Exhibits for Modeling Workgroup Quarterly Review

Modeling Temperature Dependence of Algal Growth Rate Under Climate Change Scenarios

April 5, 2023

2018 STAC Recommendation

"Over decadal time scales as water temperatures continue to warm, we would expect new types of phytoplankton to outcompete and grow faster than the current phytoplankton in the Bay. As a result, we recommends that the estuarine model should incorporate a phytoplankton temperature-growth curve that increases exponentially at high temperatures. This is not likely to alter the existing calibration since this effect will be most influential during very warm conditions that have seldom occurred in the past but will likely occur more often in future decades."

Shenk and others (2021)

My understanding of modeling team approach to STAC recommendation

- Not based directly on literature of likely adaption under future warming scenarios
- Rather, desire was for a single set of parameters that would:
  - Reproduce previous calibration
  - Simulate increasing growth rates throughout the expected temperature range up to 2050
- Temperatures above 32°C not expected or at least very rare

Climate Change Consideration

- Use different parameters for model calibration (without/with temperature inhibition)

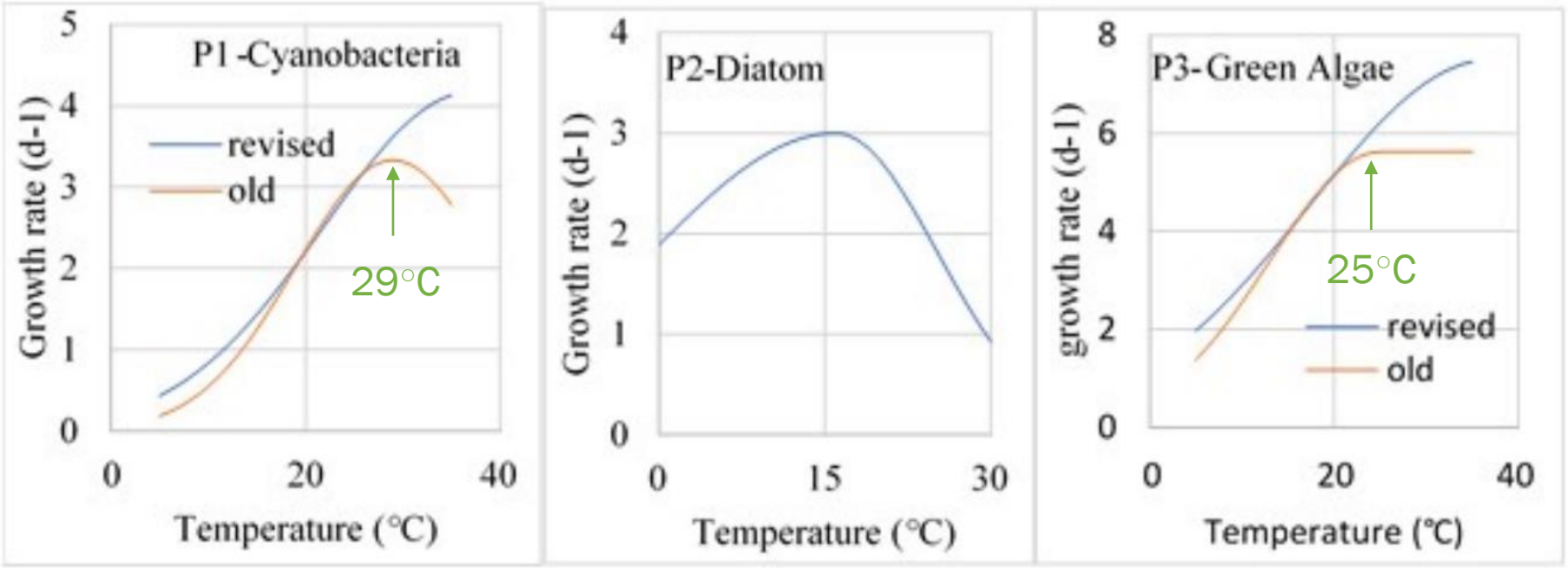
Table 1
Revised Algal Parameters for Climate-Change Scenarios

