Macrocystis production and conversion in Chile – lessons learned

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ARPA-E Macroalgae Workshop
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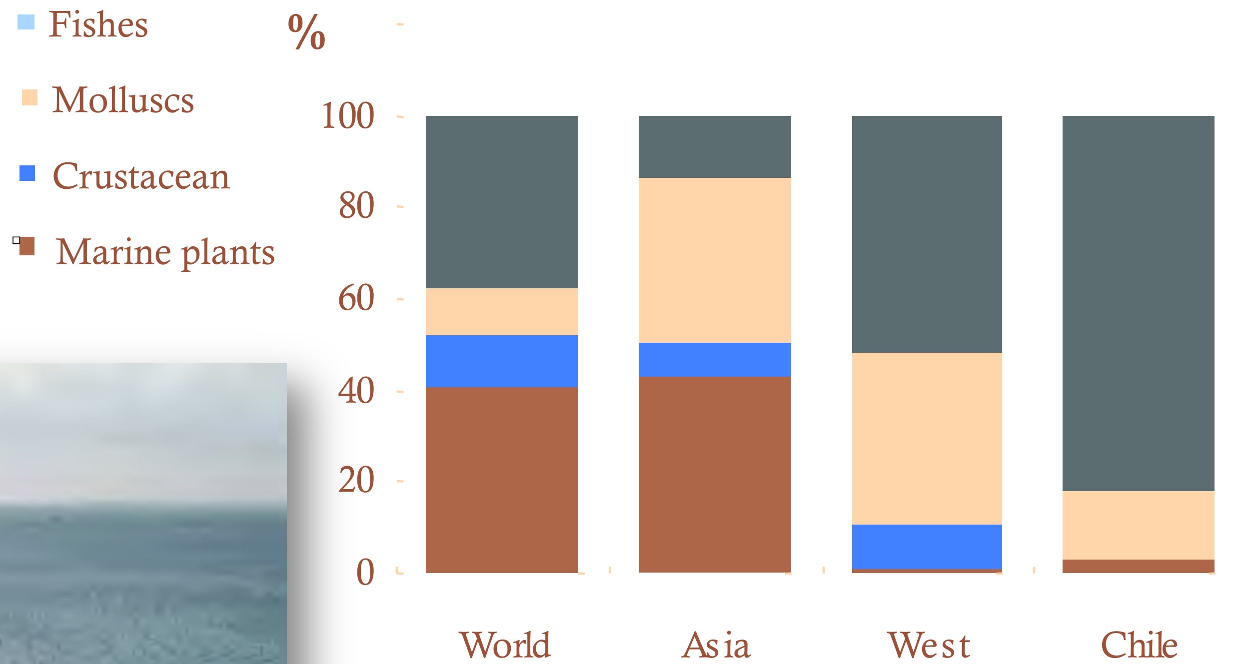
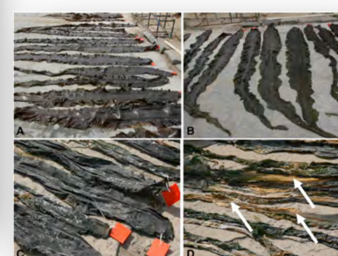
Photograph:
Javier Infante

