The Effects of Rising Ocean Temperatures on *Ecklonia Cava*

Word Count (without citations): 4039

Abstract

Ocean temperatures have been rising over the years and are the cause of declining kelp beds all over the world. *Ecklonia cava* is typically found on the coasts of Asian countries, including Japan and Korea. *E. cava* is not only beneficial for species that rely on it for reproduction and energy, but also has many positive health effects on consumers. This study is to determine the effects of high temperature on the growth of *E. Cava* around the coasts of Japan.

Key Words: *Ecklonia cava*, temperature, photosynthesis, respiration

Introduction

Ocean temperatures have been rising over the years, causing a decline in kelp beds all over the world. One specific species affected by this change in temperature is *Ecklonia cava (E. cava)*. *E. cava* is an edible, brown algae found on the coasts of Korea and Japan, and has been on a decline ever since global ocean temperatures began to rise. This herbal plant found around Japan was first documented in the mid 20th century and began to decline around 1990 (Haraguchi et al., 2009). This plant is valuable because it creates kelp forests that provide breeding grounds and habitats for organisms such as fish, shellfish, and other species (Serisawa et al., 2004; Yotsukura et al., 2010). Animals such as sea urchins and herbivorous fish also graze on *E. cava* beds as a source of energy. The decline of *E. cava* could end up harming the survival rates of the organisms that depend on *E. cava*. Due to many organisms relying on *E. Cava*, it is important to help prevent the extinction of *E. Cava*. It is an important food source in the ecosystem and also aids fishing industries by sustaining the population of abalone (Haliotidae), which is a type of large sea snail (Serisawa et al., 2004). After 1996, the decline of *E. cava* resulted in the decline of abalone. The income of Japanese fishermen depleted over the following years due to a lack of abalone .

There are many environmental threats that can endanger *E. cava* such as the changing levels of sand, radiation, and salt concentration (Yotsukura et al., 2010). However, the main threat to *E. cava* at this time is the change in seawater temperature. A major causes of this increase in temperature is global warming (Rosenzweig et al., 2008. Tanaka et al., 2012). Global warming is caused by rising carbon dioxide and greenhouse gas levels. These pollutants stay in the atmosphere and trap heat, causing the Earth to rise in global temperature. The atmosphere is also continuously thinning out, allowing light and heat to enter the Earth's atmosphere. These factors affect the rate of photosynthesis in plants (Morison et al., 2002). The Kuroshio current flows northeast towards Japan and brings in warm currents. This also brings in herbivorous fish that feed on the *E. cava*. The depletion of *E. cava* will result in more barren grounds, which results in the lost of habitats. The changing environment around *E. cava* requires it to distribute towards different locations to survive (Takao et al., 2015; Tanaka et al., 2012). Their loss or replacement by other species due to climate change could have major implications for biodiversity, ecological function, biogeochemical cycling, and human society. Higher temperatures can affect *E. cava's* productivity and rate of photosynthesis due to physiological stress (Serisawa et al., 2001; Gao et al., 2016). The three main factors that affect photosynthesis are light intensity, carbon dioxide concentrations, and temperature. As the intensity of the light increases, the rate of photosynthesis also proportionally increases. As more photons of light fall onto leaves, more chlorophyll molecules also get ionized and energy is generated. However, chlorophyll can get damaged at high light intensities, leading to a steep drop in the rate of photosynthesis (Benckiser et al., 2013).

