Title
Integrated Culture of Seaweeds and Red Abalone in Monterey Harbor

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Integrated Culture of Seaweeds and Red Abalone in Monterey Harbor

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Project Hypotheses
(1) Red algae and kelp can be effectively cultivated in Monterey Harbor and harvested as abalone feed.
(2) Mixed diets are superior to all kelp diets in enhancing farmed abalone marketability (growth and shell color)
(3) Seaweed culture can sustain a small to moderately-sized California abalone farm.

Project Goals and Objectives
Year 1 objectives: (1) initiate rope-cultivation of cultured seaweeds in the field, (2) develop seaweed harvesting methods, and (3) initiate controlled diet experiments with cultured abalone to test effects of mixed-diet composition on abalone shell color and growth. Year 2 objectives: (1) complete rope-cultivation and harvesting of cultured seaweeds in the field, (2) conduct controlled diet experiments with cultured abalones to determine the minimum quantity of red algae necessary to enhance abalone growth and shell color, and (3) determine seaweed culture necessary to support the annual production of 36,000 farmed abalone.

Briefly describe project methodology
Objective 1. Seaweed culture. We utilized well-established laboratory methods for seeding kelp zoospores onto string and then outplanting the seeded-string to rope farms within and near Monterey Harbor. We also developed techniques for vegetatively and sexually propagating Gracilaria pacifica, Gracilariopsis andersonii, and Chondracanthus corymbifera and outplanting them to Monterey Harbor.

Objective 2. Abalone diet. We conducted a controlled experiment to test the effects of mixed-diets of cultured seaweeds on abalone growth and shell color. We fed juvenile abalone various diets: (1) ad libitum kelp; (2) ad libitum kelp plus 2.5% red algae per week; (3) ad libitum kelp plus 5.0% red algae per week; (4) ad libitum kelp plus 5.0% red algae one week per month. Each treatment was replicated 3 times in the same 55 gallon plastic cages abalone densities, and feeding frequencies that are currently used at Monterey Abalone Company.
Objective 3. Operational plan. We estimated the extent of seaweed outplant farms necessary to provide enough cultured kelp winter biomass and cultured red algal year-round biomass to support the production of 36,000 abalone/year (annual production of MAC), through a total stock of 250,000 abalone. We outlined a plan for the number, type and placement of outplant lines, and the temporal strategy for seeding, transplanting, and harvesting.

Describe progress and accomplishments toward meeting goals and objectives
culture. We determined that *Gracilariopsis andersonii*, and *Chondracanthus corymbifera* were the best red algae for cultivation. Both seaweeds grew better at depth then at the surface: Gracilariopsis had optimal yield (0.5 kg/meter/week) at 3 m depth and Chondracanthus had optimal yield (0.15 kg/meter/outplant) at 4 m depth. Decreased growth and biomass yield at shallower depths appeared to be due to heavy epiphytism by algae and animals. Growth and biomass yield was highest during periods of high water quality; red tides caused rapid degradation and death of seaweed outplants at all depths. Optimal harvesting frequency for Gracilariopsis was 4 weeks; Chondracanthus required 8 weeks to reach harvestable size.

The kelp *Macrocystis integrifolia* was cultivated using vegetative propagation. Rhizomes were woven into the outplant ropes and resulted in 92% transplant success. Outplants reached the surface within 1 month and were immediately harvestable. Kelp harvests were conducted bi-weekly and plants grew well between 2 and 6 meters depth. Optimal harvests were 0.25 kg/m/week, about 90% of optimal harvests published for Chilean kelp farms. Harvests may increase as outplant populations grow in size and biomass capacity.

Kelp zoospore propagation methods were developed for *Macrocystis pyrifera*, *Nereocystis luetkeana*, and *Alaria marginata*. Outplanting of sporophytes was limited due to culturing delays caused by trace metal deficiencies in open ocean water used as culture media. All lab culturing required artificial media.

Feeding experiment. Average abalone growth rates did not differ among treatments due to skewed size distribution that developed within the cages. Diet effects were only observed when the 25% largest abalones per cage were analyzed. Abalone growth rates were enhanced only after addition of 5.0% red algae to kelp diets one week of every month. Weekly additions of 2.5% and 5.0% red algae did not significantly differ from kelp only diets. Further, these effects were conservative due to a abalone dieoff the resulted from a red tide event and killed off only the large abalones. In the end, we estimated that as little as 0.6 grams of red algae per week were necessary to provide enough pigment to color an individual abalone's shell enough to increase marketability.