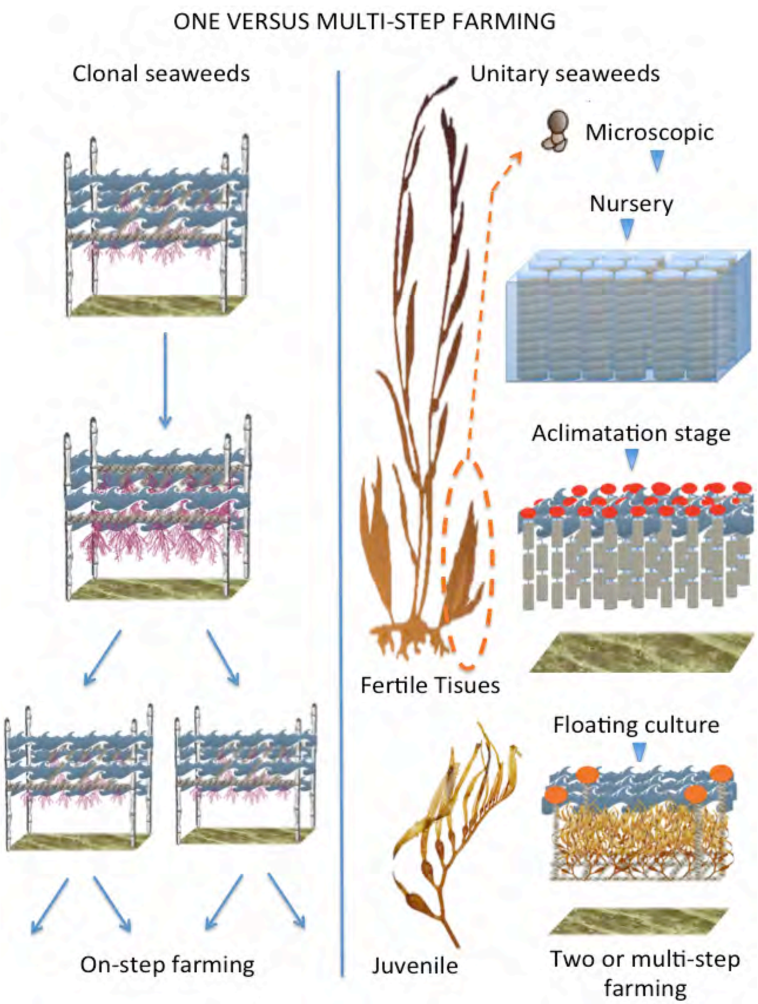
Relative World Aquaculture Production



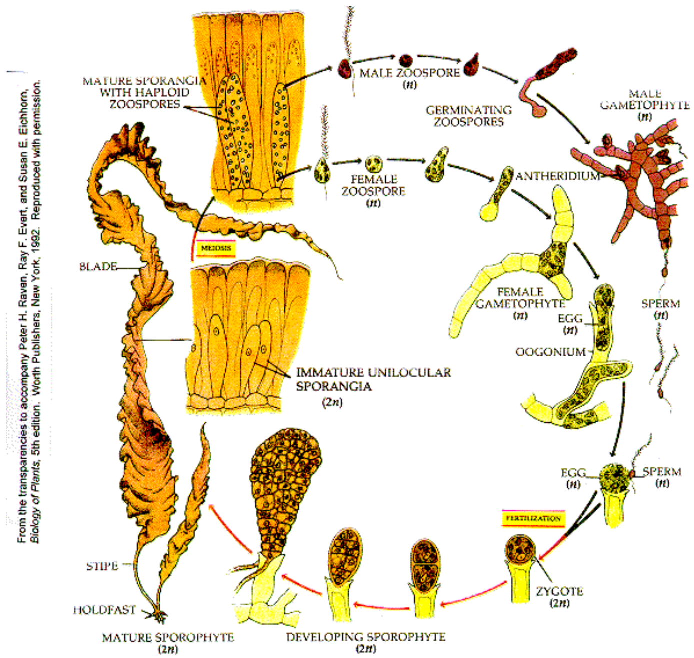


Chopin et al. 2008. Encyclopedia of Ecology 2008

TECHNOLOGICAL APROACHES TOWARDS MACROALGAL PRODUCTION



- ✓ Technology depends from the type of algae (clonal vs. unitary)
- ✓ Coastal habitat (exposure, depth, etc.)