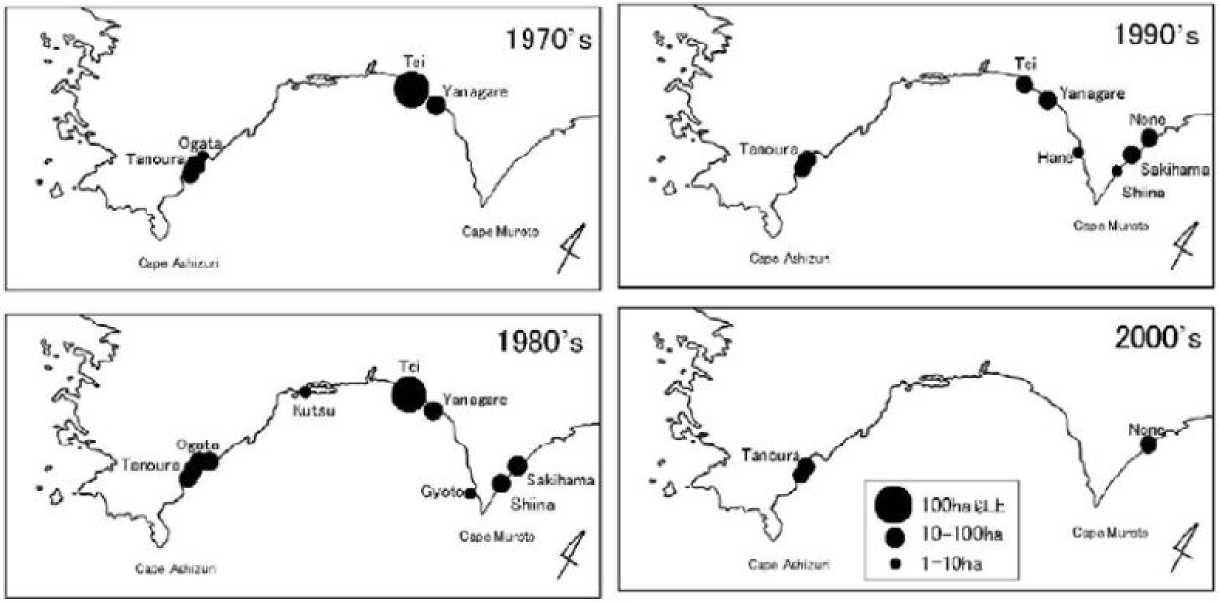
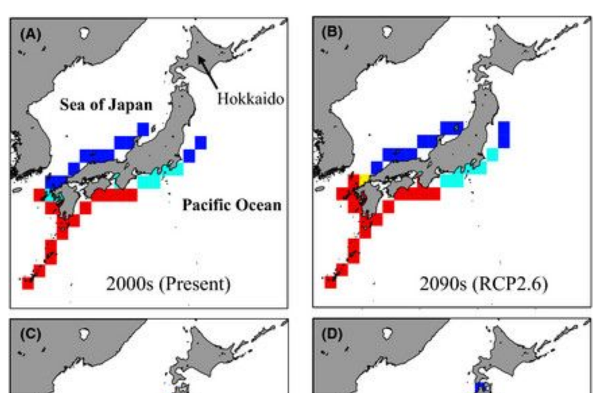


Figure 1. The *E. Cava* bed distribution over consecutive centuries in Kochi, Japan.

An increase in carbon dioxide concentration also speeds up the rate that carbon is turned into carbohydrates to supply the reaction. In effect, this increases the rate of photosynthesis until it is limited by another factor. As temperature increases, the enzymes in the plant reach the optimum temperature level. This allows the speed of photosynthesis to increase exponentially until the optimum temperature is reached. After that, the rate of photosynthesis begins to decrease until the enzymes lose its ability to function and stops. These factors are an example of the law of limiting factors. This states that the rate of a reaction will be limited by the factor that is in the shortest supply. The photosynthetic rate will increase as long as the other factors are in supply. Out of these factors, temperature is being prioritized due to it being the main contributing factor to the decline of *E. cava*. As temperature increases, the rate that carbon dioxide is



converted also increasingly responds. This is due to the decreased ratio of photosynthesis to respiration and dark respiration.

Current research would allow research to assess which habitat would be best suited for *E. cava.* A systematic review would be used to conduct this study. Analysis was run on previous research studies to determine the most effective preservation method for *E cava*. There may also be a correlation in the results between experiments that used similar methods or materials. Comparing the data sources will help identify which type of method improves *E. cava*'s chance of survival. Data will be collected from peer reviewed research articles for this project. The data collected here can contribute to future studies related to seaweed life.

