# Biological and socioeconomic impacts of marine heatwaves

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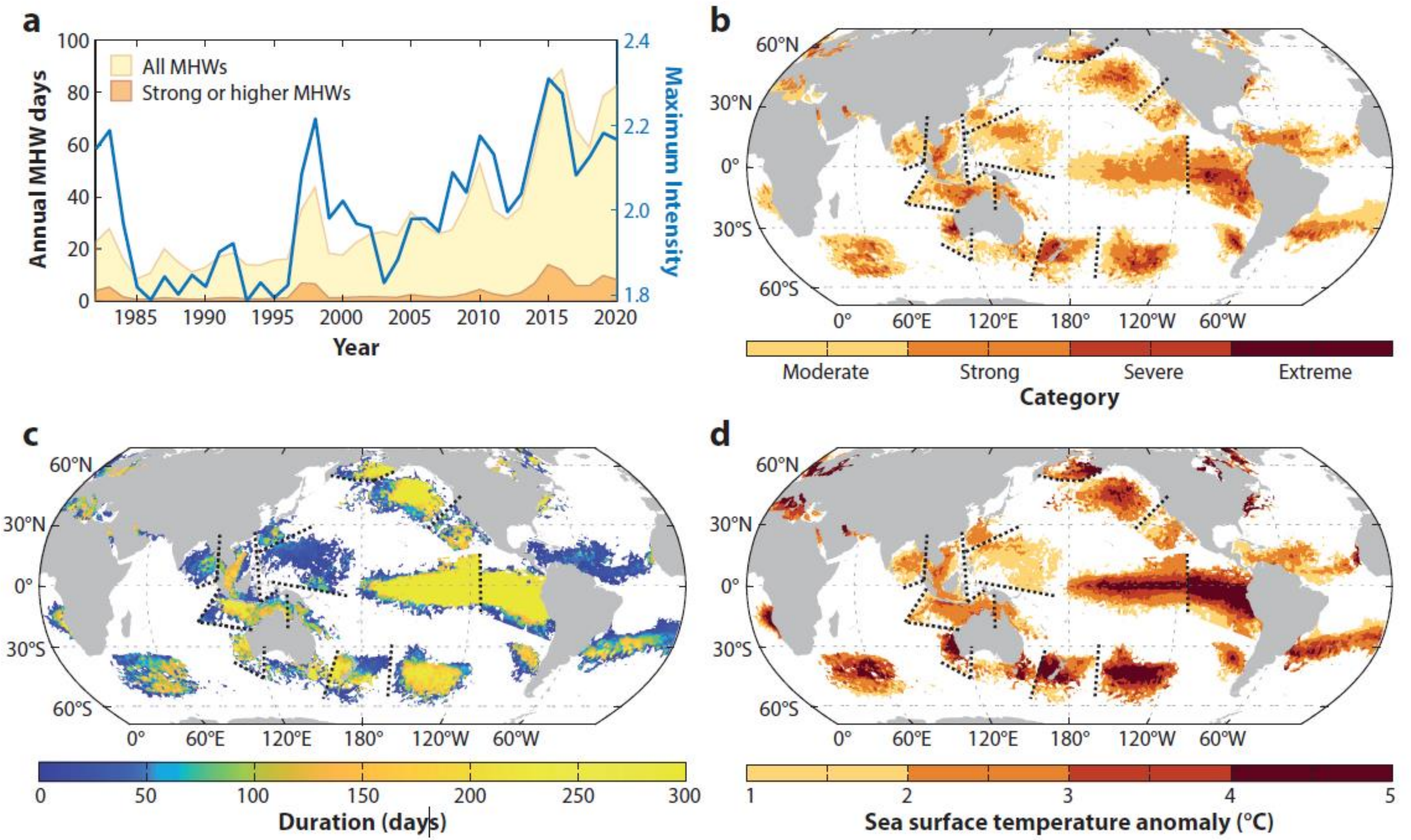
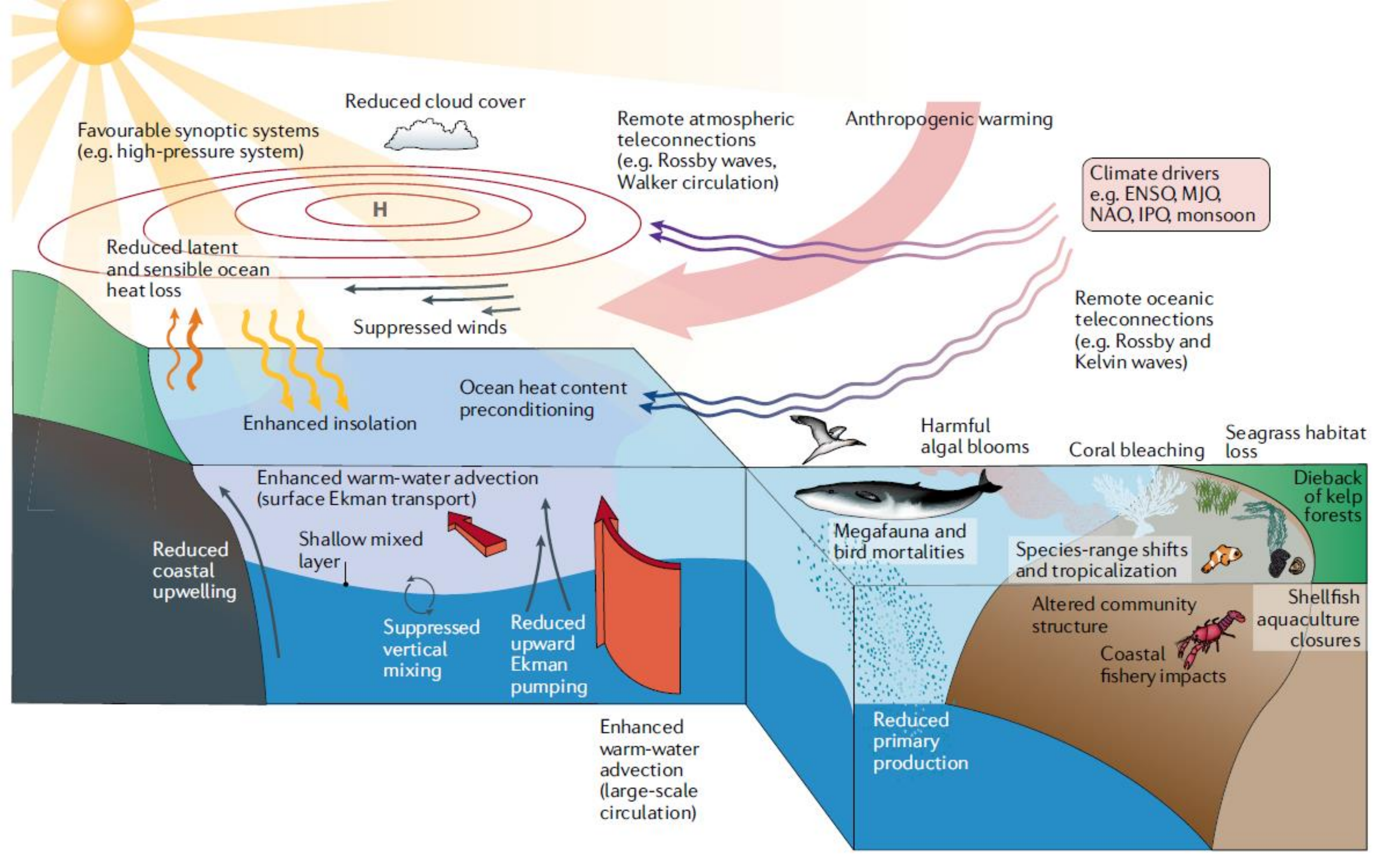

a
b
c
d
All MHWs
Strong or higher MHWs
Annual MHW days
Maximum Intensity
Year
100
80
60
40
20
0
2.4
2.2
2.0
1.8
1985
1990
1995
2000
2005
2010
2015
2020
60°N
30°N
0°
30°S
60°S
0°
60°E
120°E
180°
120°W
60°W
Moderate
Strong
Severe
Extreme
Category
0
50
100
150
200
250
300
Duration (days)
1
2
3
4
5
Sea surface temperature anomaly (°C)

# Marine heatwave drivers and impacts




Holbrook et al. 2020, *Nat. Rev. Earth Environ*

# Biological impacts of MHWs

**Broad responses which impact individuals, populations and communities**

- **Failed recruitment in benthic invertebrates**

Smith et al. 2023, *Annu. Rev. Mar. Sci.*

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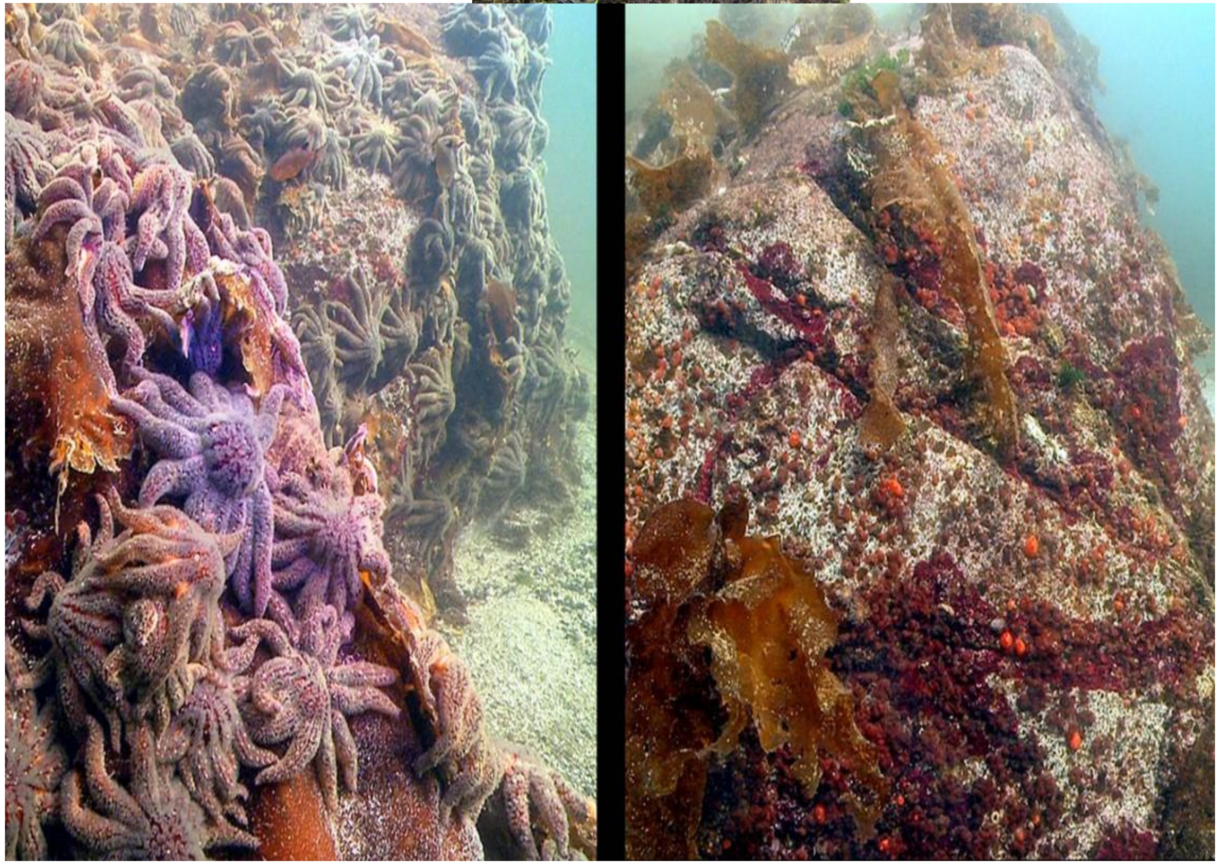
# Biological impacts of MHWs