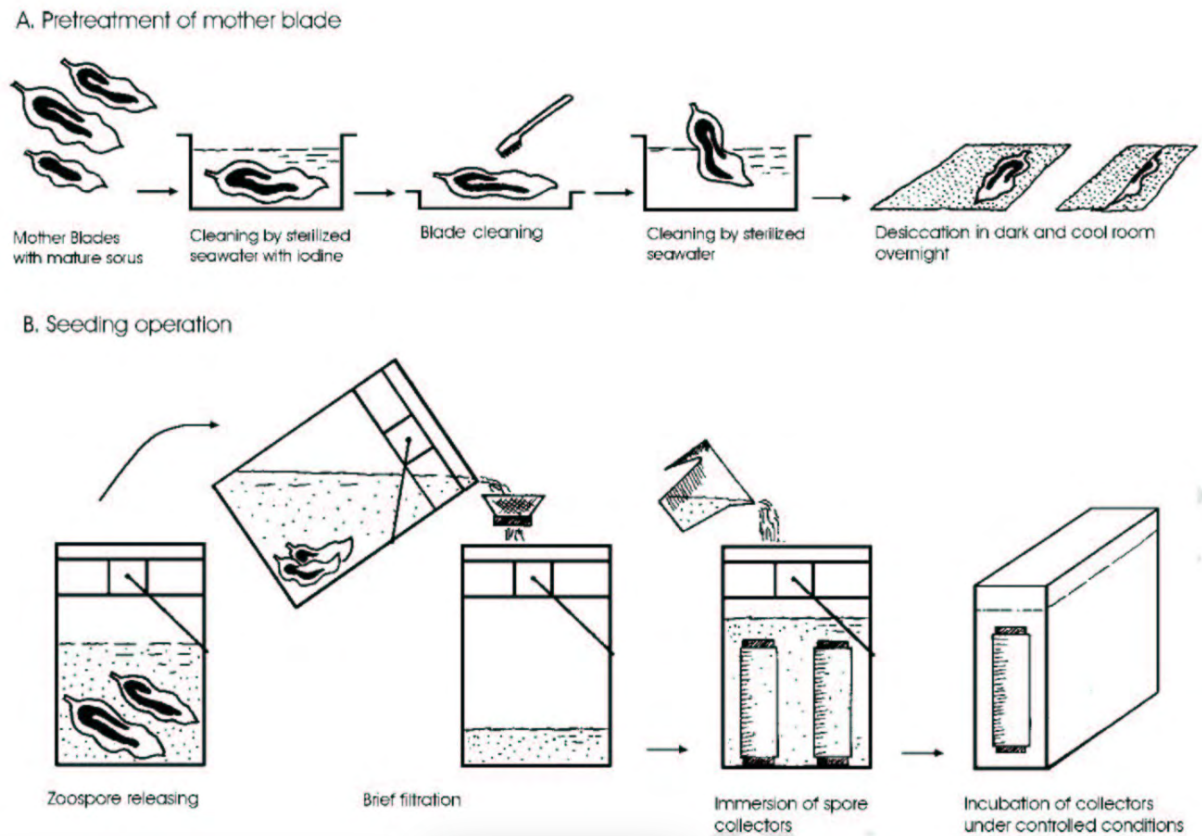


Modified from: Santelices 1999. Hydrobiologia

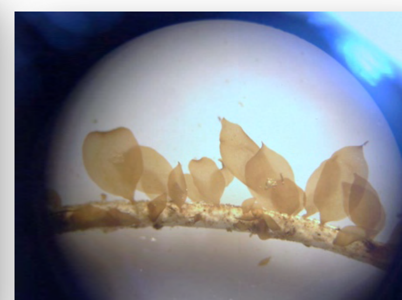
Cultivation of the Microscopic Phases





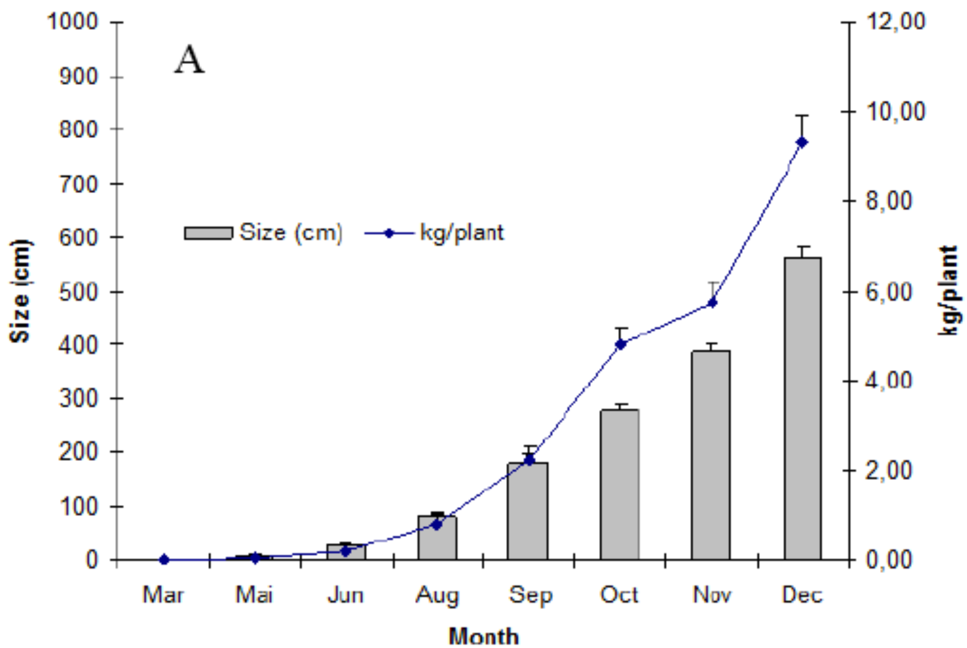




Gutierrez et al. Journal applied Phycology 2006

Hatchery

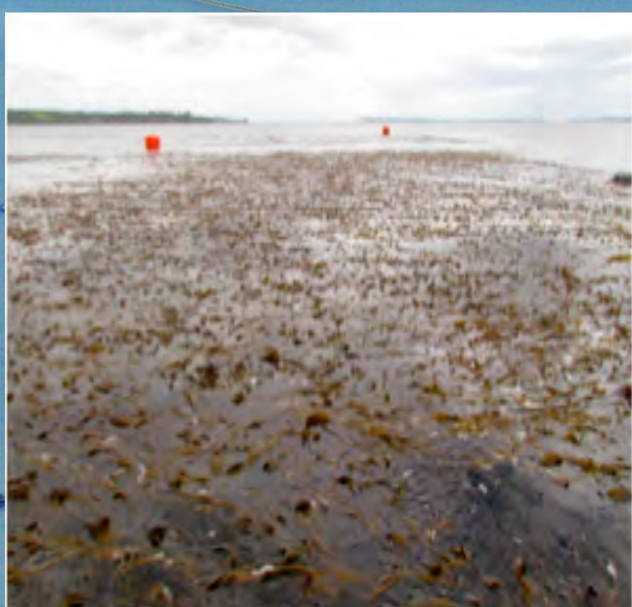
Cultivation in the sea of *Macrocystis*
(4 ha farm)



Gutierrez et al. 2006 Journal applied Phycology

Moving into Commercial Farming

Pilot La Planchada – Chiloé (20 hectares)
Pilot farm Quenac – Chiloé (21 hectares)



