# Ocean warming undermines the resilience of New England kelp forests following a trophic cascade

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# Why are kelp forests important?

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Article

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# The value of ecosystem services in global marine kelp forests

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Check for updates

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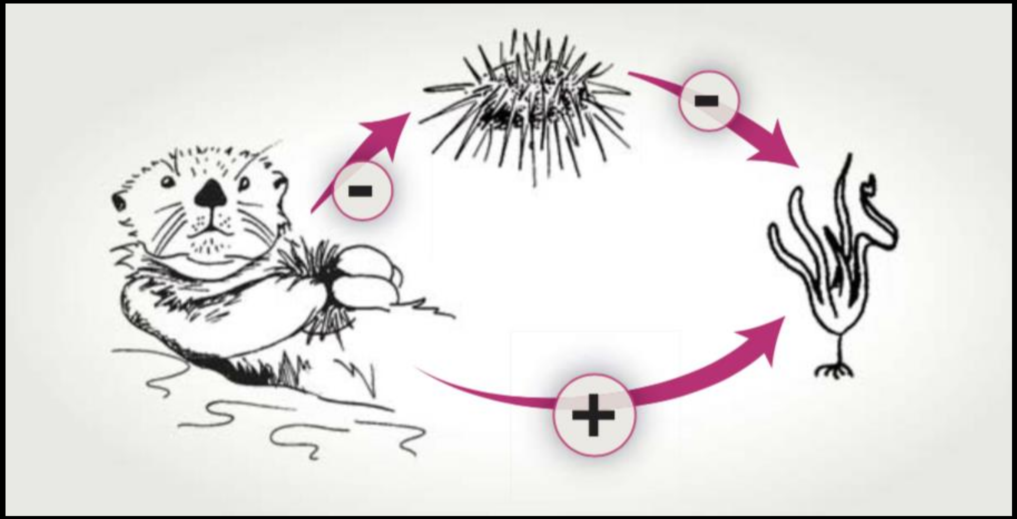
While marine kelp forests have provided valuable ecosystem services for millennia, the global ecological and economic value of those services is largely unresolved. Kelp forests are diminishing in many regions worldwide, and efforts to manage these ecosystems are hindered without accurate estimates of the value of the services that kelp forests provide to human societies. Here, we present a global estimate of the ecological and economic potential of three key ecosystem services - fisheries production, nutrient cycling, and carbon removal provided by six major forest forming kelp genera (*Ecklonia, Laminaria, Lessonia, Macrocystis, Nereocystis*, and *Saccharina*). Each of these genera creates a potential value of between $64,400 and $147,100/hectare each year. Collectively, they generate between $465 and $562 billion/year worldwide, with an average of $500 billion. These values are primarily driven by fisheries production (mean $29,900, 904 Kg/Ha/year) and nitrogen removal ($73,800, 657 Kg N/Ha/year), though kelp forests are also estimated to sequester 4.91 megatons of carbon from the atmosphere/year highlighting their potential as blue carbon systems for climate change mitigation. These findings highlight the ecological and economic value of kelp forests to society and will facilitate better informed marine management and conservation decisions.

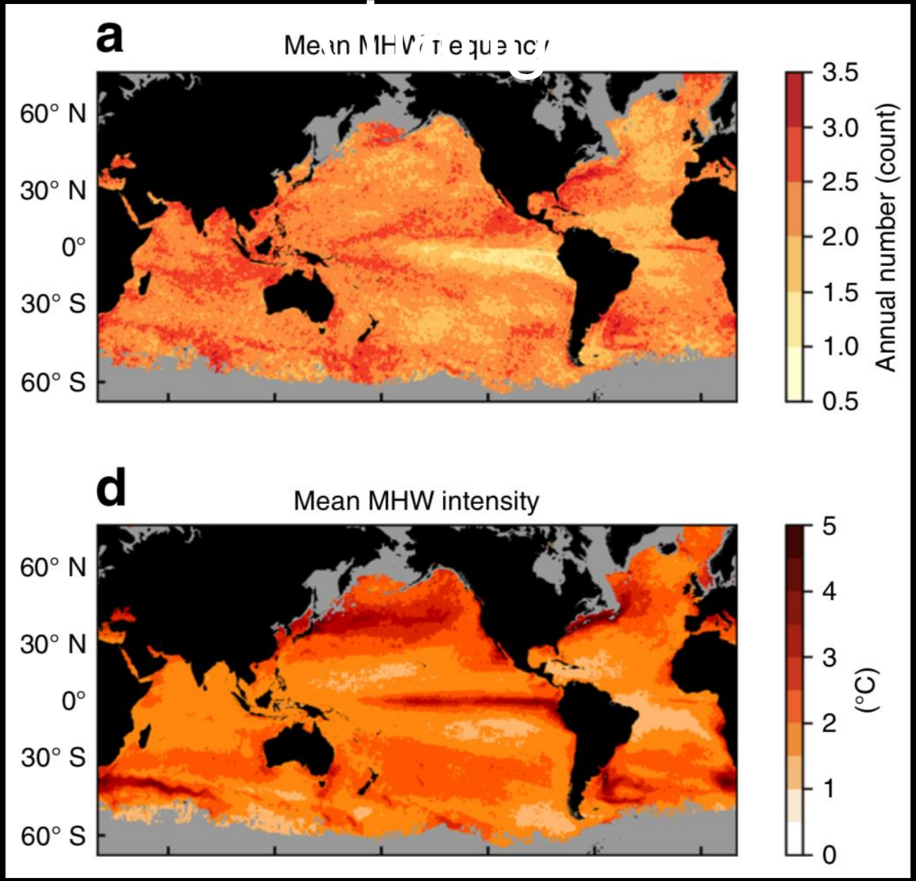
Photo: Brian Skerry / National Geographic

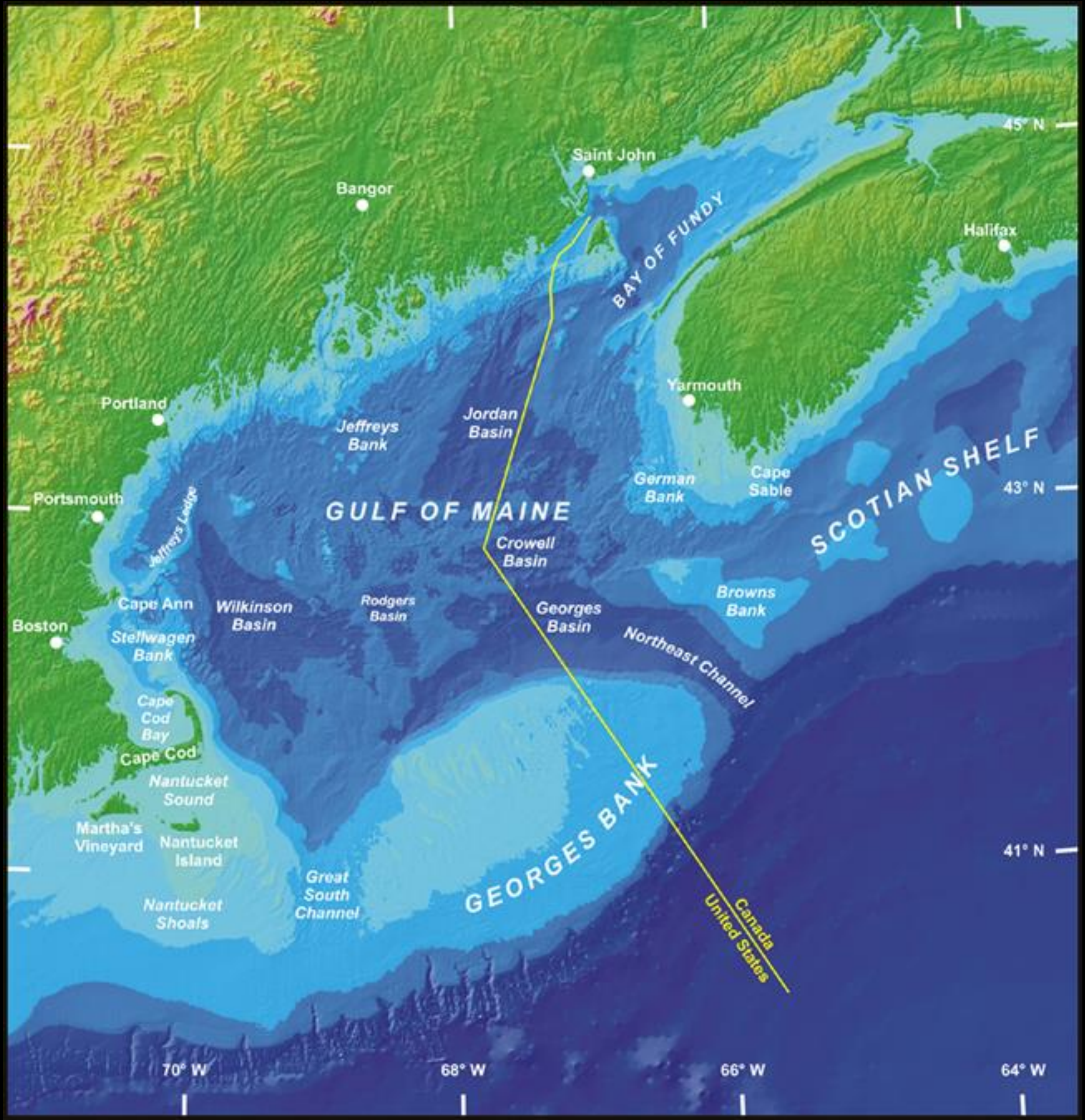
# > Drivers of kelp forest change over space and time

