Growth Rate Analysis of *Undaria pinnatifidia*: finding efficient methods of population control in foreign environments

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Growth Rate Analysis of *Undaria pinnatifidia* to find efficient way of population control in foreign environments

Abstract

Undaria pinnatifidia is an invasive species of brown algae native to the coasts of Japan, China, and parts of South East Asia. Commonly known as Wakame Algae, it can grow to be over three meters in length. Starting from the Los Angeles area and spreading North, Undaria recently manifested itself in the Monterey Harbor. By utilizing the ecological opportunity of foreign substrate, Undaria has the potential to out compete native algae for light. There is a volunteer base in the Monterey Harbor that works to control the population of the invasive algae by manual removal.

The objective of this project was to study the growth of *Undaria pinnatifidia* and determine if there is a way to cut the plant and kill it rather than having to pry it off the docks and Pylons. My methods was to section whole specimens of the algae into pieces cut above or below the meristem and observe their growth to determine if this would be an effective way to curb the invasion of *Undaria*. The goal is to provide the volunteer base at the Monterey harbor with a more efficient way to regulate the *Undaria* populations in the direct area.

Introduction

Species Background

Undaria pinnatifidia (Wakame) is considered to be a sea vegetable, or edible seaweed in many Asian cultures. It has a subtly sweet flavor and is most often served in soups and salads. Sea-farmers have grown it in Japan since early history [1].

Native to cold temperate coastal areas of Japan, Korea and China, in recent decades *Undaria pinnatifidia* has become established in New Zealand, France, Great

Britain, Spain, Italy, Argentina, Australia, and The United States.[2]. It was nominated one of the 100 worst invasive species in the world.[4] The plant was probably introduced to the marine environment of the Monterey harbor by Ships' Ballast Water.[3] However, like all invasive species, it has spread around the world by numerous means. Specimens of it were recently found on a large piece of dock from the Fishing Port of Misawa, Japan that washed ashore in Oregon as part of the debris from the Tsunami that struck Japan on March 11, 2011.[5] Scientists estimate roughly 1 1/2 million tons of Japanese tsunami debris is floating in the Pacific Ocean with the largest concentration floating between Hawaii and the west coast of the United States. The debris, along with all its hitch hiking species is expected to continue spreading around the pacific basin through 2015.[6].

Undaria pinnatifidia can grow to 3 meters in length. It grows very well in sheltered temperate waters forming dense forests at depths of up to 15 meters and can quickly displace native habitats. .[7]. The plant has a single mid rib that has long flanges attached to it. The flanges start as one single leaf and through maturation the flanges develop. The sporophyl develops in a fist size ball of folded flattened midrib. When mature, the sporophyl release millions of microscopic spores into the water that are carried by the current to develop new populations.[8].. The species has a root-like structure present at the base called a holdfast. Like a root system in plants, a holdfast serves to anchor the algae in place on the substrate where it grows, and thus prevents the algae from being carried away by the current. Unlike a root system, the holdfast generally does not serve as the primary organ for water uptake, nor does it take in nutrients from the substrate.[8]. A 1995-96 study in Busan, Korea, reported that sporophytes appeared between October and November, and then grew rapidly from winter to spring when seawater temperatures were between 10 and 16°C. Sporophytes produced zoospores in spring from sporophyl positioned on the basal part of the stipe, and died off in summer with increasing temperature.[9]

The invasive kelp has capitalized on non-natural surface areas in the Monterey harbor such as docks, pylons and break walls. By doing this it has been crowding out the native kelp species for light. In the Monterey Harbor volunteers help to control the pest by manually removing individuals from the docks, and pylons within tools reach. However, the holdfast [10] is very hard to remove.

Focus of Study

In my study, the *Undaria* thales, plant body, was cut either above or below the meristem. If one or both pieces died as a result of the cut, it may indicate a method for volunteers at the harbor to control the growth, especially of individual growths attached to docks. Due to the magnitude of spores that *Undaria pinnatifidia* release in to the water for each mature individual, controlling their growth rate is not an easy task.