Seeding

Production

Kelp Production Costs

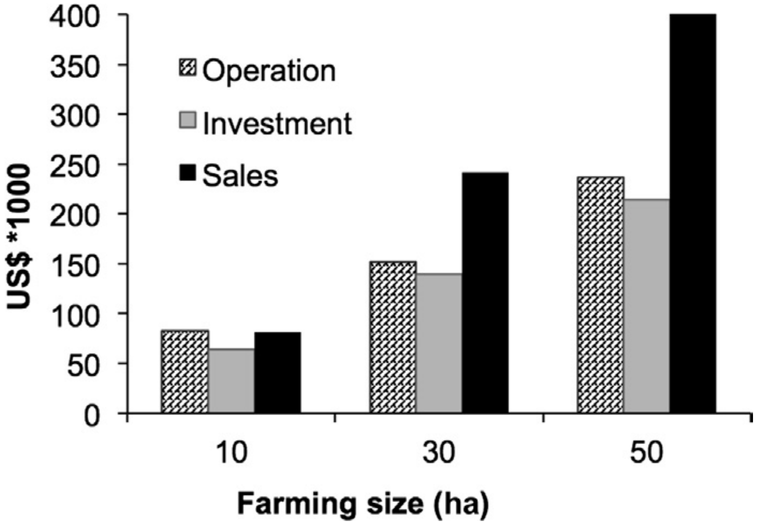


Table 1 Annual costs of a 10 ha farm of *Macrocystis pyrifera* in Chile. Values in US$ and percentage of each cost item

Costs	US$	%
Human resources	14,118	12.9
Licence of culture site	1,295	1.2
Plants	8,627	7.9
Support equipment	26,667	24.4
Culture System	37,591	34.4
Fuel	3,529	3.2
Seeding	5,804	5.3
Harvest	11,765	10.8
Total	109,396	100

Correa et al. 2016 Aquaculture Research

Economic profitability

Table 2 Economic analysis using the net present value (NPV in US$), internal rate of return (IRR in %) and the years required to obtain economic profit (YR in years) of a long-line *Macrocystis pyrifera* cultivation in southern Chile. The analysis simulation was undertaken on 3 farming scales (10, 30 and 50 ha) and 3 at different kelp prices (59, 78 and 98 US$ ton^{-1}).

Farming Scale (Ha)	PRICE (US$ ton^{-1})	IRR	NPV	YR
10	59	n.p	-657.741	n.p
	78	n.p	-544.183	n.p
	98	n.p	-430.991	n.p
30	59	n.p	-89.755	n.p
	78	153	291.101	1
	98	224	580.191	1
50	59	224	580.191	1
	78	339	1.057.136	1
	98	452	1.534.081	1

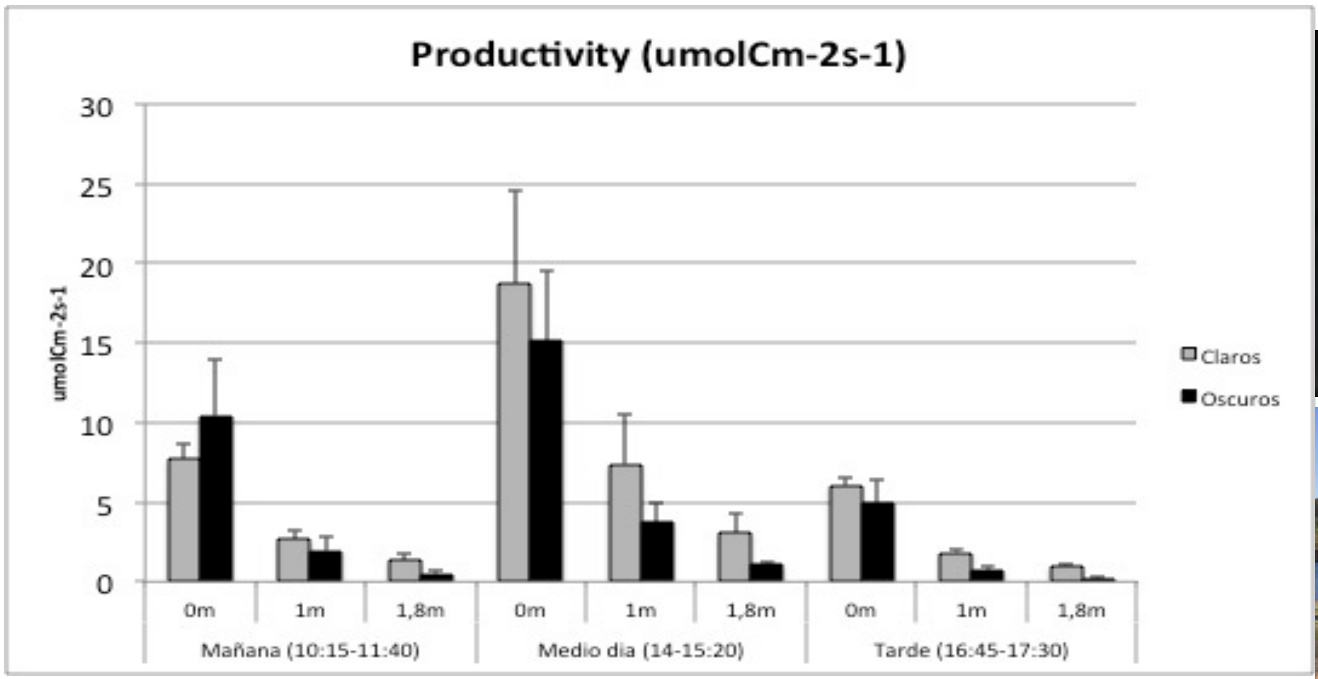
n.p, no profit.