## Broad responses which impact individuals, populations and communities

- **Failed recruitment in benthic invertebrates**
- **Mass mortality events**
- **Disease**



Smith et al. 2023, *Annu. Rev. Mar. Sci.*

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# Biological impacts of MHWs

**Broad responses which impact individuals, populations and communities**

- **Failed recruitment in benthic invertebrates**
- **Mass mortality events**
- **Disease**
- **Loss of foundation species**

Smith et al. 2023, *Annu. Rev. Mar. Sci.*

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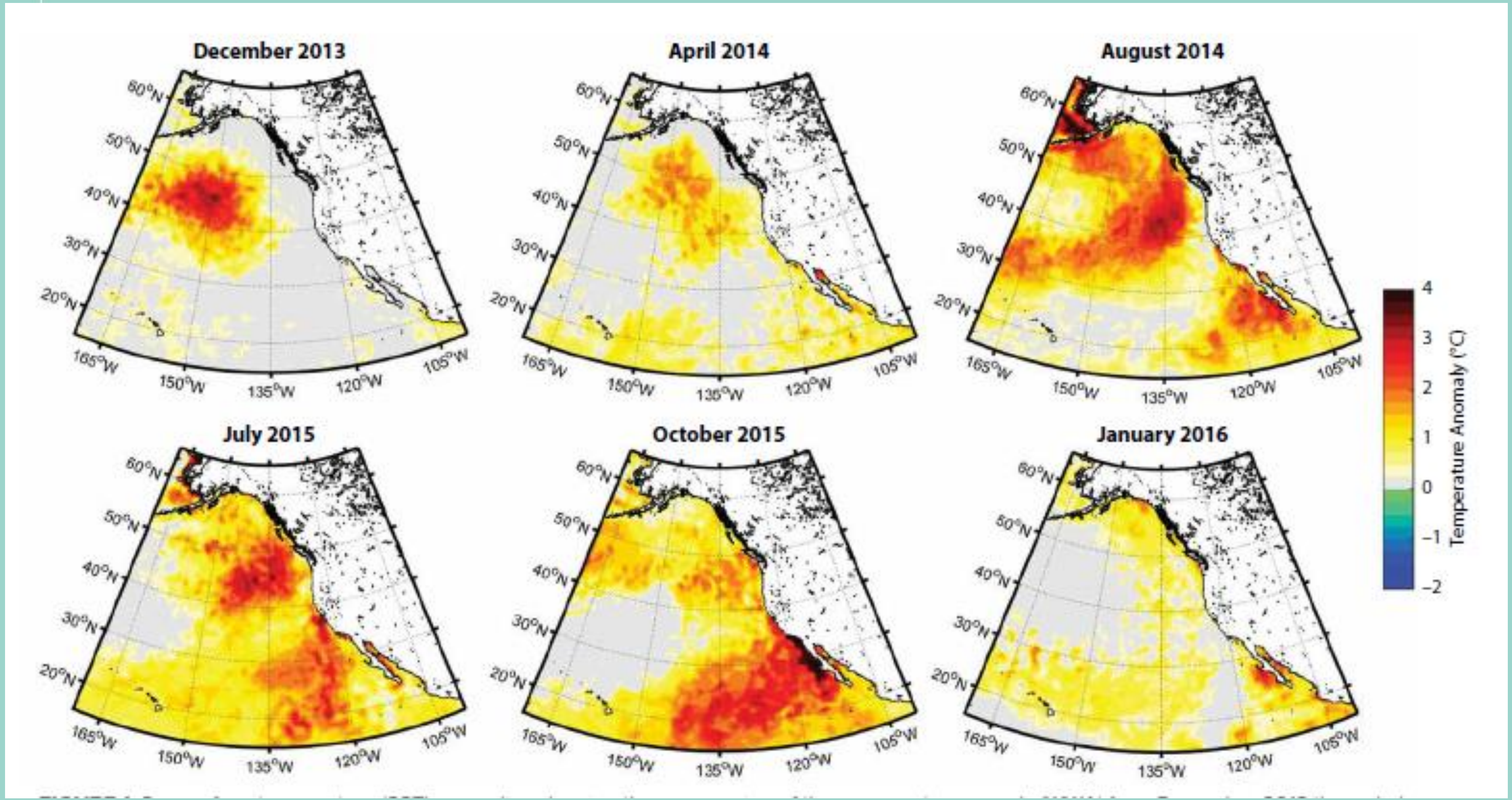
# ‘The blob’ MHW in the Northeast Pacific

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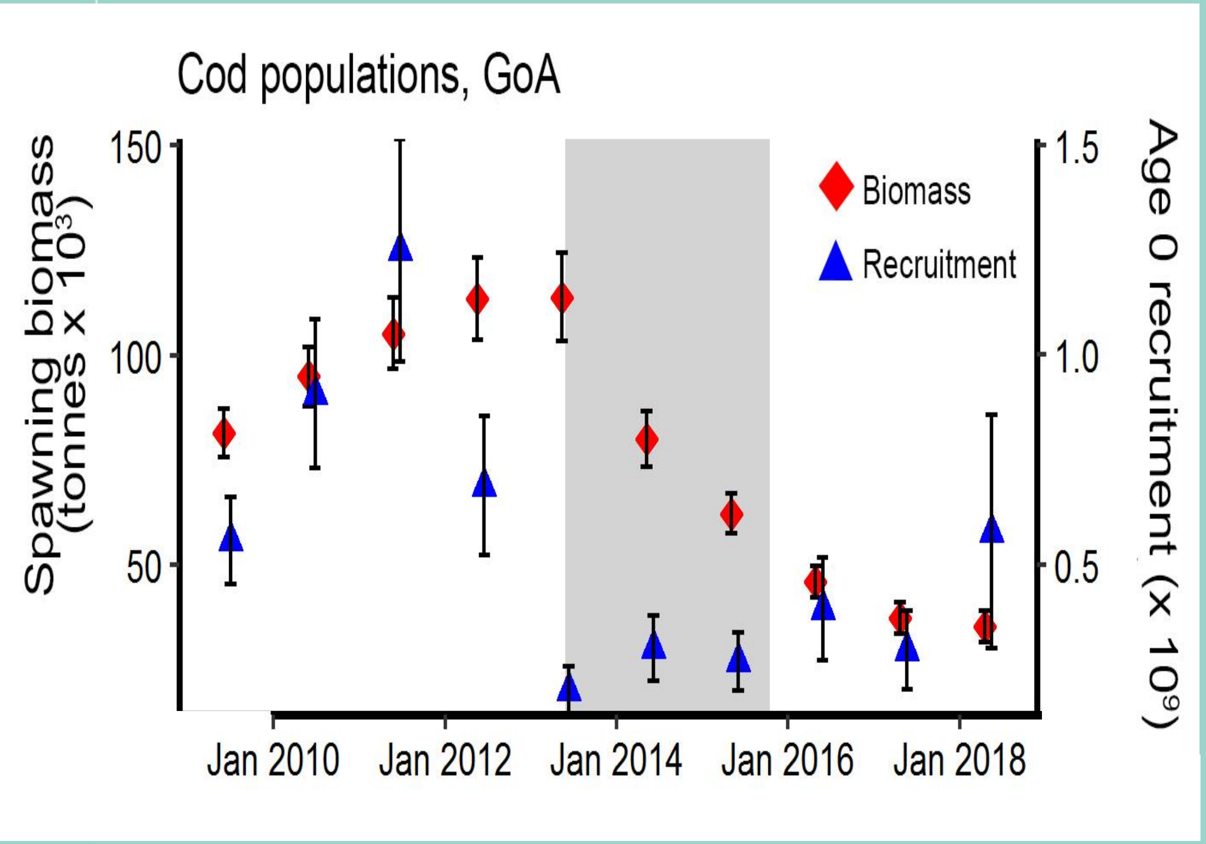


