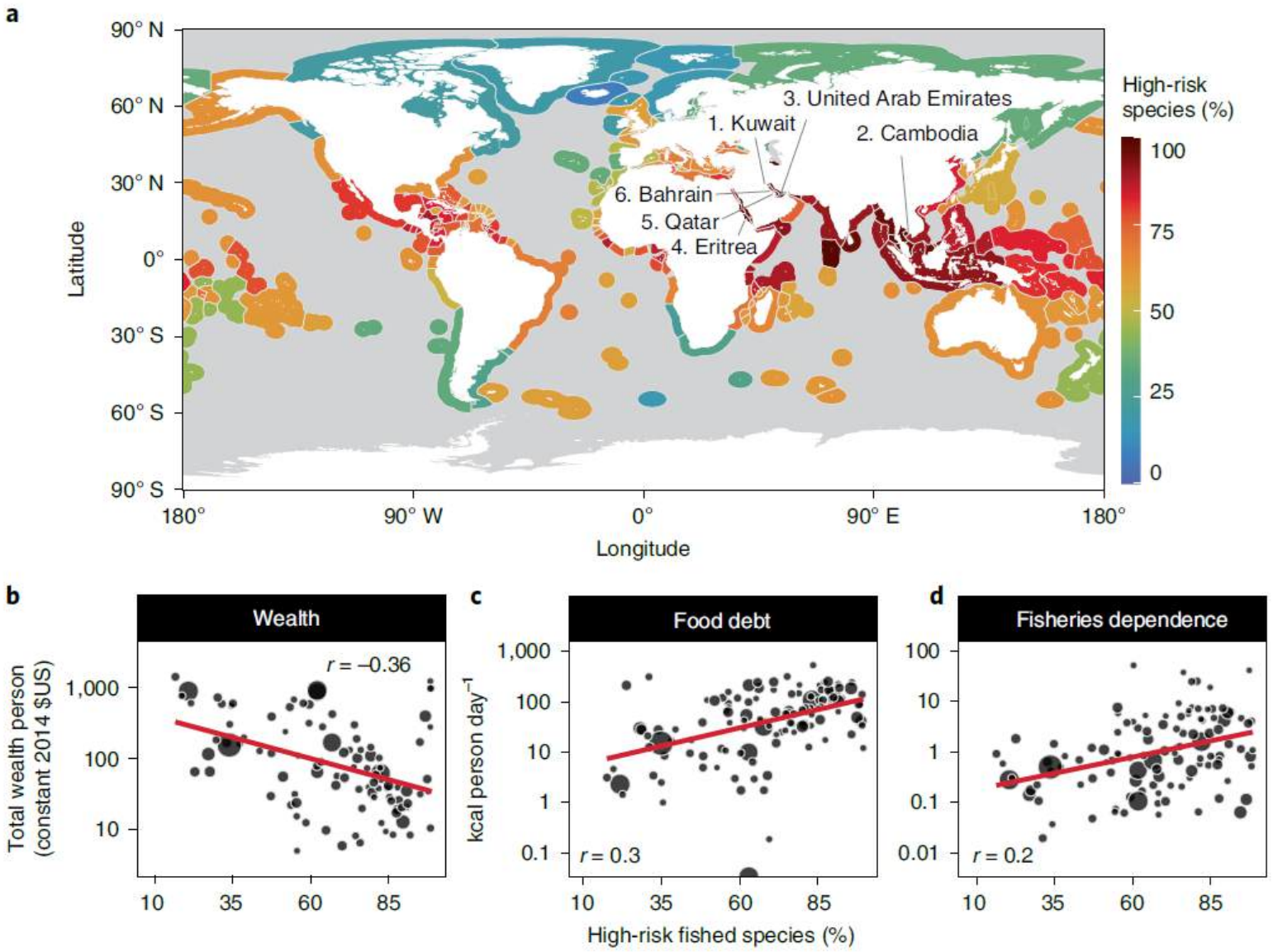
$$\breve{E}_{s,c} = [(1 - \partial)(E_{s,c})],$$

$$\breve{S}_{s,c} = [(1 + \partial)(S_{s.c})],$$

- Large discount (5%): Uncertain future state (long projections from fewer models)
- Discounts on future (exposure) are applied to the present (sensitivity)

Boyce *et al.* 2022. *Nat. Clim. Change.*

Global climate risk



Higher climate risks to fisheries for:

- low-income countries
- countries tending to have lower levels of
  - wealth and food security
  - higher dependency on fisheries

Boyce, D.G., Tittensor, D.P., Garilao, C. *et al.* A climate risk index for marine life. *Nat. Clim. Chang.* **12**, 854–862 (2022).

Environmental Variables used:

For each species within each grid cell across its geographic distribution that contained sufficient data, sensitivity, exposure, and adaptivity were calculated as the mean of the four indices that define them. The standard deviation of the vulnerability dimensions provided an estimate of their statistical uncertainty and was carried through the subsequent vulnerability calculations using inverse variance weighting

The models predict the probability of occurrence for each species as functions of bathymetry, upper ocean temperature, salinity, primary production, and the presence of, and proximity to, sea ice and coasts.

Daily SST estimates were obtained
from the NOAA 0.25° daily Optimum Interpolation Sea Surface Temperature Dataset (OISST)

The human impacts (HI) index represents the integration of 17 global anthropogenic drivers of ecological change,
including fishing pressure, pollution, invasive species, eutrophication, climate change, and others. The HI estimates were available at a global 1 km_2 native resolution and were statistically rescaled to a 0.25° grid across the AOS using bilinear interpolation. Bathymetry values were extracted from the General Bathymetric Chart
of the Oceans (GEBCO) on a native 15 arc-second interval grid and were statistically rescaled to a 0.25° grid by taking the mean