Correa et al. 2016 Aquaculture Research

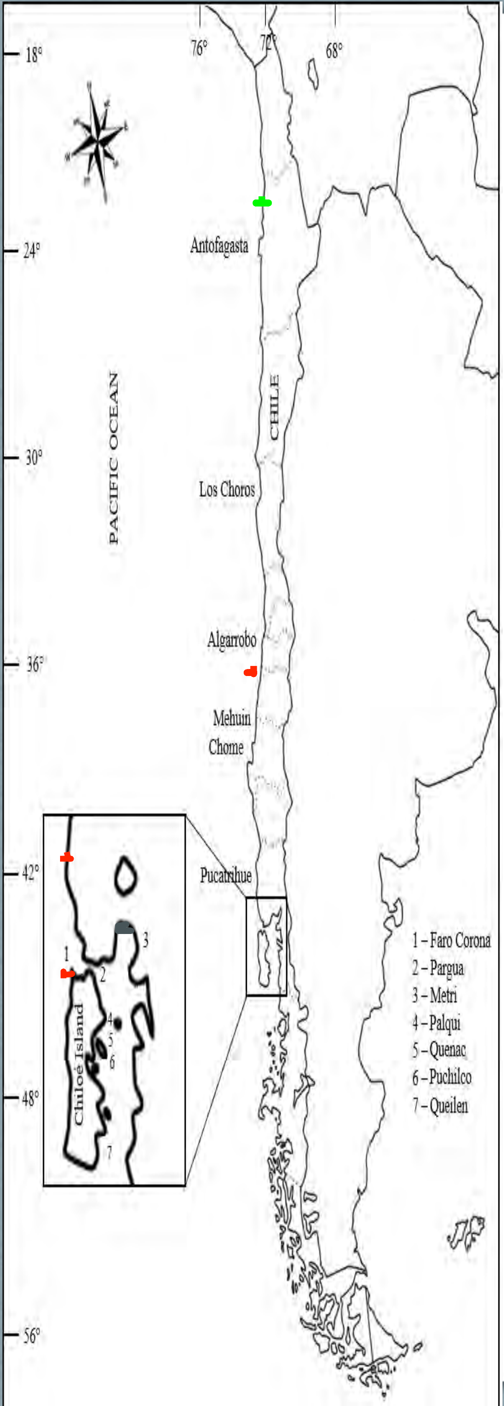
Productivity

- **Complex morphology**
- **Large size (7-10 m)**
- **Complex Environment**
  - ❖ Temperature
  - ❖ Light
  - ❖ Nutrients
  - ❖ Currents

Productivity Environment Interaction



Diving-PAM



GERMOPLASM: SAMPLING LOCATIONS

Locality	Abbreviation	Coordinates	Sampling date	Number of sporophytes collected
Antofagasta, Isla Santa María	ANT	23°27′53.99" S; 70°36′8.99" W	May 29, 2012	30
Los Choros	CH	29°16′19.37" S; 71°27′54.24" W	July 19, 2010	30
Algarrobo	ALG	33°21′23.55" S; 71°39'34.12" W	July 12, 2011	30
Chome	CHO	36°46′24.24" S; 73°12′45.09′" W	May 2, 2011	30
Mehuin	MEH	39°27′15.6" S; 73°15′37.79" W	July 24, 2012	30
Pucatrihue	PUCA	40°34′50.39" S; 73°44′13.20" W	February 15, 2011	30
Faro Corona	FAR	41°47′57.92" S; 73°53′39.69" W	May 31, 2011	30
Pargua	PAR	41°47′58.26" S; 73°28′14.7" W	June 1, 2010	30
Metri	M	41°41′19.72" S; 72°38′27.55" W	April 25, 2012	30
Chiloé Island, Dalcahue	DAL	42°22′33.64" S; 73°38′32.56" W	November 13, 2012	20
Chiloé Island, Palqui	PAL	42°24′36" S; 73°30′22.2" W	November 13, 2012	20
Chiloé Island, Meullin	CAG	42°26′30" S; 73°17′15.59" W	November 12, 2012	20
Chiloé Island, Quenac	Q	42°27′24.91" S; 73°20′13.17" W	March 22, 2011	30
Chiloé Island, Puchilco	PUC	42°35′55.45" S; 73°40′46.02" W	August 31, 2010	23
Chiloé Island, Chaulinec	CHAU	42°36′47.44" S; 73°21′13.79" W	November 14, 2012	20
Chiloé Island, Queilen	LEN	42°29′09.06" S; 73°45′39.58" W	June 28, 2011	30

Productivity and Genetics

Cross		Progeny
♀	♂	denomination
P1	P1	Bal14
P1	PU6	Bal1
P1	P20	Bal5
PU6	P1	Bal13
PU6	PU6	Bal3
PU6	P20	Bal2
P20	P1	Bal9
P20	PU6	Bal10
P20	P20	Bal4

- Female and male gametophytes used to produce different selected corosses and denomination of the progeny.
- P= Pargua
- PU=Puchilco