## Species interactions



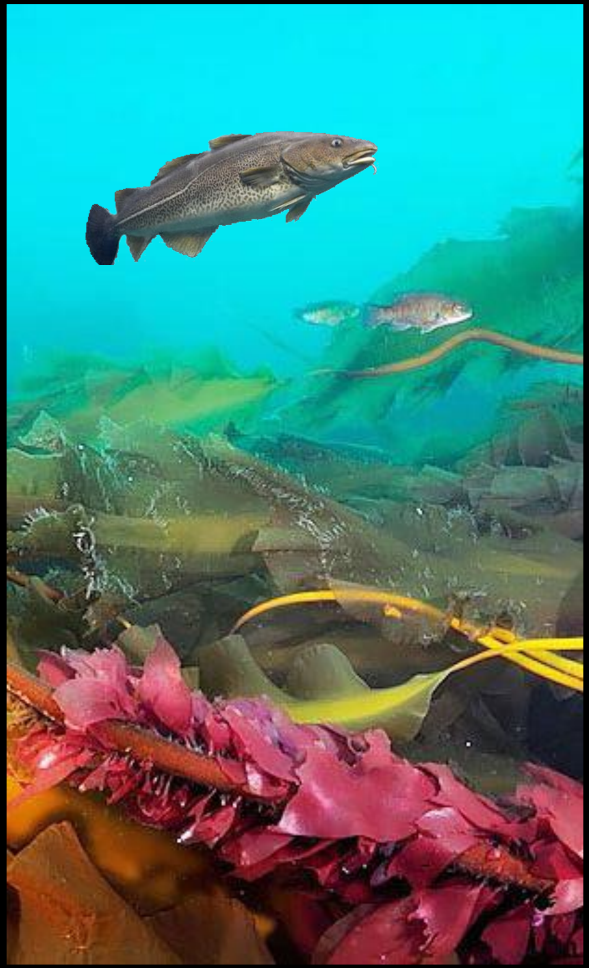
## Direct and indirect effects of climate




45° N
43° N
41° N
70° W
68° W
66° W
64° W
Saint John
Bangor
Halifax
BAY OF FUNDY
Yarmouth
Portland
Jeffreys Bank
Jordan Basin
German Bank
Cape Sable
SCOTIAN SHELF
Portsmouth
Jeffreys Ledge
GULF OF MAINE
Crowell Basin
Browns Bank
Cape Ann
Wilkinson Basin
Rodgers Basin
Georges Basin
Boston
Stellwagen Bank
Northeast Channel
Cape Cod Bay
Cape Cod
Nantucket Sound
GEORGES BANK
Martha's Vineyard
Nantucket Island
Great South Channel
Nantucket Shoals
Canada
United States

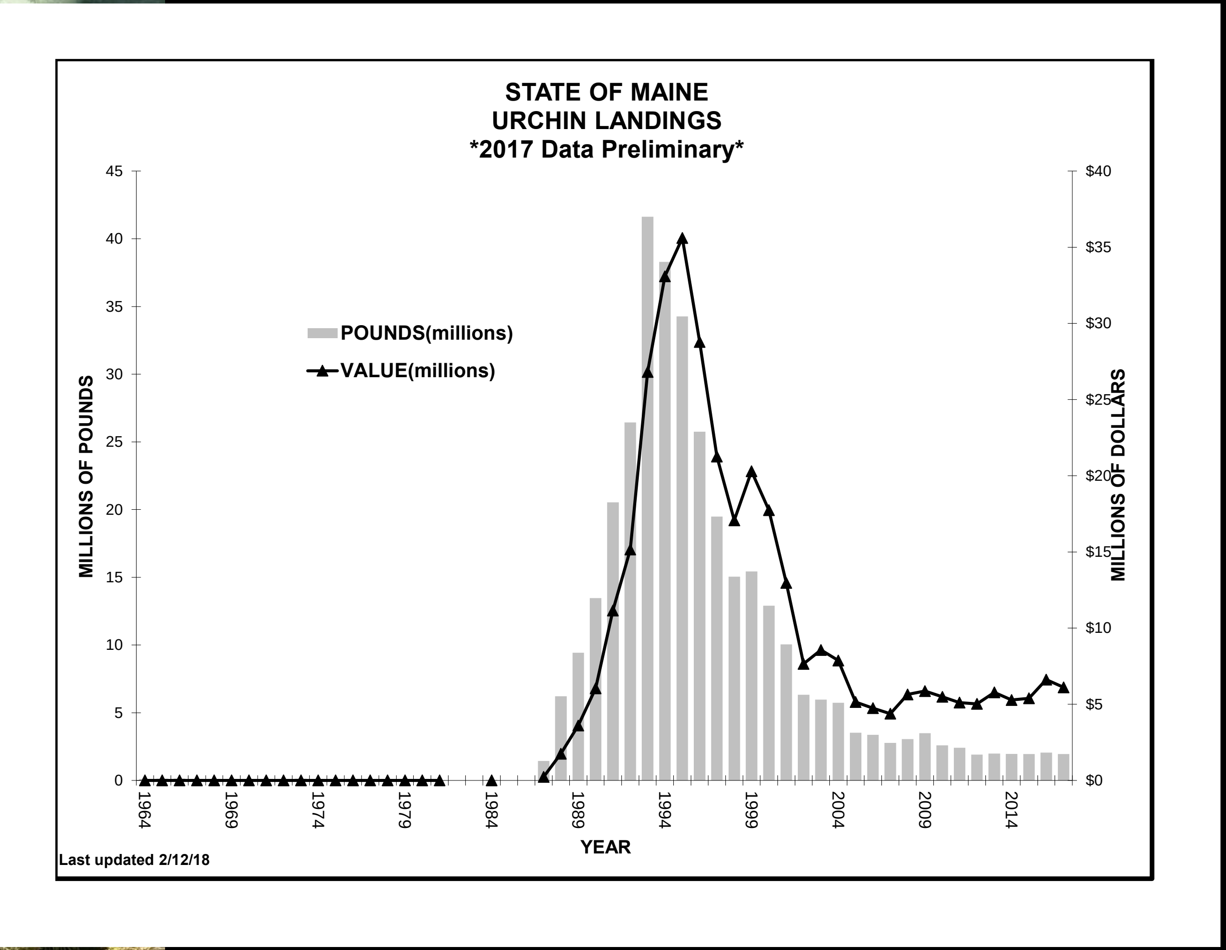
> Historically, Maine’s kelp forests were widespread, and predator-dominated

# > With overfishing, a trophic cascade ensued, causing deforestation

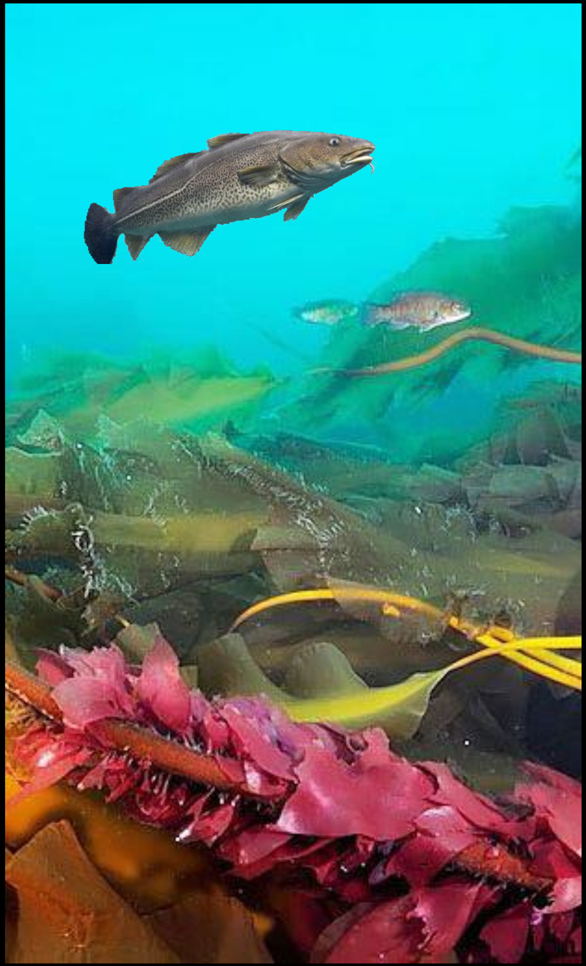


Kelp forests

Urchin barrens


STATE OF MAINE
URCHIN LANDINGS
*2017 Data Preliminary*
POUNDS(millions)
VALUE(millions)
MILLIONS OF POUNDS
0
5
10
15
20
25
30
35
40
45
MILLIONS OF DOLLARS
$0
$5
$10
$15
$20
$25
$30
$35
$40
YEAR
1964
1969
1974
1979
1984
1989
1994
1999
2004
2009
2014
Last updated 2/12/18