I expected to see the piece of the individual containing the meristem have positive growth and the piece without the meristem to show no change or progressively decrease in length. The goal was to identify where volunteers should cut the *Undaria* in order to assure that the individual will die and not grow back thus expediting the control of the algae in the Monterey Harbor.

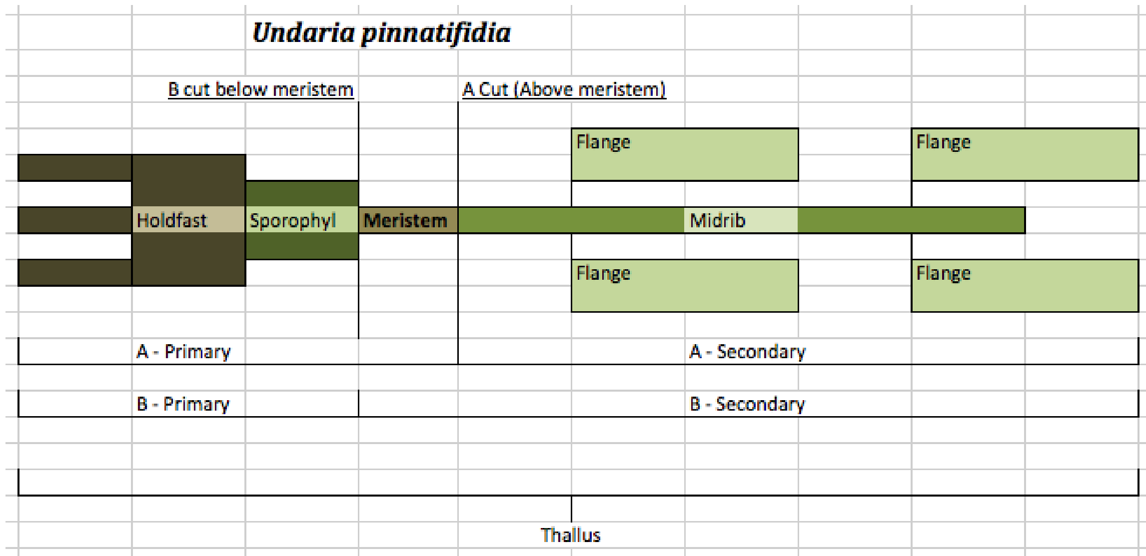
Methods and Materials

To carry out this experiment we made two racks that the specimens where connected to. The racks where composed of 1" x1" x5' wooden center beams. Three pieces of PVC pipe (1/2'' x 5' long) were screwed to the beam one foot apart starting at the bottom. That left 3' above the samples to attach the apparatus to the dock and keep all specimens submerged in the water. The three segments of PVC per rack had 16 holes drilled into them equal distance apart. Eight holes were drilled on either side of the center beam. The holes where used to zip tie the specimens to the racks.

Image 1 Materials Used

To begin the study, a diver harvested several specimens of *Undaria pinnatifidia* that were growing from the bottom of the harbor. I sorted the specimens into Small, Medium and Large sizes based on development stage. With the use of a Random Number Generator (RNG) I sorted the samples and attached them randomly between the two racks. The RNG also proved helpful when deciding which of the specimens would be "Control" (uncut) or "Manipulated" (cut) in the experiment. Each size class had three control specimens, which left six specimens from each size class to be manipulated. The racks, with the whole specimens attached, were mounted to a dock and left for five days to let them acclimate to higher light intensity and warmer water near the surface.

After five days, the specimens were measured again to check growth progress. Utilizing the RNG again, the Manipulated specimens where marked as an A or B specimen depending on if the specimen was cut **A**bove or **B**elow the meristem. When the specimens where cut, the secondary piece (that had been cut off) was zip tied to the hole directly inside of the primary piece (see Drawing #1)



Drawing #1 – Diagram of cuts to Specimens

Image 2 - Large Specimen Cut Below the Meristem

All specimens where re-measured after being cut as were the controlled specimens for reference. The racks were then re-attached to the dock and left for another six days after which they where pulled up and measured again to track growth progress.