Massive Clonal Propagation

Red light

Selected Crosses

Genetic Program

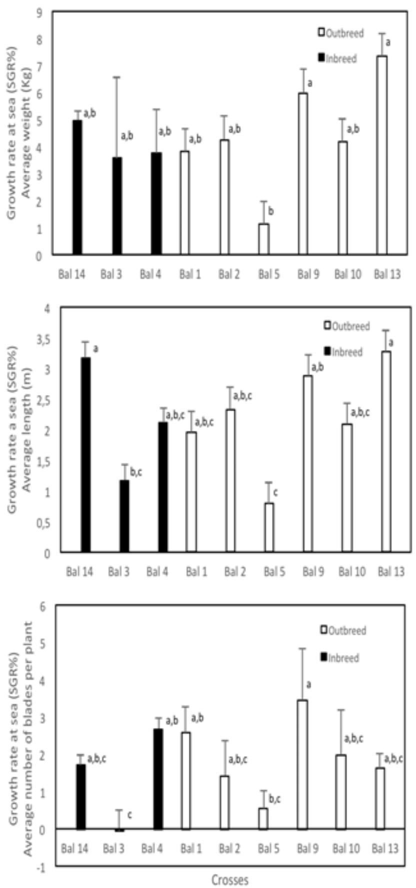


Figure 2

- Significant differences in growth of Giant kelp grown in the field

Camus, Faugeron, Buschmann. Journal of Phycology (submitted)

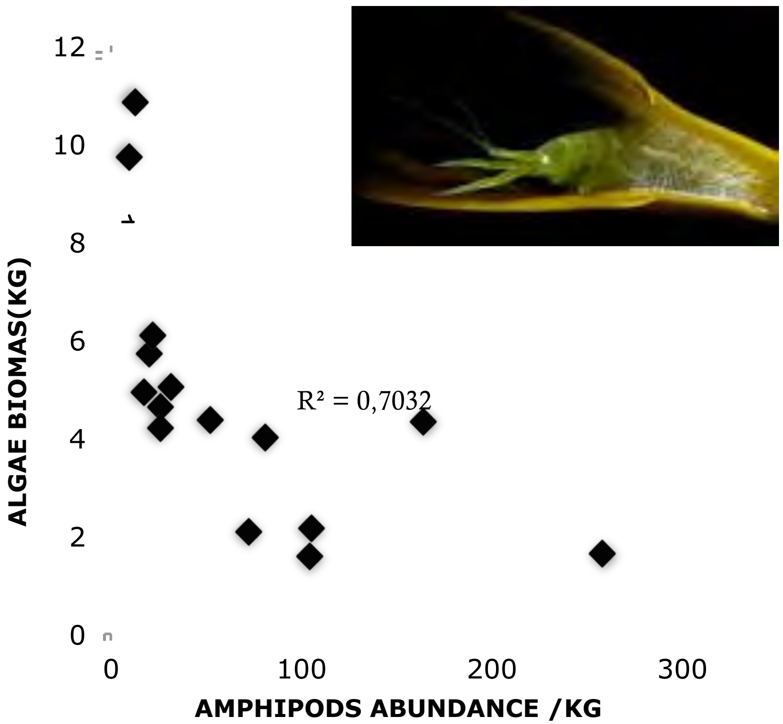
Chemical composition

Strains	Bal 1	Bal 2	Bal 3*	Bal 4	Bal 5	Bal 11	Bal 14	Bal 16	Bal 17
Carbohydrates (%DW)									
Alginate	33,0 ± 1,2[a]	31,4 ± 14,3 [a]		27,1 ± 9,2 [a,b]	20,0 ± 1,5 [a,b]	9,9 ± 5,2 [b]	10,7 ± 1,4 [b]	11,3 ± 3,3 [b]	14,6 ± 5,5 [a,b]
Mannitol	3,4 ± 0,8 [a,b]	2,6 ± 3,1 [a,b]		7,7 ± 3,1 [a]	3,1 ± 2,6 [a,b]	0,2 ± 0,3 [b]	0,4 ± 0,5 [b]	5,4 ± 1,6 [a,b]	1,0 ± 0,2 [b]
Glucans	4,1 ± 0,3 [a]	4,4 ± 0,7 [a]		3,9 ± 0,2 [a]	4,1 ± 0,1 [a]	1,9 ± 1,6 [b]	2,8 ± 0,3 [a,b]	2,9 ± 0,3 [a,b]	3,2 ± 0,1 [a,b]

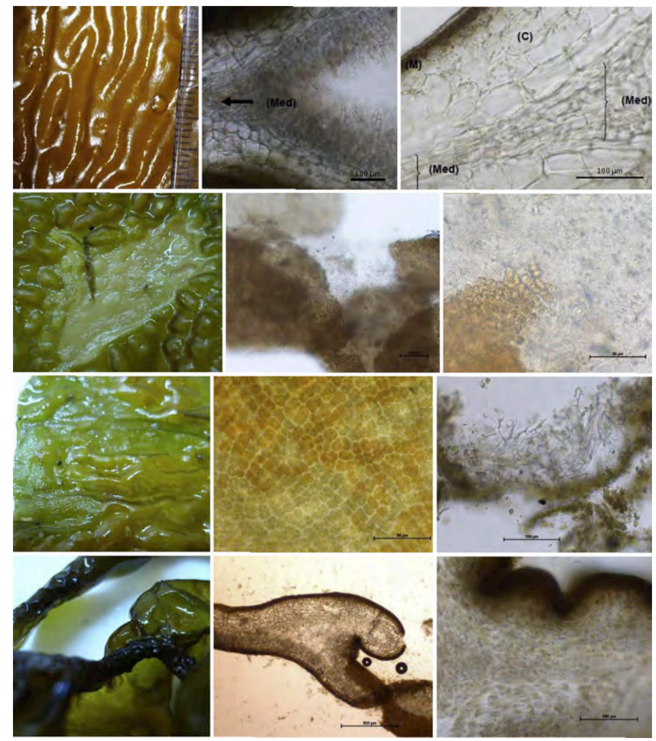
Camus, Faugeron, Buschmann. Journal of Phycology (submitted)

