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Phytoplankton & Marine Heatwaves

What 38 years of data can tell us about climate change in the ocean.

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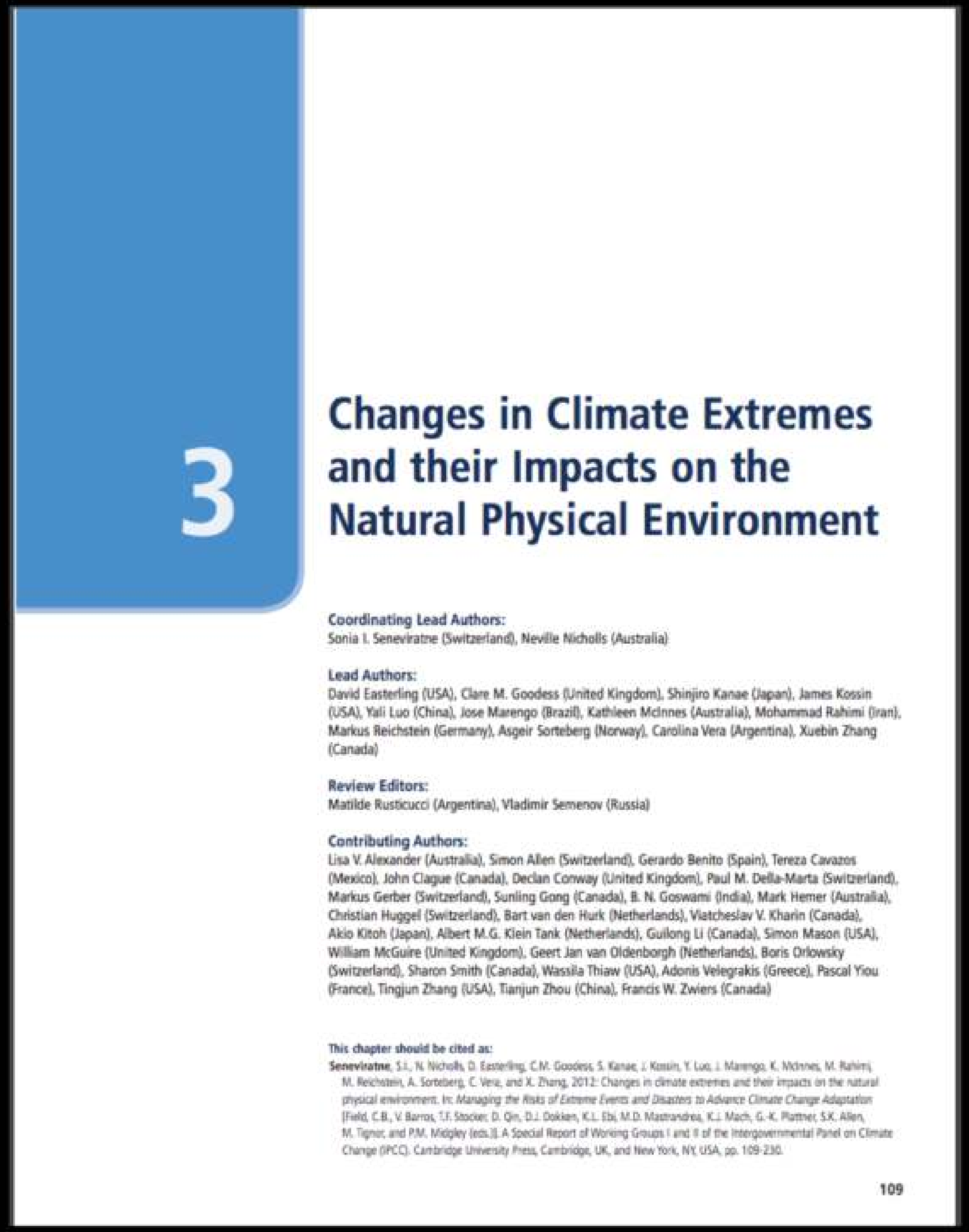
Climate Change + The New “Extremes”

- Extreme Climate Events (ECEs) ⛈️🌪️🔥
    - Floods, Wildfires, Heatwaves, Droughts, etc.
- We’re projected to have more of them.
    - *“A changing climate leads to changes in the frequency, intensity, spatial extent, duration, and timing of weather and climate extremes, and can result in unprecedented extremes.”* (IPCC SREX 2012, Ch. 3)
    - *“Models project substantial warming in temperature extremes by the end of the 21st century. It is virtually certain that increases in the frequency and magnitude of warm daily temperature extremes and decreases in cold extremes will occur through the 21st century at the global scale.”* (IPCC SREX 2012, Ch. 3)



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Changes in Climate Extremes and their Impacts on the Natural Physical Environment

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IPCC Special Report on Climate Extremes (SREX), Chapter 3. 2012.

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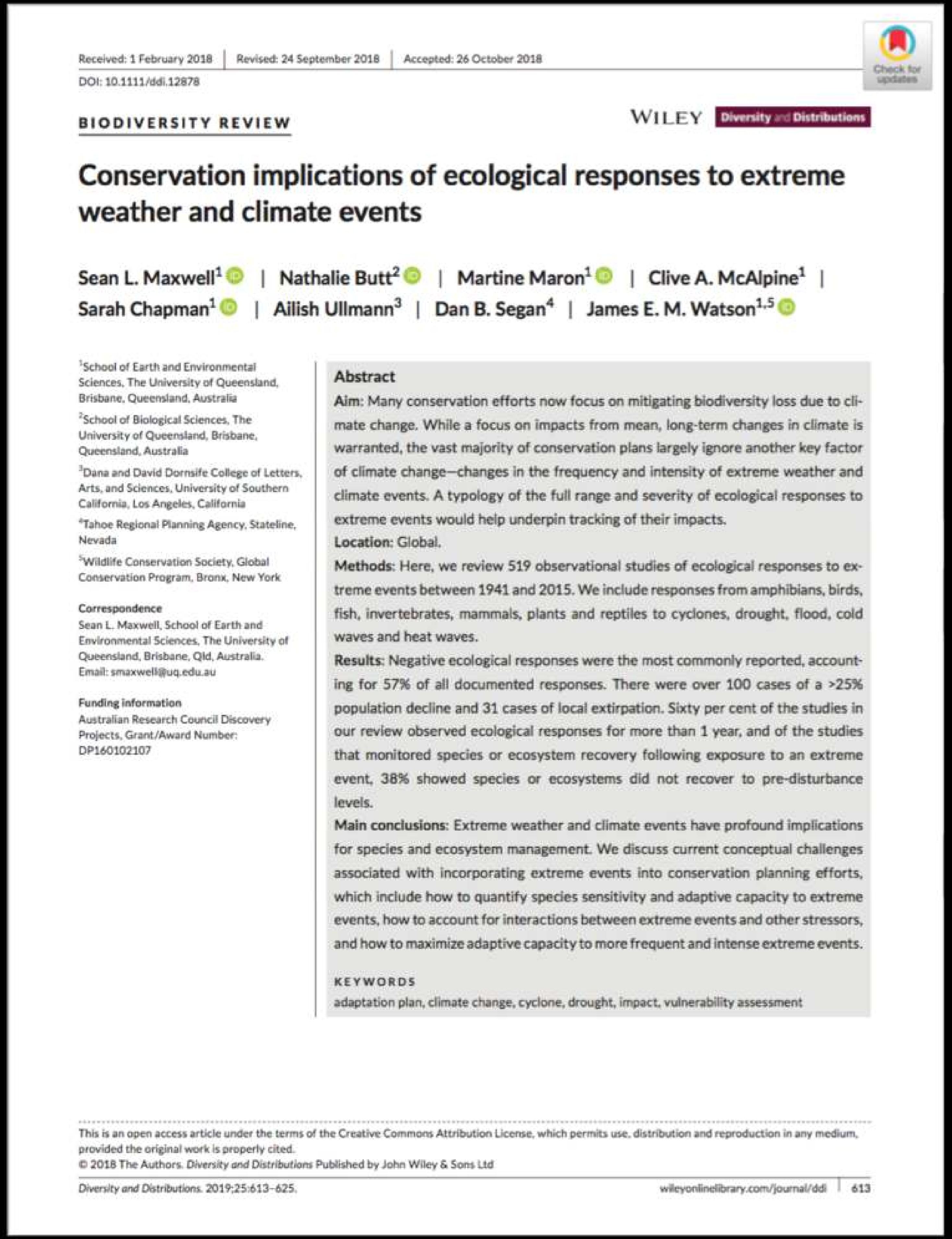
ECEs have Ecological Impact. 🌱

- Review of 519 observational studies of response to ECEs showed:
  - Over 100 cases of >25% population decline
  - 31 cases of local extirpation
  - Negative ecological responses in 57% of studies
  - Decadal recovery timescales



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BIODIVERSITY REVIEW

WILEY Diversity and Distributions

Conservation implications of ecological responses to extreme weather and climate events

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Abstract

Aim: Many conservation efforts now focus on mitigating biodiversity loss due to climate change. While a focus on impacts from mean, long-term changes in climate is warranted, the vast majority of conservation plans largely ignore another key factor of climate change—changes in the frequency and intensity of extreme weather and climate events. A typology of the full range and severity of ecological responses to extreme events would help underpin tracking of their impacts.

Location: Global.

Methods: Here, we review 519 observational studies of ecological responses to extreme events between 1941 and 2015. We include responses from amphibians, birds, fish, invertebrates, mammals, plants and reptiles to cyclones, drought, flood, cold waves and heat waves.

Results: Negative ecological responses were the most commonly reported, accounting for 57% of all documented responses. There were over 100 cases of a >25% population decline and 31 cases of local extirpation. Sixty per cent of the studies in our review observed ecological responses for more than 1 year, and of the studies that monitored species or ecosystem recovery following exposure to an extreme event, 38% showed species or ecosystems did not recover to pre-disturbance levels.

Main conclusions: Extreme weather and climate events have profound implications for species and ecosystem management. We discuss current conceptual challenges associated with incorporating extreme events into conservation planning efforts, which include how to quantify species sensitivity and adaptive capacity to extreme events, how to account for interactions between extreme events and other stressors, and how to maximize adaptive capacity to more frequent and intense extreme events.