Parameter	Definition	Group 1 Calibration	Group 1 Climate Change	Group 3 Calibration	Group 3 Climate Change
KTg1	effect of temperature below Topt on algal production ($°C^{-2}$)	0.005	0.0022	0.0035	0.0013
KTg2	effect of temperature above Topt on algal production ($°C^{-2}$)	0.004	0	0	0
Pm^B	maximum photosynthetic rate (g C g^{-1} Chl $d^{-1)}$	200	250	450	600
Topt	optimal temperature for algal production (°C)	29	37	25	37

Courtesy of Cerco

Sharp divergence of predicted rates

Adapted figure 5-14 from Shenk and others (2021)

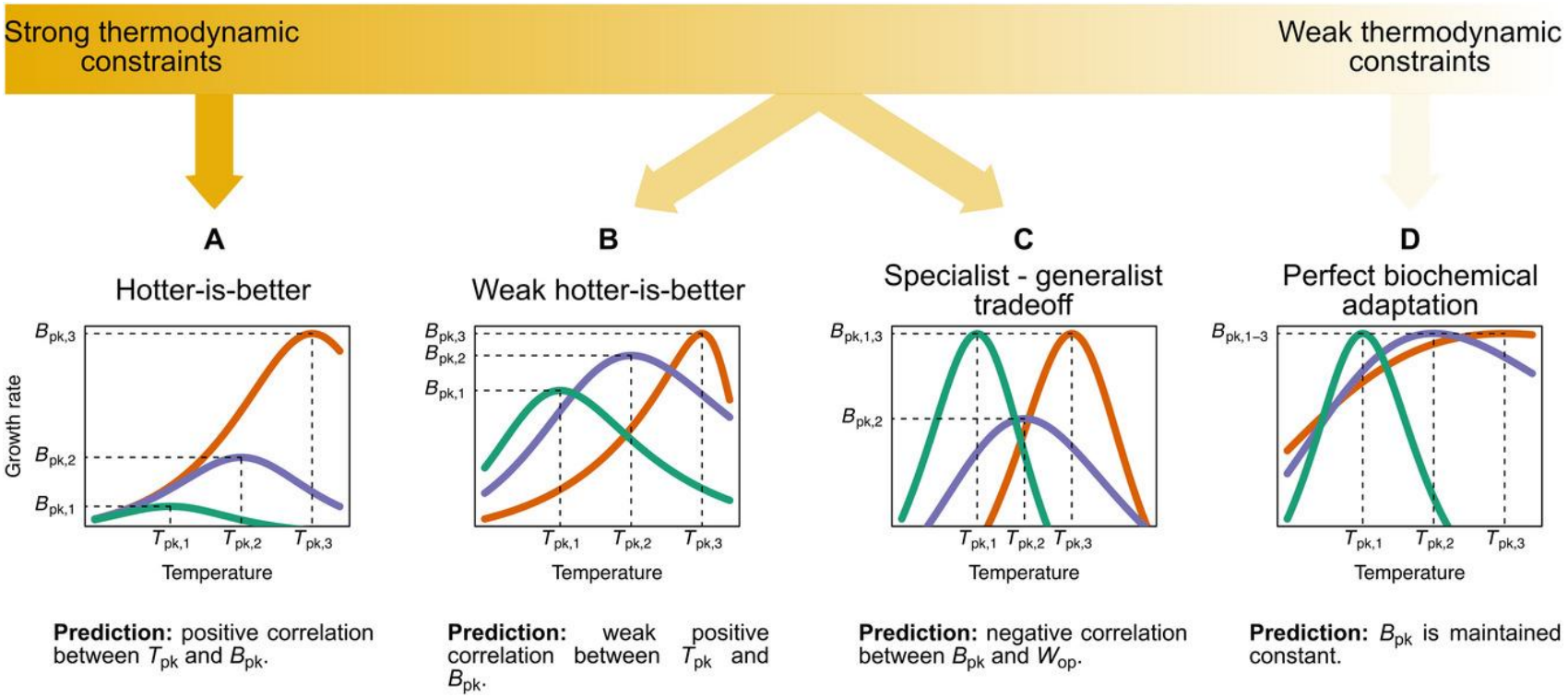


Original driver of concern: James River Chlorophyll-a

- Seasonal median and not-to-exceed criteria
- Controls WLAs in tidal freshwater and above
- July and August 2011 and 2012:
  - Calibration temperatures: 29-32°C range
  - 2025 scenario, increased to 30-33°C range
- **Flipped scenario from attainment to non-attainment**
- How much of this due to the assumption of "perfect biochemical adaptation"?
- Effect greater with future climate change scenarios

