Predicting organismal response to marine heatwaves using thermal tolerance landscape models

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Problem: Reliance on statistical methods of classifying marine heatwaves

- Marine heatwaves (MHWs) are discrete extreme thermal events exacerbated by climate change. Behaving as ‘pulse’ events, they likely pose a stronger threat to marine ecosystems than the ‘press’ of gradual warming of mean conditions.
- **Hobday et al. (2016)** developed a statistical technique to categorize marine heatwaves according to their exceedance of the 90th percentile of the historical temperature record.
- *However*:
  - Requires extensive historical data, often only available from remote sensed products
  - Only classifies based on magnitude, not intensity.
- If we are truly interested in biological effects of MHWs, we should look to responses in the ecosystem to quantify MHW strength.

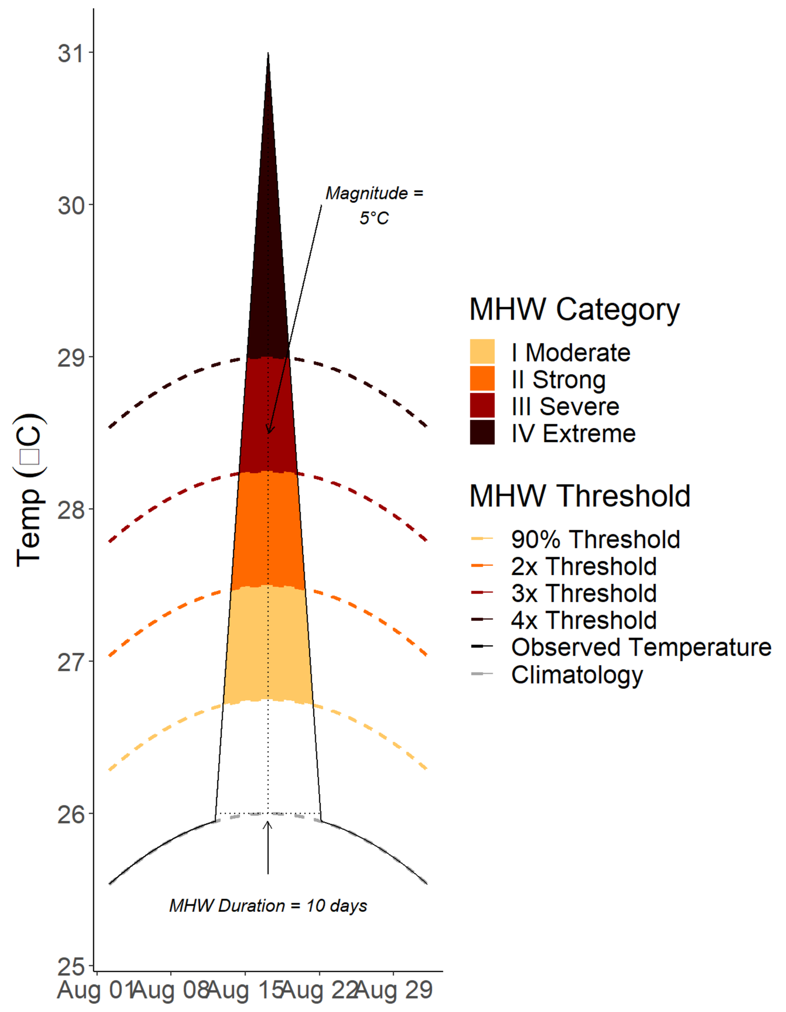
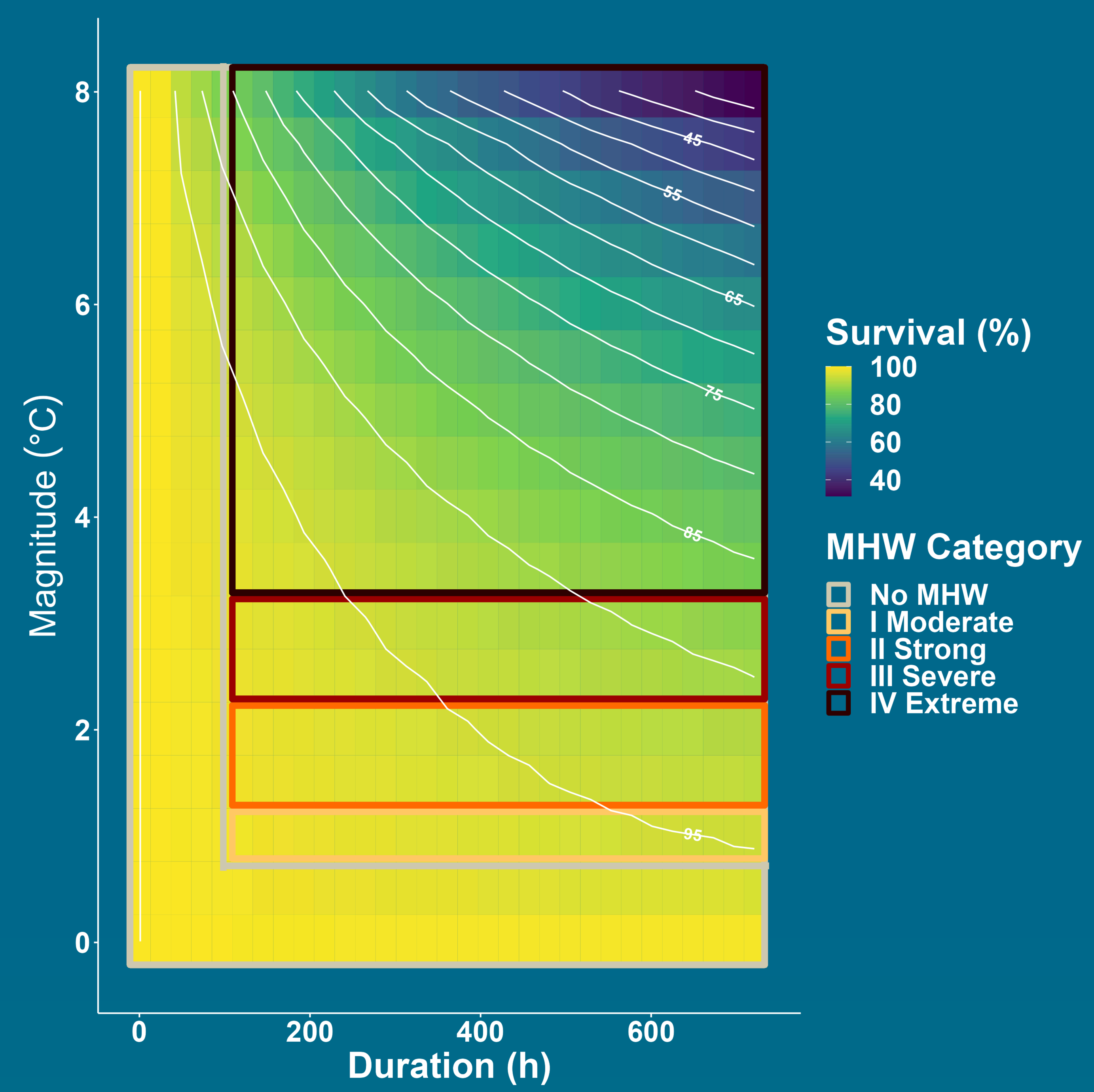