All specimens where measured with a Centimeter measuring tape, measuring from the base of the holdfast, following the midrib out to the farthest piece of flange. If the specimen did not have a holdfast then it was measured from the base of the midrib out to the farthest piece of flange. When measuring, following the contours of the midrib was difficult especially over the sporophyl region of the specimens. To provide a more accurate length assessment I would hold the tape at one end and follow the contour of the sporophyl with my thumb and pointer finger dragging the tape over the wavy contour of the midrib. If the sporophyl were fully developed I would measure over the top of the sporophyl.

All specimens though randomly assigned were placed symmetrically on the racks. Position naming played a major roll in data collection and processing. **R**ight or **L**eft rack were notated by a upper case R or L, Rows were identified as Row A, B or C, the right or left side of the row were notated with a lower case r or l and finally the specific position was numbered 1-8 starting with 1 nearest the center beam and increasing outward in both directions. For example, specimens named RBl4 = **R**ight rack, Row **B**, **l**eft side of the rack, Position Number **4** **.**

Data Collection and Analysis

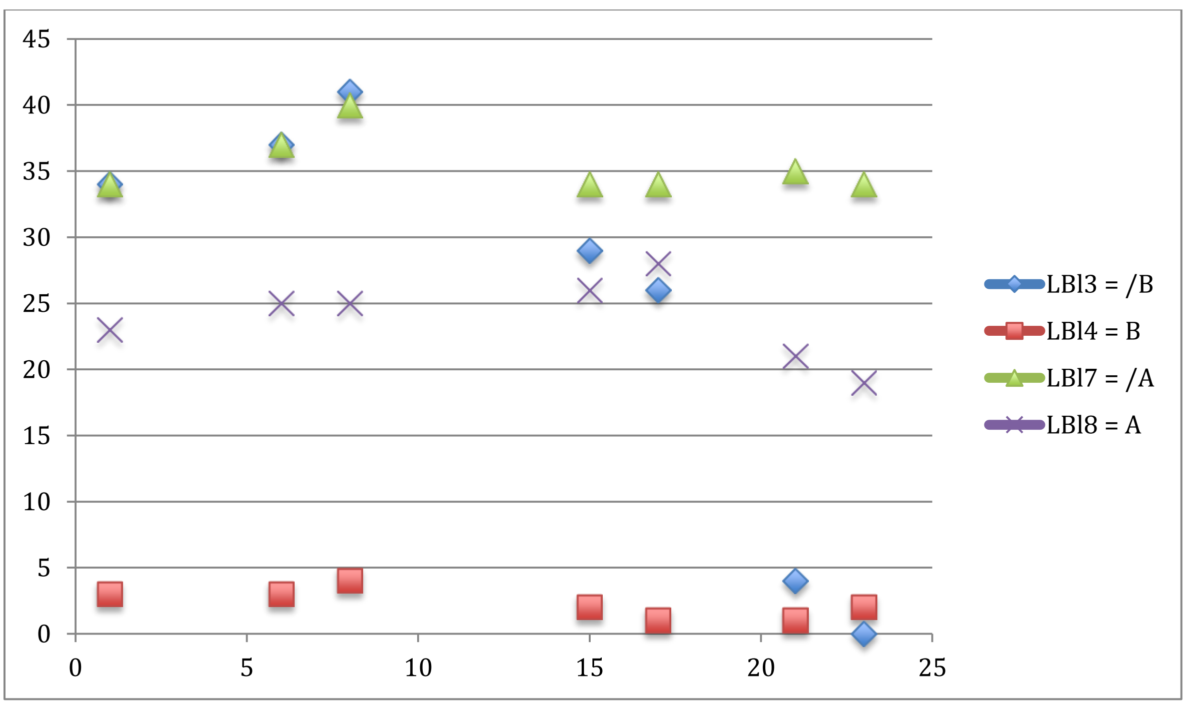
Data was recorded in the field with the field data collection sheet (Image #3), which was then recorded in a Master Data file that had individuals data per day.