Kontopoulos and others (2020):

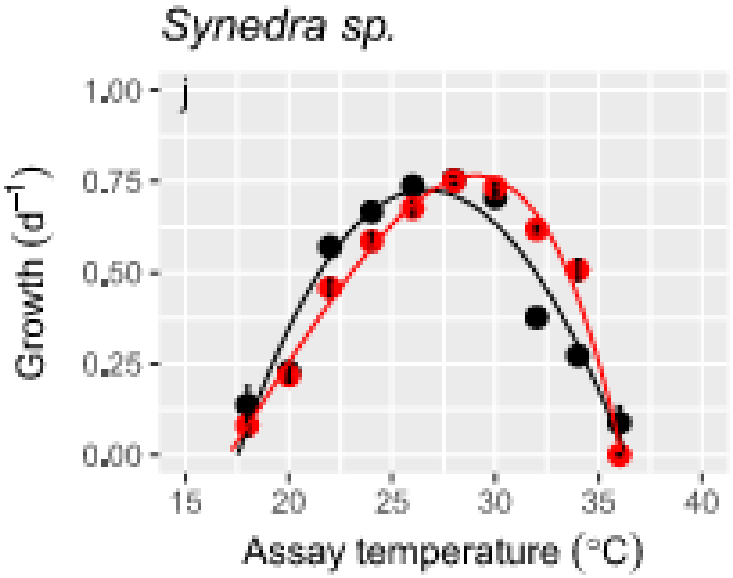
- *Perfect biochemical adaptation* is an "extreme" of a range of hypotheses
- Better supported hypothesis: *Weak hotter –is-better*

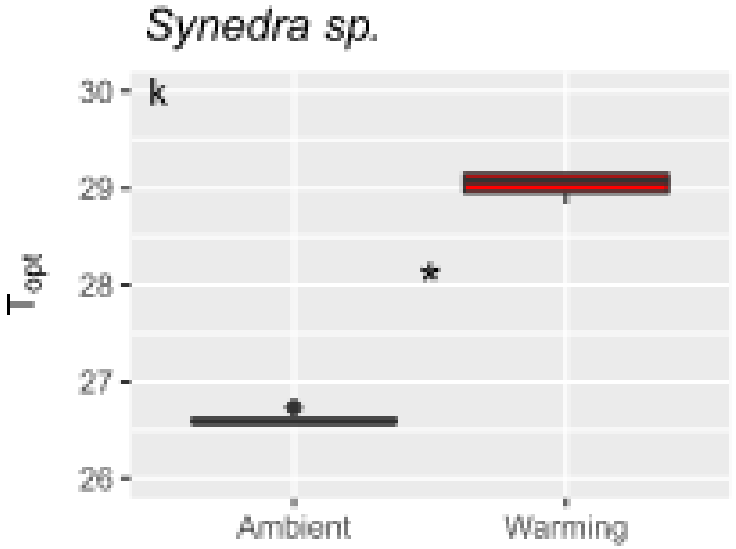


Recent Literature Review (see memo for details)

- There is literature support for adaptation of individual species and selection of warm-tolerant taxa.
- However, there are physiological limits and trade-offs with adaption
- A T_{opt} of 37°C would be unusually high even for warm water taxa
- A reduction in growth above the optimum temperature is observed even with warm water taxa
- Most (all?) models from areas to the south of the Chesa. Bay (e.g., Florida Bay) have used lower T_{opt} values and declining growth above T_{opt}
- The model adjustments seem out of proportion with the degree of expected warming