Smith et al. 2021, *Science*
www.coast.org

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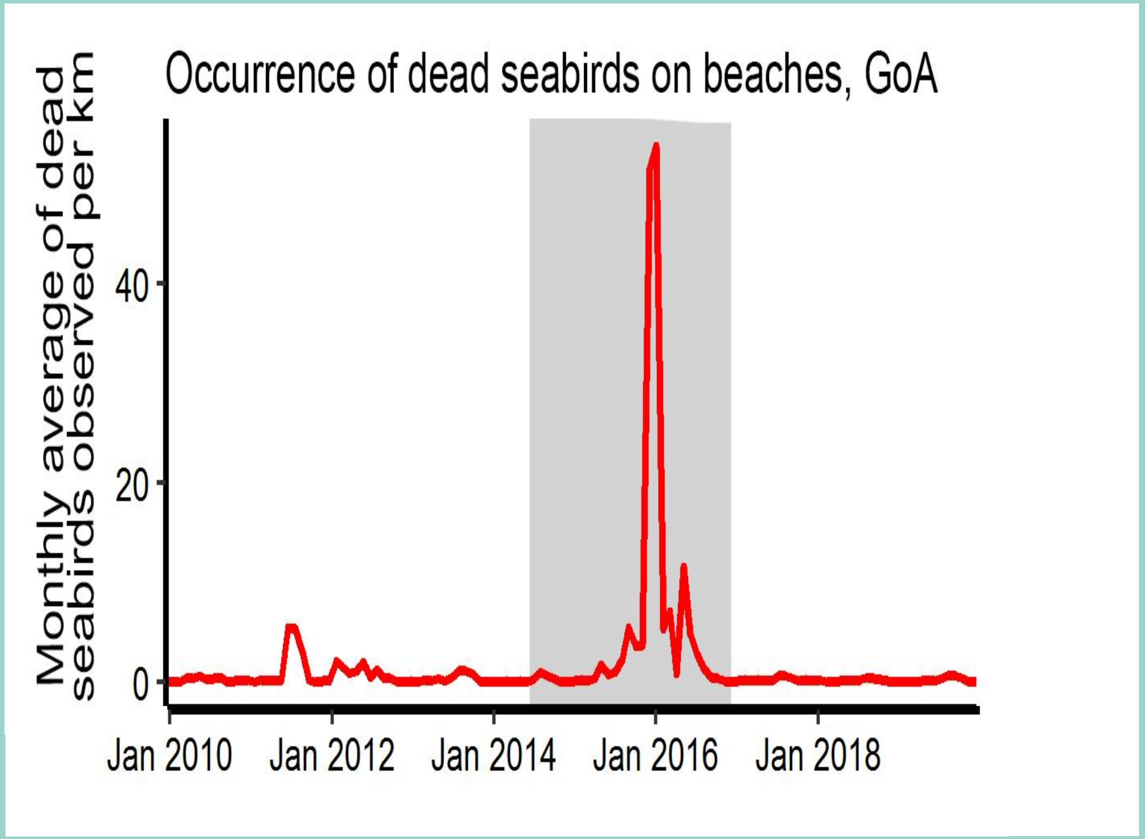
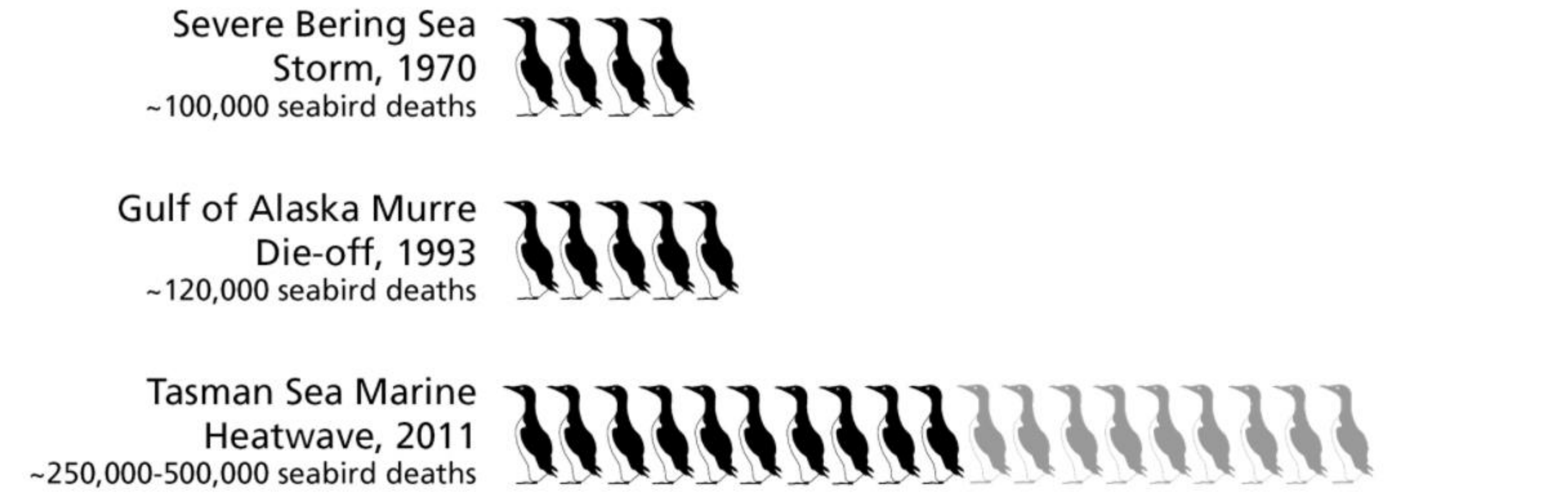
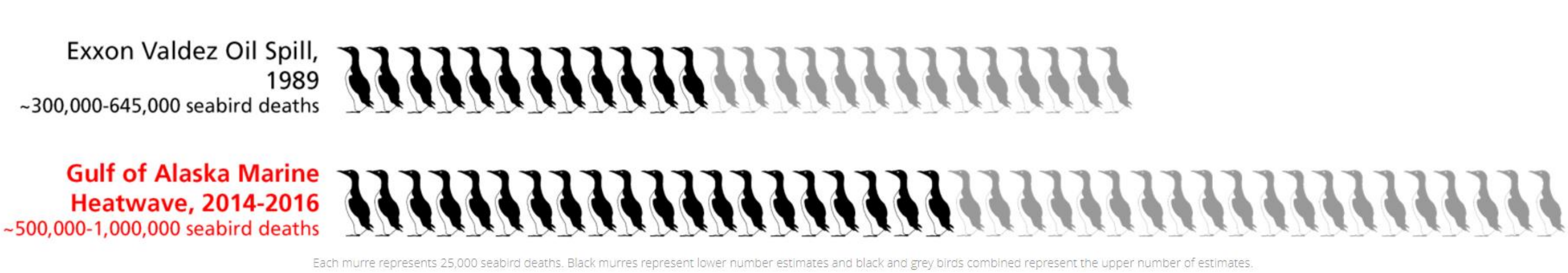



Smith et al. 2021, *Science*
www.coast.org

# Common Murre’s, Gulf of Alaska



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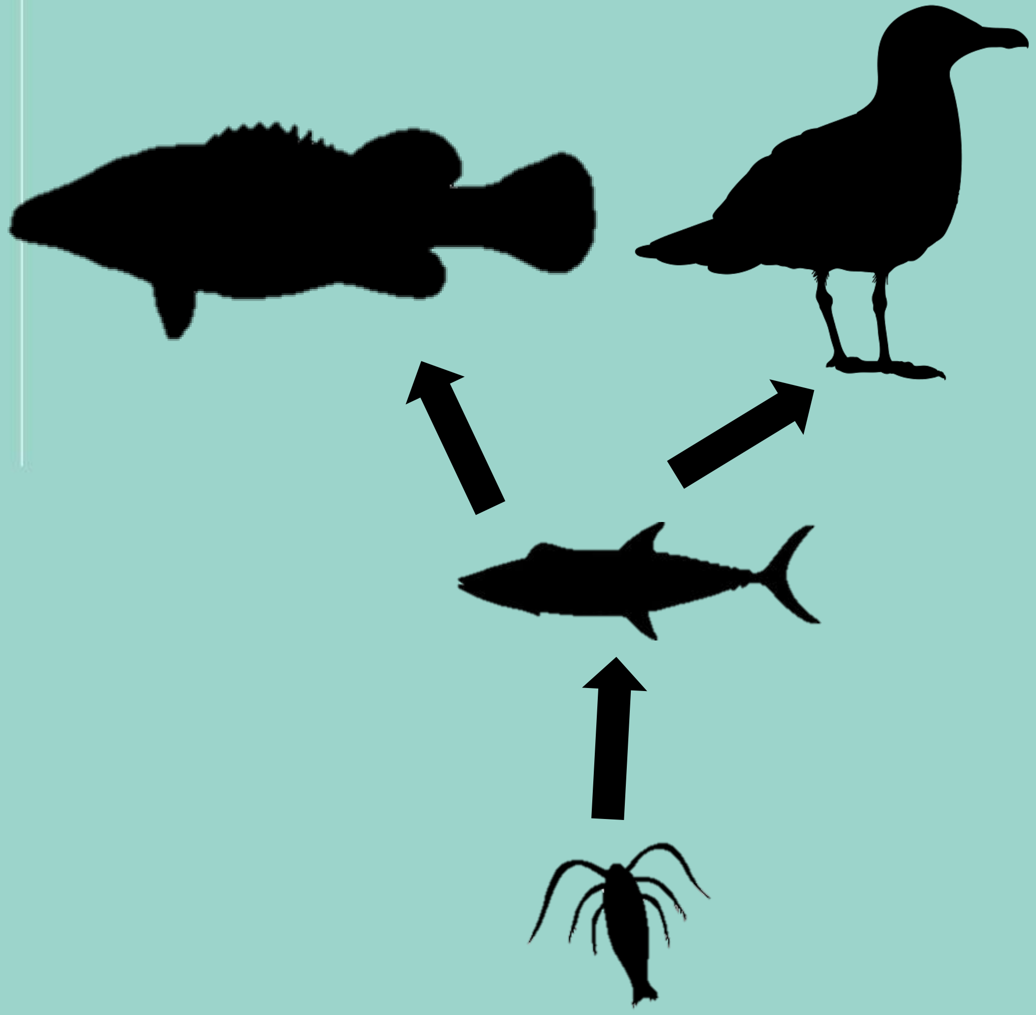
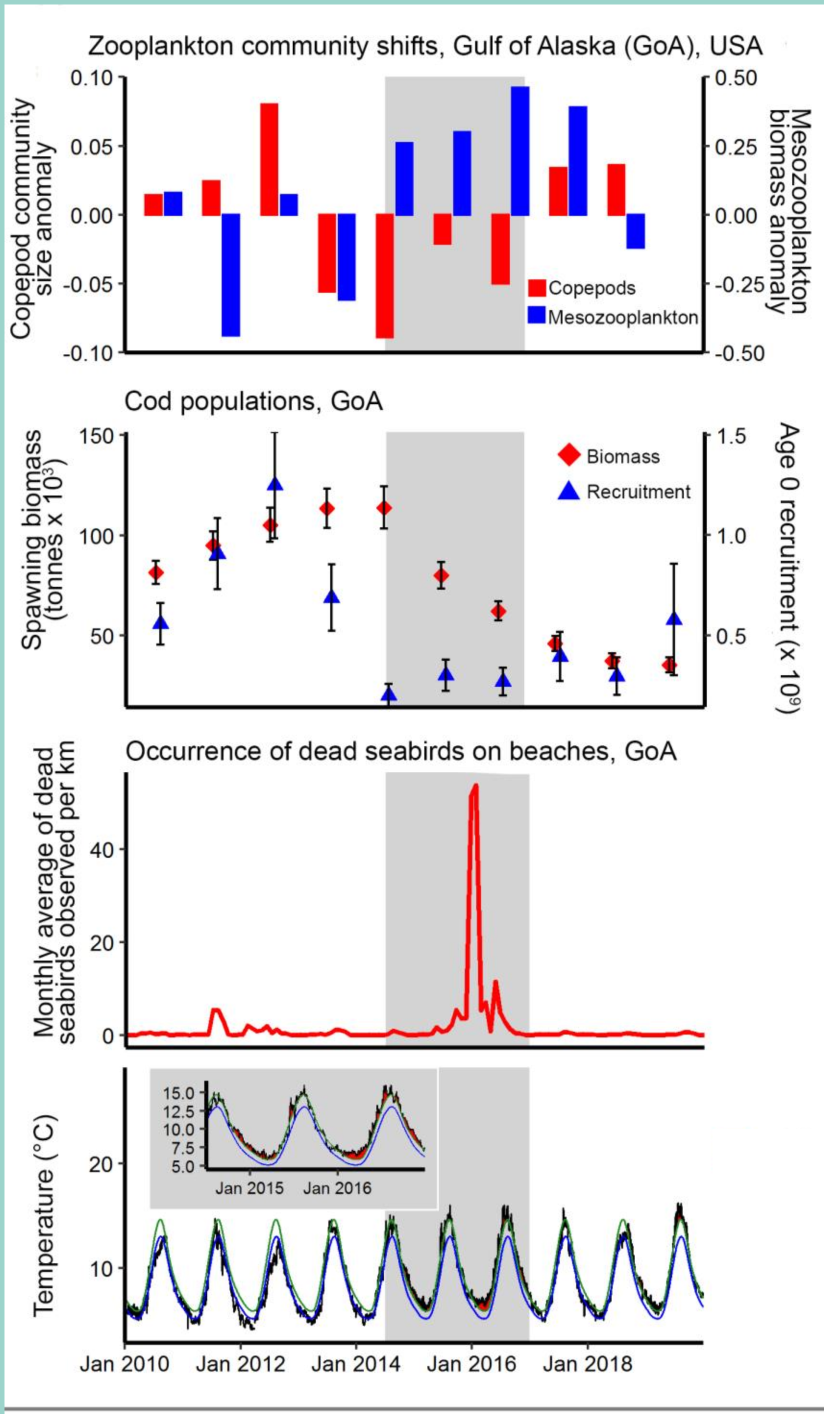