# > Another cascade ensued, reforesting the region by early 2000’s

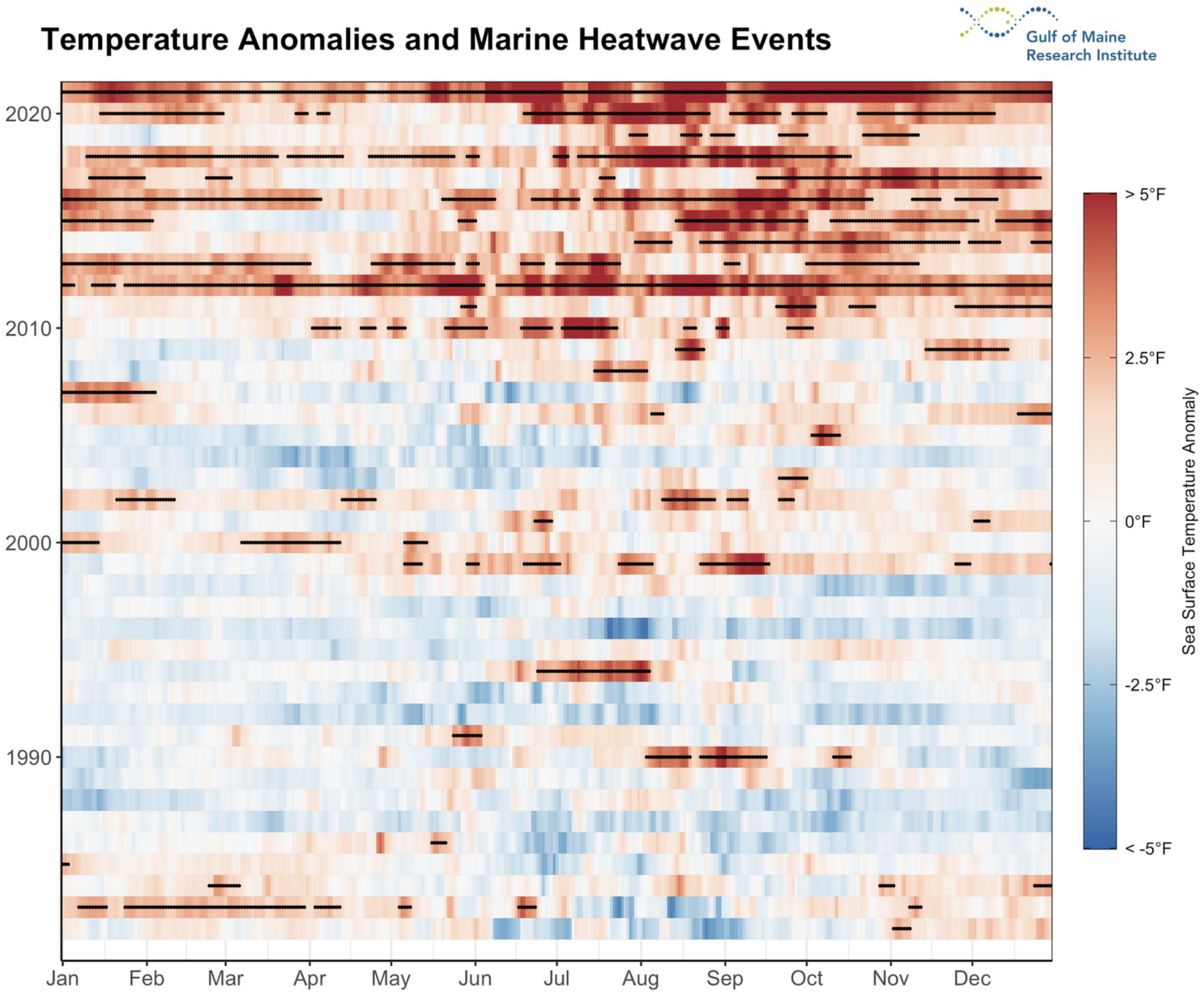


Kelp forests

Urchin barrens

Kelp forests

# Temperature Anomalies and Marine Heatwave Events




Marine heatwaves are events hotter than 90th percentile of 1982-2011 temperatures for that day.

# Have forests changed over the past 20 years? If so, what factors are responsible?

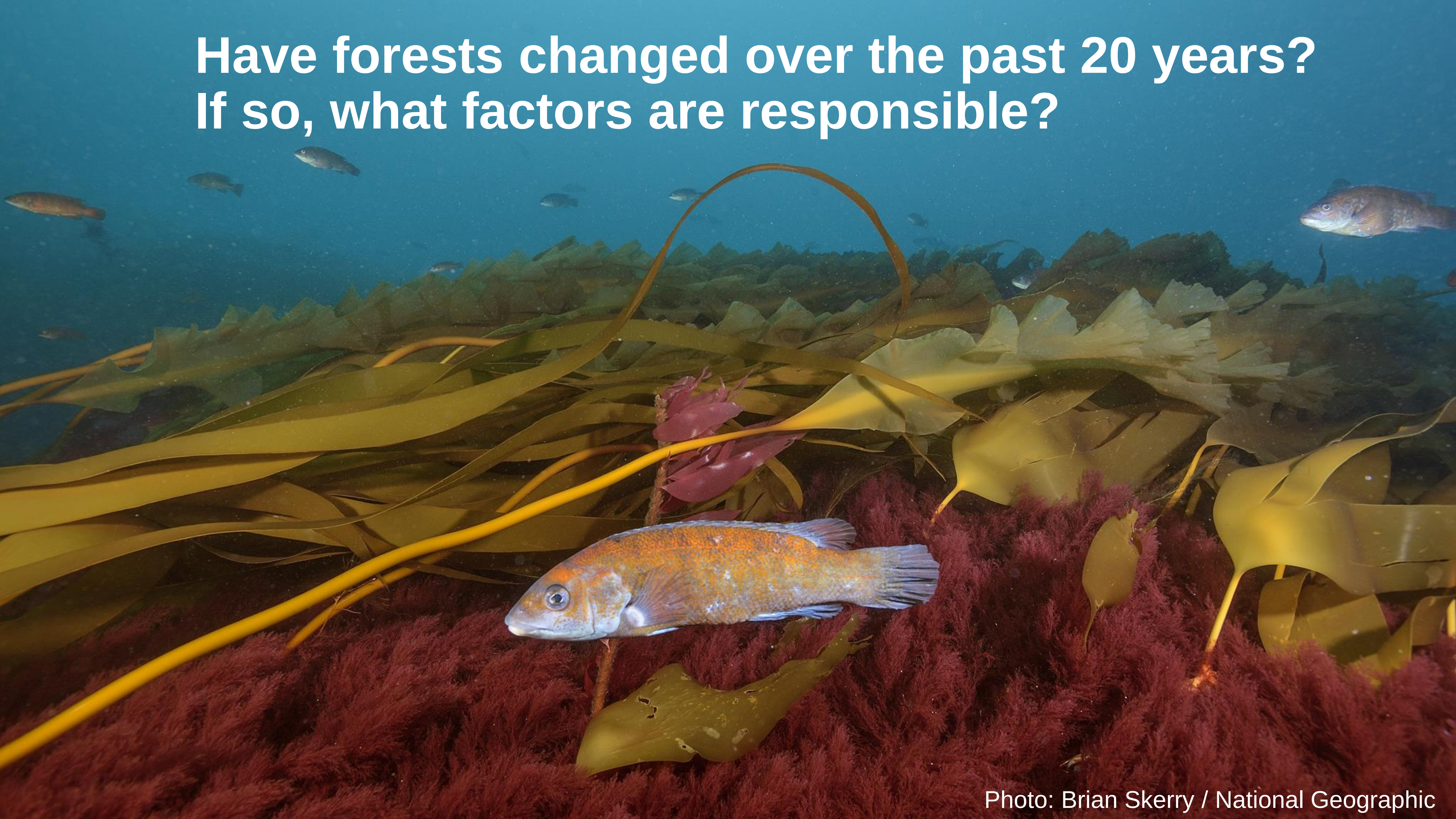
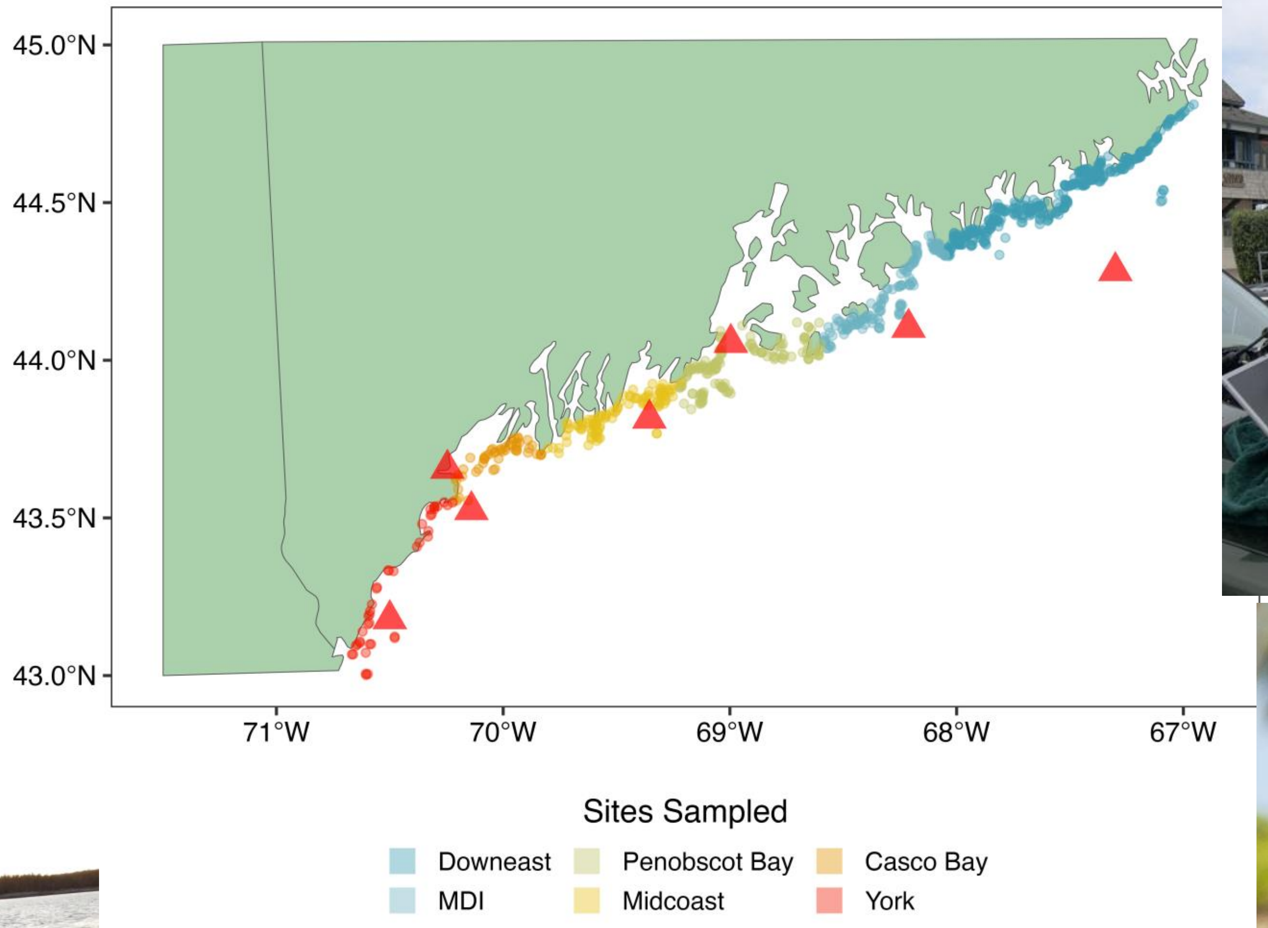