Figure 1: An example MHW overlaid by extremeness categories, calculated by times exceedance of a 90th percentile

Thermal tolerance landscape models provide mechanistic predictions of organism survival during MHWs, which outperform statistical definitions of heatwaves.



Within single statistically-defined categories of MHWs, organisms can experience a range of survival. Short duration, high magnitude events have the same effect as long duration, low magnitude events.

We can use survival outputs from thermal tolerance landscapes within population and multispecies models, scaling up our inferences of the effects of MHWs on marine ecosystems.

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Theory: Classifying heatwaves based on ecological effects requires mechanistic models

- The ultimate effect of heat stress on an organism is death. Heatwaves have been responsible for mass mortality events in corals, bivalves, and fish.
- Traditional thermal tolerance metrics do not predict survival probability over variable temperature series, like those that occur in nature.
- Thermal Tolerance Landscapes describe survival probability as a log-linear function of exposure time at a given temperature **(Rezende, Castañeda, and Santos 2014)**.

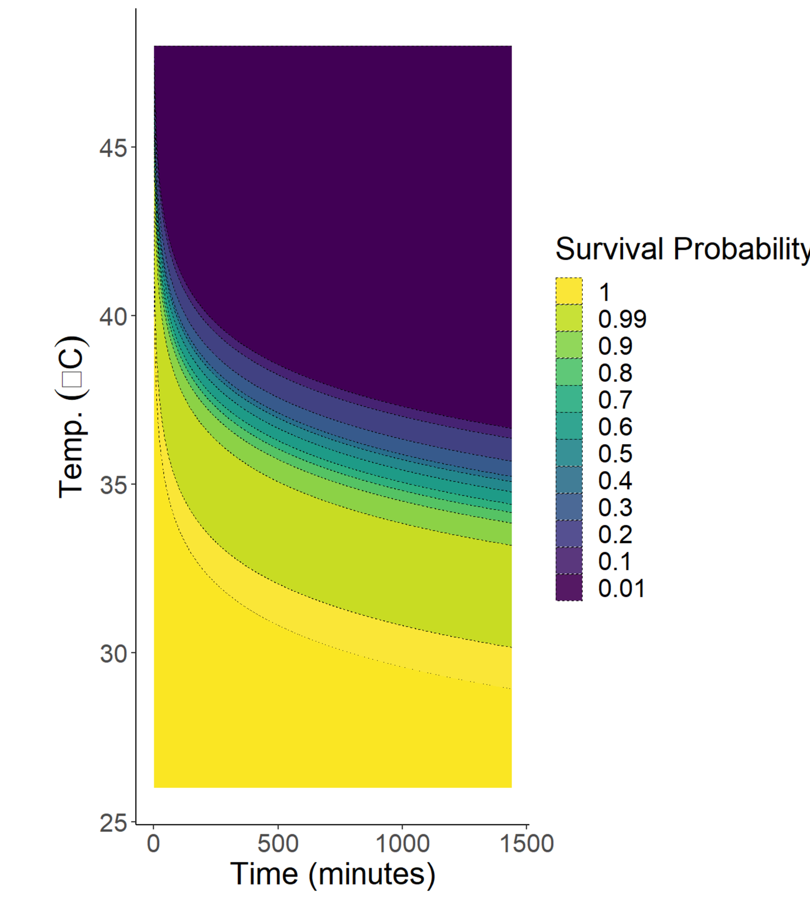

Figure 2: A hypothetical Thermal Tolerance Landscape, where survival probability is a log-linear function of temperature and duration of exposure

Solution: Dynamic Thermal Tolerance models can predict survival over any temperature

- Dynamic Thermal Tolerance models apply Thermal Tolerance Landscapes to interpolate survival over any variable temperature time series **(Rezende et al. 2020)**.
- Here, we use Dynamic Thermal Tolerance models to examine how categorization of 527 simulated MHWs differs between using a statistical tool **(Hobday et al. 2016)** and using this mechanistic, physiological tool.

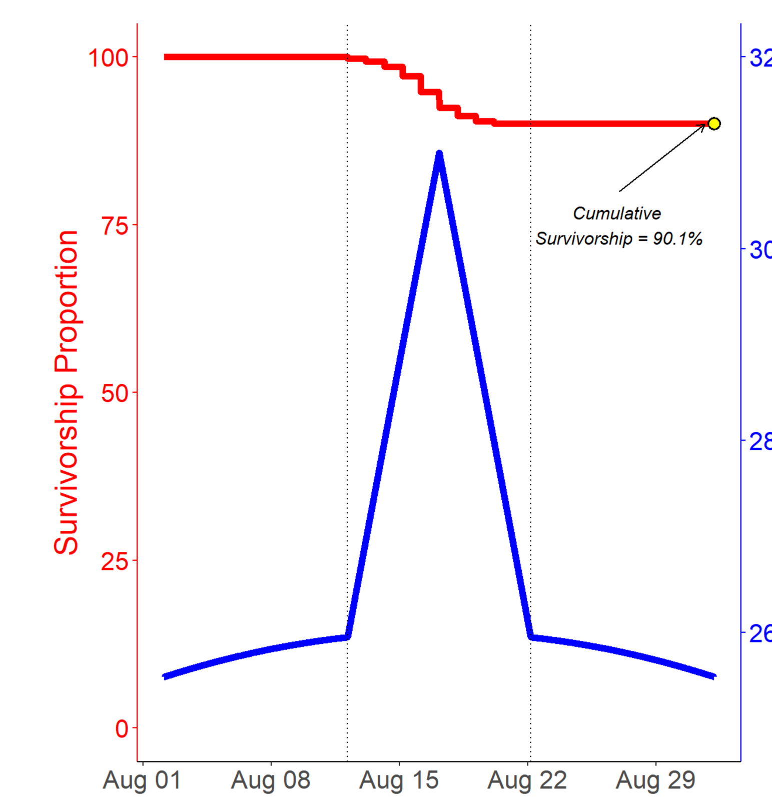

Figure 3: Survival trace of a hypothetical organism (red) exposed to a simulated marine heatwave (blue). We repeated this process for 527 MHWs.

Hobday, Alistair J., Lisa V. Alexander, Sarah E. Perkins, Dan A. Smale, Sandra C. Straub, Eric C. J. Oliver, Jessica A. Benthuysen, et al. 2016. “A Hierarchical Approach to Defining Marine Heatwaves.” *Progress in Oceanography* 141 (February): 227–38. https://doi.org/10.1016/j.pocean.2015.12.014.
Rezende, Enrico L., Francisco Bozinovic, András Szilágyi, and Mauro Santos. 2020. “Predicting Temperature Mortality and Selection in Natural Drosophila Populations.” *Science* 369 (6508): 1242–45. https://doi.org/10.1126/science.aba9287.
Rezende, Enrico L., Luis E. Castañeda, and Mauro Santos. 2014. “Tolerance Landscapes in Thermal Ecology.” Edited by Charles Fox. *Functional Ecology* 28 (4): 799–809. https://doi.org/10.1111/1365-2435.12268.