Adaptation of individual species is observed but physiological limited





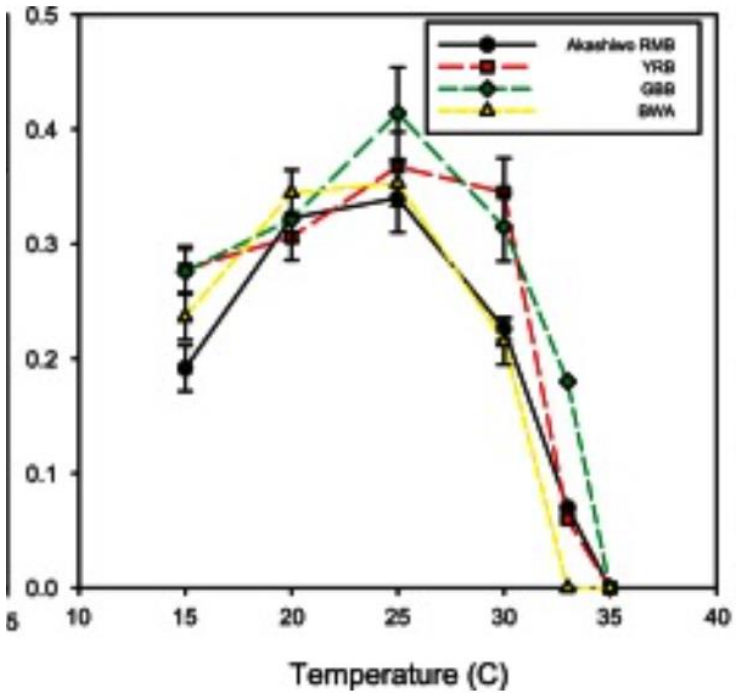
Source: Jin and Agusti, 2018

Fast adaptation of tropical diatoms to increased warming with trade-offs

Same curve shape from tropical to polar species

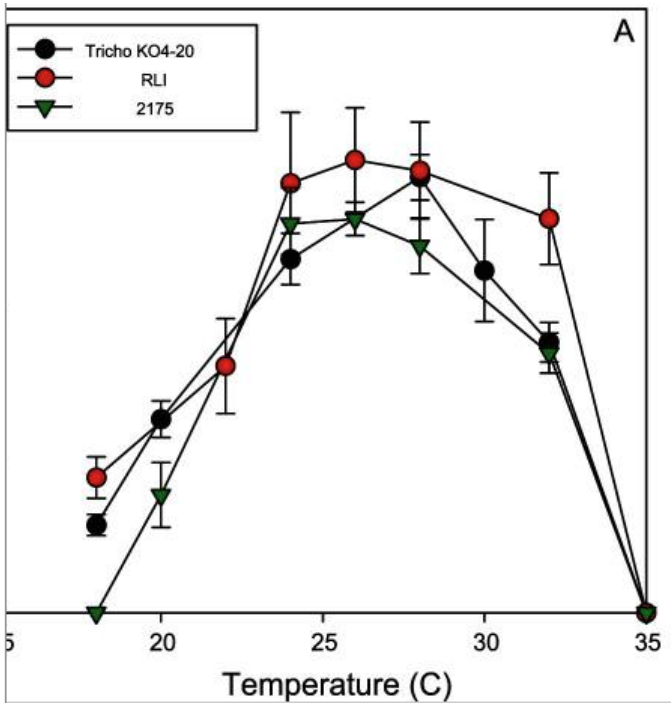
Mid-latitude dinoflagellate

(*Akashiwo sanguinea*)