Pest Control

Herbivory



Potential Diseases (Symptoms)



Buschmann et al. 2014. Adv. Bot. Research

Kelp Germoplasm


Contents lists available at ScienceDirect
Algal Research
journal homepage: www.elsevier.com/locate/algal
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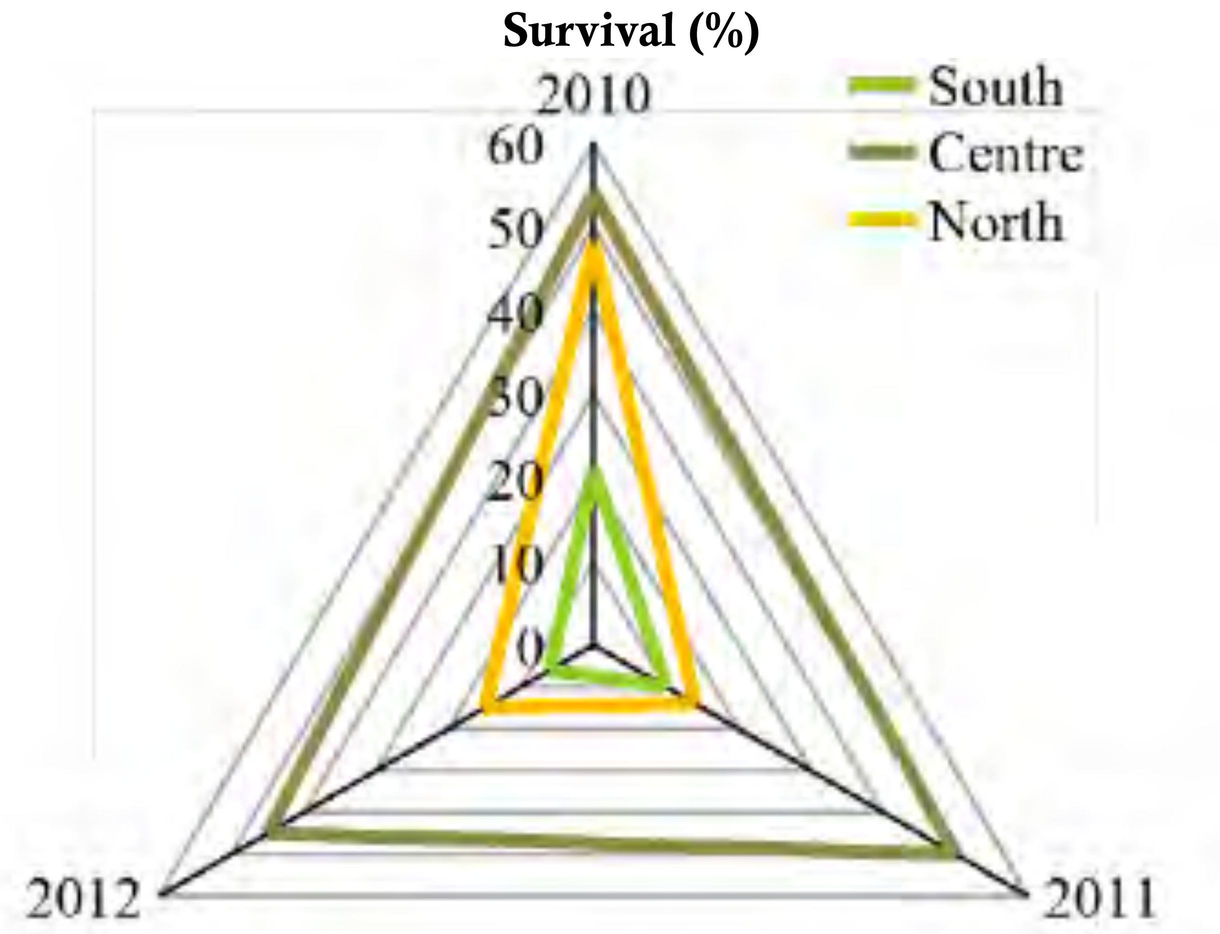
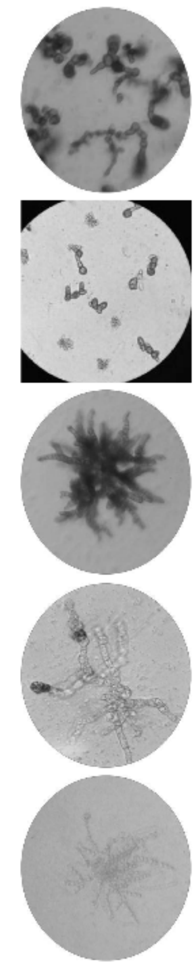
Germplasm banking of the giant kelp: Our biological insurance in a changing environment