Seaweed farm design. Advances were made in understanding optimal species, cultivation depths, and harvesting frequencies for red algae. Kelp data were lacking due to cultivation delays. Many additional data were being acquired in new Seagrant award for 2008-2009 and final farm design is pending. However, given the number listed above, it is expected that only 75 kg of red algae would be needed per week to pigment 250,000 abalone and enhance abalone growth. Kelp requirements for a similar sized farm is 900 kg per week. Using our current numbers we would require 3000 linear meters of farm to supply the necessary kelp and red algal biomass to fully sustain this moderate sized farm. Our current 4 module experimental farm has a capacity of 500 linear meters.

Project modifications
Red tides in Monterey bay greatly disrupted algal culturing and abalone survival. The tides killed the entire seaweed farm and many of the largest experimental abalone. This effect resulted in muted experimental differences and farm reestablishment. Actions against red tides could not be developed.

Project outcomes
This was the first study to effectively propagate *Gracilariopsis andersonii*, and *Chondracanthus corymbifera* in the world. We also mimicked Canadian and Chilean advances in kelp culture and developed the only active kelp farm in California. Furthermore, we established that seaweed yields in Monterey Harbor equal or exceed those from other farms worldwide. Finally, we established that the addition of 5.0% red algae once a month to abalone diets enhance abalone biomass yields by 20% and turn abalone shells the red color desired by the market. Further advances made in current Seagrant award will allow completion on a seaweed farm development plan.

Impacts of project
This project established seaweed farming as a viable means for growing abalone food in California. Target species were identified and major growth limitations were overcome. The project also indicated the market benefits of mixed abalone diets.

Benefits, commercialization and application of project results
Monterey Abalone Company and the Cayucus Abalone Farm are both utilizing our results in adding red algae to abalone diets. Monterey Abalone Company is currently outplanting and harvesting *Gracilariopsis andersonii*, and *Chondracanthus corymbifera* for commercial abalone feed.

Economic benefits generated by discovery
Establishment of enhanced diets through addition of red algae decreases food requirements of farmed abalone and enhanced growing rates decrease husbandry costs and time to market. Additional kelp and seaweed biomass produced by the seaweed farm decreased reliance of commercial abalone companies on natural kelp stocks.

Issue-based forecast capabilities
This study indicated the clear vulnerability of abalone and seaweed culture to decreases in water quality caused by red tides in Monterey Bay.

Tools, technologies and information services developed
Seaweed farming manual is still in production.

Media Coverage
Numerous press releases and trade articles were produced by Christina Johnson.

Dissemination of results
Due to the short duration of the funding but long duration of the feeding experiments, we currently have 3 papers in preparation and we are initiating production of a trade manual.

Students
Matthew Suskiewicz
San Jose State University
Moss Landing Marine Labs
Degree program enrolled in: MS Marine Science
Theses/dissertation title: Recriutment processes in Nereocystis
Supported by Sea Grant funds? [X] yes [] no
Start date: 3/1/2006
End date: 6/30/2008

Gregory Schroeder
San Jose State University
Moss Landing Marine Labs
Degree program enrolled in: BA Marine Biology
Theses/dissertation title: N/A
Supported by Sea Grant funds? [X] yes [] no
Start date: 6/01/2006
End date: 08/31/2006

Jasmine Ruvalcaba
CSU Monterey Bay
Moss Landing Marine Labs
Degree program enrolled in: BA Env Sci Policy
Theses/dissertation title: N/A
Supported by Sea Grant funds? [X] yes [] no
Start date: 06/01/2007
End date: 08/31/2007

How many student volunteers were involved in the project? 7

Cooperating organizations
Local and state
Monterey Harbormaster, Steve Scheiblauer, provided space for seaweed farm in Monterey Harbor

International
iMAR, Universidad de Los Lagos, Chile, Dr. Alejandro Buschmann, advised on seaweed farm design and initial culturing and harvesting methods

Industry
Monterey Abalone Company, Art Seavey President, provided logistical support, abalone seed, abalone husbandry, small boat facilities
Other Sea Grant programs

Academic Institutions
Moss Landing Marine Labaoratories, provide analytical and office space

International implications
The enhancement of abalone growth due to mixed diet will be useful in Chile, South Africa, and Australia in abalone aquaculture. Chondracanthus culturing techniques will be useful in Canada where less efficient spore seeding techniques are currently being used.

Keywords
red, abalone, kelp, farming, seaweed, algae, Macrocystis, Gracilariopsis, Chondracanthus, diet

Notes
This project was critical to the acceptance of our follow-up work, R/A/-129, and has led to significant interest in the use of farmed seaweeds as abalone feed, biofuel, and nutrient scrubbers. We are currently working on 3 grants that are spinoffs of this project and we have established formal collaborations in Chile, British Columbia, and New Brunswick as a result.