Tropical cyanobacterium

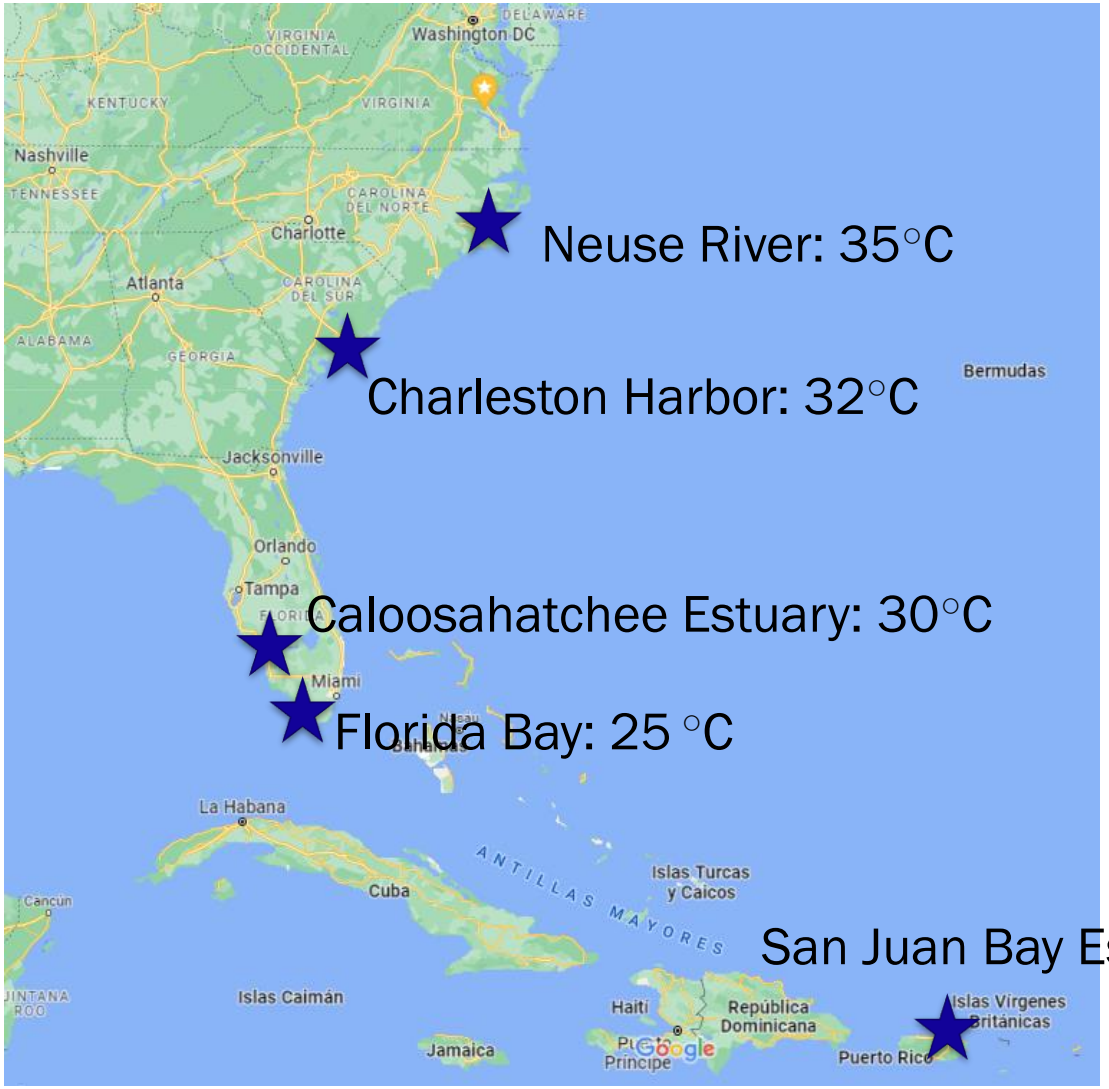
(*Trichodesmium erythraeum*)



Source: Boyd and others 2013

Marine Phytoplankton Temperature versus Growth Responses from Polar to Tropical Waters – Outcome of a Scientific Community-Wide Study