Range shift

Failed recruitment

Mass mortality events




Smith et al. 2021, *Science*

# ‘The blob’ MHW in the Northeast Pacific

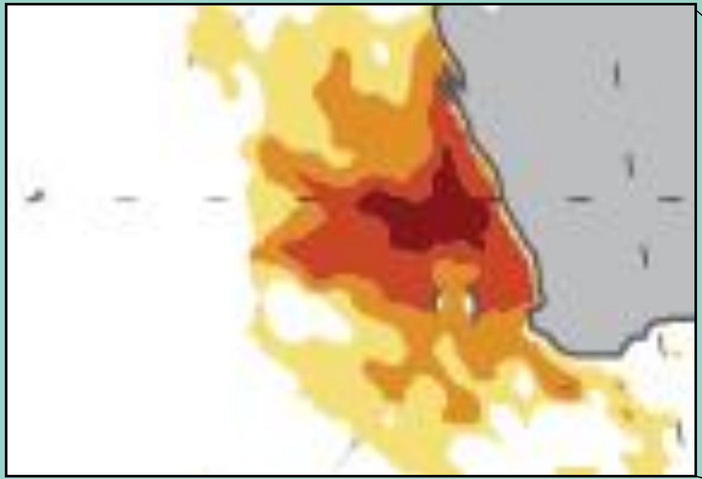
- Starvation in seals and sea lions

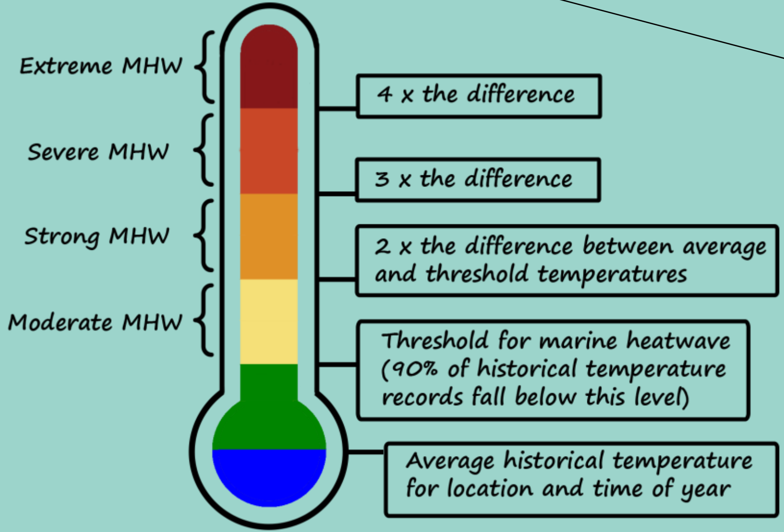
- Increase in warm-water game fish (e.g. Tuna)
    - Increased tourism

- Whales moved inshore to feed
    - Increased tourism
    - Increased whale entanglements

Cavole et al. 2016, *Oceanography*

# Example 2: The 'Ningaloo Niño' MHW off Western Australia in 2011




- 10 weeks long
- Extreme
- 2,000 km of coastline impacted

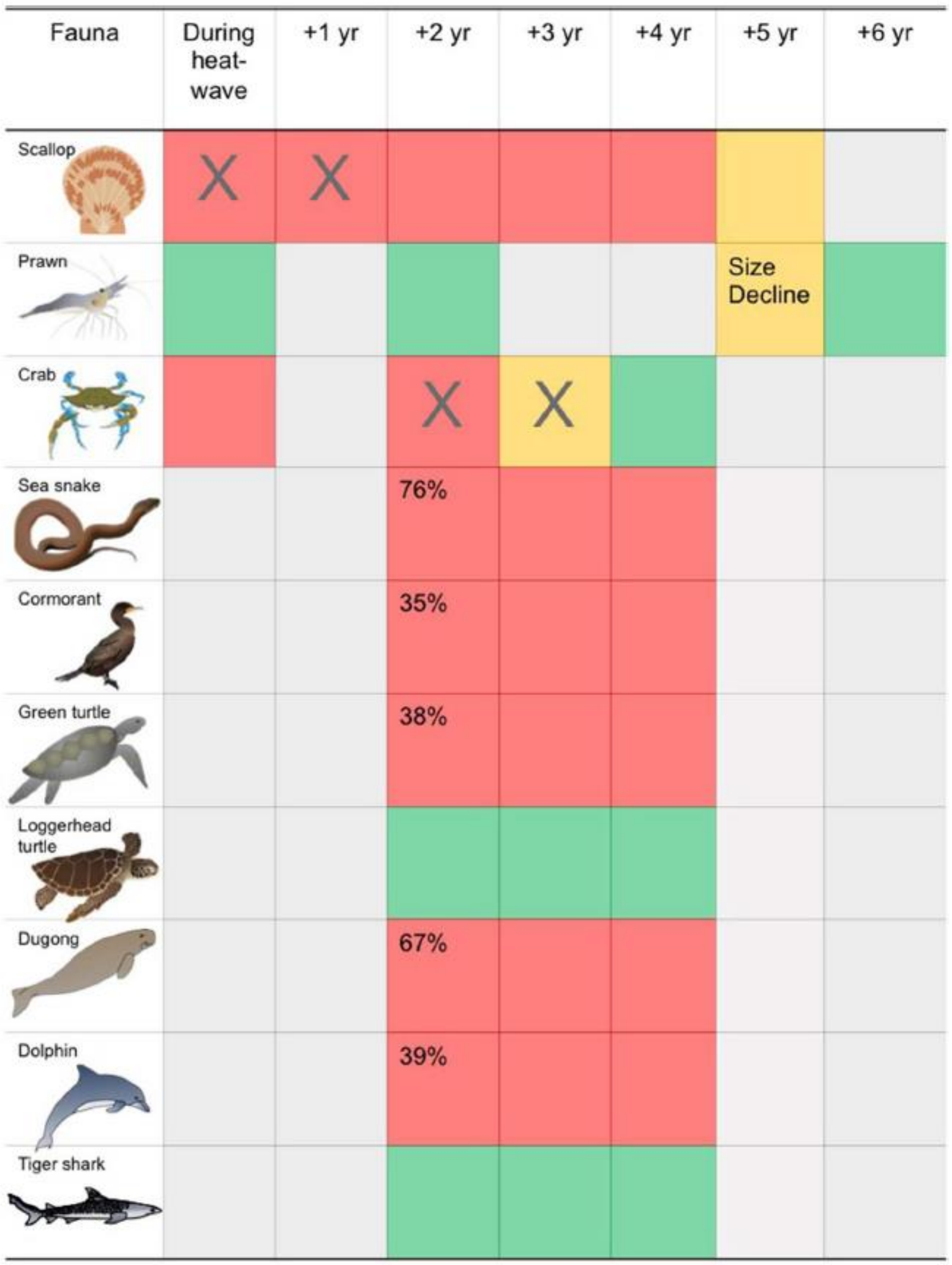
# The ‘Ningaloo Niño’ MHW off Western Australia in 2011

- Shark Bay seagrass
    - Worlds largest seagrass carbon stock
    - UNESCO world heritage site
    - 1,300 km$^2$ seagrass lost during the Ningaloo Niño (equivalent to 243,000 American foodball fields)
    - 2-9 Tg carbon dioxide released
    - A decade later, 1,000 km$^2$ remained lost
    - Large temperate seagrass species have been replaced with small tropical species

Kendrick et al. 2019 *Front. Mar. Sci.*

# The ‘Ningaloo Niño’ MHW off Western Australia in 2011

- Blue swimmer crab, scallop and prawn fisheries closed
- Decline in population of sea snakes, cormorants, green turtles, dugong and dolphins
- Generalist and opportunistic consumers remained stable = more resilient?



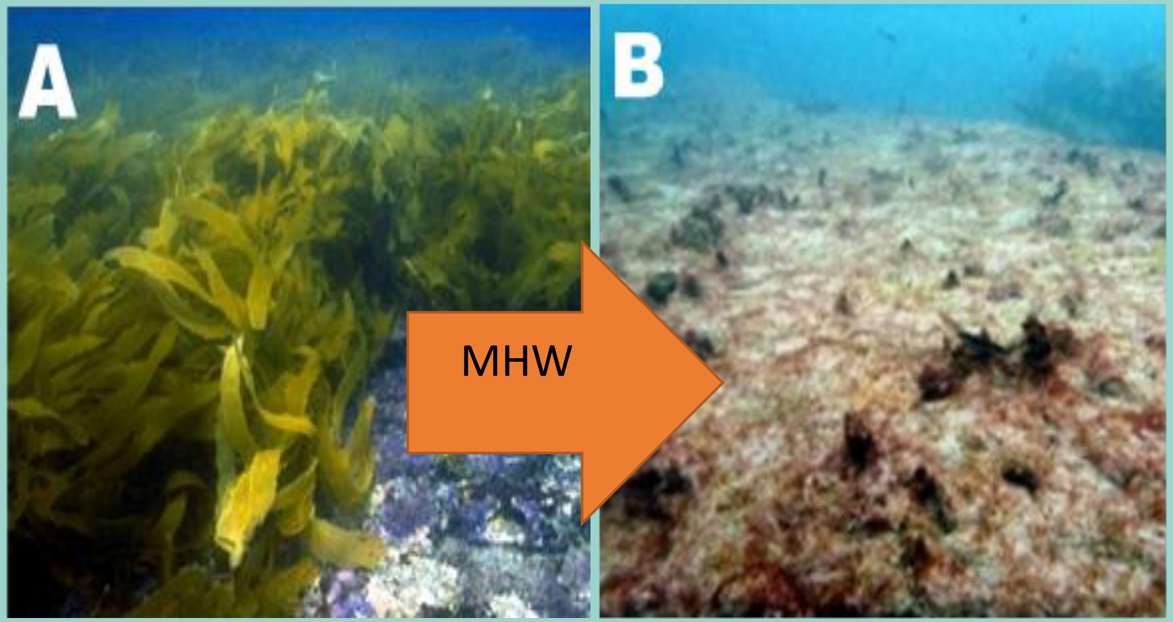
| Fauna | During heat-wave | +1 yr | +2 yr | +3 yr | +4 yr | +5 yr | +6 yr |
|---|---|---|---|---|---|---|---|
| Scallop | X | X | | | | | |
| Prawn | | | | | | Size Decline | |
| Crab | | | X | X | | | |
| Sea snake | | | 76% | | | | |
| Cormorant | | | 35% | | | | |
| Green turtle | | | 38% | | | | |
| Loggerhead turtle | | | | | | | |
| Dugong | | | 67% | | | | |
| Dolphin | | | 39% | | | | |
| Tiger shark | | | | | | | |