KEYWORDS
adaptation plan, climate change, cyclone, drought, impact, vulnerability assessment

Diversity and Distributions. 2019;25:613–625. wileyonlinelibrary.com/journal/ddi | 613

(Maxwell et al., 2019)

ECEs have Ecological Impact. 🌱

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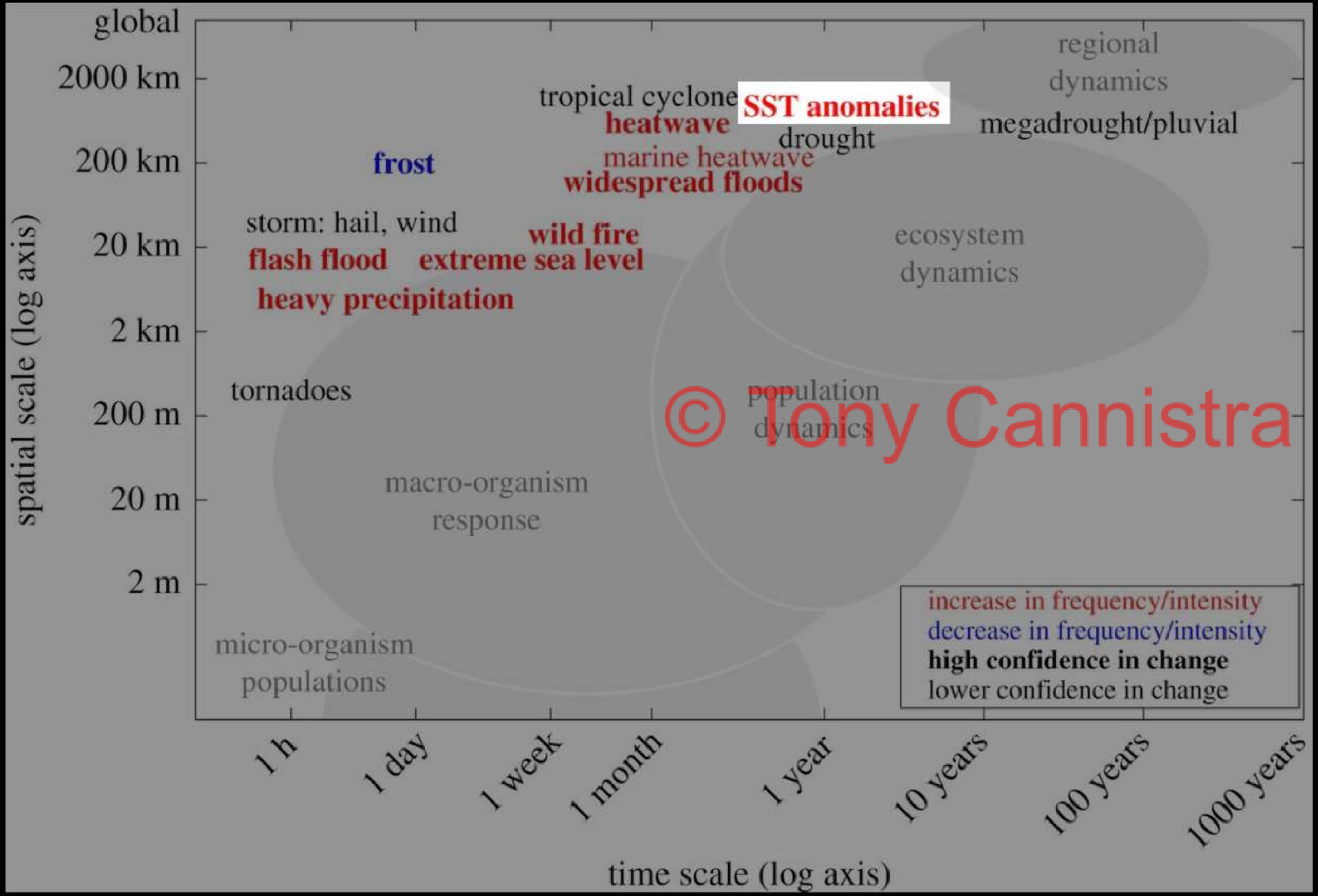

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Review

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One contribution of 14 to a theme issue 'Behavioural, ecological and evolutionary responses to extreme climatic events'.

Subject Areas:
environmental science

Keywords:
extreme events, climate variability, climate change, detection and attribution, event attribution, ecological impacts

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Extreme weather and climate events with ecological relevance: a review

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Robust evidence exists that certain extreme weather and climate events, especially daily temperature and precipitation extremes, have changed in regard to intensity and frequency over recent decades. These changes have been linked to human-induced climate change, while the degree to which climate change impacts an individual extreme climate event (ECE) is more difficult to quantify. Rapid progress in event attribution has recently been made through improved understanding of observed and simulated climate variability, methods for event attribution and advances in numerical modelling. Attribution for extreme temperature events is stronger compared with other event types, notably those related to the hydrological cycle. Recent advances in the understanding of ECEs, both in observations and their representation in state-of-the-art climate models, open new opportunities for assessing their effect on human and natural systems. Improved spatial resolution in global climate models and advances in statistical and dynamical downscaling now provide climatic information at appropriate spatial and temporal scales. Together with the continued development of Earth System Models that simulate biogeochemical cycles and interactions with the biosphere at increasing complexity, these make it possible to develop a mechanistic understanding of how ECEs affect biological processes, ecosystem functioning and adaptation capabilities. Limitations in the observational network, both for physical climate system parameters and even more so for long-term ecological monitoring, have hampered progress in understanding bio-physical interactions across a range of scales. New opportunities for assessing how ECEs modulate ecosystem structure and functioning arise from better scientific understanding of ECEs coupled with technological advances in observing systems and instrumentation.

This article is part of the themed issue 'Behavioural, ecological and evolutionary responses to extreme climatic events'.

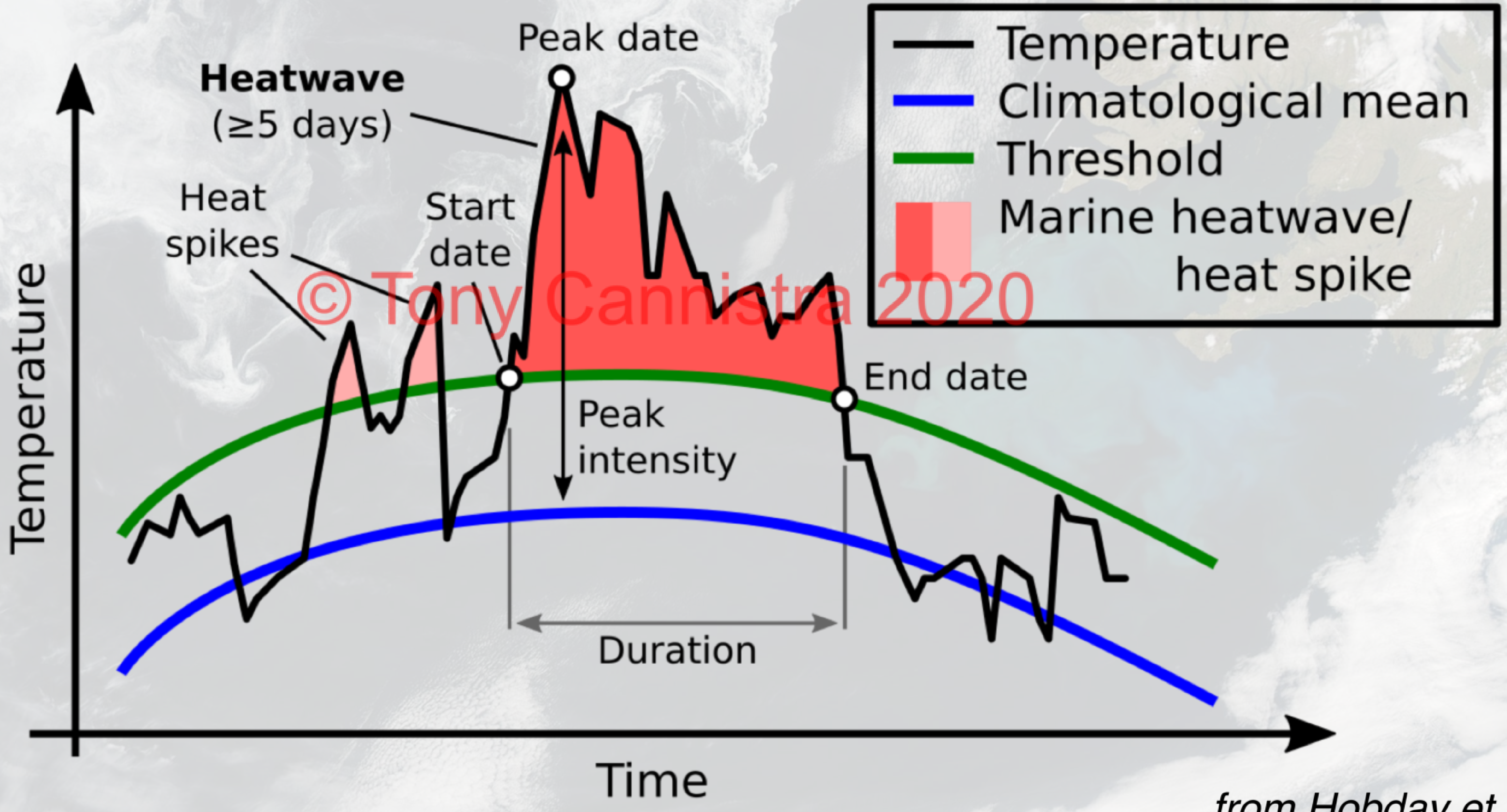
1. Introduction and motivation

A recent publication by the National Academy of Sciences [1] is the latest addition to a series of focused summary reports [2–4] that highlight mounting evidence that extreme weather and climate events have been changing in regard to intensity, frequency and duration in the last few decades. Daily temperature and precipitation extremes in particular have been observed to increase in frequency and intensity, which has been linked to human-induced climate change [5–7].

By contrast, the degree to which climate change impacts an individual extreme weather or climatic event is more difficult to determine and quantify. This applies especially when considering that a variety of natural and anthropogenic factors, such as internal modes of climate variability, various man-made emissions, land-use change, and so on, need to be taken into account when attributing individual weather or climate events to causal factors. Solow [8] cautioned that the concept of attributable risk for single events in a climate change context is inherently difficult given the rarity of extreme climatic events (ECEs) and the limited reliable climatic record. Extreme events by definition are rare occurrences and in most places few examples of past events are seen in the observational record [1].

(Ummenhofer and Meehl, 2017)

