

Could *Nereocystis* adapt to rapid water temperature increase in the San Juan Islands?

Abstract

This project is an initial effort to determine the effects of increasing temperatures on photosynthesis-irradiance (P-I) relationships, respiration and the daily metabolic carbon balance of *Nereocystis luetkeana* at Friday Harbor Laboratories, in San Juan Island, USA. P-I Curves were performed at 11°C and 16°C. *Nereocystis luetkeana* in the San Juan Islands seems to be favored by higher temperatures as lower respiration rates, lower I_c , higher photosynthetic rates and significantly higher DMCB were recorded for 16°C compared to 11°C. However these results are preliminary and only analyze one factor of change: temperature. There are other abiotic stressors changing due to climate change which could have other effects on *Nereocystis luetkeana* ecophysiology. It is also important to consider that climate change can directly affect not only physiological stress but also indirectly via changing relationships among species. Thus, to better understand ecological change we should understand the ways in which biotic and abiotic factors interact to determine the distribution and abundance of species in space and time.

Introduction

The concentration of carbon dioxide in Earth's atmosphere now exceeds 380 ppm, which is more than 80 ppm above the maximum values of the past 740,000 years (Petit *et al.*, 1999), if not 20 million years (Raven *et al.*, 2005). As a result of anthropogenic greenhouse gas emissions, global mean sea-surface temperature has increased approximately 0.6°C over the past 100 years and is predicted to continue increasing by approximately 3°C the next 100 years (IPCC 2007). Oceans have a major role in the global Carbon cycle and so will directly impact the pace and extent of climate change (Field *et al.*, 2002). Oceans cover 71% of the surface of the Earth and thus we must understand how a changing climate will affect the biota not only in terrestrial systems, but also in marine environments (Miller, 2004).

Changes in global temperature and ocean chemistry associated with increasing greenhouse gas concentrations are forcing widespread shifts in biological systems. In response to warming, species ranges are shifting towards the poles, up mountainsides, and to deeper ocean depths (Parmesan and Yohe 2003, Perry *et al.* 2005). Factors including warming and ocean acidification are causing the reorganization of local communities as species are added or deleted and as interactions among species change in importance (Wootton *et al.* 2008, Harley 2011). Because greenhouse gas emission rates continue to accelerate, the climatically-forced ecological changes will be even higher in the coming decades in comparison to last half century.

Global change is a global phenomenon; however some biological systems have received more attention than others. Although many studies have focused on coral reefs and terrestrial forests (e.g., Hoegh-Guldberg *et al.* 2007, Aitken *et al.* 2008), fewer studies

have focused on seaweed-dominated systems. Like corals and trees, seaweeds are key structuring agents that harbor biodiversity and support productive food webs that include economically valuable species (Graham 2004, Norderhaug et al. 2005, Christie et al. 2009). Alterations to the physical and chemical environment will directly impact seaweed physiology at all stages of the life cycle, resulting in changes in growth, reproduction and/or survival.

One of the effects of climate change is the increase of temperature. Temperature determines the performance of seaweeds (and all organisms) in enzymatic processes, metabolic function, and ultimately growth and reproduction (Raven and Geider 1988). Within a species' thermal tolerance range, temperature is positively related to performance up to an optimum temperature, above which the balance between energy produced by photosynthesis and energy required for respiration becomes less favorable (Fain and Murray 1982, Davison et al. 1991).

Given the importance of ocean biota and of studies focusing in climate change, the present project constitutes an initial effort to determine the effects of increasing temperatures on photosynthesis-irradiance (P-I) relationships, respiration and the daily metabolic carbon balance of the kelp *Nereocystis luetkeana*.

The objective of this project is to answer the question how does *Nereocystis* react to increasing ocean temperatures caused by global climate change?

Methods

Study site and algal sampling

The study was performed at Friday Harbor Laboratories (FHL), San Juan Island, WA, USA. *Nereocystis luetkeana* was collected (four blades of the same plant) at 0.5 meters depth on the dock.