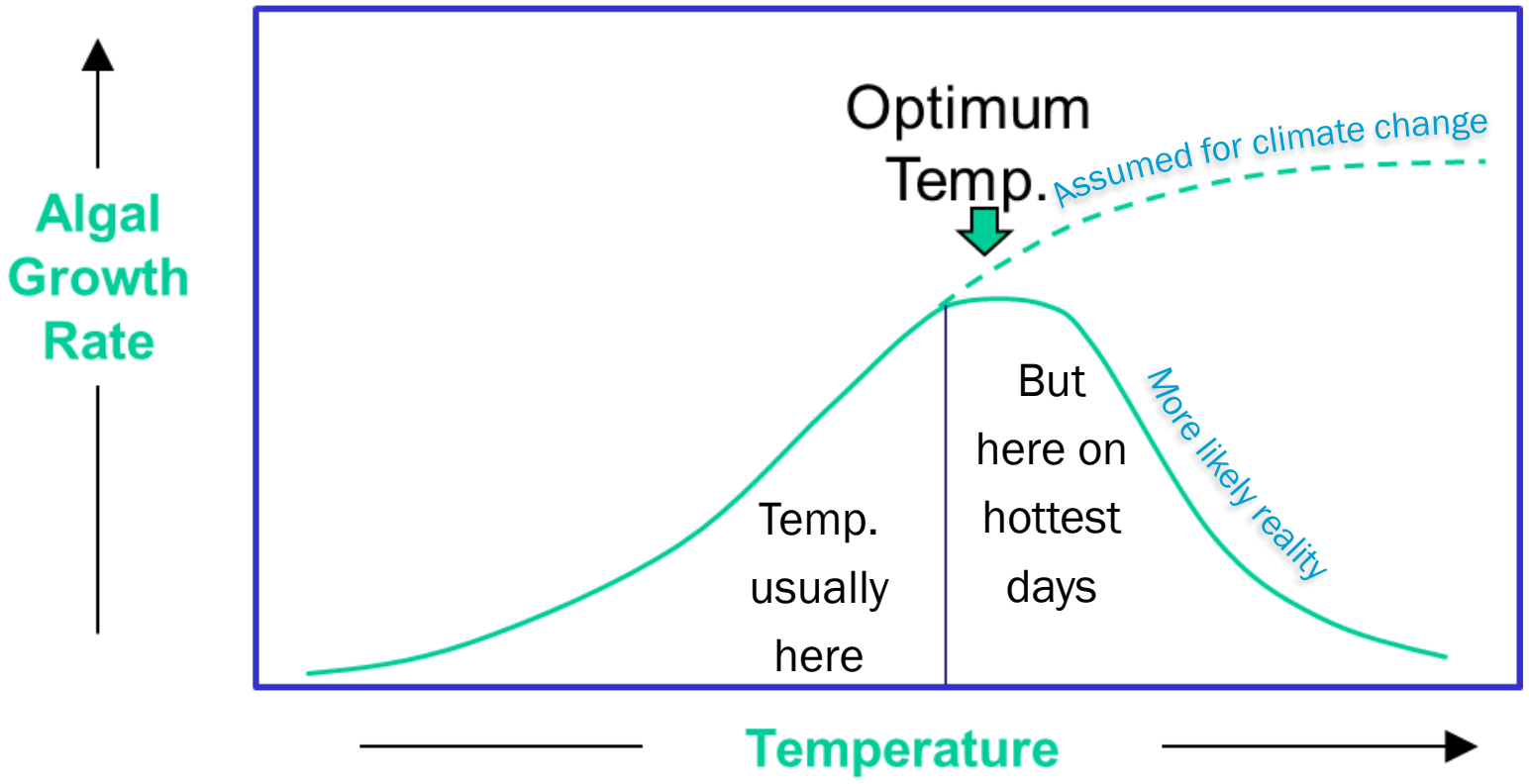
Calibrated Models from Southern Waters Use Lower Optimum Temperatures



Consideration of Degree of Warming

- Algae are adapted more to average or average maximum temperatures than to extremes
- 1-2°C warming projected between 2000 and 2035 (based on Hinson and others, 2021)
- Contrasts with 8-13°C "increase" in T_{opt} from original calibration
- Also contrasts with 25% increase in maximum growth rate
  - ….~9% might be more realistic (based on simple calc. from Sal and others, 2015)

Importance of issue depends in part on frequency of temperatures “over the hump”



Potential Objectives for a Refinement of the Thermally-Dependent Algal Kinetics

- Retain STAC recommendation of simulating thermal adaption under future climate scenarios
- Avoid overestimating rates, particularly on days that are very hot even for these scenarios
- Retain calibrated predictions for low to moderate temperatures?
- Avoid a difficult work flow?
- Others?

Two Potential Approaches

1. Find one set of rates that:
   - Reproduces calibration
   - Simulates thermal adaption
   - Simulates beyond-optimum conditions

Two Potential Approaches (cont.)

2. Start with calibrated rates, and adjust them for climate scenarios based on amount of projected warming.

e.g.,
1.5 degree of warming is expected so
so increase T_{opt} by 0.8 – 1.5 degrees

Is it important that scenario rates reproduce the calibration results?

- Yes, because:
  - Otherwise, we introduce changes between calibration/scenarios that are difficult to verify
  - Impacts to workflow or post-processing the data?
- No, because:
  - We're not using the scenarios for calibration
  - A thermally-adapted alga community wouldn't be expected to give identical results
  - Differences modest under approach #2

Path Forward

1. Examination of the shallow water monitoring continuous temperature and chlorophyll measurements
2. Updating the literature search
3. Sensitivity analysis
4. Convening a STAC workshop/session in the first or second quarter of 2024.