Enter: Marine Heatwaves. 🌊



from Hobday et al., 2016

Δ = Longer, More Frequent MHWs

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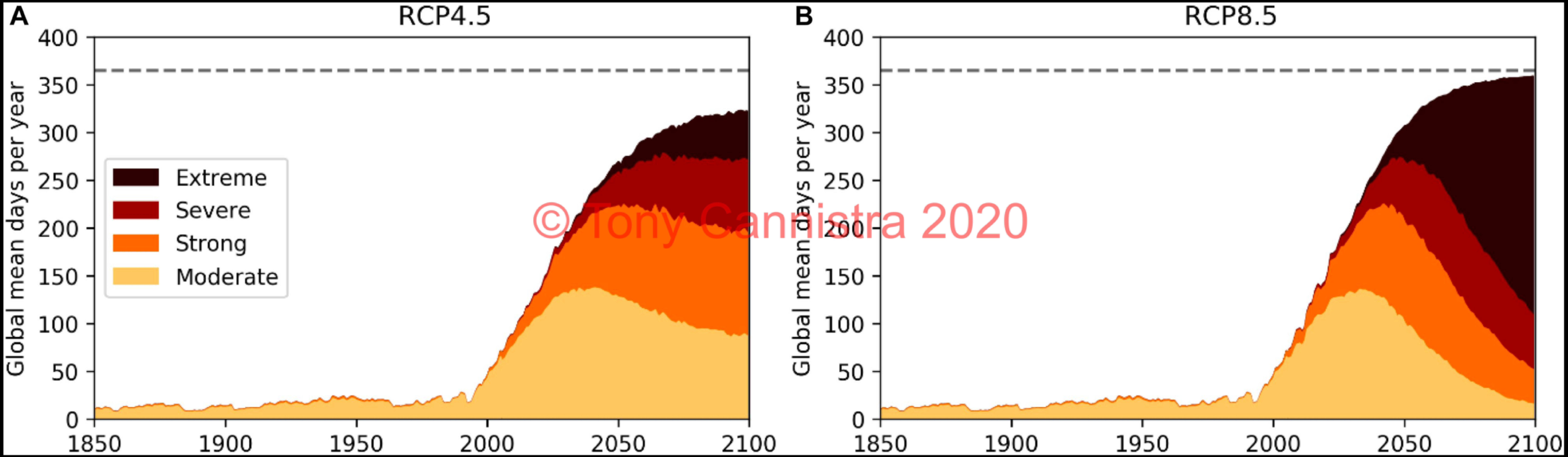
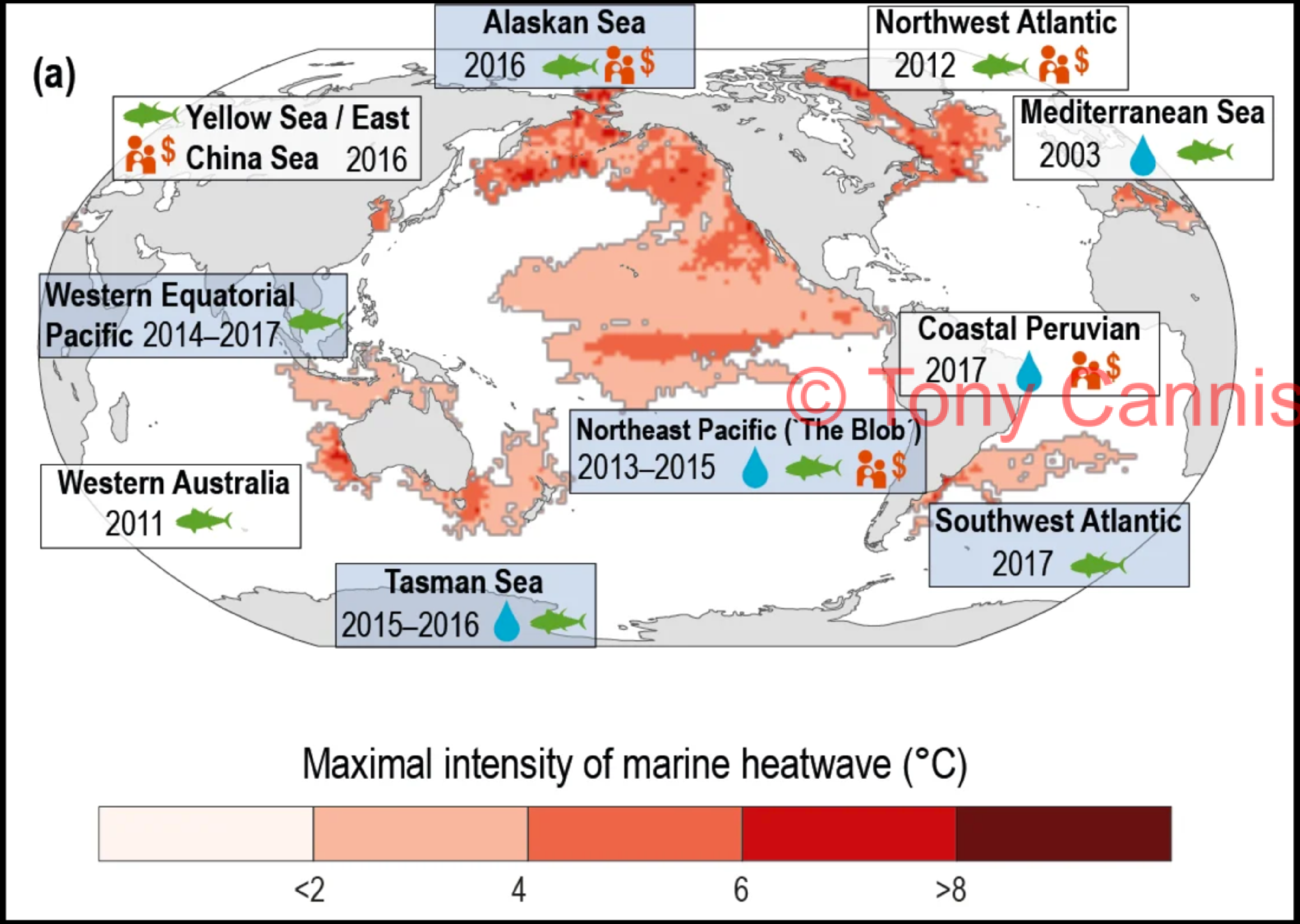
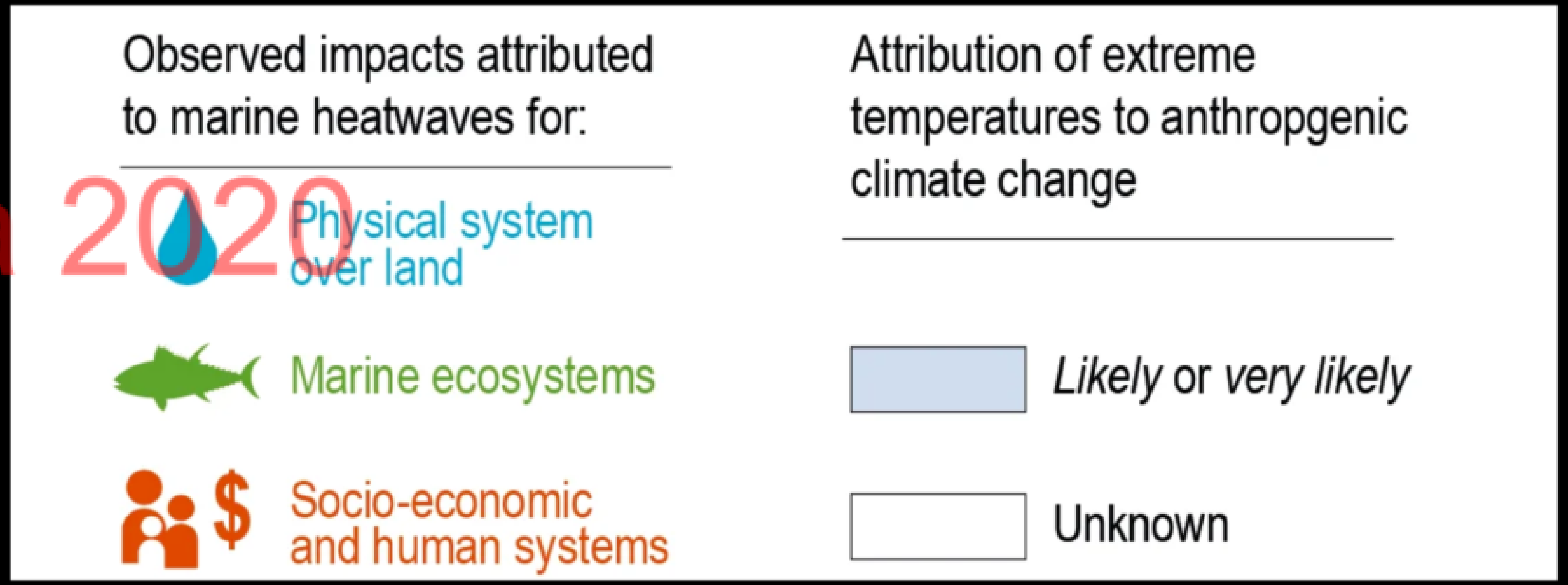


(Oliver et al., 2019)

MHWs have varied effects.