Figure 2. Potential habitats for *E. cava*

Health Benefits

E. cava is not only beneficial for species that rely on it for reproduction and energy, but also has many positive health effects on consumers (Wijesekara et al., 2010). *E. cava* extract could be used for lipase inhibitory activity (Kim et al., 2012). Lipase is an enzyme used to break down fat, so lipase inhibitory activity would increase the breakdown of fat. Pancreatic lipase inhibitors could be used for the direct inhibition of fat absorption. However, pancreatic lipase inhibitors have shown side effects on the respiratory system, central nervous system, and gastrointestinal system (Kim et al., 2002). As a result, further analysis of the lipase inhibitory activity in *E. cava* showed that dieckol had the highest lipase inhibitory act. Dieckol in *E. cava* could then be used to fight against obesity. This shows that *E. cava* has the potential to become a natural antiobesity agent by breaking down fat into fatty acids. They are also known to benefit humans by stimulating hair growth and blood circulation. People could use *E. cava* daily products to help improve hair growth and increase their blood circulation. Phlorotannins are *E. cava* is also one of the highest sources of phloroglucinols, organic compounds found to decrease blood pressure, blood glucose, and inflammation. Wijesekara, Yoon, and Kim (2010) explored the effects of phlorotannins from E. cava: biological activities and potential health benefits. To do this, they researched the potential benefits that *E. cava* can produce, and this article suggests *E. cava* can be put in foods to help benefit the human body. Studies were continued by Pangestuti and Kim (2011) when they did research on neuroprotective effects of marine algae. To do this, they tested the many different uses of *E. cava* and how effective it is. The uses were recorded and compared to medicines currently being used to see if it could replace it. *E. cava* has also been studied as an agent for hair growth (Bak et al.,, 2012, Kang et al., 2012). Kang et al., (2012) researched the effect of dieckol, a component of E. cava, on the promotion of hair growth. They evaluated the effect of *E. cava* and the component dioxinodehydroeckol on hair growth in mice. To do this, *E. cava* extract was treated to rat vibrissae follicles, which is the mammalian hair used for tactile sensing. Twenty-one days later, the difference was taken between the control and the treated. The treated mice resulted in increased hair growth compared to the control group. This demonstrated that E. cava extract is a potential treatment for hair loss. In the future, E. cava extract must be tested on humans to see the potential of how efficient they are. Flukes et al., (2015) did research on phenotypic plasticity and biogeographic variation in physiology of habitat-forming seaweed and their response to temperature and nitrate. Nitrate is important because it is recognized as a major component of nutritional compounds that are necessary for the *E. Cava's* survival. As a result, enriched seawater could have a significant impact on the photosynthetic rate (Gao et al., 2016). To do this, they took seaweed and changed the type of seawater that they were in. It was found that long term temperature rises have severe negative impacts at the individual level. Serisawa (2004) and a group of researchers also evaluated the dark respiration of the stipe of E. cava in relationship to temperature. To do this, they cut up E. cava and put it in a darkroom water bath and used a dissolved oxygen meter to measure the respiration. It was found out that higher temperature led to higher respiration which is unhealthy for the algae.

Previous Methods

Researchers have attempted to preserve *E. cava*, but they failed to come up with a successful solution. Haraguchi et al (2009) tested three different methods of afforestation: The establishment of seeds in a barren land. The first method used was the spore bag method. Spore bags containing one or two *E. cava* were set in different areas during the autumns of three consecutive years 1999, 2001, and 2002. The following spring, plants had grown around the bags and on the ground. However, herbivorous fish grazing damaged several plants and the plants disappeared by 2005. The second method used was the net cage method. Plants were transplanted to an artificial reef and placed in and around the cages. Three months later, herbivorous fish had destroyed plants outside the cages while those inside were dormant during the summer. The blades that were leaning on the cages were also bleached and dissolved. This revealed that research on changes in seawater temperatures was necessary. The third method used was the action of transplantation using seedlings at artificial reefs. This method was the most successful because the temperature did not affect the growth of *E. cava*. While there are multiple solutions that decrease the rate of decline for *E. cava*, none of them secure the population of *E. cava*. However, if signs of decay could be noticed in advance, measures could be taken to prevent it more quickly. With this in mind, Yotsukura et al., (2010) did an experiment on temperature stress-induced changes in the proteomic profiles of *E. cava*. To do this, they retrieved *E.cava* samples and put them under different temperatures. They then analyzed the protein levels to analyze how the growth rate of *E. cava* had fluctuated. The protein levels could be used to determine whether marker proteins could be identified. These marker proteins react to environmental stresses such as rising temperature levels, and would allow for efficient methods to preserve *E. cava*. However, mucilaginous polysaccharides are commonly found in large amounts of kelps, and prevent the isolation of proteins. They found out which temperature levels were the most beneficial to the *E. cava*, but some results could not be evaluated because of other factors that could not be accounted for have affected the *E. cava* in the wild.

Serisawa et al., (2002) did a morphometric study of E. cava sporophytes in two localities with different temperature conditions. Researchers then measured the dimensions of the different E. cava. Stipe diameters, primary blade widths, and largest bladelet lengths were from Nabeta. The number of bladelets that were similar were from both areas. Further studies are still needed to find the causes of these differences. Serisawa et al., (2001) also researched photosynthesis and respiration in bladelets of E. cava. To do this, they cut blades of E. cava and put them in water baths at a constant water temperature. Dark respiration of the intact stipe of E. cava was measured at various water temperatures ranging from 15 to 27.5°C in winter and 15–30°C in summer in a closed system by using a dissolved oxygen meter. The stipe respiration was compared on whole stipe, length, surface area, volume, wet weight and dry weight bases. On each basis, the stipe respiration always increased with a rise in water temperature within the temperature range investigated. The stripes of *E. Cava* showed similar respiration rates on each basis of length, surface area, volume, wet weight and dry weight at each temperature, irrespective of the stipe length. They were then observed with a product meter to see the rate of photosynthesis and respiration under different conditions. The results fluctuated over different seasons. In the case of low light conditions, despite an optimum temperature for maturation, the fragments did not form sori and laminaran was not accumulated during the culture period. In the case of sufficient light and non-optimum temperature conditions, the fragments did not form sori, but laminaran was accumulated. When the fragments were cultured under optimum light and temperature conditions for maturation, laminaran was accumulated in the early stage of maturation, just before or after cortex of the bladelets thickened, and decreased with the progress of maturation, and all fragments matured regardless of the length of the photoperiod. So, these results support the idea that laminaran is used as the main respiratory substrate in the maturation of E. cava.