	Date			Time				Undaria Data Collection									
								Right Rack									
Row	Left Side									Right Side							
A	8	7	6	5	4	3	2	1		1	2	3	4	5	6	7	8
			M		L								M				L
length																	
sporophyl																	
B	8	7	6	5	4	3	2	1		1	2	3	4	5	6	7	8
	M				S						L		S				M
length																	
sporophyl																	
C	8	7	6	5	4	3	2	1		1	2	3	4	5	6	7	8
	L		S		M								L				M
Length																	
sporophyl																	

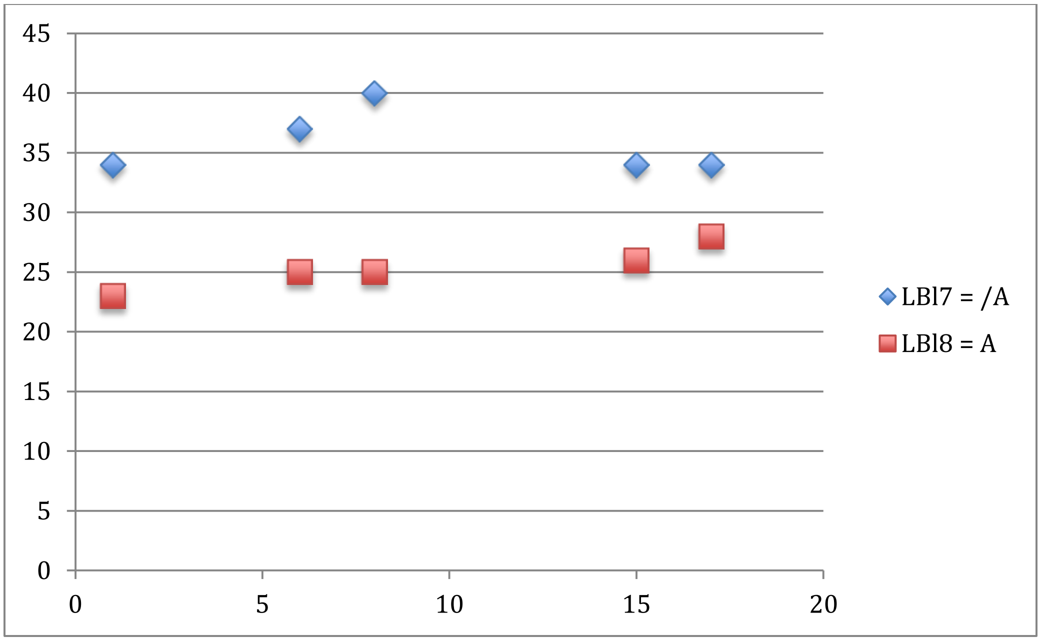
Image 3 - Sample data table

Each specimen had its own position on the rack that was distinguished by vertical and lateral location (ex. Specimen name). The initial file was organized into a flat EXCEL file and converted to a pivot table for analysis. By utilizing the flat file I was able to perform simple calculations to find the change in length between sample dates and growth rate per day.