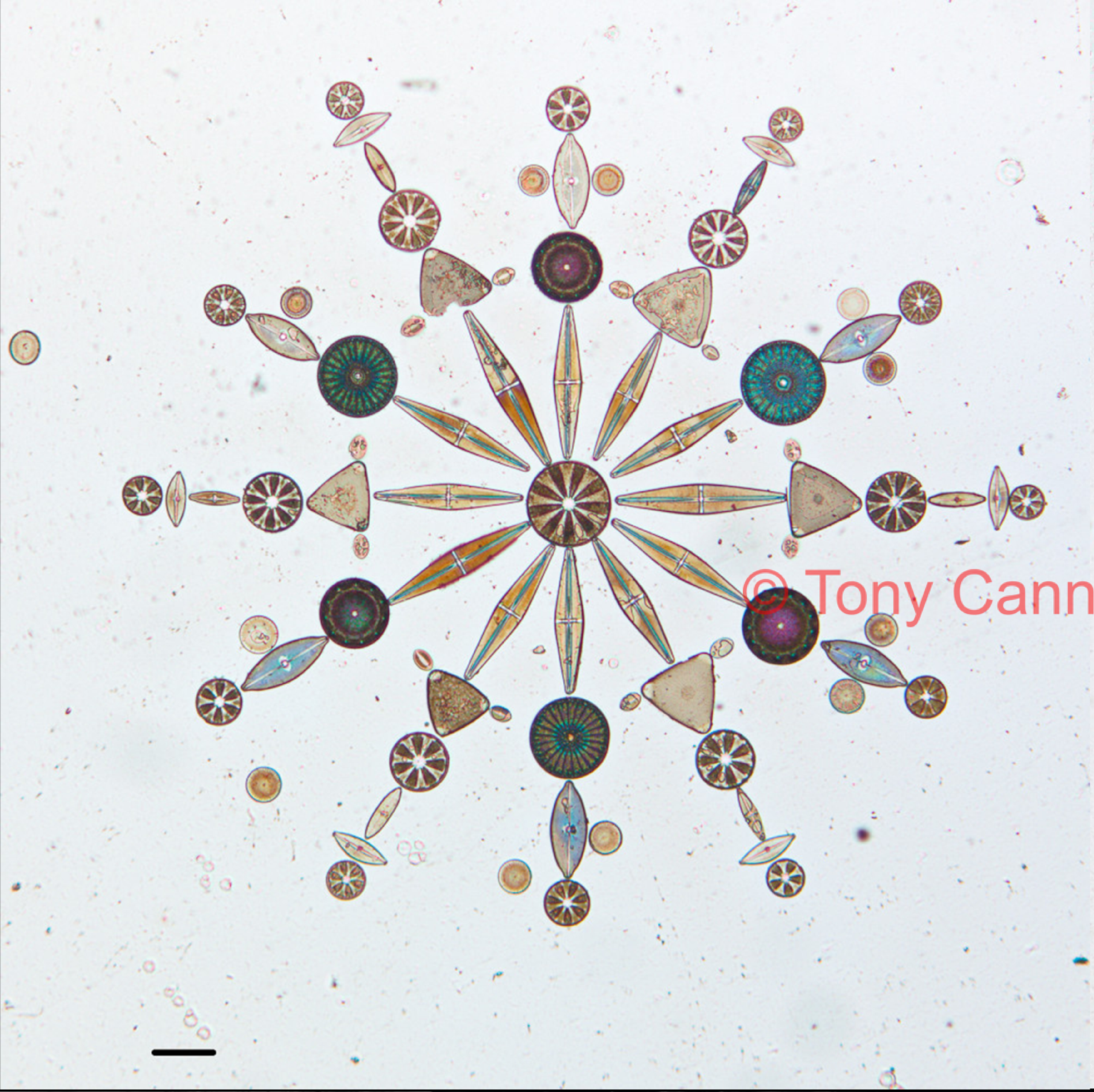


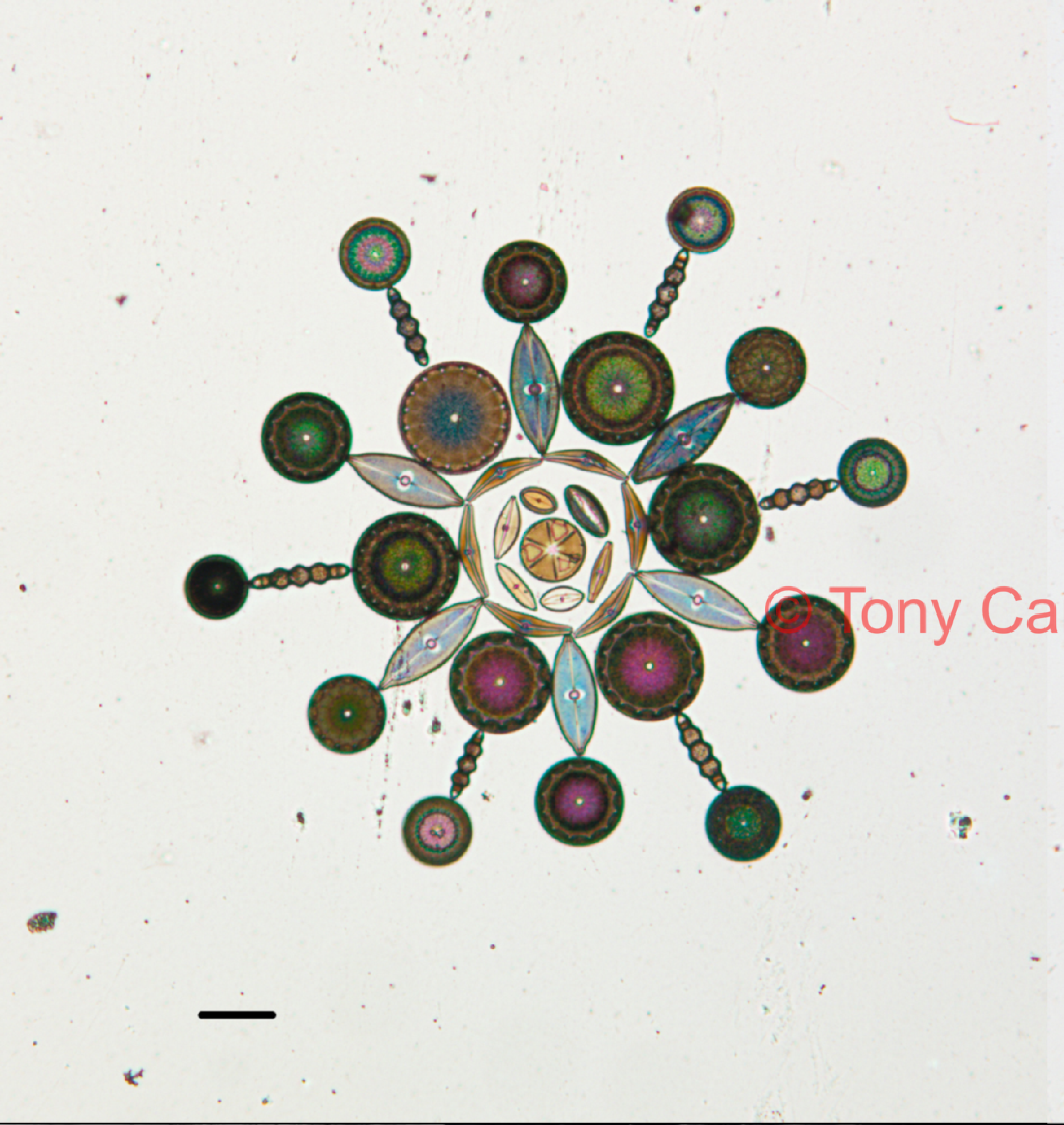


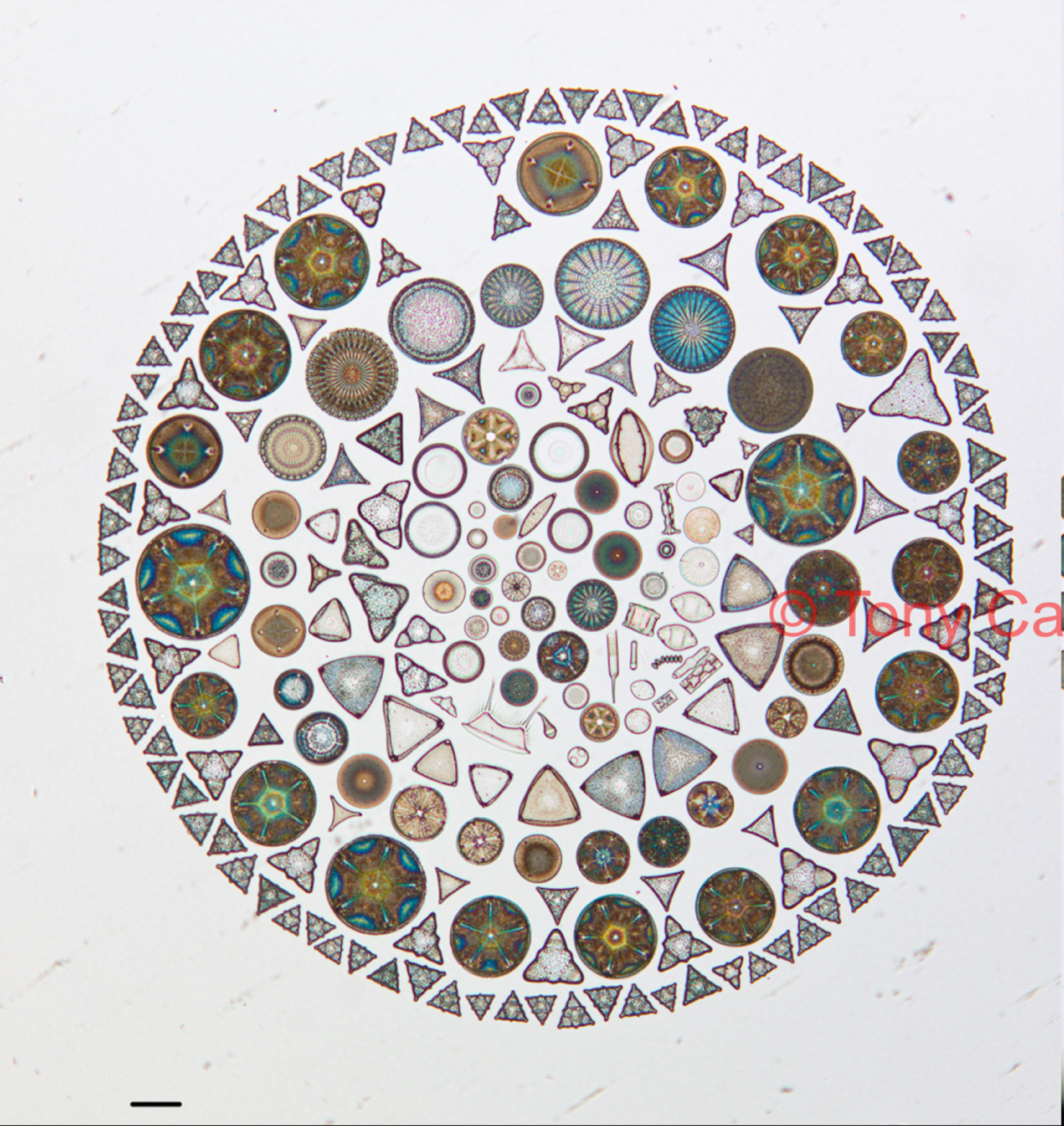
(IPCC SROCC 2019, Ch. 6.4)

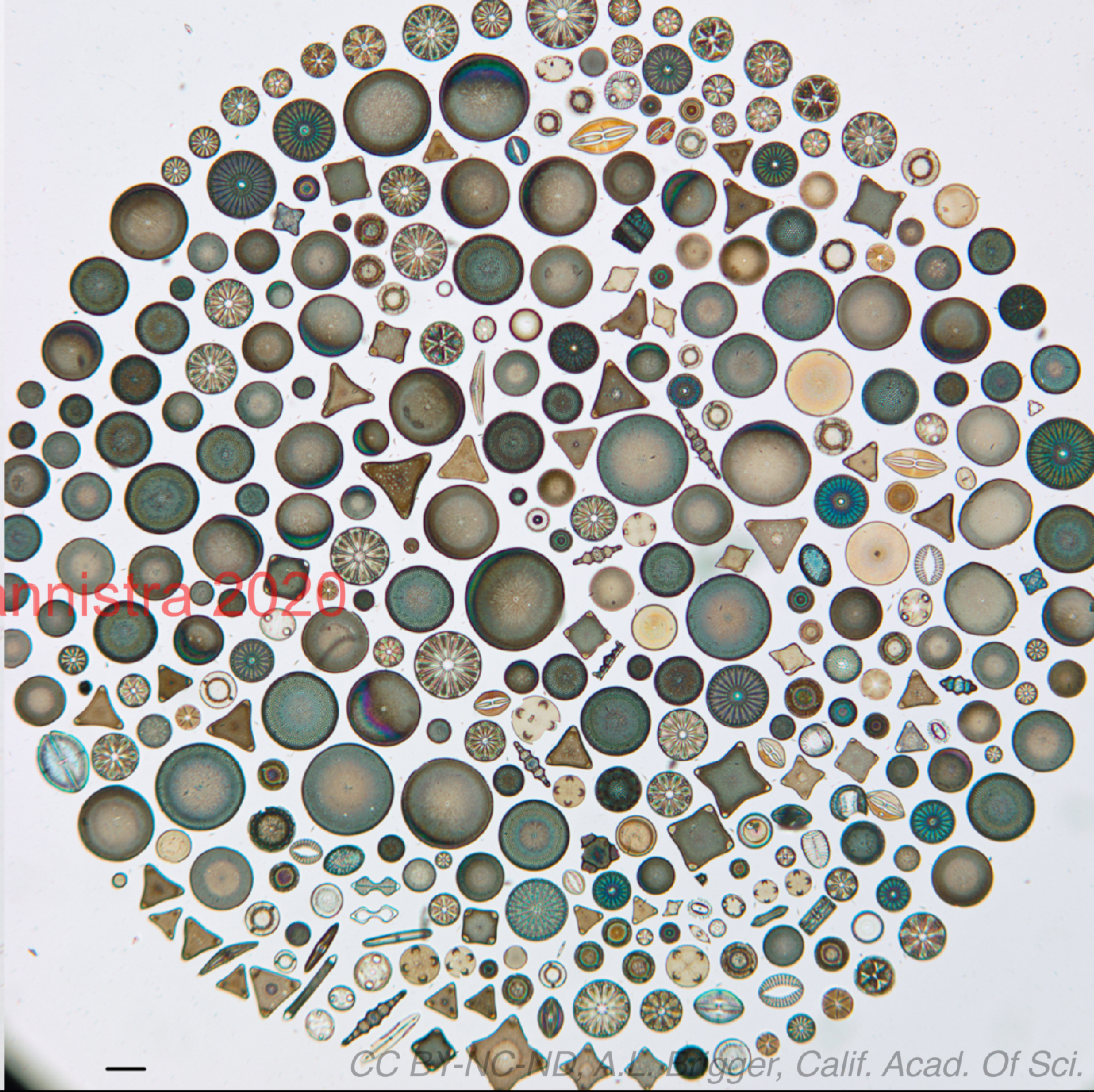
MHWs have biological consequences.

- The 2015/16 Tasman Sea:
  - increased mortality in oyster, abalone, and salmon populations (Oliver et al., 2017)
- 2013-2015 NE Pacific ("the blob"):
  - novel community compositions; an increase in warm-water copepod species in the Northern California region, and increased mortality of sea lions, whales, and sea birds (Cavole et al., 2016; Frölicher and Laufkötter, 2018)
- **But:** most of what we know is taxonomically and geographically limited.