Photo: Brian Skerry / National Geographic



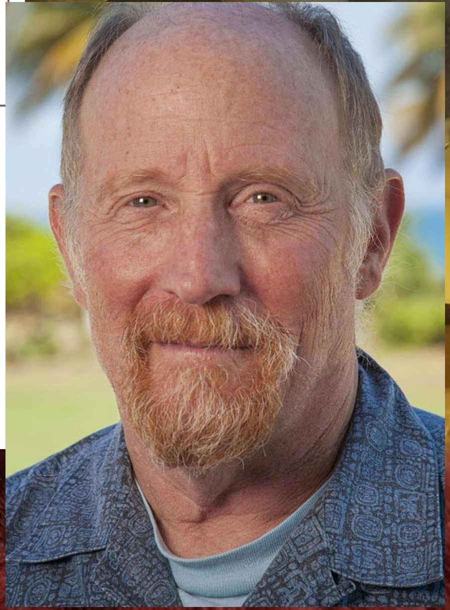
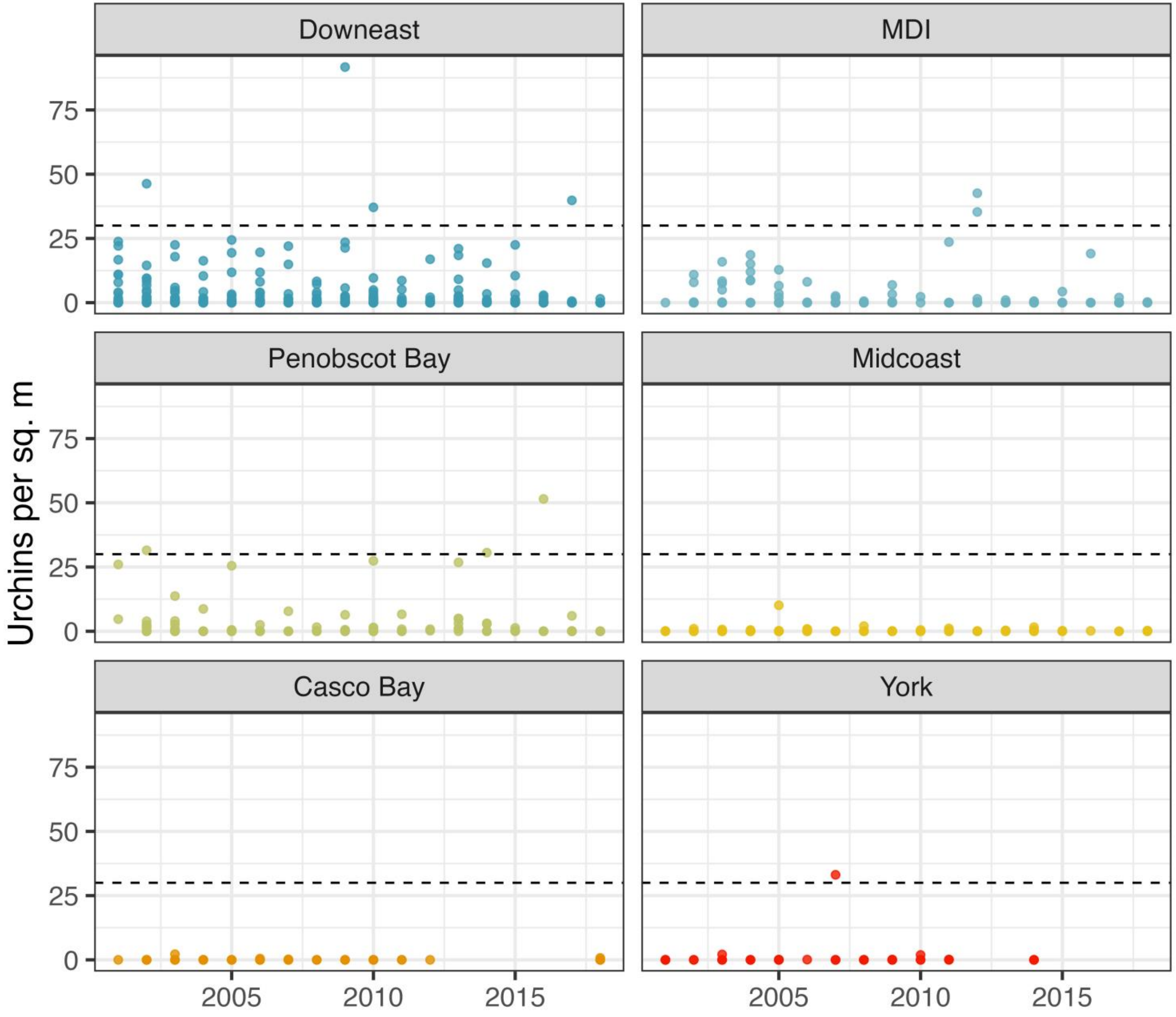
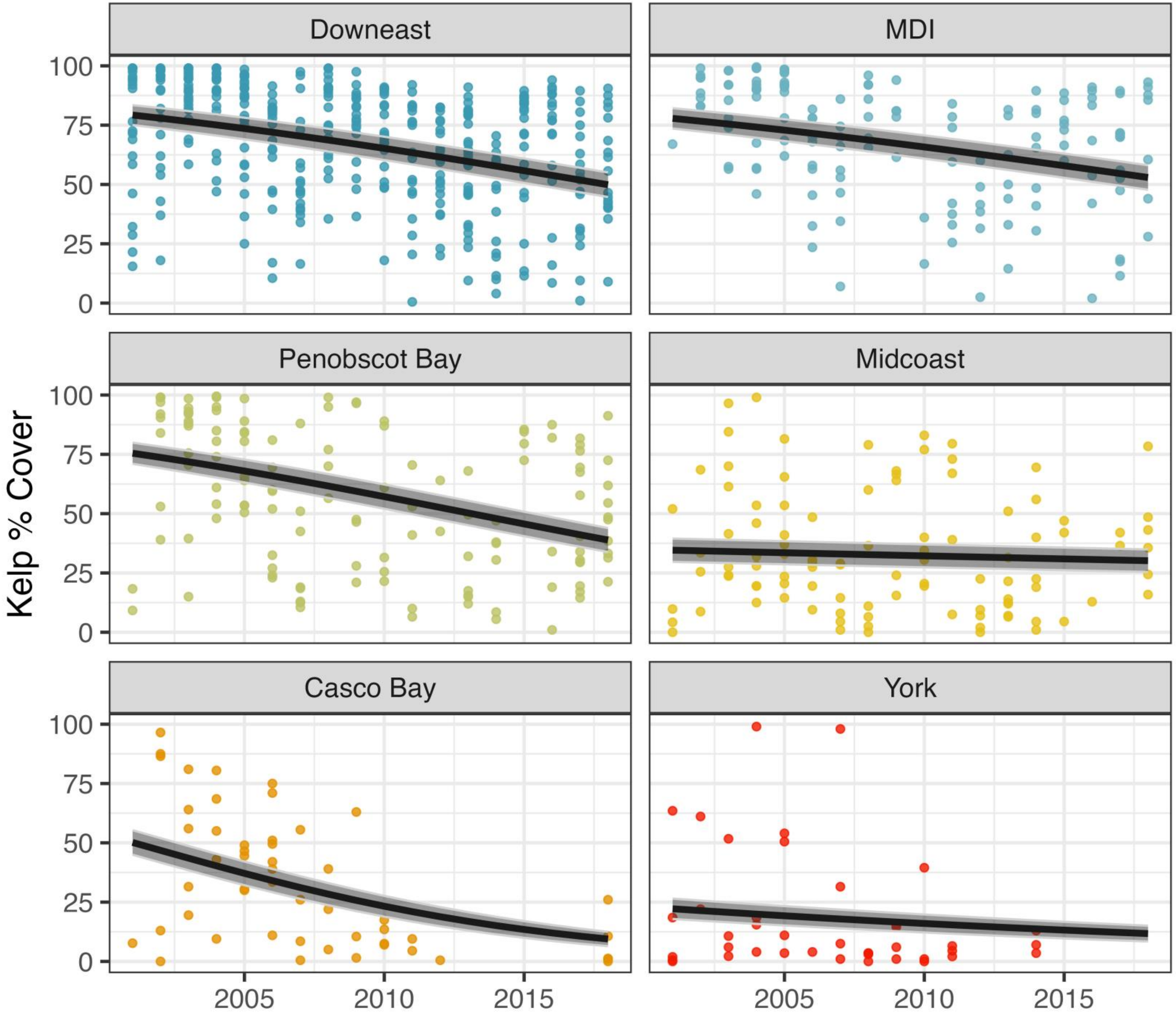