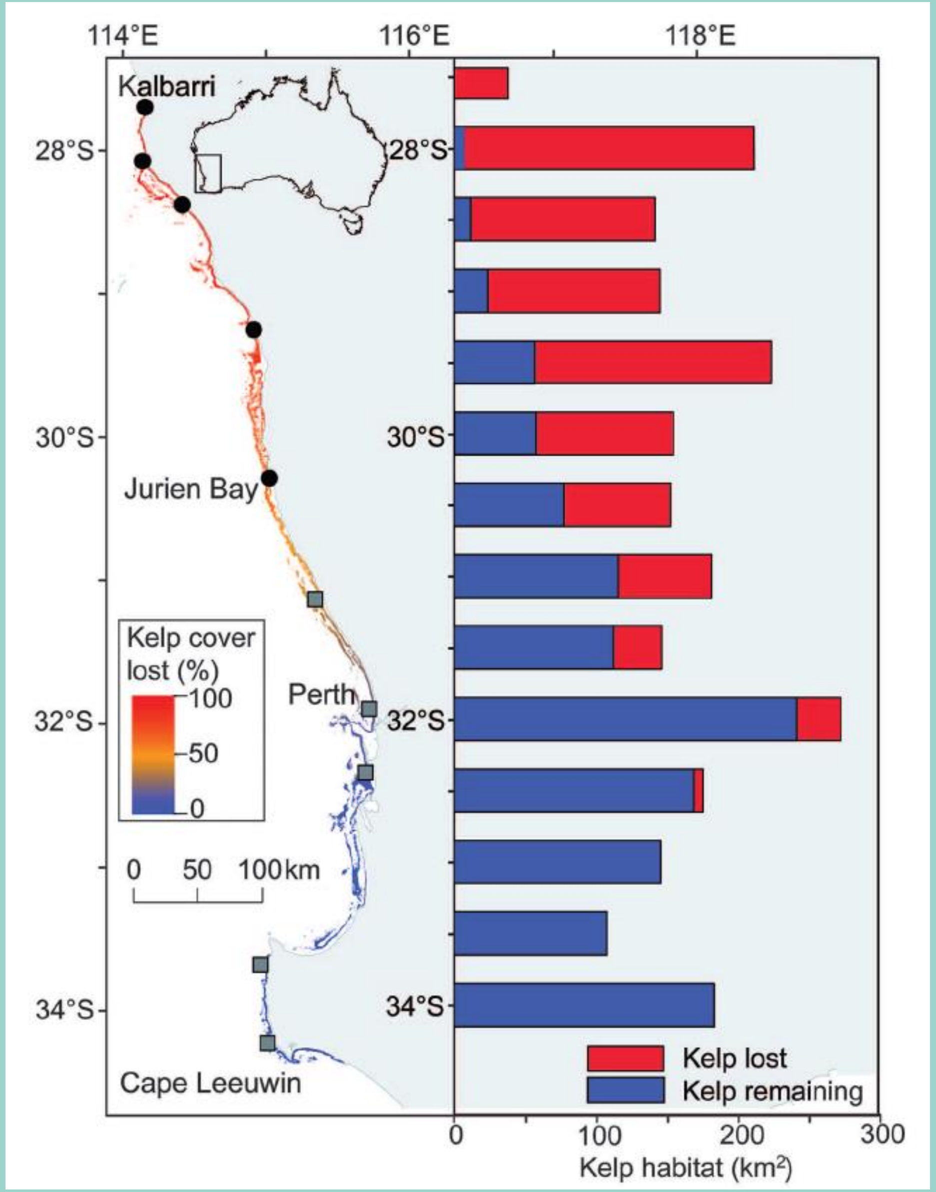
**FIGURE 6 |** Generalized timeline of change in seagrass associated biota before to after the 2011 heatwave. Red, population decline; Yellow, other change to population; Green, no decline in population; Gray, no data; “X”, fishery closure (see Nowicki et al., 2019 for details).

Kendrick et al. 2019 *Front. Mar. Sci.*

# The ‘Ningaloo Niño’ MHW off Western Australia in 2011

- West Coast Kelp forests
  - 100 km range retraction of kelp
  - Dense forests replaced with algal turf
  - No sign of recovery a decade later




Wernberg et al. 2016 *Science*

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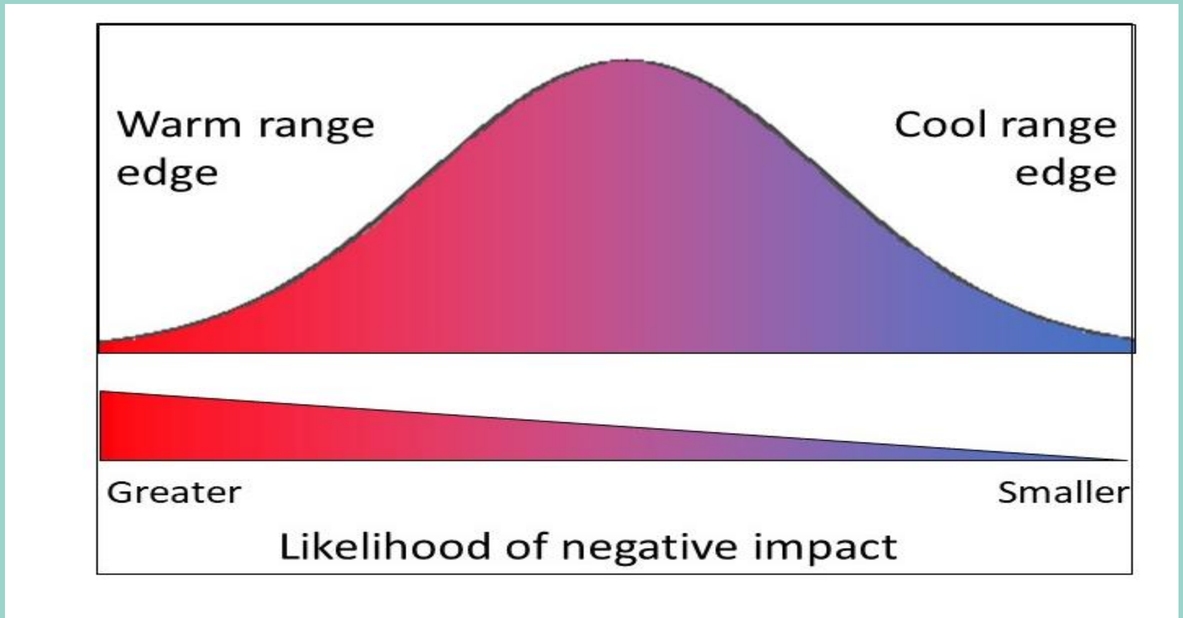
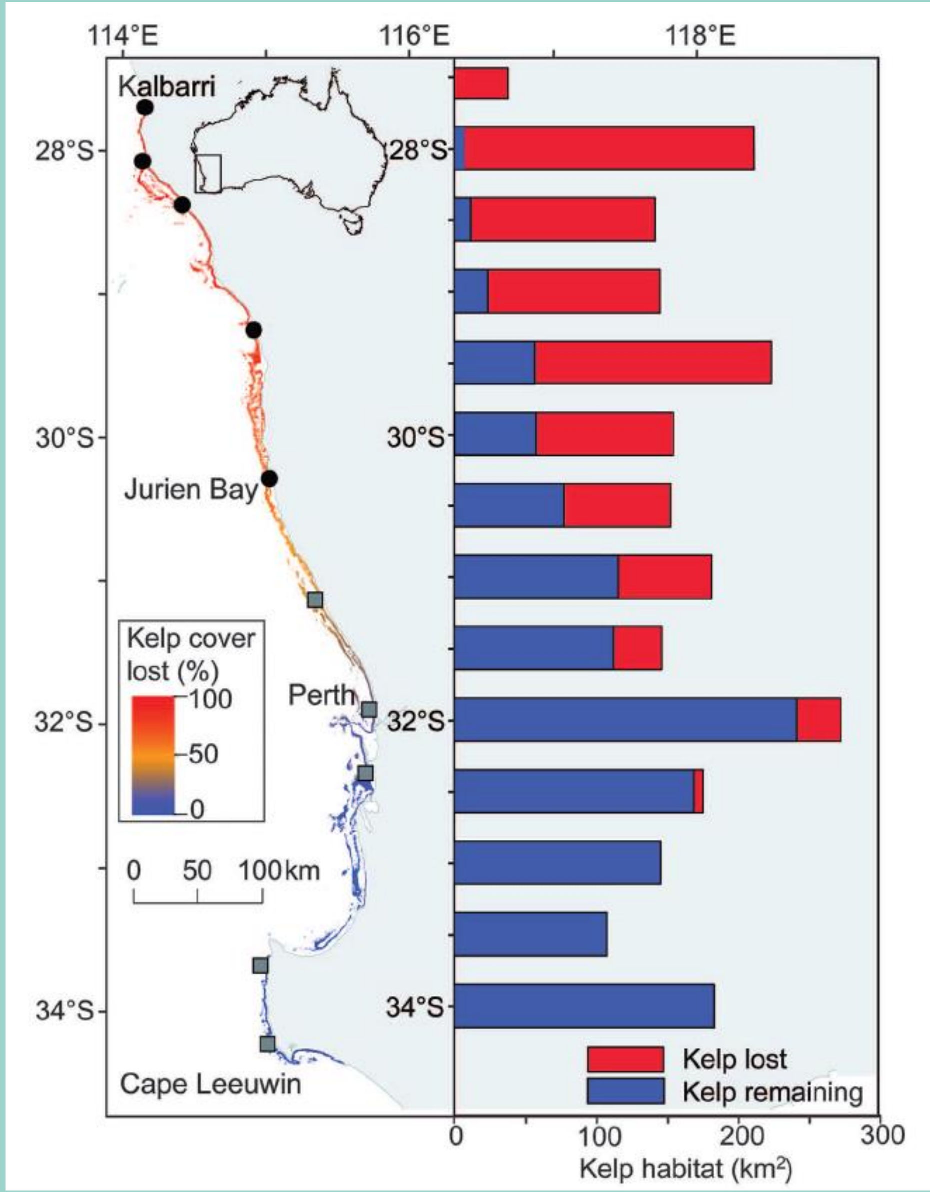
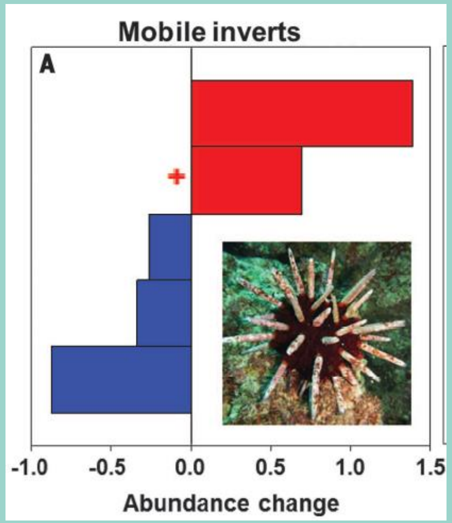