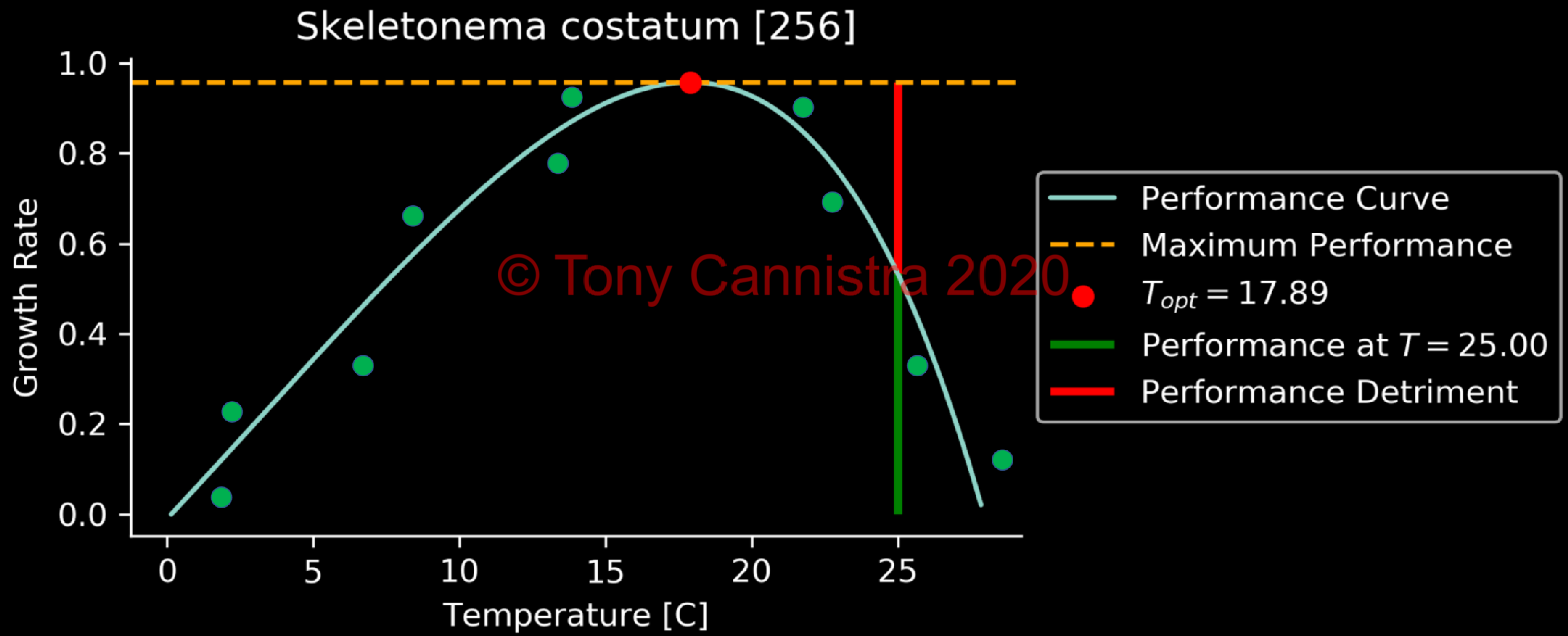




Phytoplankton as Proxies

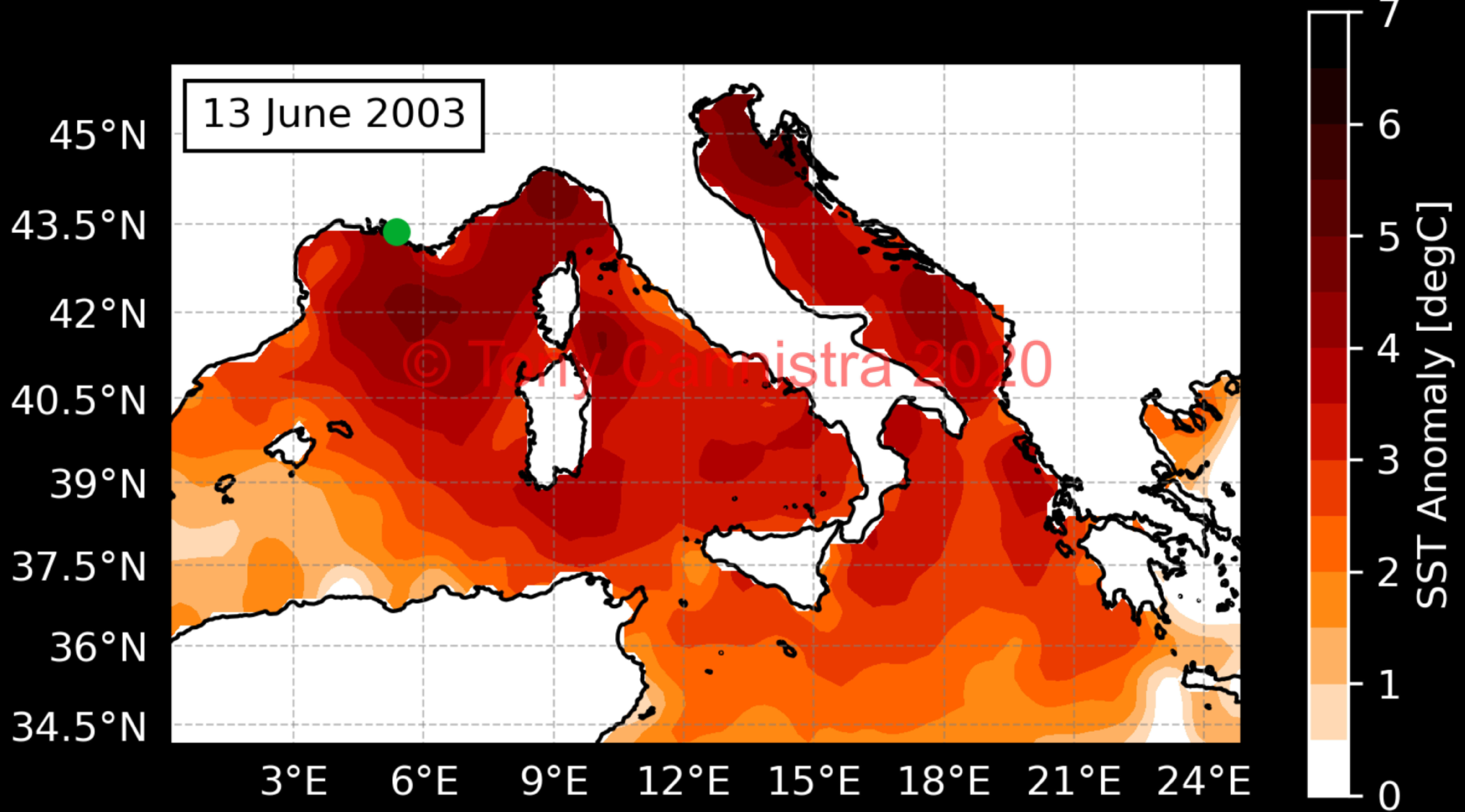
- Phytoplankton have an important biogeochemical role as <u>drivers of C and Si nutrient cycles</u> (Falkowski, 1994)
- The <u>primary production role</u> of phytoplankton in their trophic context suggests that phytoplankton responses to MHWs could be <u>extrapolated to higher trophic levels</u>.
  - e.g. via temperature-dependent herbivory (O'Connor et al., 2011).
- We know quite a bit about how phytoplankton growth rate depends on environment, especially temperature. (Thomas et al., 2012, 2016)