Quantum-irradiance measurements

Photosynthetically active radiation (PAR, 400-700 nm) was recorded during seven continuous days at the FHL weather station data. In addition, PAR was measured using a LiCor light meter Model LI-250A at 0.5 meters depth during three days at noon.

Oxygen flux measurement and photosynthetic parameters

After macroalgal collection eight discs were extracted using a 2cm cork borer from four blades of the same individual (two discs from each blade). Discs were kept overnight in seawater to avoid wound effects.

Photosynthesis and respiration were measured in a chamber (10 ml volume) using oxygen production using an Oxymeter Hansatech Oxygraph System. A slide projector Argus 300 (360 watts) and filters were used to expose the algae disc to 20 minutes of darkness and five increasing light intensities (17, 36, 128, 450 and 1250 $\mu\text{moles photons m}^{-2} \text{s}^{-1}$). Four replications were carried out at 11°C and four replications were performed at 16°C using disks taken out from four blades of the same individual plant. Photosynthesis vs.

Irradiance curves (P-I Curves) were performed and an hyperbolic tangent function (see Jassby and Platt, 1976) was fitted to the data of each sample disc. Subsequently photosynthetic parameters were calculated: P_{max} (maximum photosynthetic rate at saturating irradiances, R (dark respiration rate), alpha (initial slope of the curve at low

irradiance), I_k (light saturation point), I_c (light compensation point). Four P-I Curves were performed at a temperature of 11°C (“normal”) and four P-I Curves at 16°C (simulating a “future scenario” of climate change).

Daily Metabolic Carbon Balance (DMCB) was determined using the obtained photosynthetic parameters and the estimated underwater PAR data at 0.5 m depth.

Statistical Treatment

Differences among temperatures (11°C vs. 16°C) were tested for each photosynthetic parameters: P_{max} , R , α , I_k , I_c and DMCB values, (1-way ANOVA, Tuckey test).

Results

Underwater quantum irradiance

The daily course of irradiance measured for air and at 0.5 m depth during summer in Friday Harbor laboratories revealed that subtidal habitats in this area were illuminated over a period of 15.5 hours per day (Fig. 1).

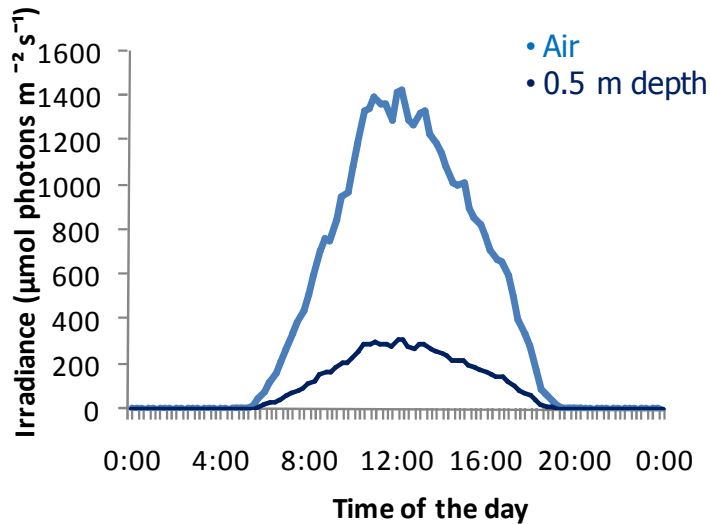


Figure 1. Daily course of irradiance for air measurements and at 0.5 m depth. Data is an average of seven continuous days at Friday Harbor Laboratories in August 2012. 0.5 m depth curve was used to estimate the daily metabolic carbon balance for the studied species (*Nereocystis luetkeana*).