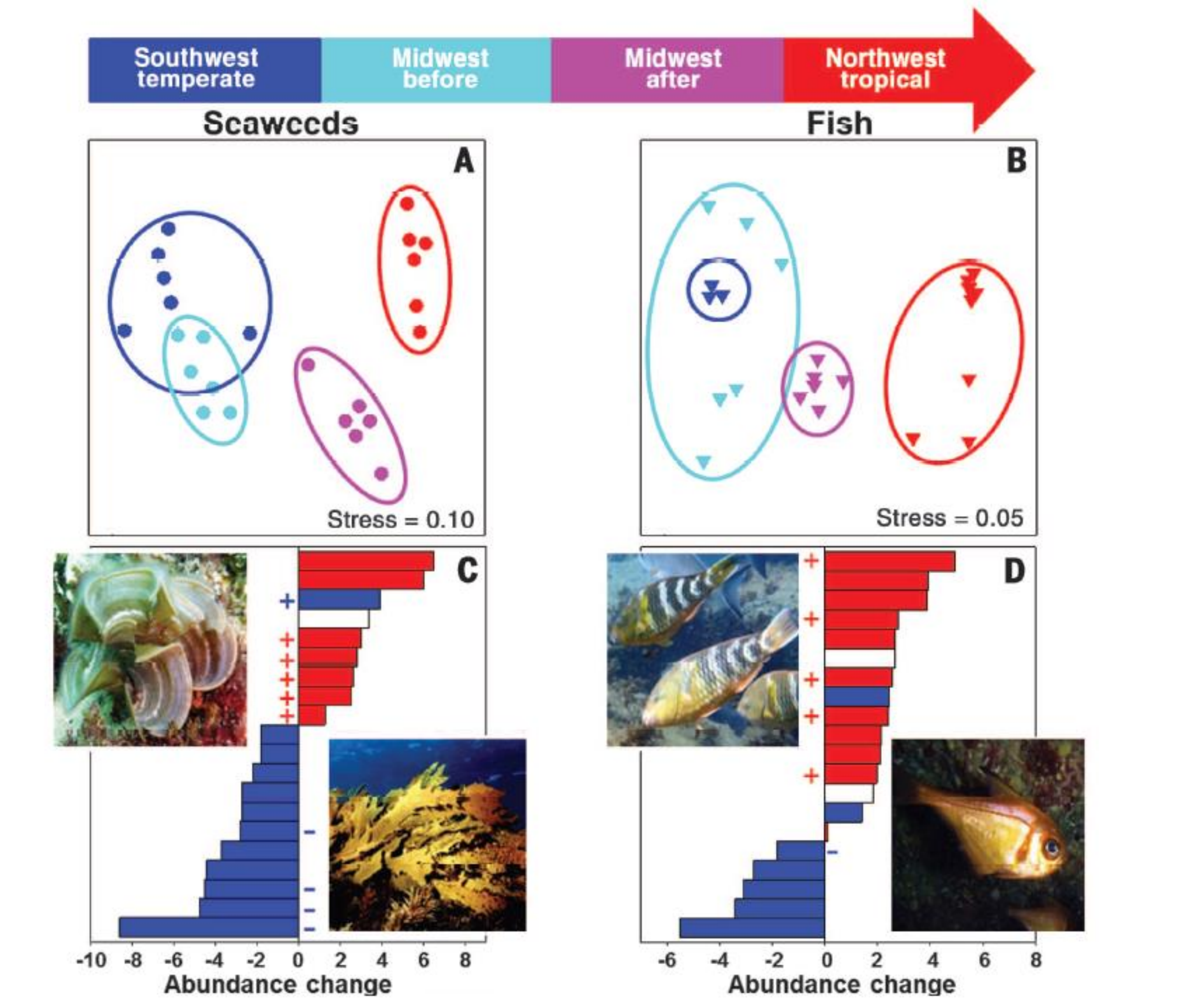




Wernberg et al. 2016 *Science*

# The ‘Ningaloo Niño’ MHW off Western Australia in 2011

- West Coast Kelp forests
  - Complete ecosystem reconfiguration
  - Tropicalisation of species

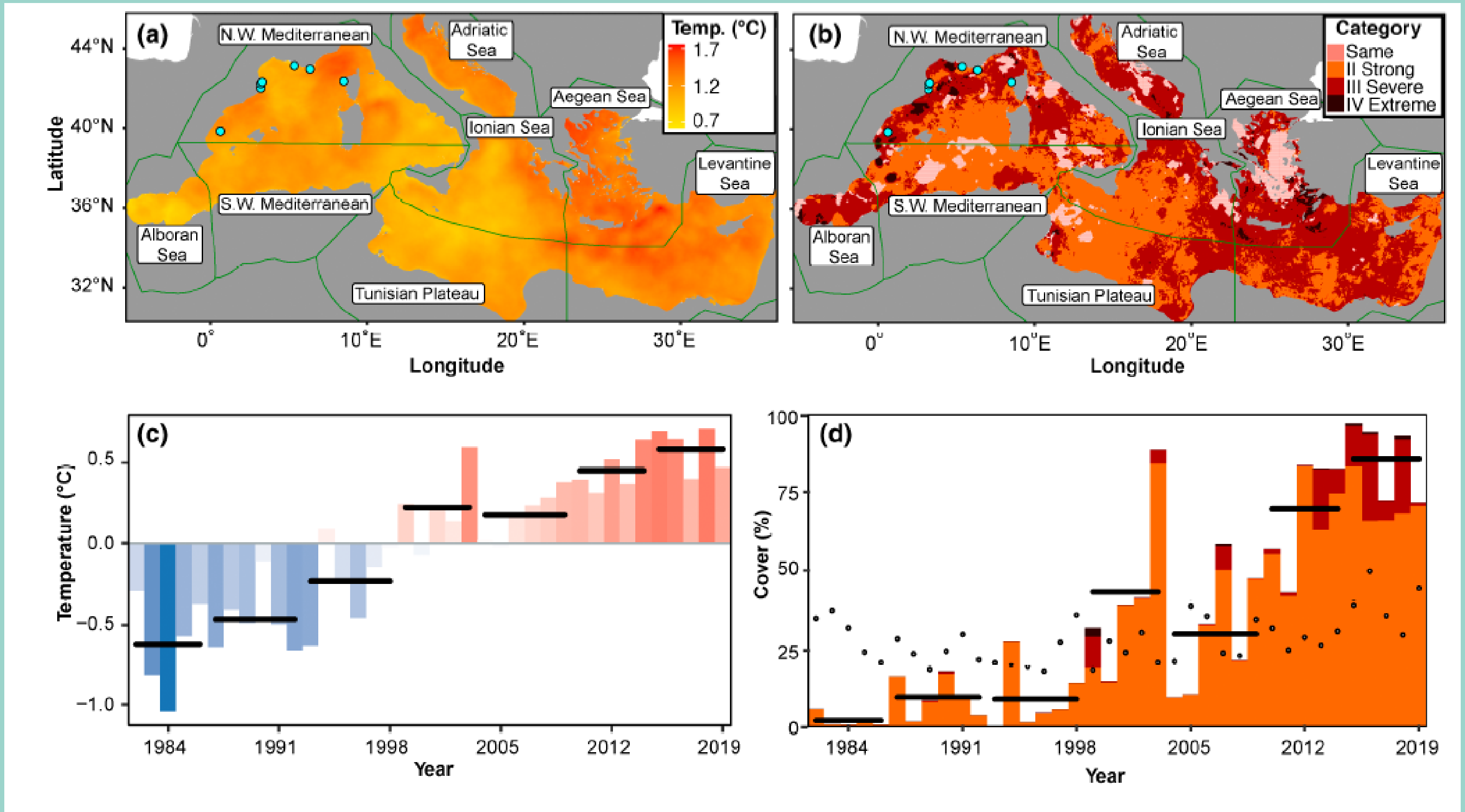



Wernberg et al. 2016 *Science*

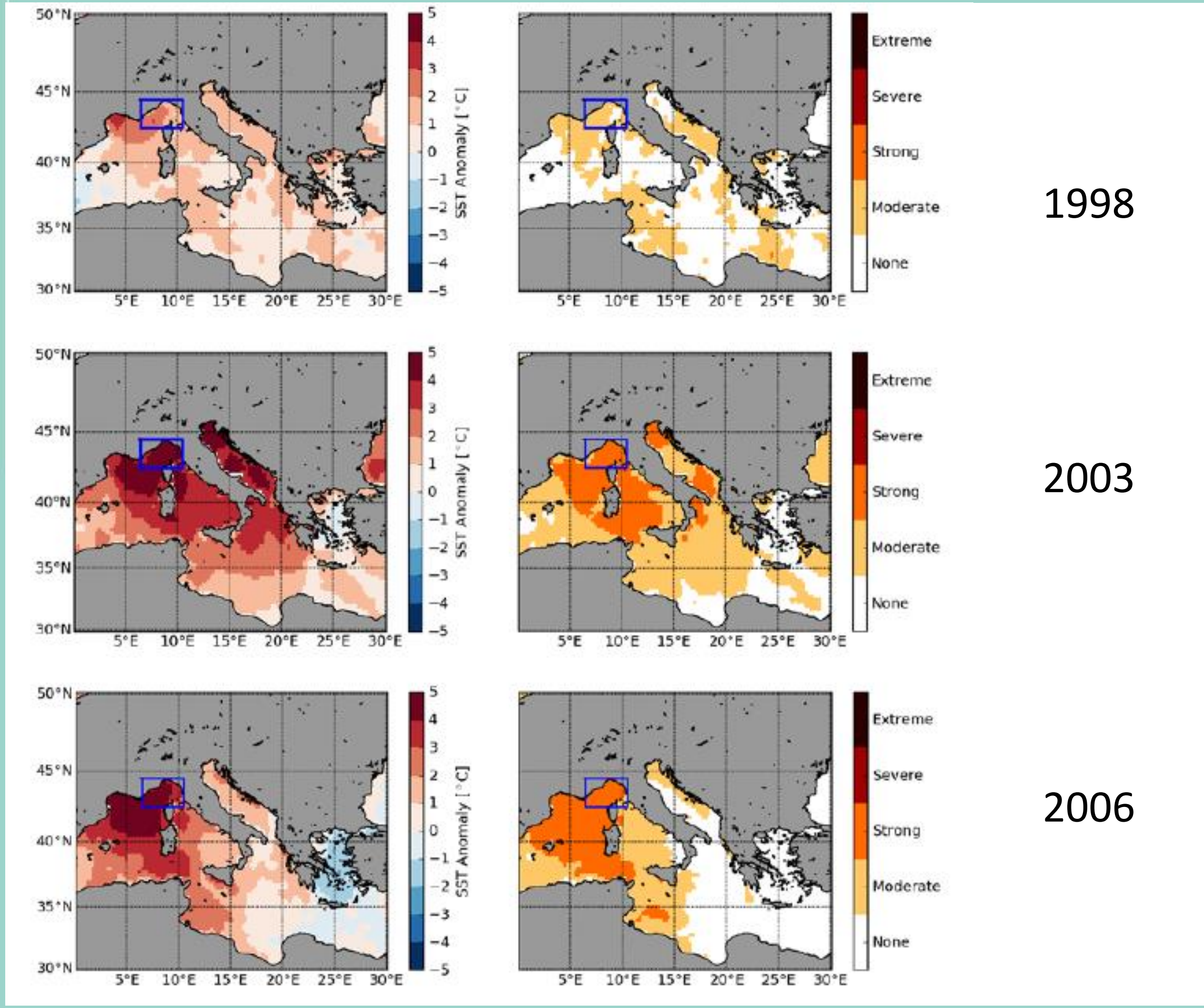
# Example 3: Mediterranean Sea MHW events

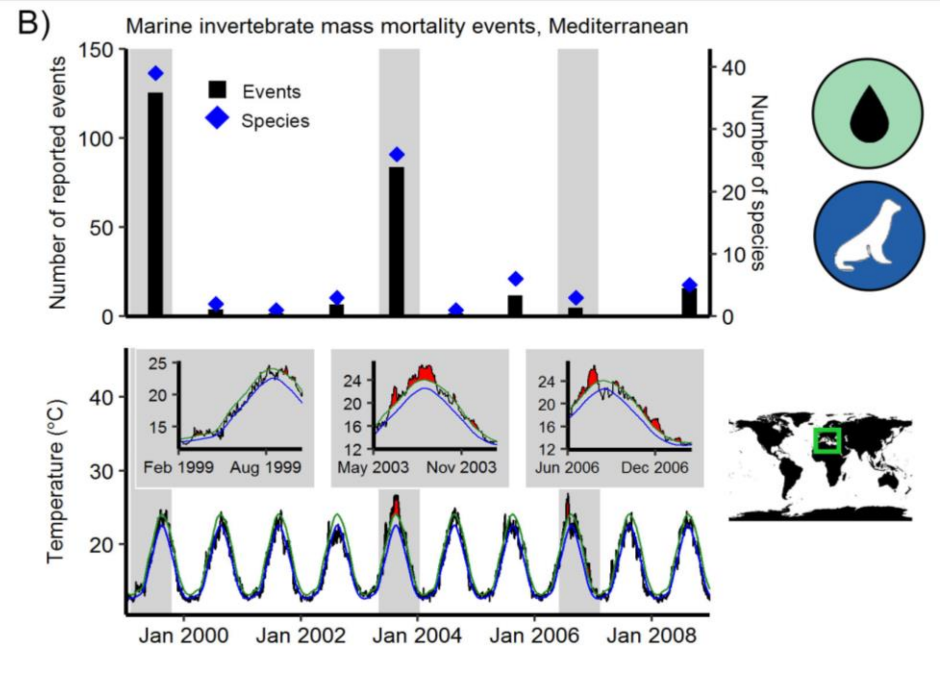
- Multiple marine heatwaves across the Med occurring with increasing frequency