Thermal Physiology 101



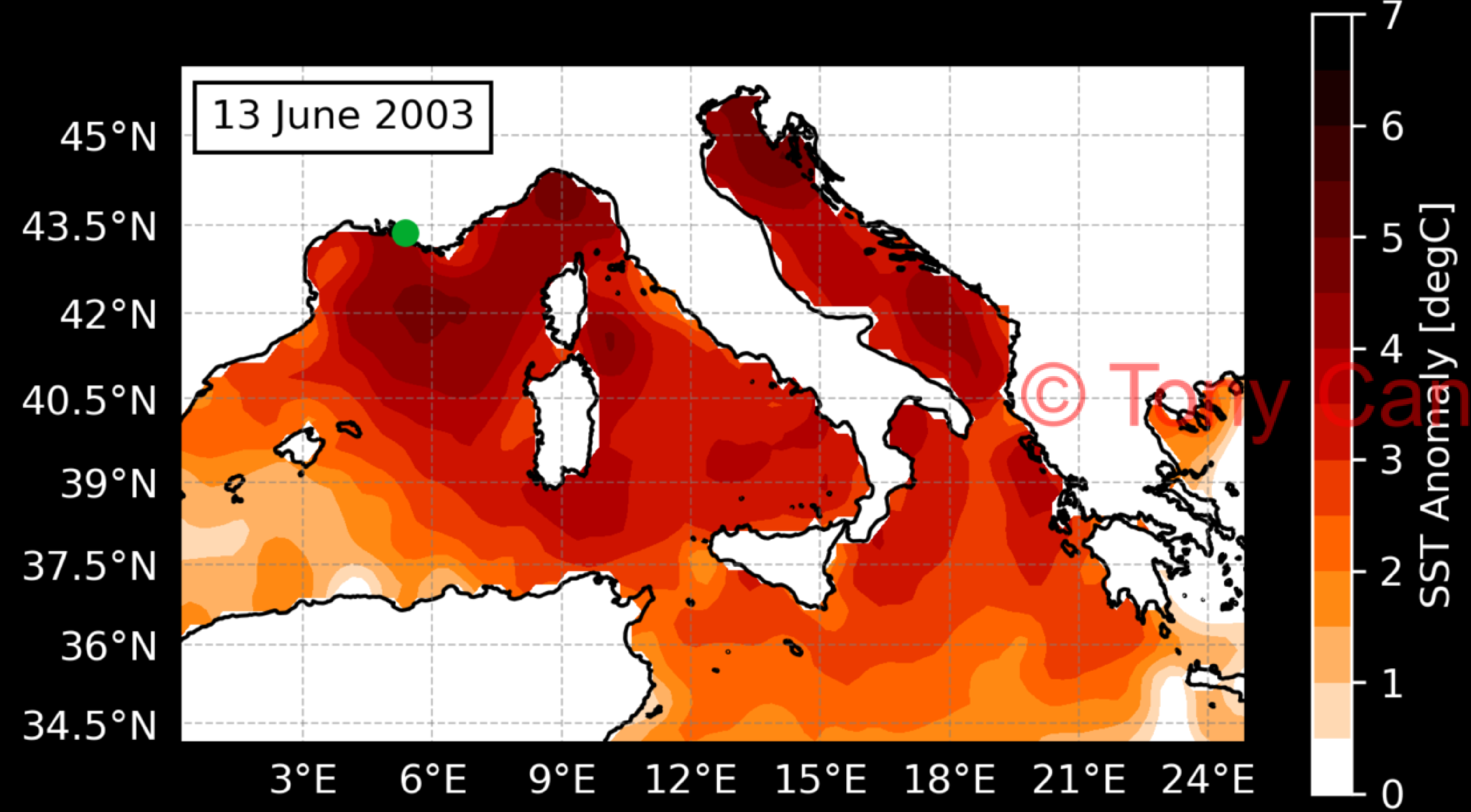
Data: Thomas et al., 2012/2016

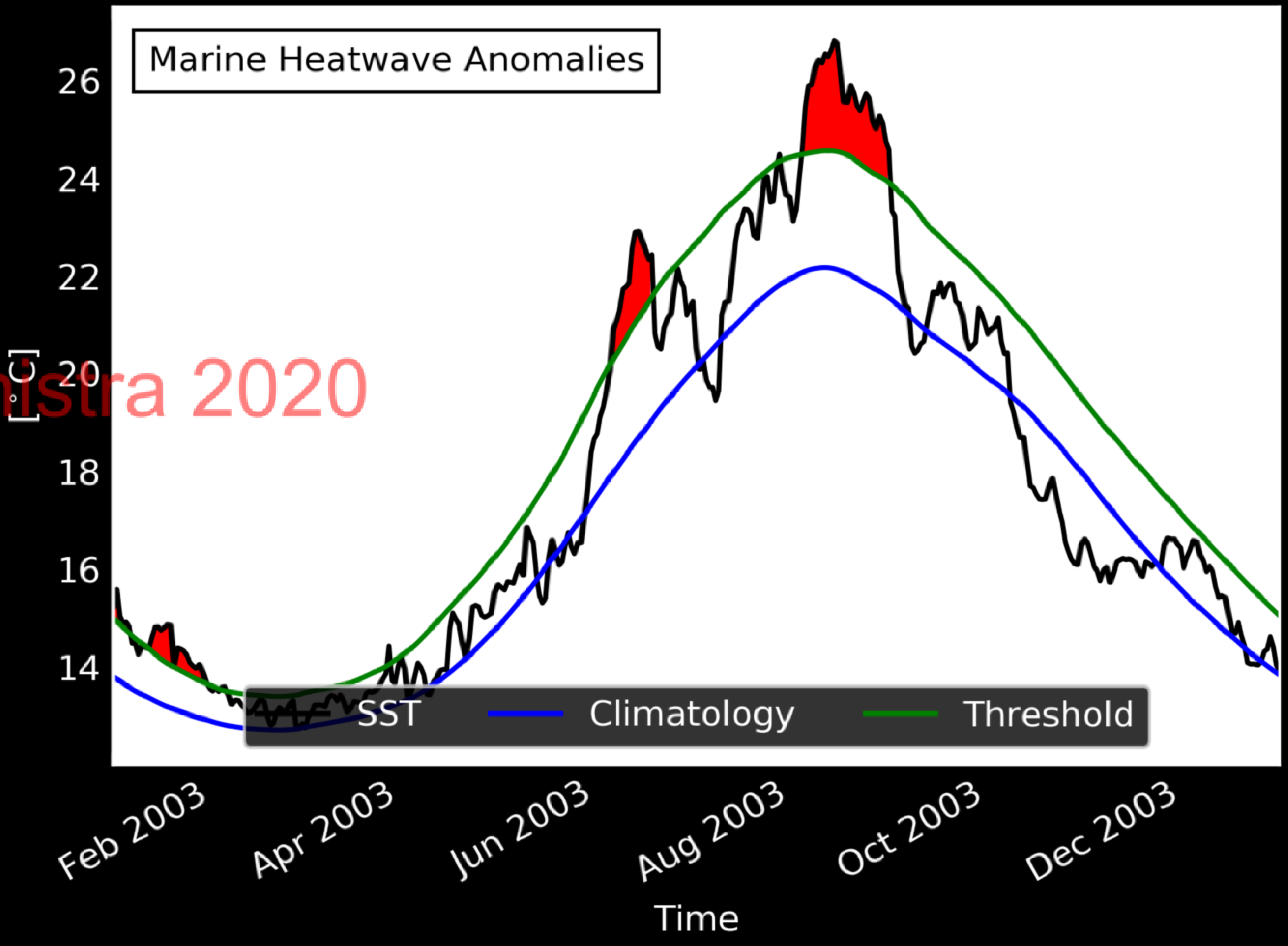
The 2003 Mediterranean MHW



Data: NOAA OISST v2

The 2003 Mediterranean MHW





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The 2003 Mediterranean MHW

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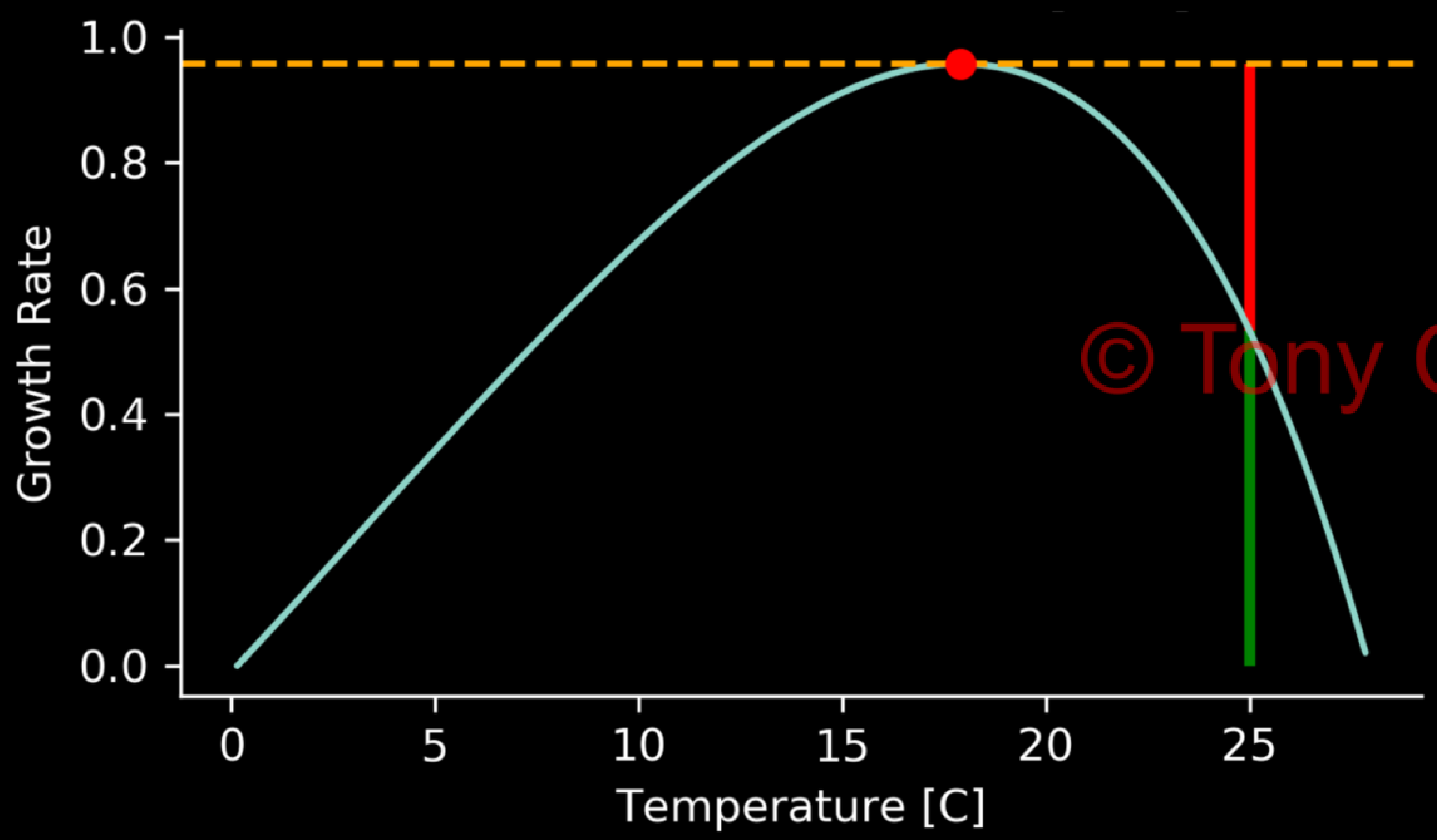

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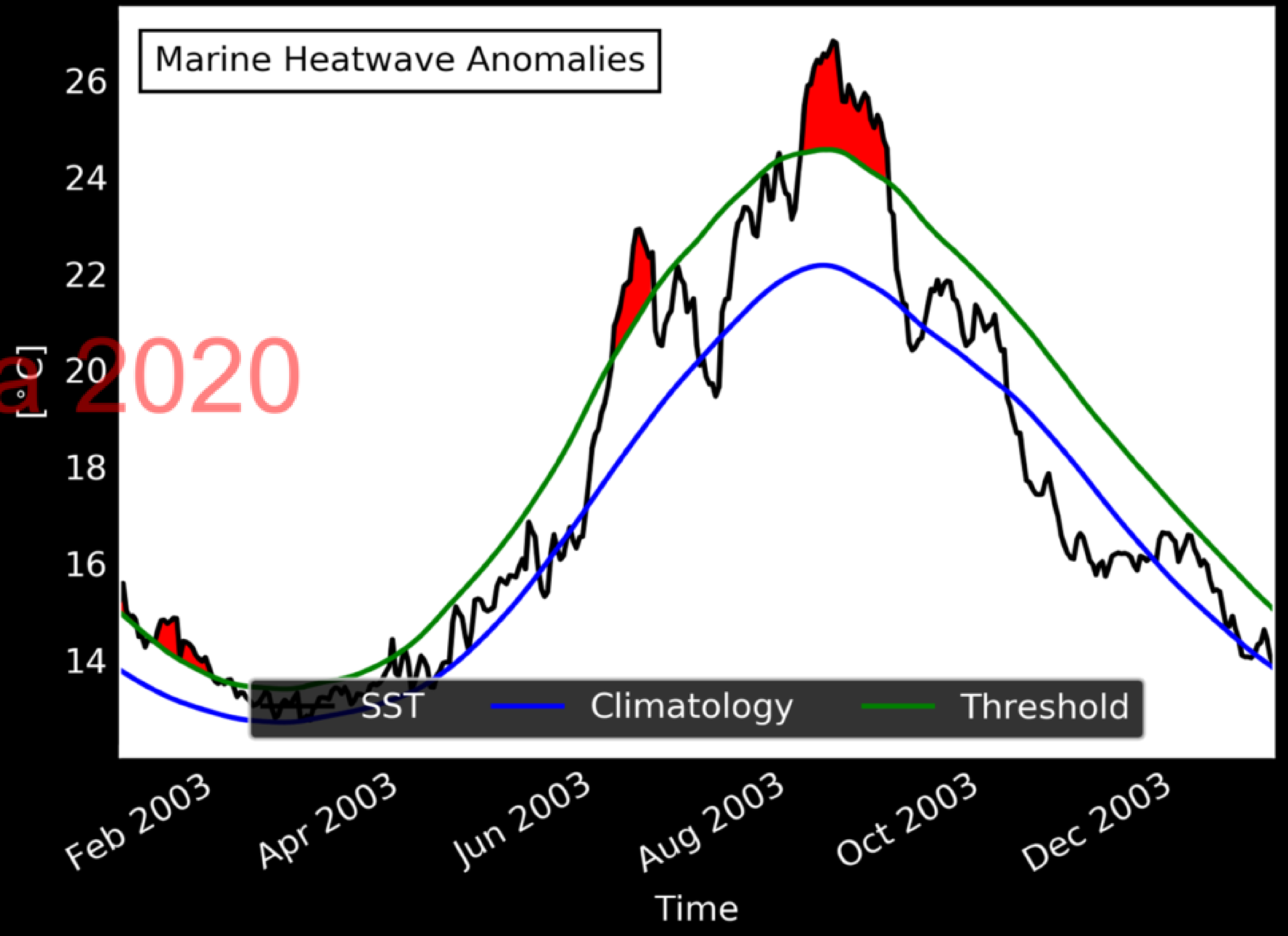