Photo: Brian Skerry / National Geographic

# > Urchins were generally rare from 2001-2018



# > Recent kelp forest trajectories



# > Drivers of change – our modeling approach

$$logit(\widehat{k_{ijt}}) = \beta_0 + \beta_1(u_{ijt} - \bar{u}_j) + \beta_2(s_{jt} - \bar{s}_j) + \beta_3(l_{jt} - \bar{l}_j) + \beta_4\bar{u}_j + \beta_5\bar{s}_j + \beta_6\bar{l}_j + \alpha_j + \alpha_t$$

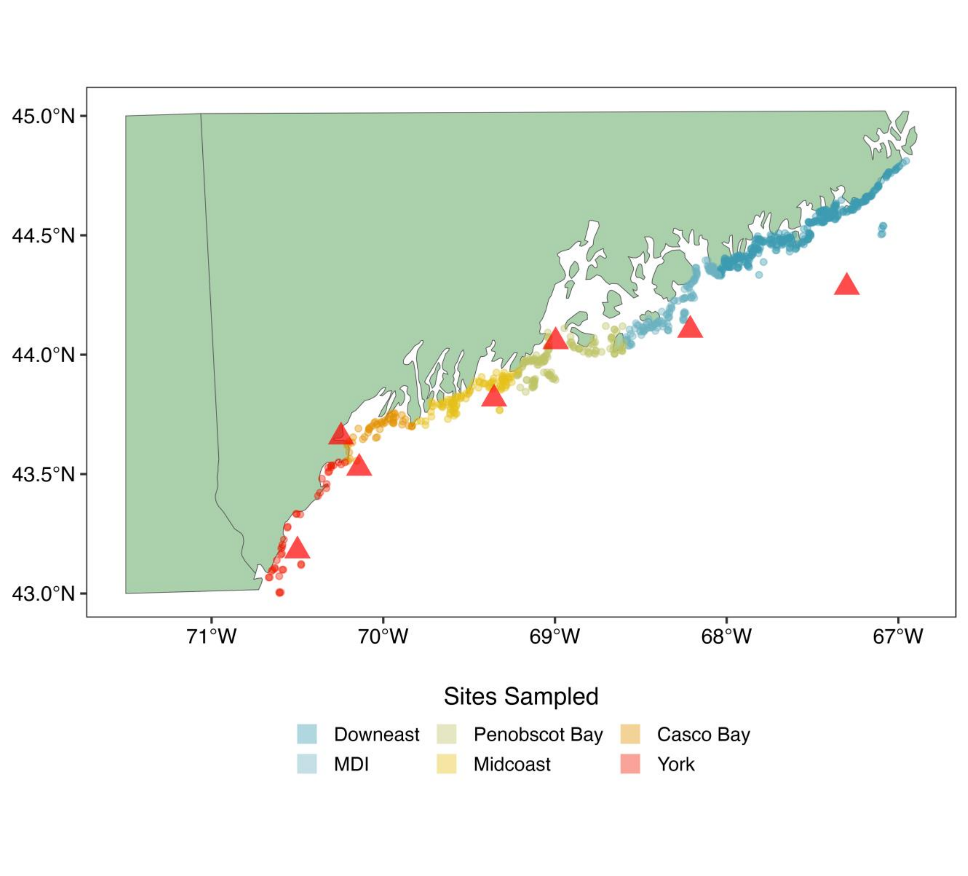



Photo: Brian Skerry / National Geographic

# > Results of model, and underlying mechanisms

**Drivers of kelp decline:**

- Unusually warm spring temperatures
- Unusually warm summer temperatures the year prior
- Abnormally high sea urchin densities
  (in a few select places and years)