Purpose

The purpose of this study is to determine the effects of high temperature on the growth of *E. Cava* around the coasts of Japan.

Research Question

Does high temperature affect the growth of *E. Cava* around the coasts of Japan?

Alternate Hypothesis

Temperature affects the growth *E. cava* around the coasts of Japan.

Null Hypothesis

Temperature does not affect the growth of *E. cava* around the coasts of Japan.

- Dependent variable: The growth of *E. cava* measured in length and width.
- Independent variable: The temperature measured in degrees.

Methods

Systematic review was used to collect articles studying the effects of temperature on *E. cava*. To do this, many different articles from various researchers were collected to get a variety of proposals and solutions that they had discovered. This study design had helped me understand the different ways and approaches available to understand how *E. cava* can be preserved. Sources such as EBSCOhost, Google Scholar, ResearchGate, human kinetics journals, CLU Library, CSUCI databases, PLOS, SpringerLink, etc. were used to collect data. Researchers who have access to more articles have also been of assistance in article collection. Keywords such as *Ecklonia cava*, temperature, photosynthesis, and respiration were used to collect articles.

Data from 1800 to the present was collected because the decline of *E. cava* was first recorded in this year, so the data from this time period would be most beneficial to the research. This study design has been done previously, although research on this topic is limited because the topic was mostly researched in the 1900s. *E. cava* is also located in Japan and Korea, so a language barrier exists. To address this issue, translators were used to help understand the meaning of the paper.

Systematic review was the primary method. Data was analyzed through a t-test. This is most appropriate for this study because the way different researchers used different methods to find solutions to their problems can be evaluated and compared.

Data on variables that are affecting the growth rate or the population of *E. cava* was collected. Different methods that researchers used to try to prevent the decline of *E. cava* have been recorded. The different methods and results gathered have also been categorized. These may be formatted in a chart to compare the different results gathered. The variables that affect the *E. cava* lead to the different methods that can be used to prevent those variables from affecting the population. The statistical results revealed information showing what variables affect *E. cava* the most, which will then tell me which solution would help prevent the decline of *E. cava* successfully.

Selection Criteria

The articles collected in the systematic review were based on the following criteria:

1. The paper is peer reviewed
2. The study must include various temperatures at when *E. cava* started to decline
3. The study was conducted post 1990

Results

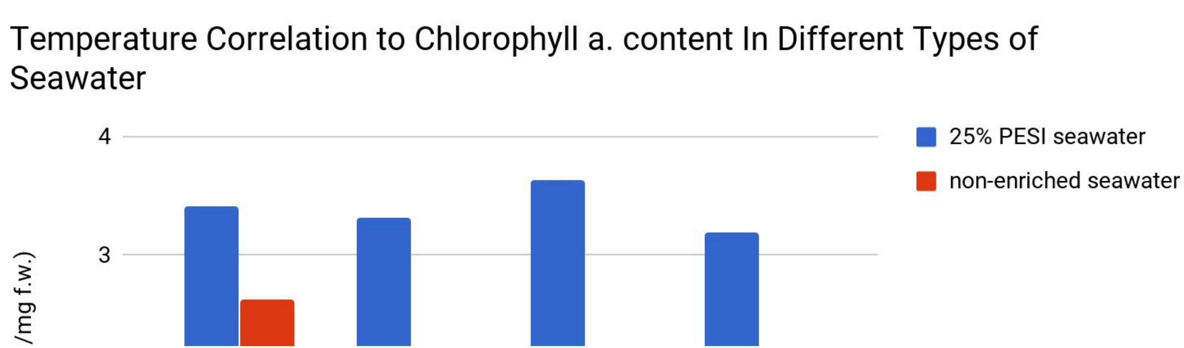


Figure 3. The correlation of Chlorophyll a. Content to different temperatures.