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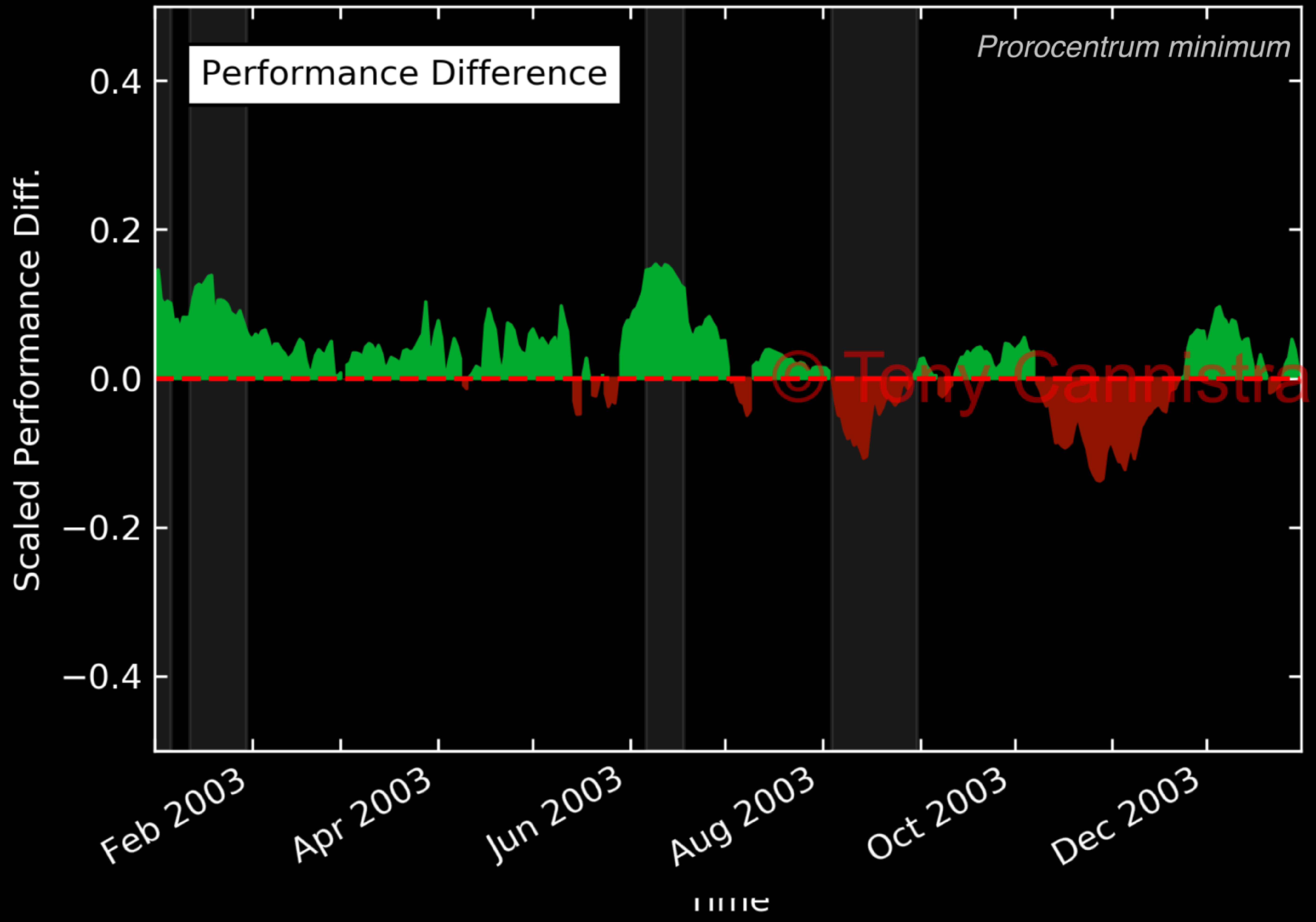
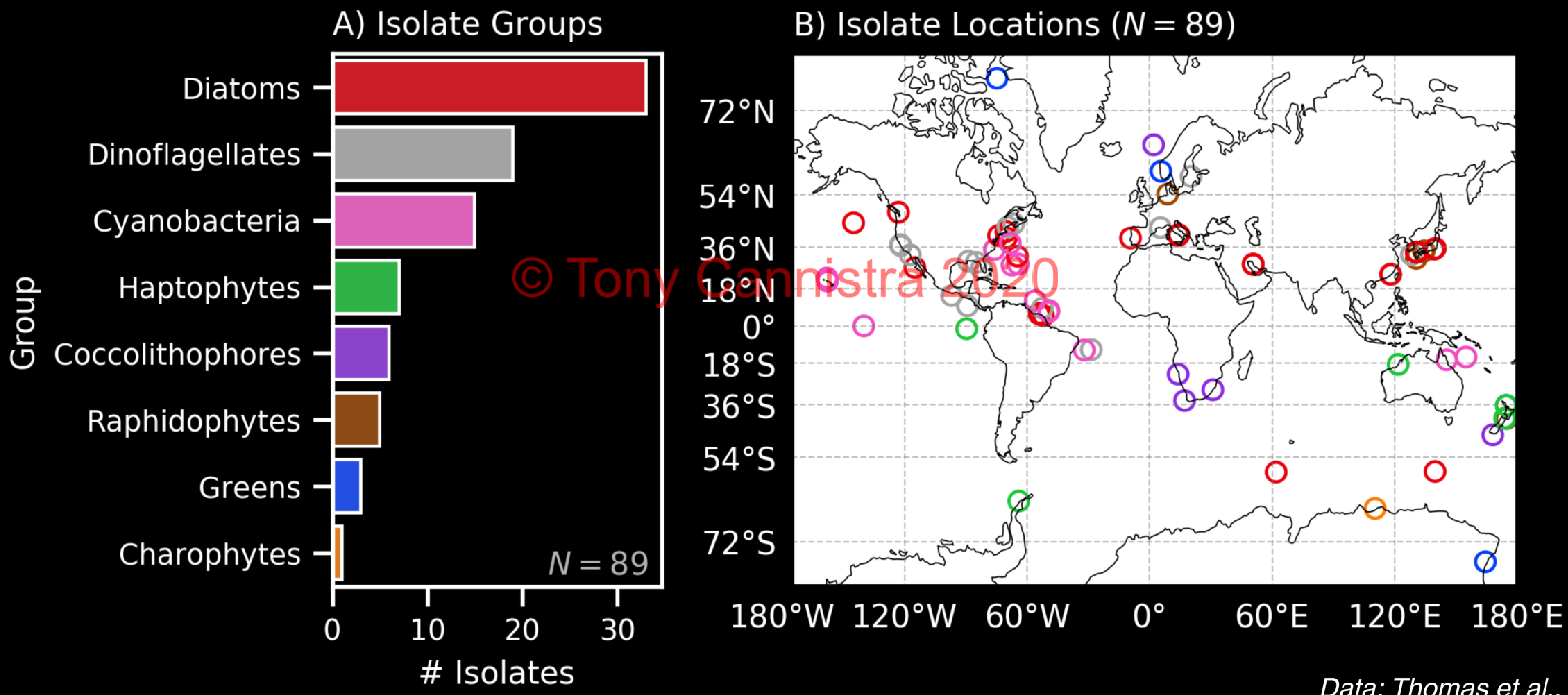
The 2003 Mediterranean MHW



Heatwaves can have *positive* and *negative* performance consequences.

A tool for global analysis.



Data: Thomas et al., 2012/2016

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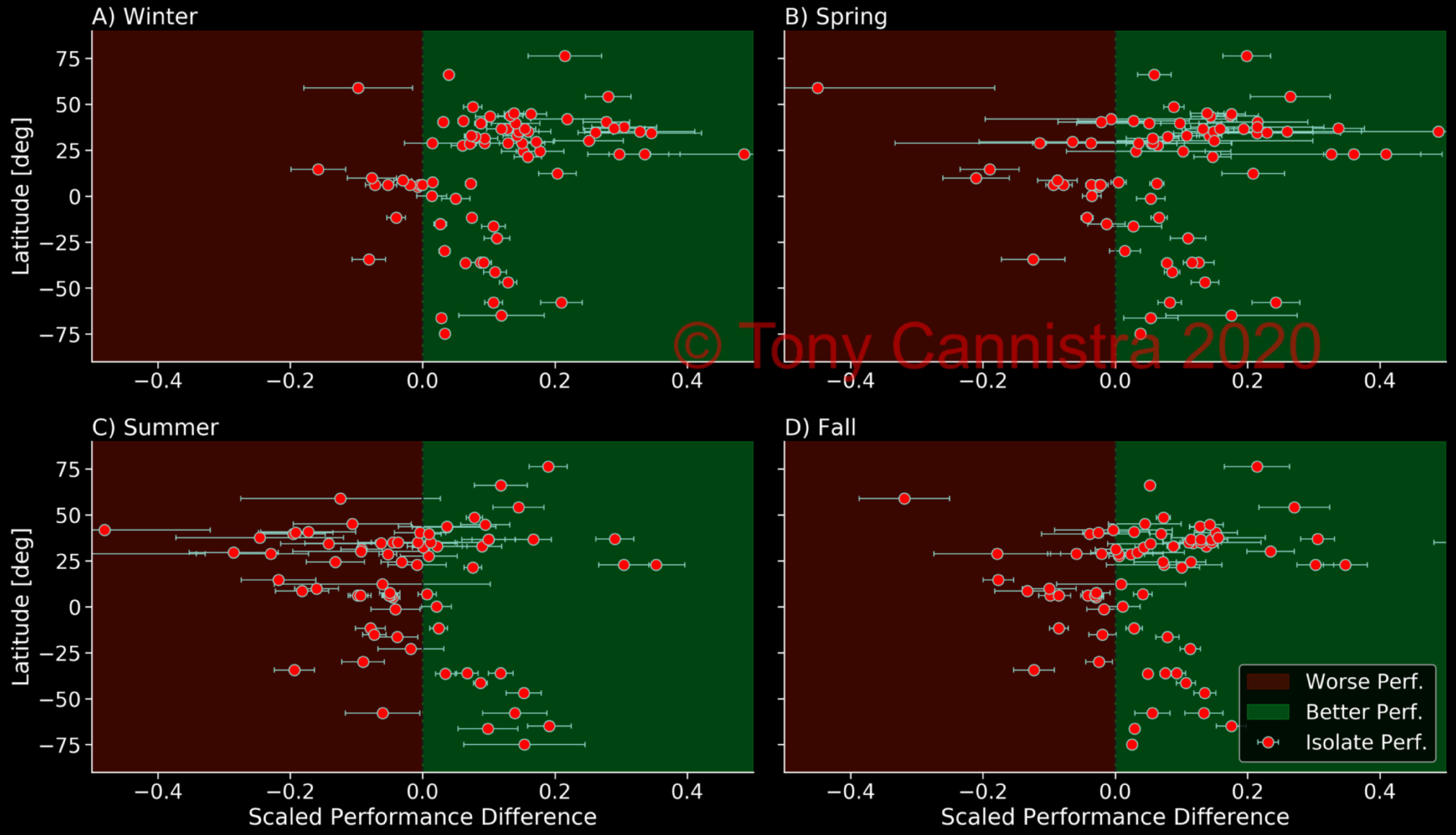
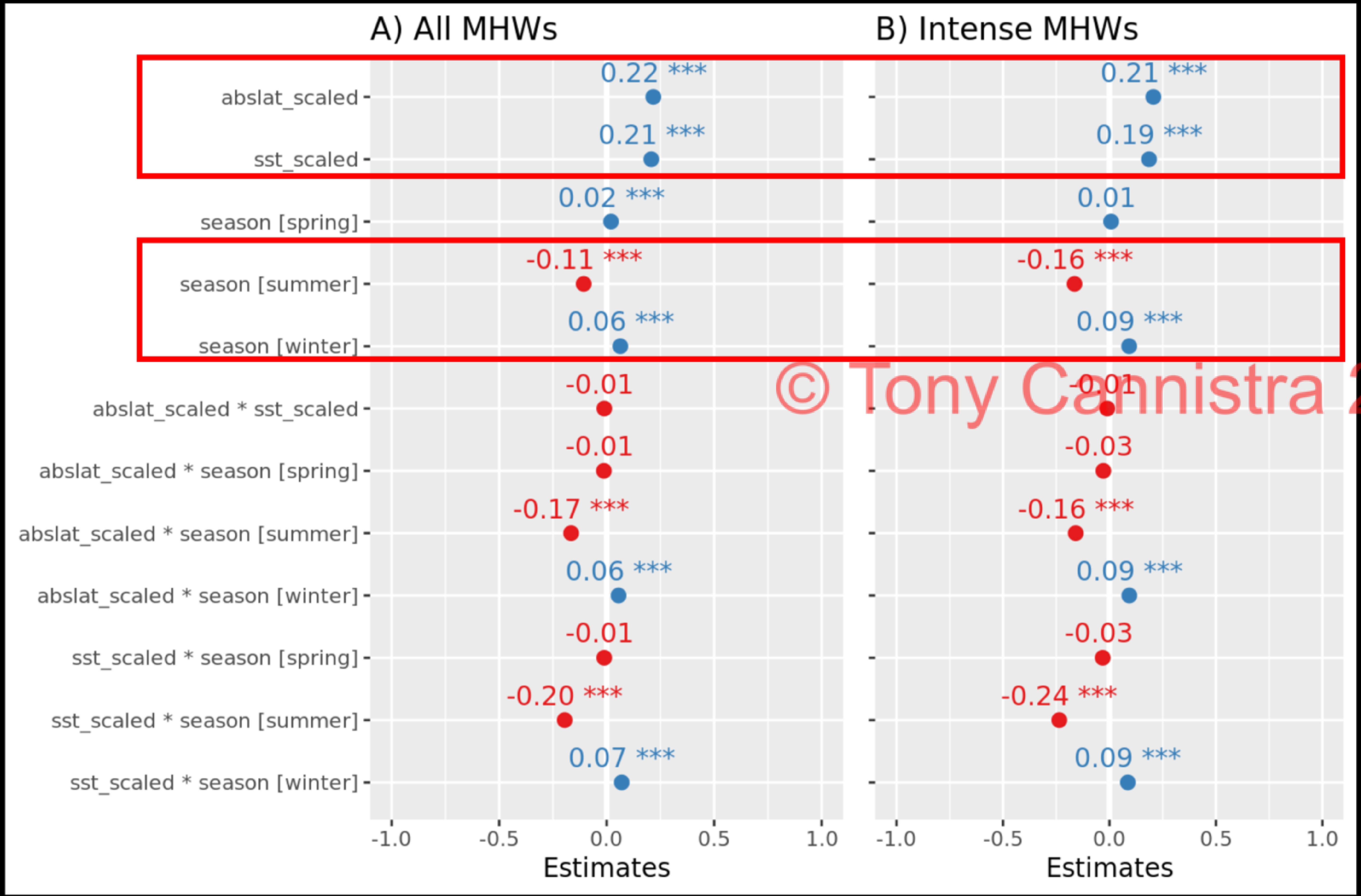
A "Global" Perspective