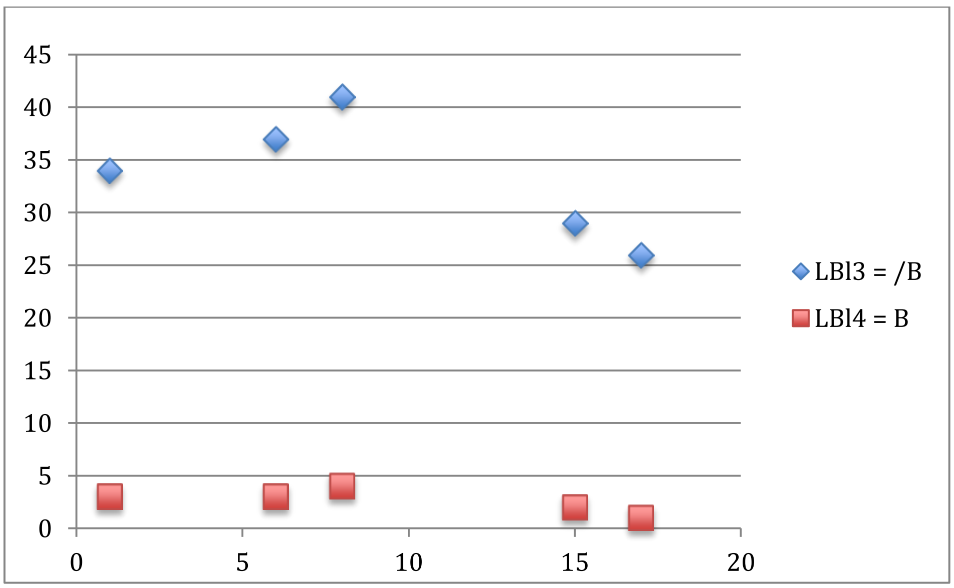
Analysis of the data was based on day one being when the specimens were cut (day 5 after initial sampling) which synched my sample days to the life span of the cut specimens. I was able to look at the specimens' growth progression on a scale of day one through 30. I did not sample every day but with a scatter plot the relative difference in time between sample days was evident.



Graph 1 – one specimen of *Undaria* from each classification with their respective secondary piece.



Graph 2 – Both pieces of one *Undaria* Specimen cut above the meristem. (A, /A)



Graph 3 – Both Pieces of one Undaria Specimen cut below the meristem. (B, /B)

Results

The analysis of this data shows a very sporadic and negative growth trend. The individuals left whole for comparison were no exception to this negative trend. With the control specimens we should have seen a consistent positive growth trend; however, there was very little growth evident in any specimen after the fourth or fifth sample day. This was about half way through the sampling period. For all specimens there was a negative growth trend towards the end of the sampling period.

In light of the specimens length being severely decreased after sample day four or five, the data, up until that point was fairly dynamic. Isolating a set of individual specimens and their secondary pieces showed a positive growth trend in the /B and A specimens for the two specimens that where graphed. The rest of the specimens where progressively eliminated from the racks and only a few specimens made it to the end of the sampling period.

Discussion

The data shown in graphs one through three (above) demonstrate a simple correlation of the two pieces of the *Undaria* plant to each other. For the first three to four sample dates there was a difference in growth trend of the two pieces (Graph 2,3) where the piece with the meristem showed positive growth in comparison to the piece without the meristem. The piece without the meristem showed little growth and eventually died. After sample date four or five there was consecutive drop in length for all specimens that clearly indicated predation. Some of my specimens ended up like the specimen in Image 4 having little round holes in the specimens or grooves carved out of the specimen. On two of the days I found the two organisms in Image 5 and 6. Both organisms where found wrapped in a couple of my larger *Undaria* specimens.

There was little evidence of predation before the specimens where cut. This suggest that by cutting the specimens predators where drawn to the samples. On the other hand specimens did not start getting seriously consumed until after the fourth or fifth sample date about halfway though the sampling period. This suggests that the samples did not necessarily attract the predators but were discovered and therefore had no trigger that made them easier to find.