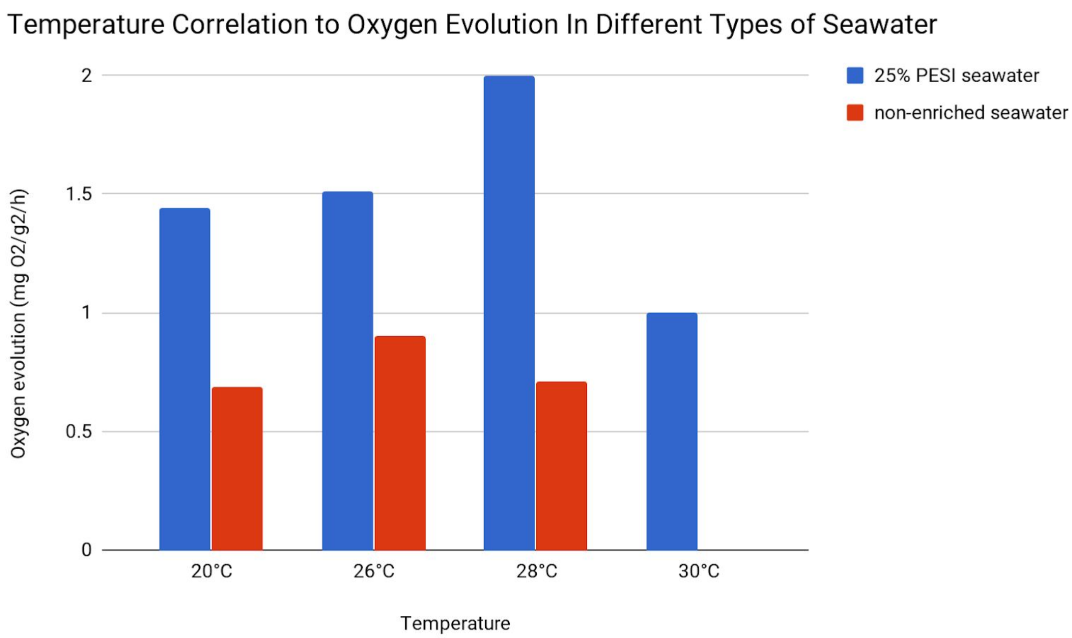


Figure 4. The correlation of oxygen evolution in different types of seawater.