5299 MHWs
across
89 Isolates
reveal
Seasonal
+
Latitudinal
Patterns

A "Global" Perspective



Coefficients of Linear Mixed Effects Model of Scaled Performance Difference.

Positive, Significant effects of latitude & Annual Mean SST

Significant differences in *magnitude* and *direction* of effect of MHWs on phytoplankton performance across summer and winter

	All MHWs	**Intense MHWs**
Observations	5299	2721
Marginal R^2 / Conditional R^2	0.249 / 0.746	0.314 / 0.744

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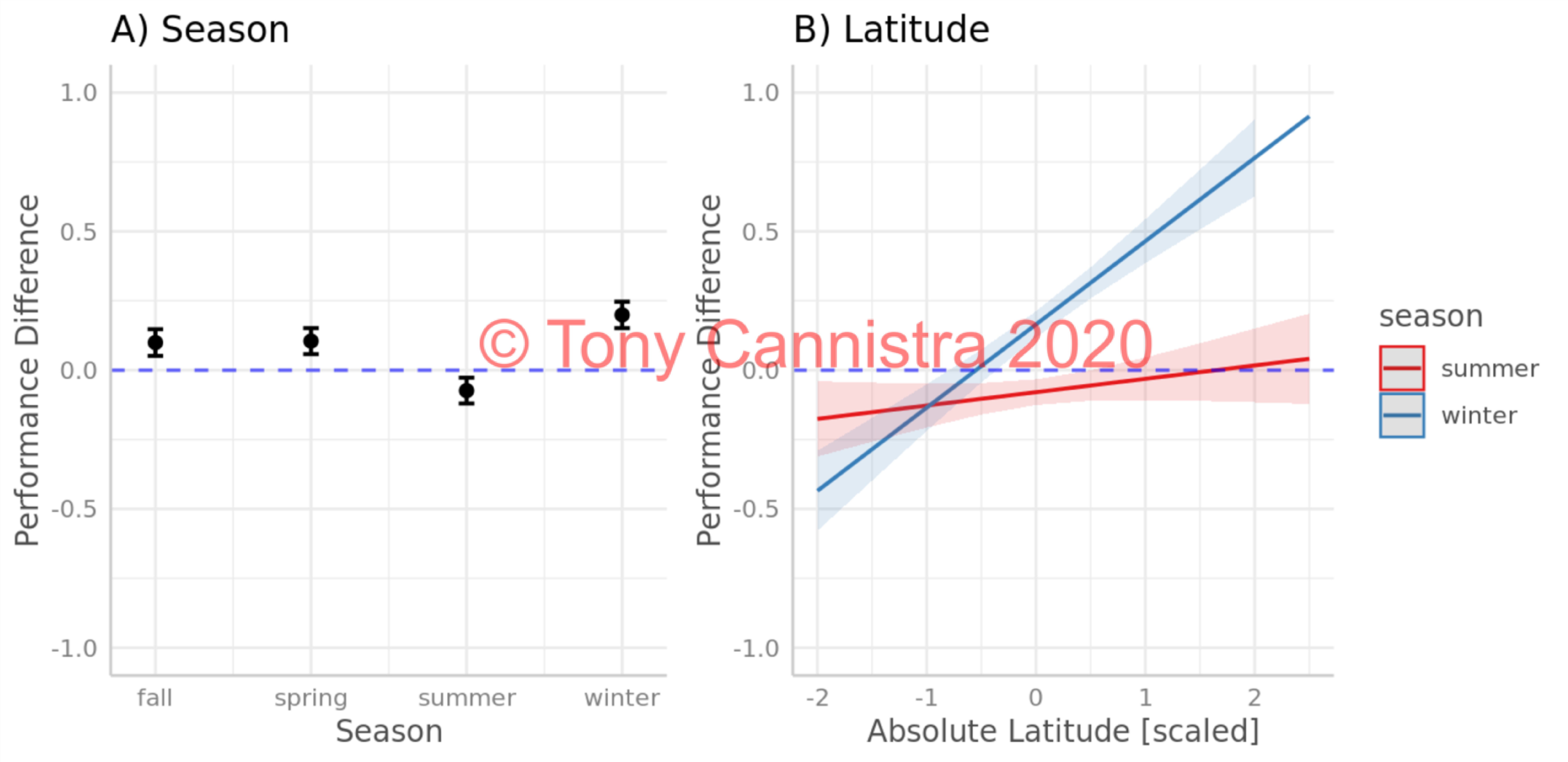
A “Global” Perspective



Marginal Effects of Linear Mixed Effects Model of Scaled Performance Difference.

Takeaways

- MHWs can lead to <u>positive *and* negative</u> performance consequences depending on <u>latitude</u> and <u>timing</u>.
- Thermal physiology *might* be an avenue to understand phytoplankton organismal responses, but more investigation is needed:
  - *nutrient limitations, upwelling events, temperature-dependent herbivory, etc.*
- Phytoplankton *might* help us understand broadly the risk of open ocean ecosystems to more frequent/intense MHWs.

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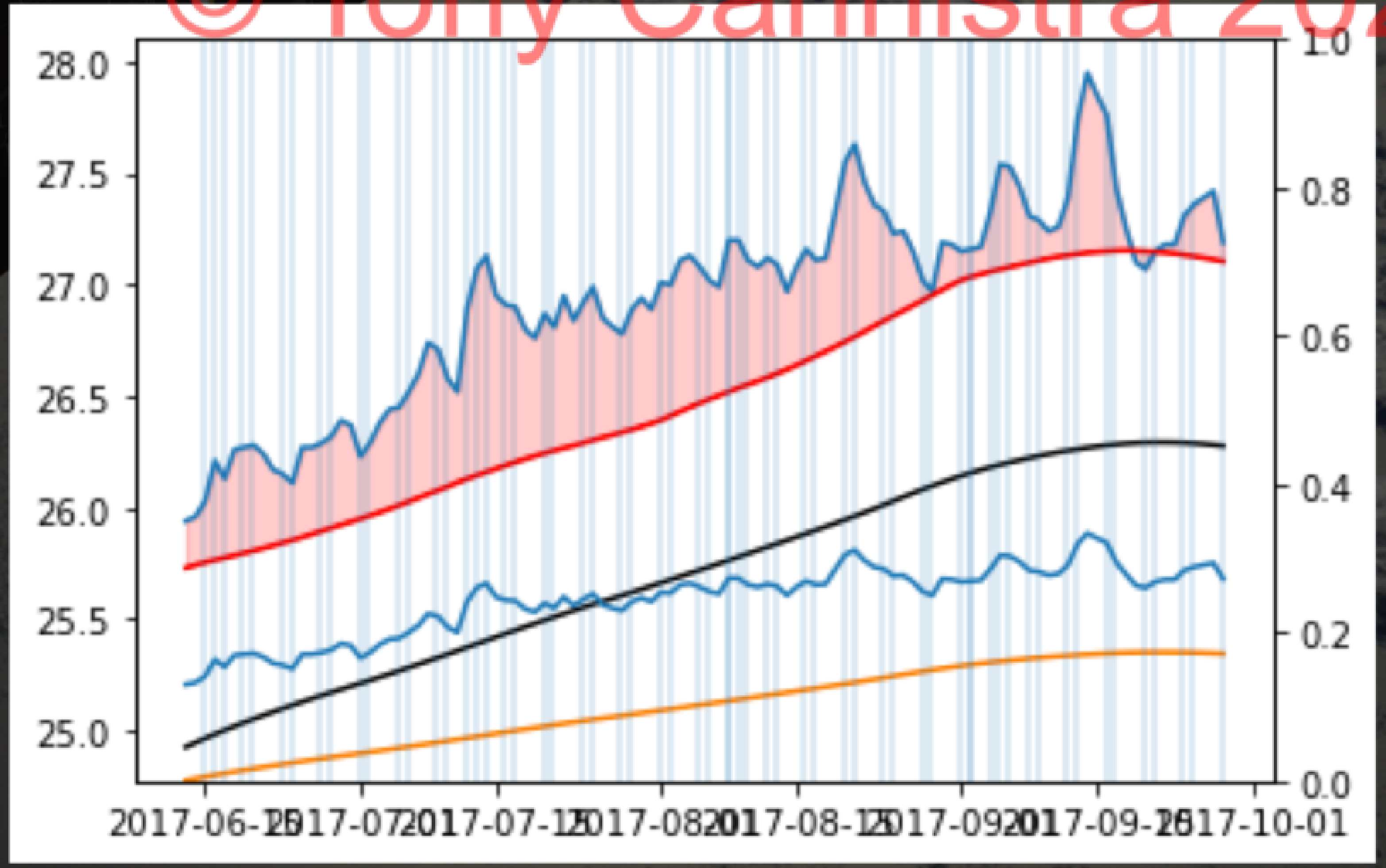
Next Steps

- Validation with Sentinel-3 OLCI chlorophyll-α
- **Q**: "Are patterns of MHW phytoplankton responses visible in chlorophyll-α patterns from space"



sentinel-3

esa

"Data Science" Methods

https://github.com/HuckleyLab/phyto-mhw

- NOAA OISST data are in daily or yearly .nc files
  - this is annoying for long-term analysis
- Used xarray (nD array library) to convert many .nc files to one "zarr store" (open-source cloud-native nD array format) & stored on AWS S3
- Used xarray + dask (local+cluster parallelism library) for MHW detection + physiology computations on EC2 (m5.8xlarge: 32core, 128GB, $1.54/hr)
  - Zarr + xarray + dask allow for trivially selecting regions + timeframes without worrying about files or memory or parallelism (...mostly)

Questions?

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