Image 4 Evidence of Predation - holes in sample

Image 5 - Dungeness Crab(Juvenile) - Metacarcinus magister

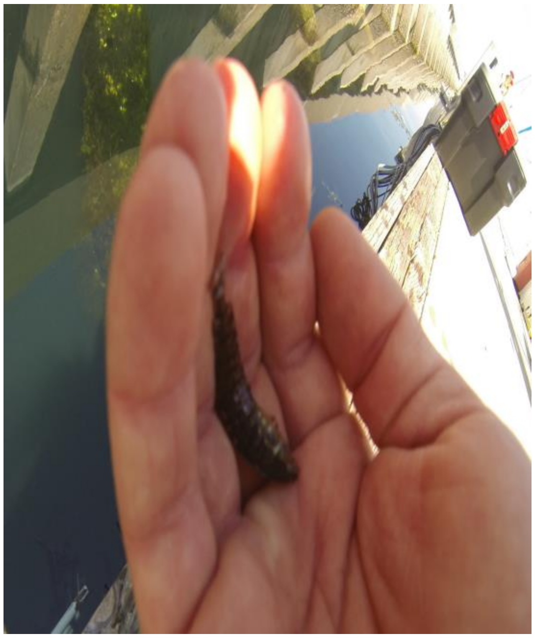


Image 6 - Kelp Greenling (Juvenile): Hexagrammos decagrammus

Another point to consider is the regrowth potential of the *Undaria* brown algae. As stated previously, the algae is fast growing and rapidly spreading up the coast of California. With a specimen cut above the meristem the primary piece would contain the holdfast, meristem and potentially the sporophyl. With the meristem still attached, the Thallus would have the potential to regrow a flange and efficiently photosynthesize. Even if the meristem could not regrow flanges for efficient photosynthesis the organism would still have the potential to develop a sporophyl and release spores into the water column. This was not the primary focus of this study but could lead to studies in the future.

Improvements

1. Materials - One of the first issues we came across was the design of the racks. The center beams were made of wood which when placed in the water for several days swelled making it difficult to get them off the bolts that attached them to the dock. A simple solution of course would be to drill larger holes.

2. The bolt and wing nut began corroding rapidly in the salt water and were tough to screw together tightly, giving the racks slight wiggle room to move. In a tidal flux due to the buoyancy of the wood beam the racks would rotate up exposing some of the specimens to the air. There are a few solutions to this problem. First, use stainless steel or brass hardware that doesn't react to salt water quite so readily. Second, use two bolts to mount the rack to the dock. That would reduce the influence of waves and tide changes. Another option would be to fasten a weight to the base of the center beam in order to counterbalance the buoyancy of the wooden beam even in a tidal flux.
3. Rotation and Buoyancy – Consider changing the design of the racks from one center beam to two end beams to prevent swiveling. This would eliminate the need for a weight to keep the racks in the water.
4. Predators - In order to better isolate the racks holding the *Undaria pinnatifidia* specimens from predators we could stretch a rope across the dock slip and suspend the racks in the middle of the slip. Drill holes in the beams large enough for rope to feed through. The rope would replace the dock mounting bolt and wing nut. Appropriate weight(s) would be needed to address rack buoyancy and hold them vertical. Drilling the holes perpendicular to the rope would be a simple way to keep the racks from moving along the rope. Utilizing plastic plates to block predators from climbing along the rope would also help to reduce specimen degradation. To reduce degradation from kelp greenlings, we could use a canvas net to encompass the specimens. With these revisions in place the specimens would be better protected from biological predators thus providing a larger database of specimens.
5. Finally, when taking periodic measurements, visual inspection and removal of obvious predators would also help to reduce specimen degradation.

Conclusion

Undaria pinnatifidia is invasive fast growing brown alga that is causing major issues on the California Coast. From the sample of manipulated specimens that survived the entire experiment, I could see that of specimens cut above the meristem had a much higher survivability and growth rate than specimens cut below the meristem.

<u>Study Limitations</u>

The data I used in analysis was limited to the first five to six sampling periods because after that there is a unanimous negative growth trend, which made the data less conclusive; however, even in observing the deteriorating samples I could see that the cut samples without the meristem died off faster than those that contained a meristem. Although the majority of the data collected did not show a common trend and not enough specimens survived to the end of the experiment to adequately validate the hypothesis, the experiment showed promise and is worth repeating with incorporation of the recommendations stated above.

<u>Other possible experiment variations</u>

1. Cut specimens below the meristem leaving the holdfast and the sporophyl attached to the substrate to see if the sporophyl would still mature and release spores.

2. Cut *undaria* specimens below the meristem and observe, if the cut piece containing the meristem were to be in contact with a substrate would it regrow a holdfast.

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