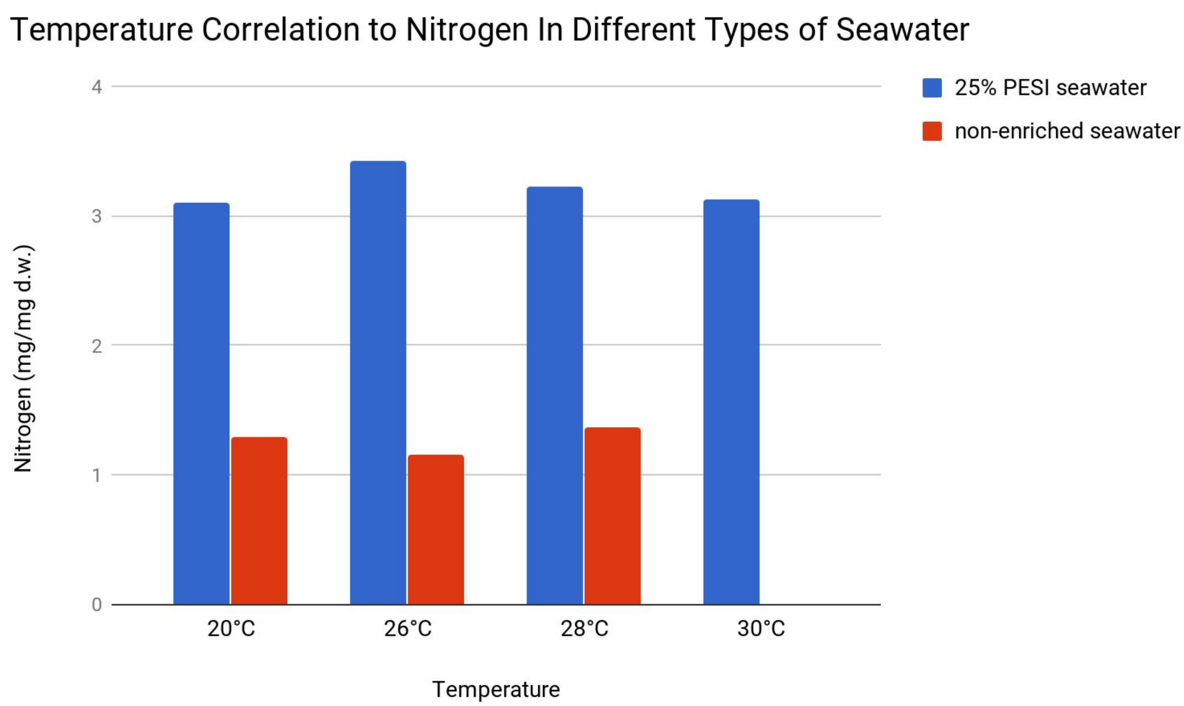


Figure 5. The correlation of nitrogen to temperature

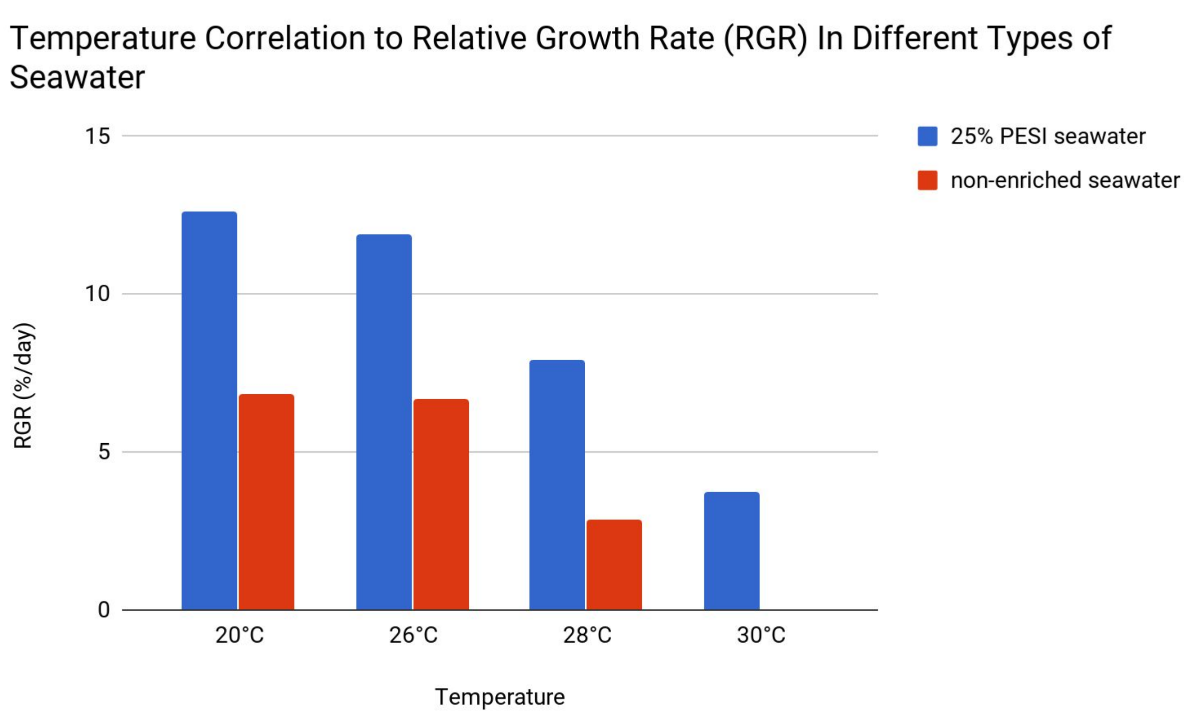


Figure 6. The temperature correlation to relative growth rate (RGR) in different types of seawater.

Table 1a. The correlation of ocean temperatures in Tei (Winter).

February 1998 (winter) Tei	Area (cm)	Chl.a (µg)	Dry weight (mg)	Photosynthesis
10°C	24.4	0.86	3.65	54.2
15°C	36	1.26	5.36	68
20°C	44.7	1.57	6.67	75.8
25°C	52.7	1.92	7.56	103.1
27°C	52	1.89	7.49	118.4
29°C	48.6	1.77	7	123.2

Table 1b.. The correlation of ocean temperatures in Tei (summer).

August 1998 (Summer) Tei	Area (cm)	Chl.a (µg)	Dry weight (mg)	Photosynthesis
10°C	22.1	0.74	3.25	61.1
15°C	30	1.01	4.43	69.8
20°C	36.6	1.23	5.38	74.1
25°C	42.1	1.5	5.88	77.9
27°C	46.1	1.64	6.49	91.3
29°C	42	1.49	5.93	91.2

Table 1c. The correlation of ocean temperatures in Nabeta (Winter).