Photosynthetic performance

The photosynthesis-irradiance (*P-I*) curves determined for the two different temperatures are shown in Fig. 2. P_{max} values were significantly higher for 16° C compared to 11° C (1-way ANOVA, $p < 0.05$). Also, respiration was significantly higher for 11° C compared to 16° C (1-way ANOVA, $p < 0.05$). The efficiency at low irradiance represented by α was similar between the studied temperatures (1-way ANOVA, $p < 0.05$). I_c was significantly higher for 11° C compared to 16° C (1-way ANOVA, $p < 0.05$). I_k was similar between the studied temperatures (1-way ANOVA, $p < 0.05$).

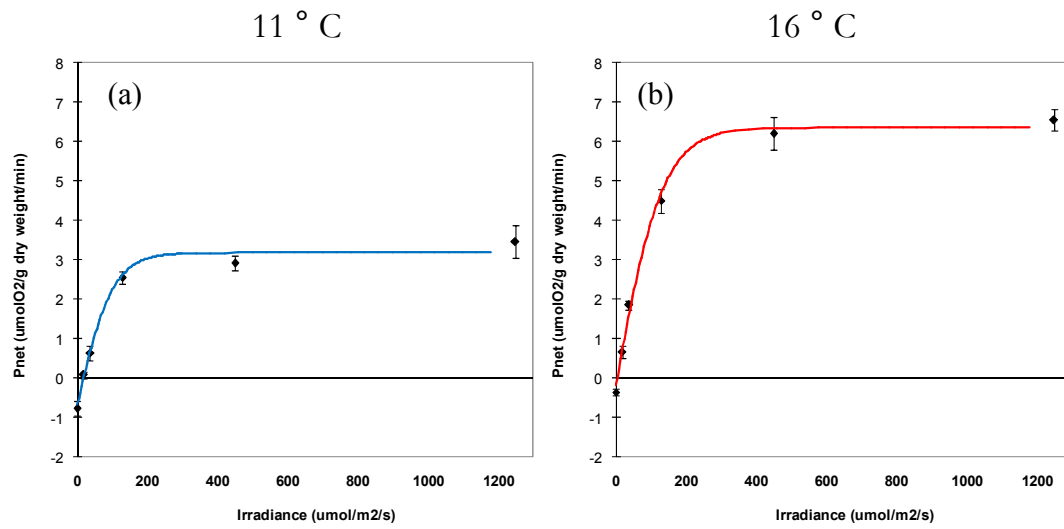


Figure 2. Photosynthesis-light (P-I) curves from *Nereocystis luetkeana* at 11°C (a) and at 16°C (b). Points represent means SD of 4 measurements. See text for details of curve fitting.

Estimated metabolic carbon balance

The Daily Metabolic Carbon Balance determined for the two different temperatures are shown in Fig. 3. DMCB was significantly higher for 16°C compared to 11 ° C (1-way ANOVA, $p < 0.05$).