Garrabou et al. 2022 *Glob. Change Biol.*

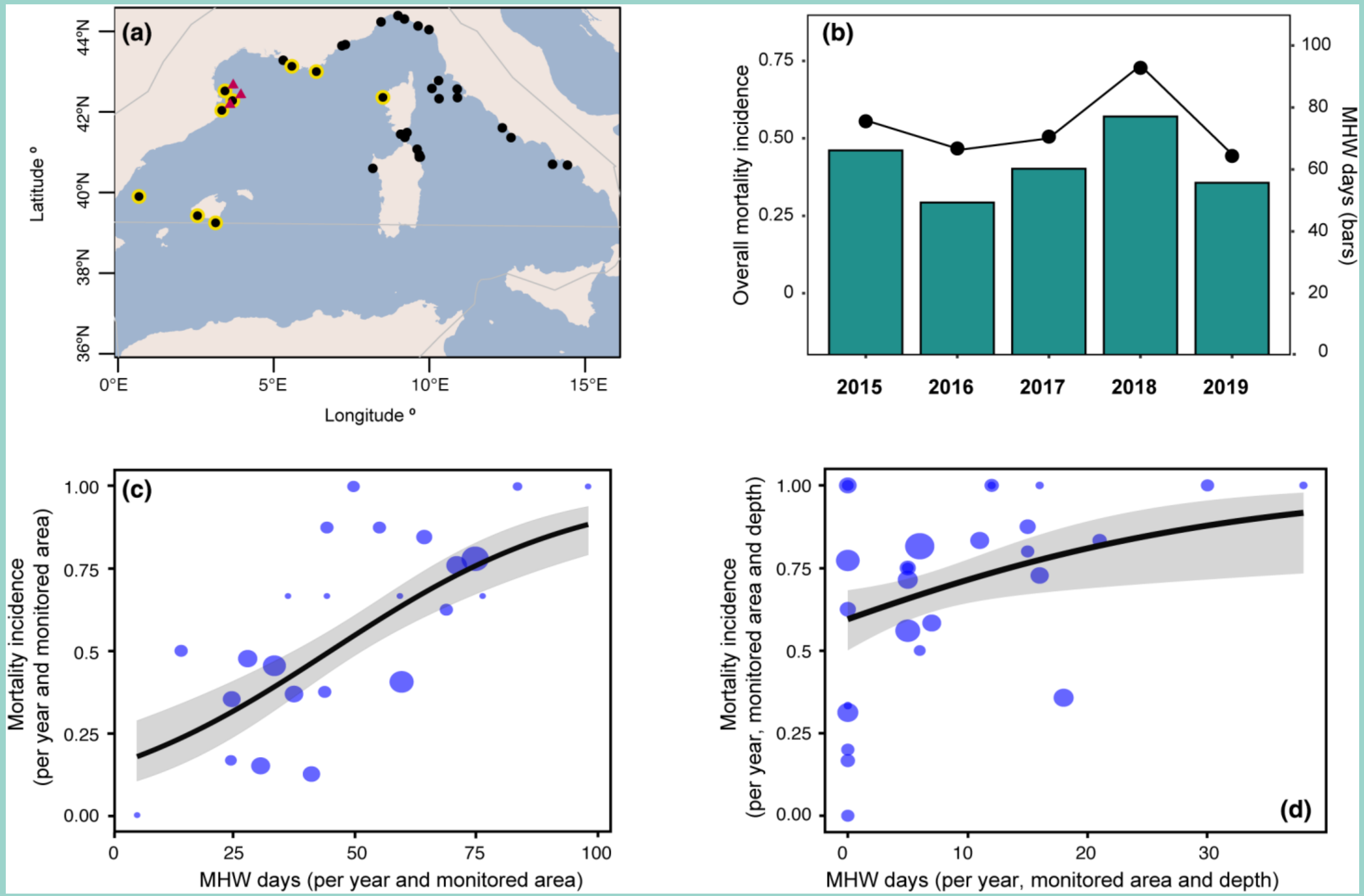
# Mediterranean Sea MHW events




- Mass mortality events recorded in benthic invertebrates due to thermal anomalies
    - >580 MMEs during 1998, 2003 & 2006 MHWs (> 80 spp., 6 taxa)

# Mediterranean Sea MHW events




- MMEs in the Mediterranean Sea from 2015-2019

Garrabou et al. 2022. *Glob. Change. Biol.*

# Socioeconomic impacts of MHWs


## Direct and indirect socioeconomic impacts

- Shifts in aquaculture/fisheries
- Impacts to tourism
- Reduced water quality
- Reduced storm protection

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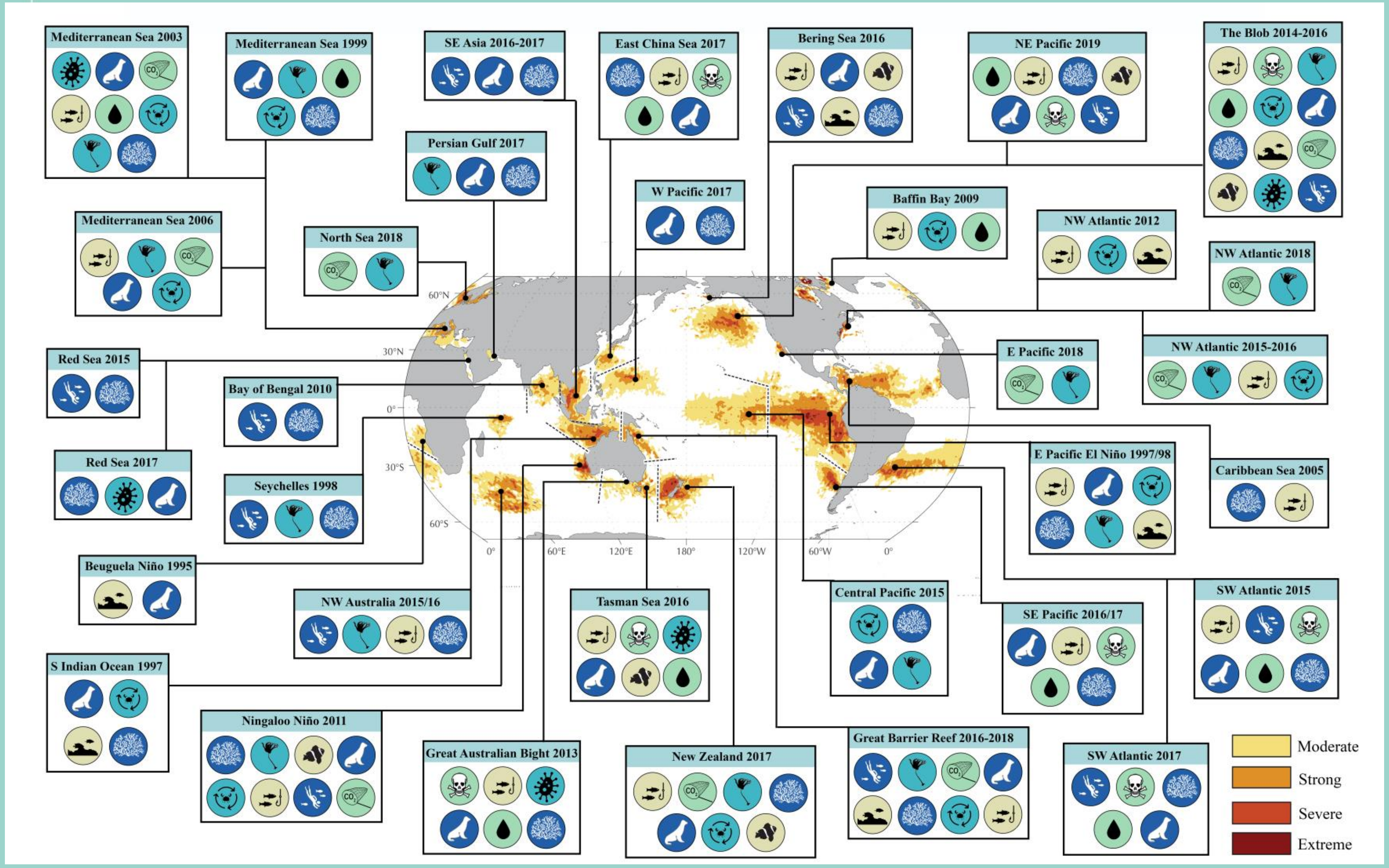
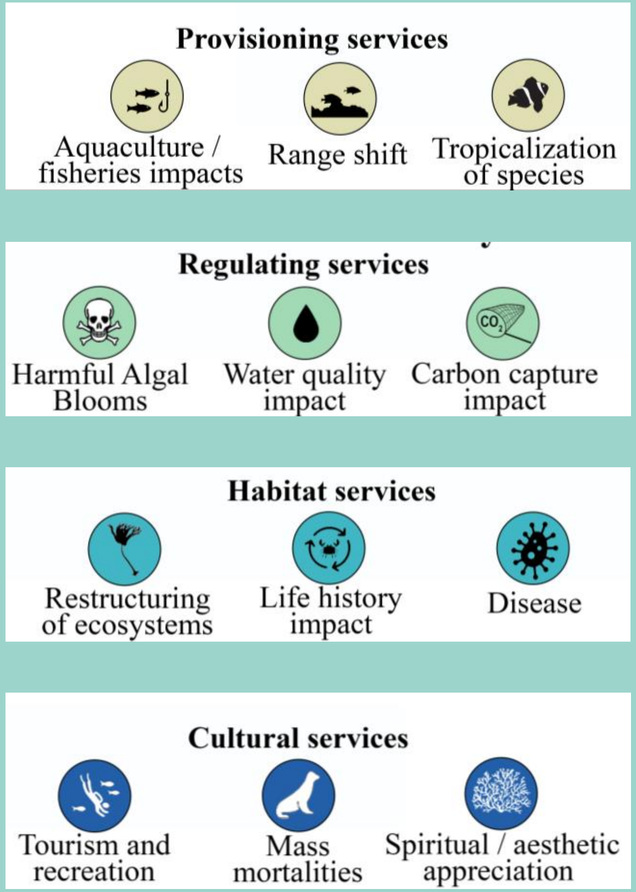
# 34 MHW events with socioeconomic impacts since 1995




Smith et al. 2021, *Science*

The Economics of Ecosystems and Biodiversity (TEEB) ecosystem services classifications (www.teebweb.org)



# Examples of global ocean assets

- Global ocean assets valued at ca. US$24 trillion

- Coral reefs valued at ~ US$35.8 billion per annum in tourism alone

- Australian kelp forests valued at ~ US$7.8 billion per annum in fishing and tourism

- USA saltwater fishing industries generate ~ US$210 billion in sales annually, supporting 1.7 million jobs.