February 1998 (winter) Nabeta	Area (cm)	Chl.a (µg)	Dry weight (mg)	Photosynthesi s
10°C	25.1	0.81	4.37	52.2
15°C	35.1	1.13	6.05	65.2
20°C	41.3	1.33	7.17	68.2

25°C	47.8	1.55	8.36	89.5
27°C	47.6	1.55	8.31	98.5
29°C	44.6	1.45	7.8	106.4

Table 1d. The correlation of ocean temperatures in Nabeta (Summer).

August 1998 (Summer) Nabeta	Area (cm)	Chl.a (µg)	Dry weight (mg)	Photosynthesis
10°C	20.8	0.71	2.79	56.7
15°C	26.4	0.89	3.56	61.5
20°C	32.8	1.11	4.41	68.4
25°C	37.7	1.32	4.93	71.3
27°C	41.6	1.46	5.44	82
29°C	35.9	1.26	4.7	79.9

This table includes *E. cava* taken from two different areas. The variables are the area (cm^2), the dry weight (mg),and the chlorophyll (ug). It also contains the seasons at when the data was collected. The photosynthesis-light curves were collected at Tei and Nabeta Bay in 1996 and 1997. The data shows that *E. cava* from Nabeta Bay was more prosperous than the ones from Tei. Respiration rates increased with the stipe length and rising temperatures. (Takano et al., 2004).

The area of the bladelet in Tei at 10°C, 15°C, 20°C, 25°C, 27°C, and 29°C during February 1998 was 24.4±1.4cm^2, 36.0±1.7cm^2, 44.7±1.2cm^2, 52.7±1.0cm^2, 52.0±2.1cm^2, and 48.6±1.4cm^2 respectively. The area of the bladelet increased with the temperature until it hit 29°C, where it started to then decline. The area of the bladelet in Tei at 10°C, 15°C, 20°C, 25°C, 27°C, and 29°C during August 1998 was 22.1±0.7cm^2, 30.0±1.1cm^2, 36.6±1.2cm^2, 42.1±0.7cm^2, 46.1±1.6cm^2, and 42.0±2.2cm^2 respectively. The area of the bladelet increased with the temperature until it hit 29°C, where it started to then decline. The area of the bladelet in Nabeta at 10°C, 15°C, 20°C, 25°C, 27°C, and 29°C during February 1998 was 25.1±0.3cm^2, 35.1±0.7cm^2, 41.3±0.8cm^2, 47.8±1.6cm^2, 47.6±1.3cm^2, and 44.6±1.2cm^2 respectively. The area of the bladelet in Nabeta at 10°C, 15°C, 20°C, 25°C, 27°C, and 29°C during August 1998 was 20.8±0.9cm^2, 26.4±1.1cm^2, 32.8±1.6cm^2, 37.7±2.3cm^2, 41.6± 1.5cm^2, and 35.9±1.5cm^2 respectively. The values at 27°C and 29°C resulted in the p value of 0.0065.

The chlorophyll a. content of the bladelet in Tei at 10°C, 15°C, 20°C, 25°C, 27°C, and 29°C during February 1998 was 0.74±0.02µg, 1.01±0.07µg, 1.23±0.06µg, 1.5±0.04µg, 1.64±0.08µg, and 1.49±0.09µg respectively. The chlorophyll a. content of the bladelet in Tei at 10°C, 15°C, 20°C, 25°C, 27°C, and 29°C during August 1998 was 0.74± 0.02µg, 1.01±0.07µg, 1.23±0.06µg, 1.50±.04µg, 1.64±0.08µg, and 1.49±0.09µg respectively. The chlorophyll a. content of the bladelet in Nabeta at 10°C, 15°C, 20°C, 25°C, 27°C, and 29°C during February 1998 was 0.81±0.04µg, 1.13±0.05µg, 1.33±0.07µg, 1.55±0.07µg, 1.55±0.08µg, and 1.45±0.08µg respectively. The chlorophyll a. content of the bladelet in Nabeta at 10°C, 15°C, 20°C, 25°C, 27°C, and 29°C during August 1998 was 0.71±0.03µg, 0.89±0.01µg, 1.11±0.03µg, 1.32±0.05µg, 1.46±0.04µg, and 1.26±0.04µg respectively. The values at 27°C and 29°C resulted in the p value of 0.0072.