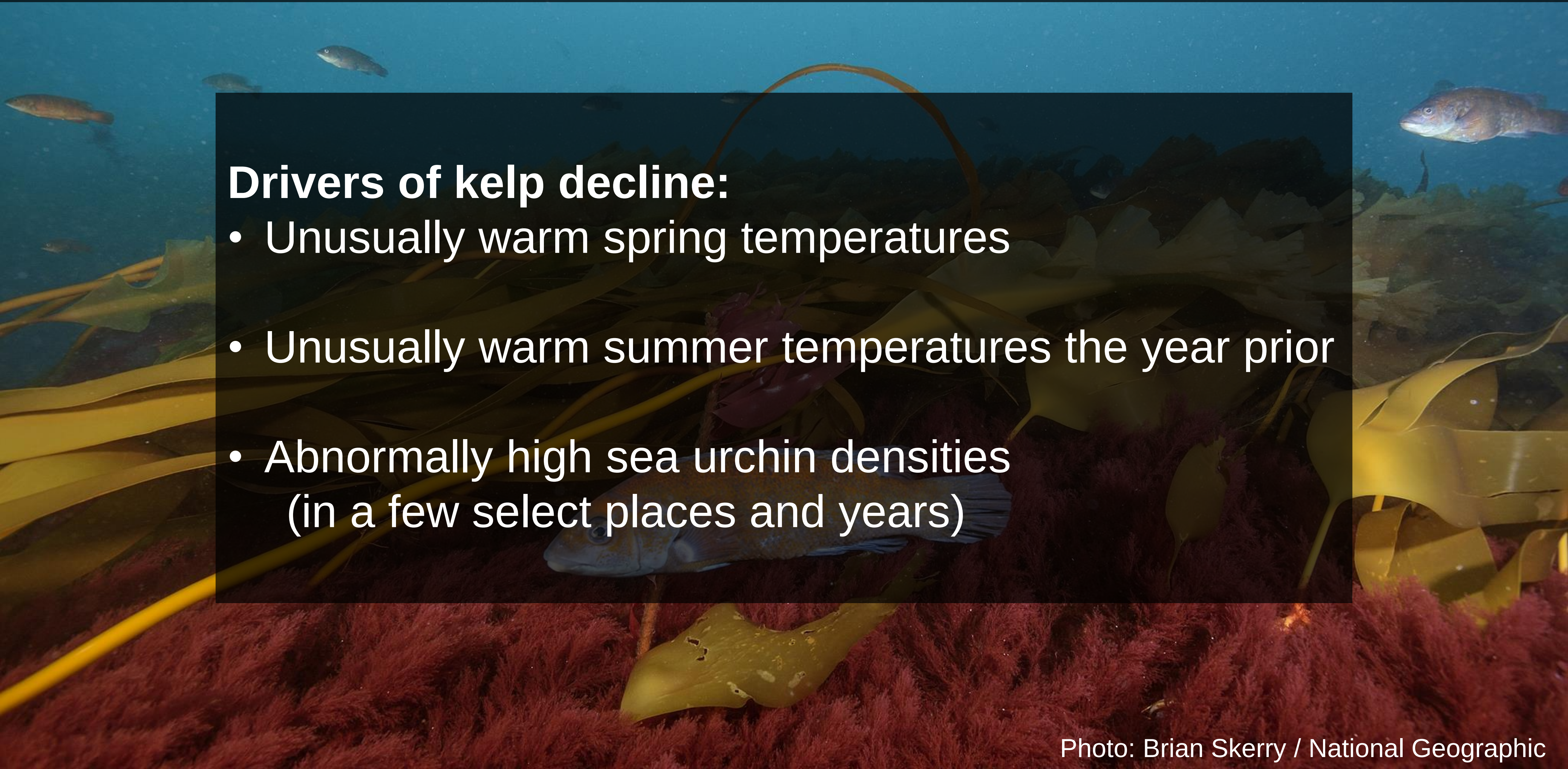
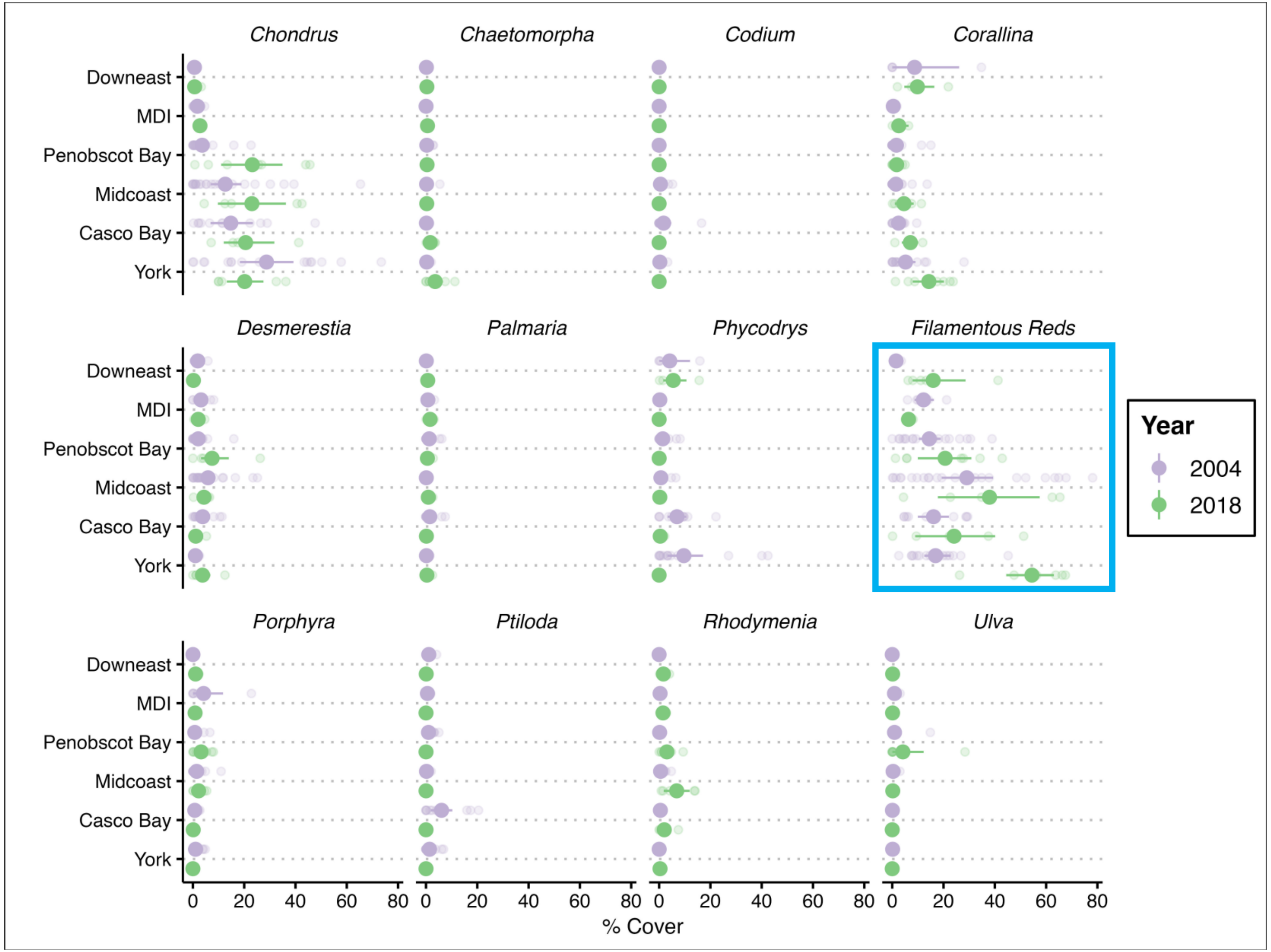
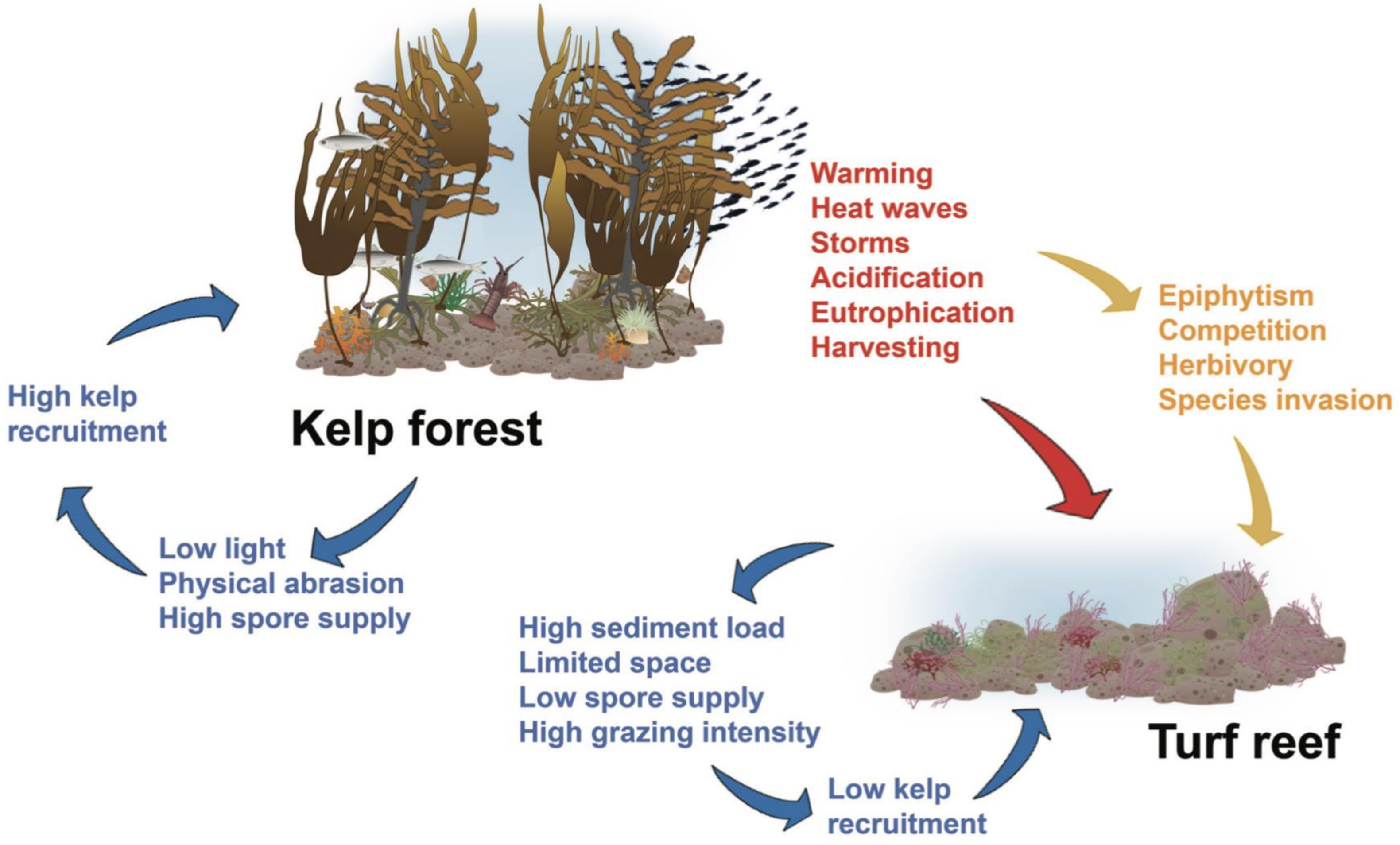