Smith et al. 2021, *Science*

# Value of ecosystem services

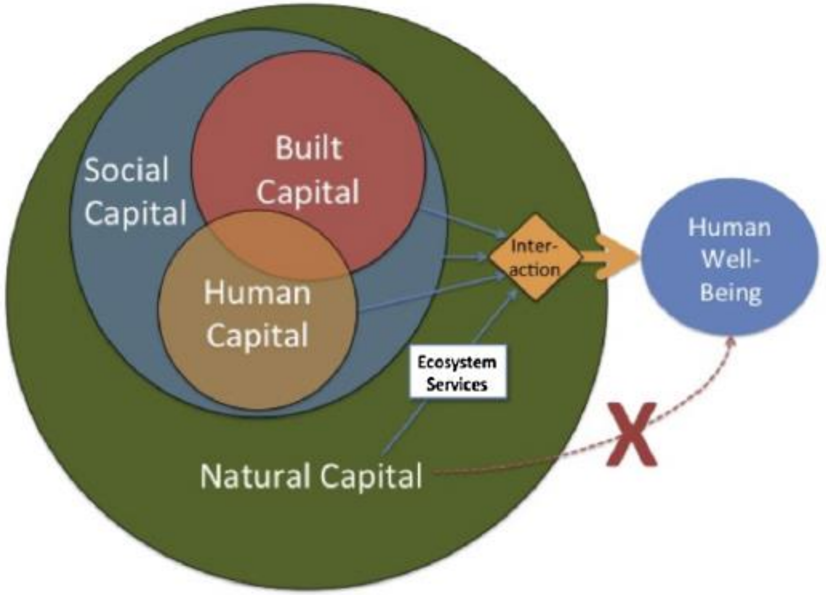



**Fig. 1.** Interaction between built, social, human and natural capital required to produce human well-being. Built and human capital (the economy) are embedded in society which is embedded in the rest of nature. Ecosystem services are the relative contribution of natural capital to human well-being, they do not flow directly. It is therefore essential to adopt a broad, transdisciplinary perspective in order to address ecosystem services.

| **Biome** | **Unit values** 2007$/ha/yr | | Change |
|---|---|---|---|
| | **1997** | **2011** | 2011-1997 |
| **Marine** | 796 | 1,368 | 572 |
| **Open Ocean** | 348 | 660 | 312 |
| **Coastal** | 5,592 | 8,944 | 3,352 |
| Estuaries | 31,509 | 28,916 | -2,593 |
| Seagrass/Algae Beds | 26,226 | 28,916 | 2,690 |
| Coral Reefs | 8,384 | 352,249 | 343,865 |
| Shelf | 2,222 | 2,222 | 0 |

Costanza et al. 2014, *Glob. Env. Change.*

# Value of ecosystem services

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Costanza et al. 2014, *Glob. Env. Change.*

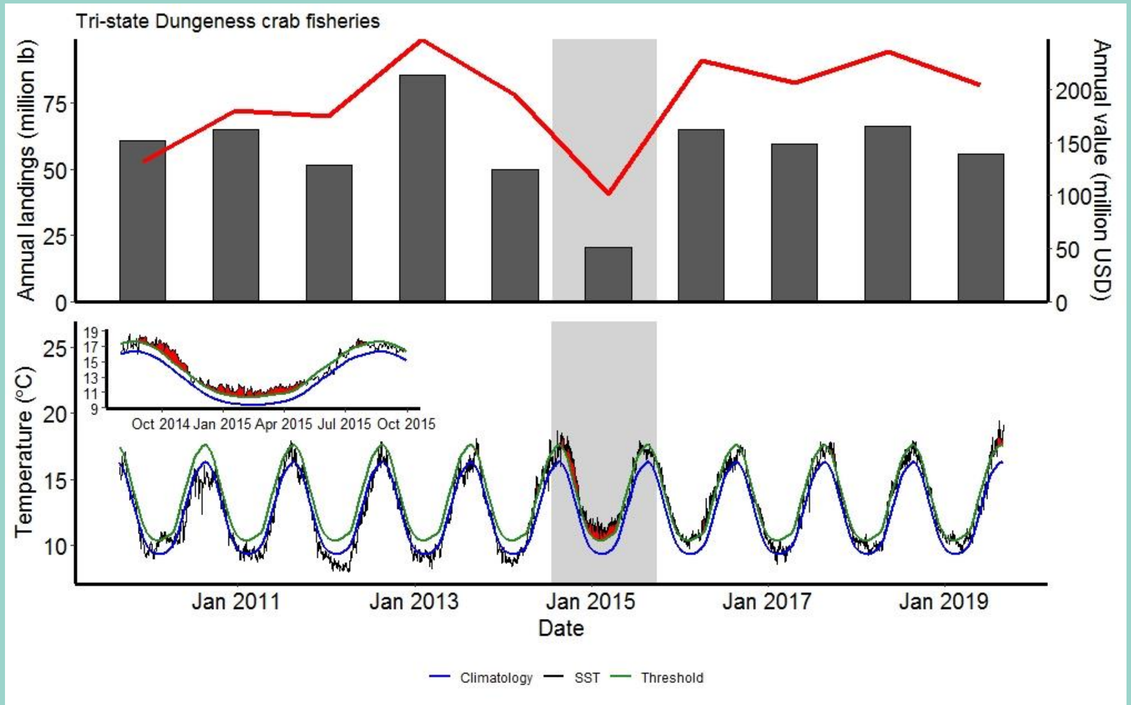
Kendrick et al. 2019 *Front. Mar. Sci.*

Smith et al. 2021, *Science*

Ecosystem service value of 1,300 km$^2$ seagrass lost from Shark Bay in 2011 valued at $3.1 billion pa

# ‘The blob’ MHW in the Northeast Pacific

- Harmful algal blooms led to the closure of:
  - Commercial tri-state Dungeness crab fishery (California, Oregon, Washington)
    - Estimated US$97 million in loss of earnings
  - Washington recreational razor clam fishery
    - Estimated US$40 million in tourist spending




Smith et al. 2021, *Science*

# ‘The blob’ MHW in the Northeast Pacific

- Loss of kelp forest led to the closure of:
  - California recreational abalone fishery
    - Estimated US$44 million in loss of tourist spending
  - California commercial red sea urchin fishery
    - Estimated US$3 million in loss of earnings

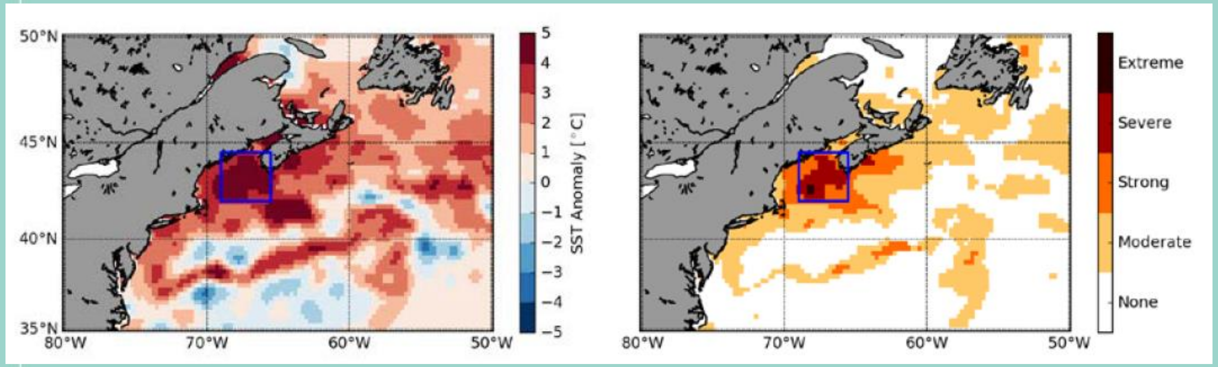
Smith et al. 2021, *Science*

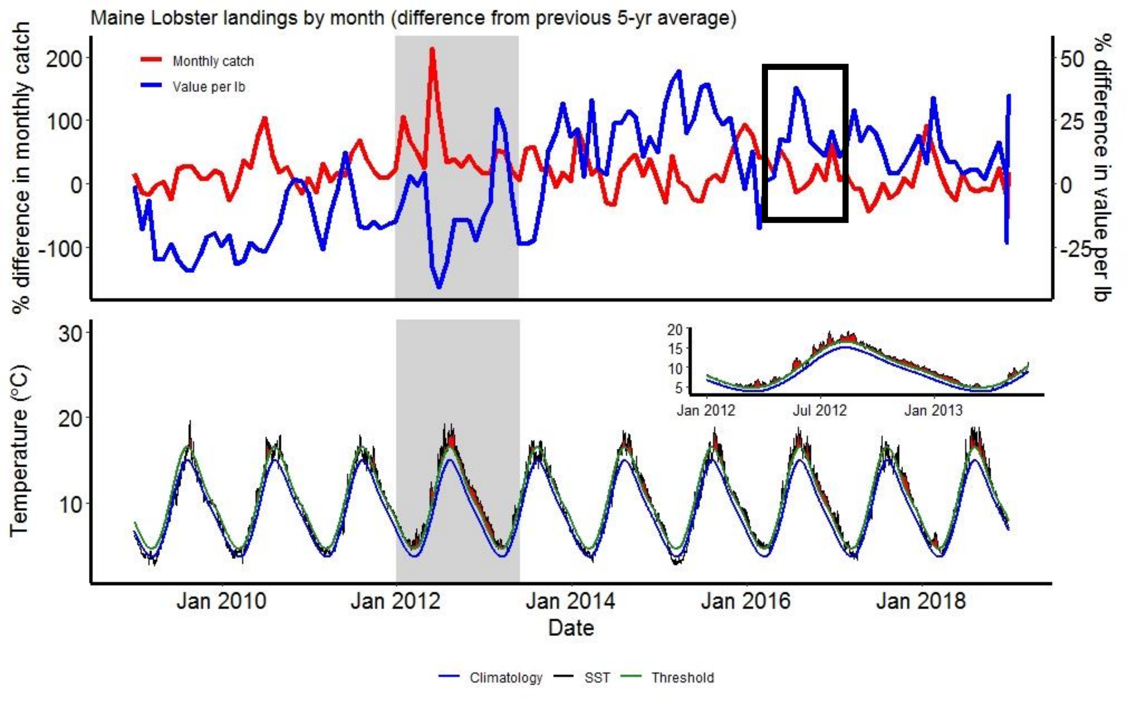
# Example 2: Coral reef tourism

- Coral bleaching and mass mortalities of coral in the South East Asia seas during a MHW in 2010
  - US$49-74 million loss in tourist spending
- Mass bleaching has been seen on the Great Barrier Reef over multiple years recently.
  - Value of the GBR is US$4.2 billion pa
  - Loss unknown
  - Gains related to ‘last chance tourism also unknown

Smith et al. 2021, *Science*

# Example 3: Impacts of the 2012 MHW in the Northwest Atlantic




- Early moult and migration to shallow water in Lobster led to very high spring landings
- Lobster price crashed as supply exceeded processing capacity and demand (US$38 million loss)
- BUT... Lessons were learned and in 2016 when another heatwave occurred, quotas were reduced and gain was US$108 million

# Management strategies

Combine forecasting with current biological knowledge

- Management strategies include:
  - Put quotas into place
  - Alter timing of stocking
  - Alter timing of harvesting
  - Reduce other local stressors
  - Alter timing of restoration efforts

# Conclusions

- Both the biological and the socioeconomic impacts of MHWs are broad and widespread globally
- Understanding these impacts helps us to predict what will happen during future MHWs
- This knowledge can then be used to guide management decisions to put practices in place to help reduce the MHW impacts

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