The dry weight of the bladelet in Tei at 10°C, 15°C, 20°C, 25°C, 27°C, and 29°C during February 1998 was 3.65±0.29mg, 5.36± 0.33mg, 6.67± 0.35mg, 7.56± 0.56mg, 7.49± 0.66mg, and 7± 0.60mg respectively. The dry weight of the bladelet in Tei at 10°C, 15°C, 20°C, 25°C, 27°C, and 29°C during August 1998 was 3.25±0.22mg, 4.43±0.38mg, 5.38±0.36mg, 5.88±0.42mg, 6.49±0.72mg, and 5.93±0.74mg respectively. The dry weight of the bladelet in Nabeta at 10°C, 15°C, 20°C, 25°C, 27°C, and 29°C during February 1998 was 4.37± 0.40mg, 6.05± 0.36mg, 7.17± 0.68mg, 8.36± 0.28mg, 8.31± 0.21mg, and 7.8± 0.21mg respectively. The dry weight of the bladelet in Nabeta at 10°C, 15°C, 20°C, 25°C, 27°C, and 29°C during August 1998 was 2.79± 0.08 mg, 3.56± 0.20mg, 4.41± 0.25mg, 4.93± 0.32mg, 5.44± 0.28 mg, and 4.7± 0.32mg respectively. The values at 27°C and 29°C resulted in the p value of 0.002

The light-saturation indices of the bladelet in Tei at 10°C, 15°C, 20°C, 25°C, 27°C, and 29°C during February 1998 was 3.65±0.29mg, 5.36± 0.33mg, 6.67± 0.35mg, 7.56± 0.56mg, 7.49± 0.66mg, and 7± 0.60mg respectively. The light-saturation indices of the bladelet in Tei at 10°C, 15°C, 20°C, 25°C, 27°C, and 29°C during August 1998 was 3.25±0.22mg, 4.43±0.38mg, 5.38±0.36mg, 5.88±0.42mg, 6.49±0.72mg, and 5.93±0.74mg respectively. The light-saturation indices of the bladelet in Nabeta at 10°C, 15°C, 20°C, 25°C, 27°C, and 29°C during February 1998 was 4.37± 0.40mg, 6.05± 0.36mg, 7.17± 0.68mg, 8.36± 0.28mg, 8.31± 0.21mg, and 7.8± 0.21mg respectively. The light-saturation indices of the bladelet in Nabeta at 10°C, 15°C, 20°C, 25°C, 27°C, and 29°C during August 1998 was 2.79± 0.08 mg, 3.56± 0.20mg, 4.41± 0.25mg, 4.93± 0.32mg, 5.44± 0.28 mg, and 4.7± 0.32mg respectively. The values at 27°C and 29°C resulted in the p value of 0.33.

Discussion

With the systematic review taken place to analyze multiple articles, it was discovered that high temperatures do harm the growth of *E. cava*. The hypothesis proposed was correct, and this supports the decline of *E. cava*. Due to higher temperatures, the *E. cava* has been declining. Data was found correlating increasing temperatures with lower *E. cava* population levels.

The data collected showed that 27°C was the optimal temperature level for the growth of *E. cava*. Up until 26°C, the growth rate was constantly increasing. However, after 27°C, the light saturation, Chlorophyll a. content, and area started to decline. The data collected from the two areas were very similar. In both Tei and Nabeta, the increasing light intensity led to a linear increase in the photosynthetic rate until it reached the light-saturation point. After this point, both photosynthetic rates started to drop. This was due to the light-saturation point limiting the function of light as a growth factor. However, the increase in temperature allowed the light-saturation point to exceed its normal level. The light-saturation point was able to increase until the temperature reached 27°C, where it started to decline.

This factor applies to the different measurement of units calculated. Along with light saturation, the area, dry weight, and clorophyl a. content was measured.

Limitations

The limited research was a critical limitation in this review. Since to *E. cava* being located around the coasts of Japan and Korea, some articles were unavailable due to language differences. *E. cava* had also declined since the 1990s, so there was a minimal quantity of research from the present.

Conclusion

In this study to determine whether increasing ocean temperatures were causing the decline of *E. cava*, evidence was gathered that increasing temperatures harm the growth rate of *E. cava* at a certain point. This systematic review provides evidence that supports the hypothesis of this study that temperature changes in the ocean do harm the growth of *E. cava*. A correlation was shown between temperature and photosynthetic rate.

Further Work

To further contribute to this study, more research on potential solutions to this problem could be done. Knowing that temperature is one of the main causes of the decline of *E. cava* can be used to solve that problem. Relocating the habitats of *E. cava* to areas with lower temperature levels could assist the growth of *E. cava* and help it repopulate. More research on specifically *E. cava* can also be done to gain more data on the species. Health benefits can also be researched to support why *E. cava* is important to humans and the coastal ecosystem.

Data collected on this algae could be transferred to different plants that are also declining. The information gained from this study could assist preventing the declination of many other algaes in the ocean. Future research should also focus on cross-transplantation between cold and warm temperatures to determine the thermal tolerance. Ultimately, the findings of the correlation between temperature and *E. cava* growth could be used to conduct more research on the growth of other species.

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