Photo: Brian Skerry / National Geographic

# > Changes to "understory" algal community

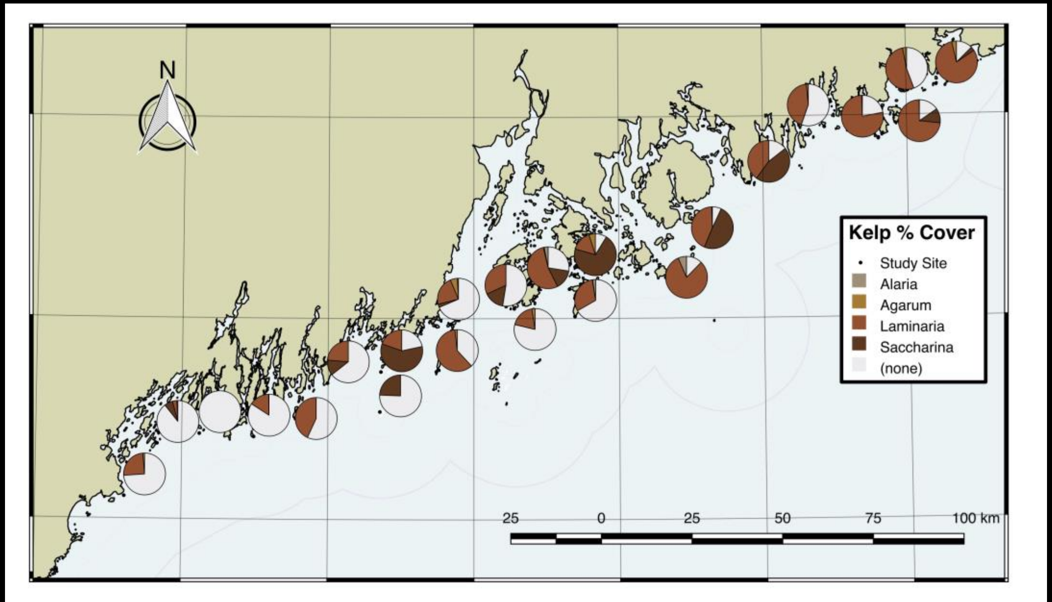


# > The rise of algal turfs and ecological feedbacks




Filbee-Dexter and Wernberg 2018, *Bioscience*

# > Range shifts are unfolding real-time




**Loss of subarctic kelps and understory algae**

**Introduced species**

**Arrival of species from the south**

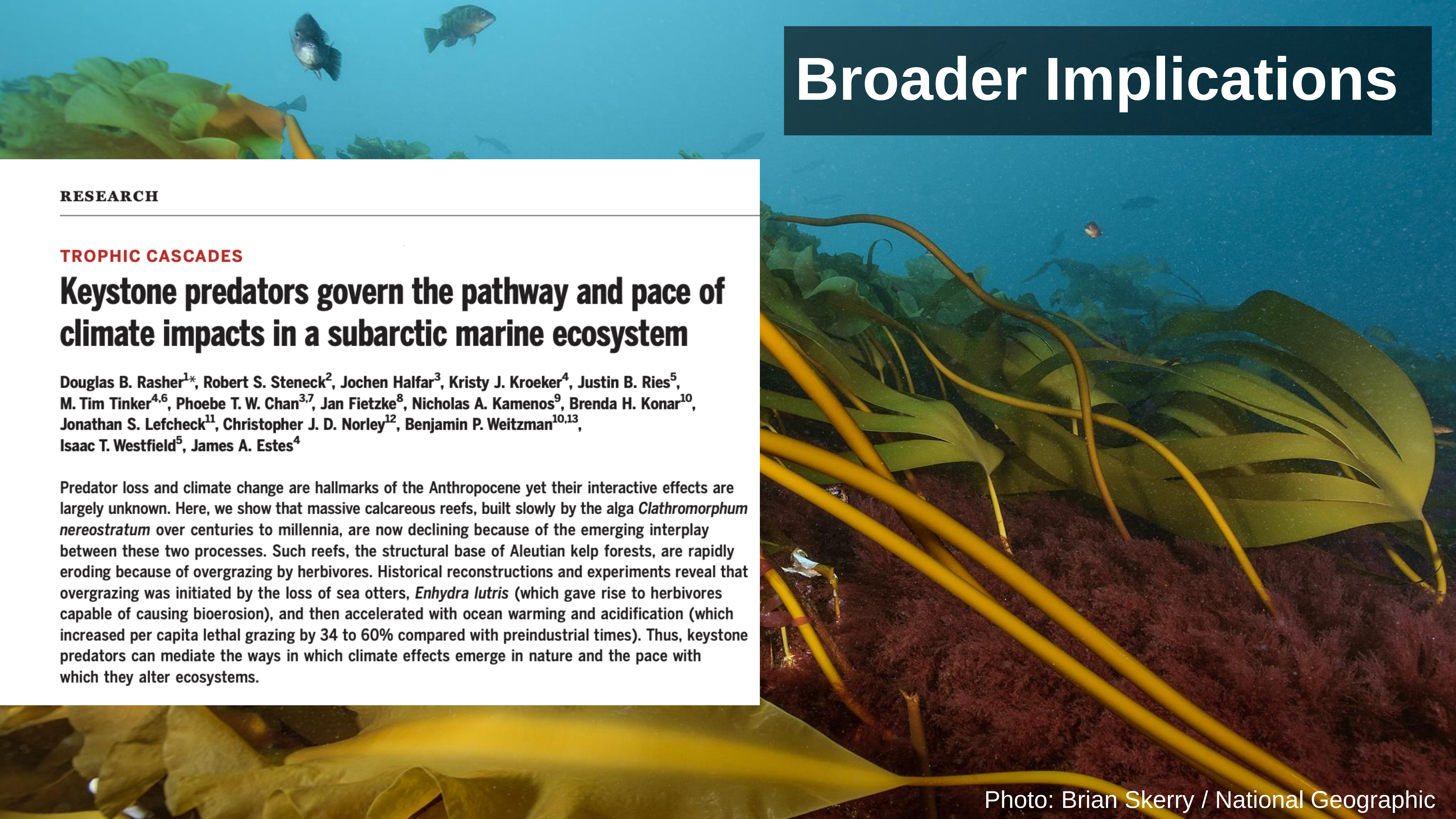
NSF

MAINE eDNA

# > Recap of key findings

- Sea urchins remain scarce in the ecosystem
- Theory and history predict herbivore removal should have led to a lasting dominance by kelp – the ecosystem’s foundation
- Instead, the outcomes were (1) a waning dominance of kelp (north) or (2) an ecosystem state shift to other, diminutive algae (south)
- Such changes are primarily due to unusually warm temperatures in both the spring and summer

# Broader Implications



RESEARCH

TROPHIC CASCADES

## Keystone predators govern the pathway and pace of climate impacts in a subarctic marine ecosystem

Douglas B. Rasher[1]*, Robert S. Steneck[2], Jochen Halfar[3], Kristy J. Kroeker[4], Justin B. Ries[5], M. Tim Tinker[4,6], Phoebe T. W. Chan[3,7], Jan Fietzke[8], Nicholas A. Kamenos[9], Brenda H. Konar[10], Jonathan S. Lefcheck[11], Christopher J. D. Norley[12], Benjamin P. Weitzman[10,13], Isaac T. Westfield[5], James A. Estes[4]

Predator loss and climate change are hallmarks of the Anthropocene yet their interactive effects are largely unknown. Here, we show that massive calcareous reefs, built slowly by the alga *Clathromorphum nereostratum* over centuries to millennia, are now declining because of the emerging interplay between these two processes. Such reefs, the structural base of Aleutian kelp forests, are rapidly eroding because of overgrazing by herbivores. Historical reconstructions and experiments reveal that overgrazing was initiated by the loss of sea otters, *Enhydra lutris* (which gave rise to herbivores capable of causing bioerosion), and then accelerated with ocean warming and acidification (which increased per capita lethal grazing by 34 to 60% compared with preindustrial times). Thus, keystone predators can mediate the ways in which climate effects emerge in nature and the pace with which they alter ecosystems.

Photo: Brian Skerry / National Geographic

# Acknowledgements

MAINE DMR MARINE RESOURCES

KEEN
KELP ECOSYSTEM ECOLOGY NETWORK

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MAINE SEA GRANT
Marine Science for Maine People