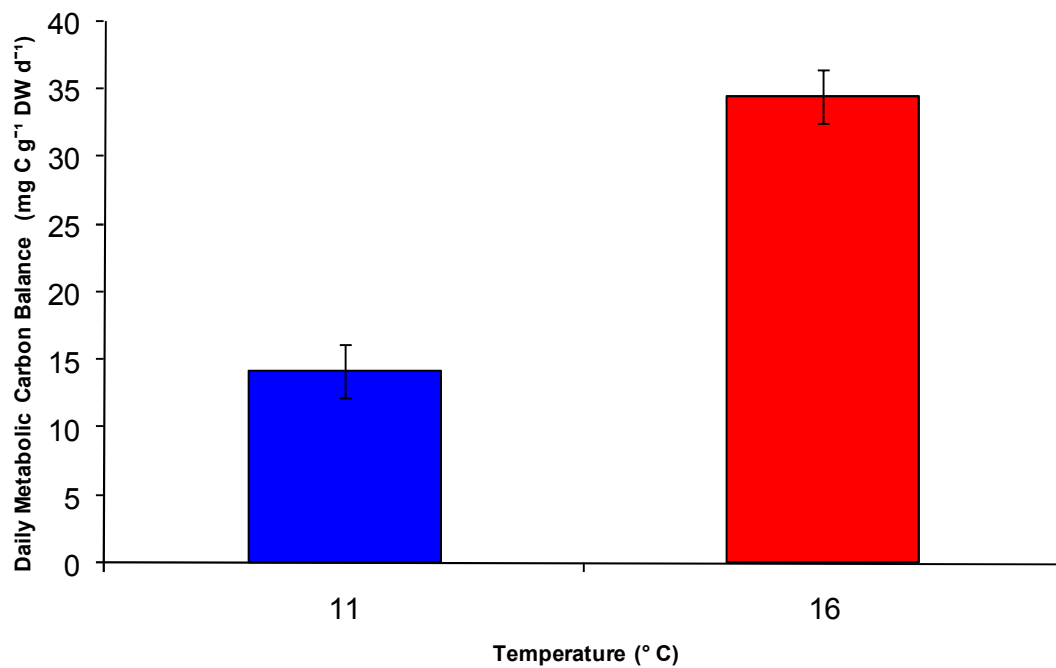


Figure 3. Daily Metabolic Carbon Balance from *Nereocystis luetkeana* at 11°C and at 16°C. Bars represent means SD of 4 measurements.

Discussion

Nereocystis luetkeana in the San Juan Islands seems to be favored by higher temperatures as lower respiration rates, lower I_c , higher photosynthetic rates and significantly higher DMCB were recorded for 16°C compared to 11°C (the response was very clear in all the replicates). However these results are preliminary and only analyze one factor of change: temperature. There are other abiotic stressors (as for example salinity, sediment input, ocean acidification, etc) changing due to climate change which could have effects on *Nereocystis luetkeana* ecophysiology. Also, because thermal optima and tolerance limits can vary among life history stages within a species (e.g., Fain and Murray 1982), it is important to consider the entire life cycle when attempting to link seaweed distribution and abundance to environmental temperature (e.g., Ladah and Zertuche-González 2007). Consider that climate change can not only directly affect via physiological stress but also indirectly via changing relationships among species (Harley, 2011). Ecological change

can only be accurately anticipated if we are able to understand the ways in which biotic and abiotic factors interact to determine the distribution and abundance of species in space and time (Harley, 2011).

Although progress has been made in recent years, there are still significant gaps in our understanding to predict the outcomes of global change in seaweed-dominated systems. There is lack of understanding in the importance of rates, timing, magnitude, and duration of environmental change, at non-additive effects of multiple stressors, at population-level implications of variable environmental impacts among life-history stages, at the scope for population- or species-level adaptation to environmental change, and at ecological responses at the level of communities and ecosystems (Harley et al., 2012). We require additional ecophysiological and ecomechanical studies – especially ones that move beyond single-factor ANOVA designs – to identify key environmental drivers or combinations of drivers. Of particular use would be a physiological framework from which the impacts of multiple stressors could be predicted *a priori* (Pörtner and Farrell 2008). Once understood, these drivers can be incorporated into demographic models to better describe and predict changes in population growth or decline. Developing accurate predictions for the ecological effects of climate change in seaweed-dominated systems is a high priority, as it will be invaluable for effective conservation and management. Identifying when and where conservation and management practices are most effective should continue to be a major focus of ecological research.

Future Studies

To fully understand these preliminary results:

- More experiments (more individuals, different populations and different distribution areas) should be tested.
- Additional long term studies considering seasonality.
- Include sedimentation, salinity and ocean acidification data (other consequences of climate change besides rapid temperature rise).
- Analyze the effect of rapid temperature increase in all the life cycle of the algae.
- Analyze the effect of rapid temperature increase in other seaweed species.
- Analyze the effect of rapid temperature increase in species that interact directly or indirectly with *Nereocystis* (herbivory, wound effects, etc).

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