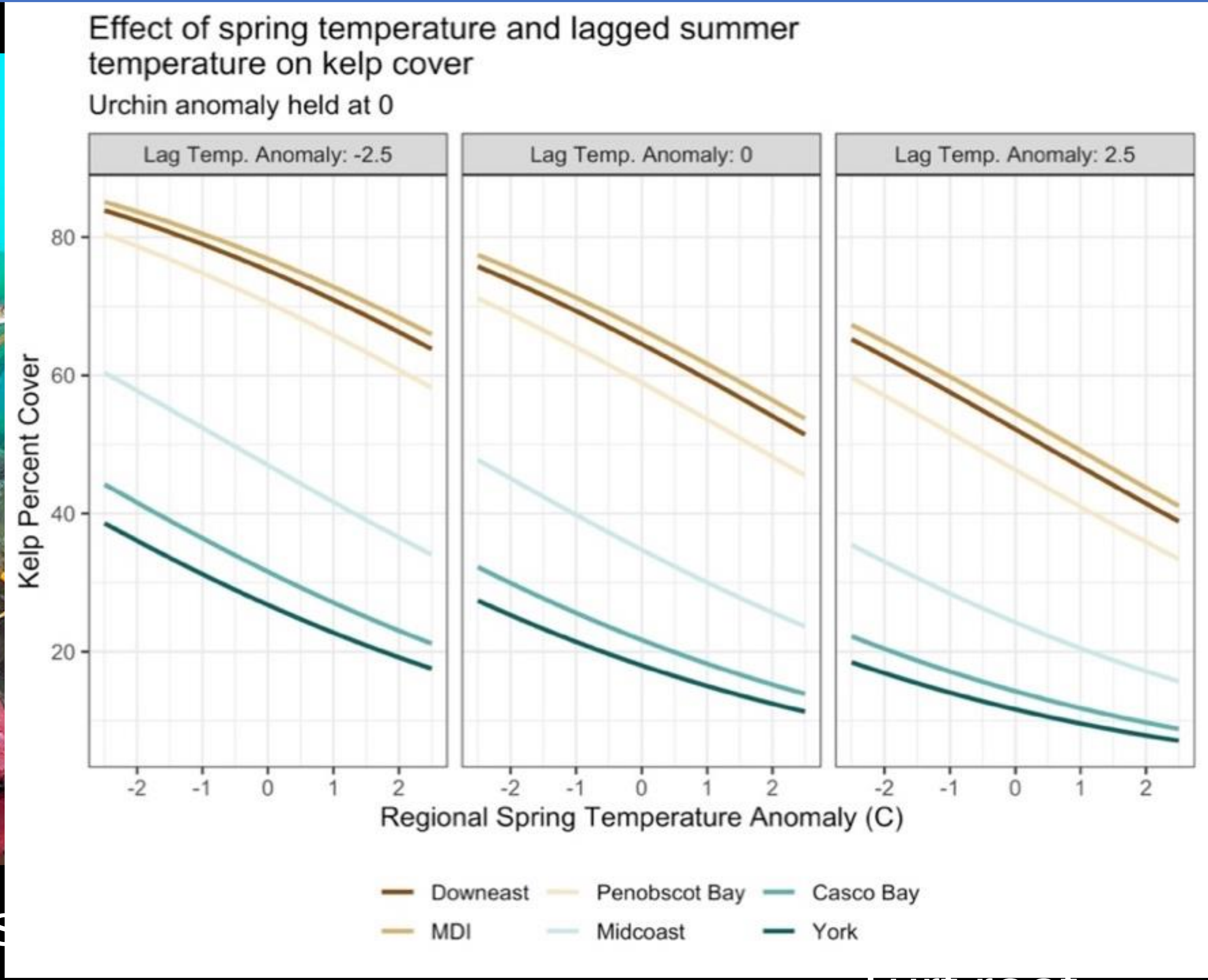
Bigelow | Laboratory for Ocean Sciences

1865 THE UNIVERSITY OF MAINE
Darling Marine Center

Hurricane Island Foundation

# Questions?

# Time

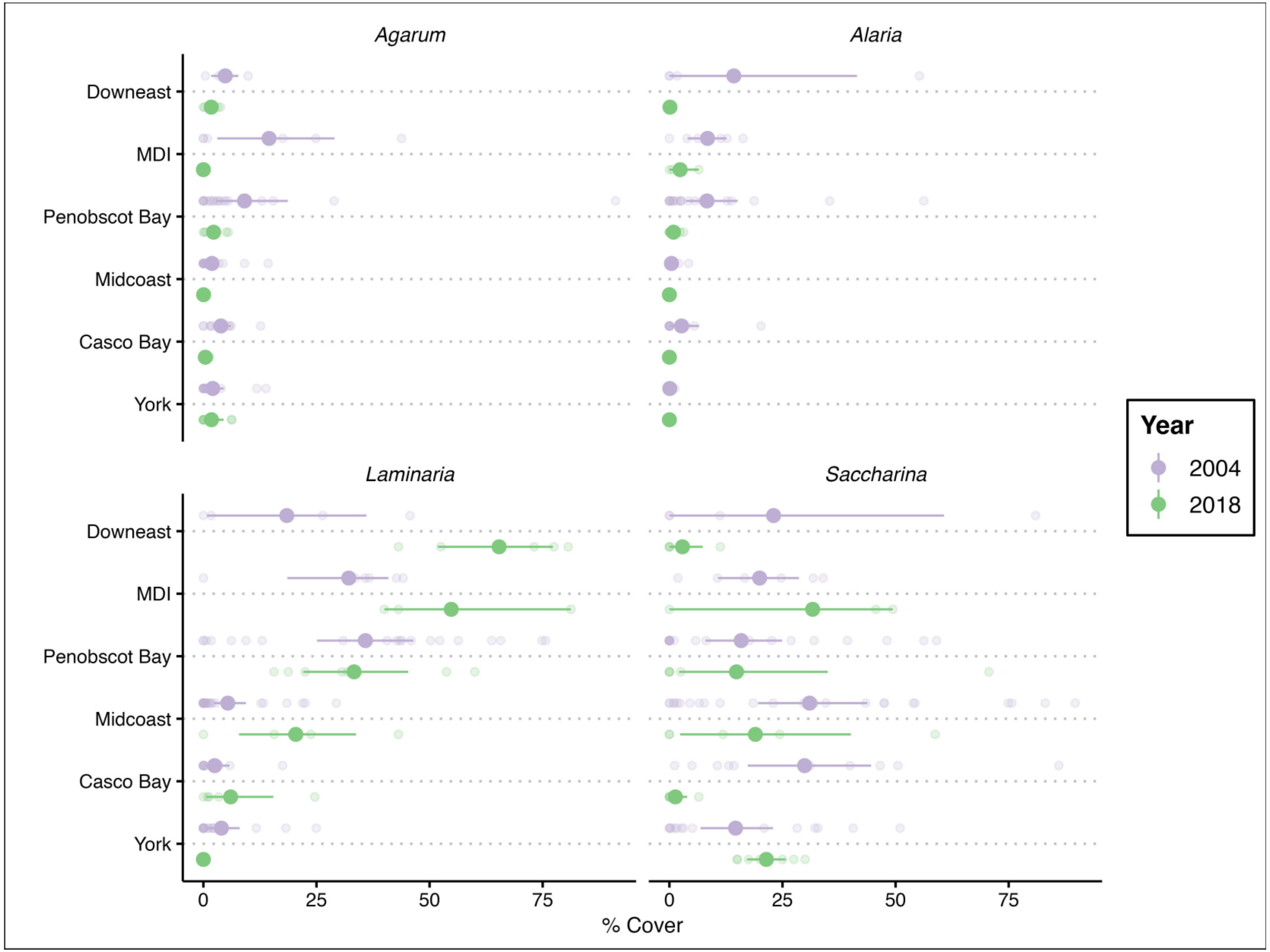




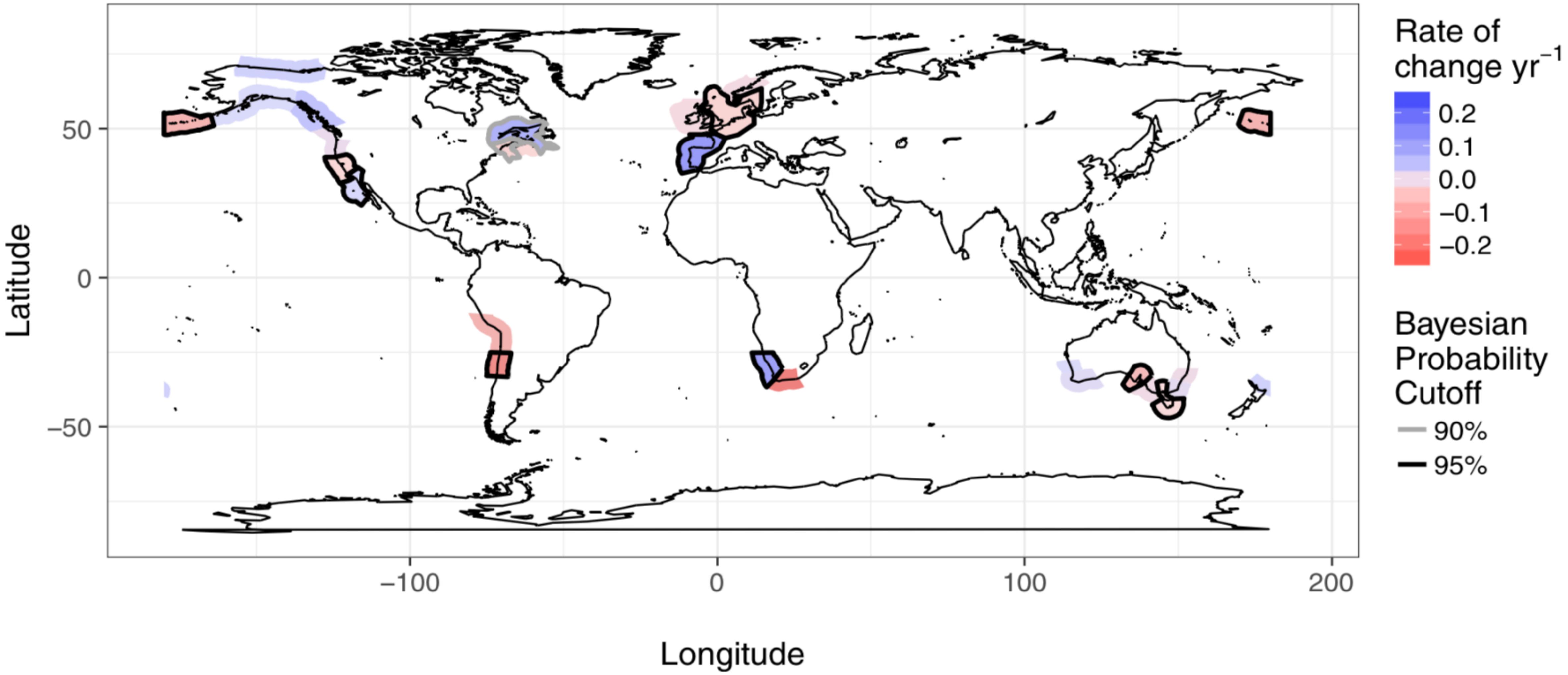


Kelp forests

Turf reef



Agarum
Alaria
Laminaria
Saccharina
Downeast
MDI
Penobscot Bay
Midcoast
Casco Bay
York
0
25
50
75
% Cover
Year
2004
2018




Krumhansl et al. 2016, *PNAS*