Sara Barrento [a,*], Carolina Camus [b], Isabel Sousa-Pinto [a], Alejandro H. Buschmann [b]



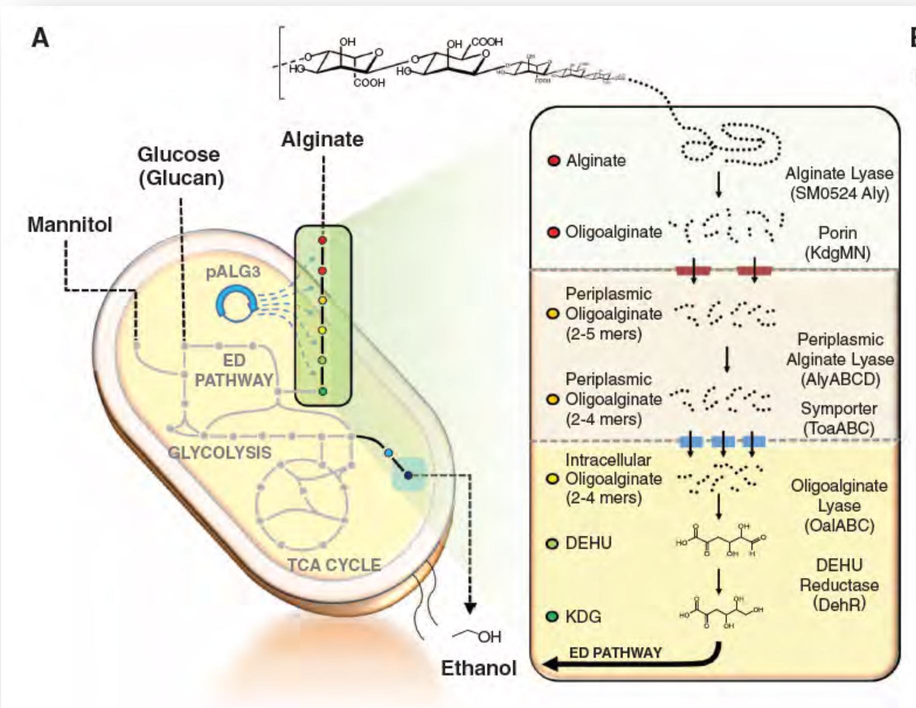


Seaweed Uses:
commodity type vs. high value product

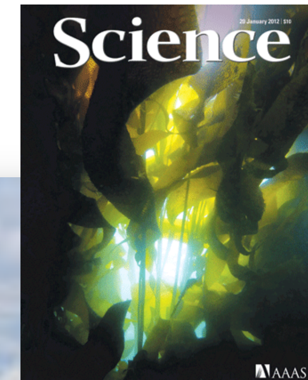
Carotenoids	Light	*A. nodosum* *Macrocystis pyrifera*	Stengel and Dring (1998), Colombo-Pallotta et al. (2006)
	Thallus section	*A. nodosum* *Macrocystis* sp.	Stengel and Dring (1998), Colombo-Pallotta et al. (2006)
	UV exposure	*Devaleraea ramentacea*	Karsten et al. (1999)
Mycosporine-like amino acids	UV exposure	*Pyropia leucosticta*	Korbee et al. (2005)
	Nutrient availability	*Asparagopsis armata*	Figueroa et al. (2008)
Polyamines	UV exposure	*Pyropia cinnamomea*	Schweikert et al. (2014)
Phenolics	UV exposure	Laminariales	Swanson and Fox (2007)
	Light climate	Fucoids	Connan et al. (2004)
	Reproductive stage	Fucoids	Ragan and Jensen (1978), Swanson and Fox (2007)
	Grazing pressure	*C. tamariscifolia*	Abdala-Diaz et al. (2006)
	Eutrophication (light, turbidity)	*F. vesiculosus*	Koivikko et al. (2005)
Phlorotannins	Nutrient availability Grazing pressure	*A. nodosum* *F. vesiculosus*	Pavia and Toth (2000)
	Salinity	*A. nodosum* *F. vesiculosus*	Connan and Stengel (2011)
	Light climate	*S. latissima* *Nereocystis luetkeana*	Swanson and Fox (2007)
	Sampling location	*Sargassum muticum*	Tanniou et al. (2013)
	Genotype	*F. vesiculosus*	Honkanen and Jormalainen (2005)
Antioxidant capacity	Sampling season Grazing pressure	*Caulerpa racemosa* *Codium capitatum* *Halimeda cuneata* *Ulva fasciata* *Amphiroa bowerbankii* *Amphiroa ephedraea* *Dictyota humifusa*	Stirk et al. (2007)

Hafting et al. 2015. J. Phycol.

Bioethanol


A
Glucose
(Glucan)
Alginate
Mannitol
pALG3
ED
PATHWAY
GLYCOLYSIS
TCA CYCLE
Ethanol
OH
COOH
HO
Alginate
Oligoalginate
Periplasmic
Oligoalginate
(2-5 mers)
Periplasmic
Oligoalginate
(2-4 mers)
Intracellular
Oligoalginate
(2-4 mers)
DEHU
KDG
ED PATHWAY
Alginate Lyase
(SM0524 Aly)
Porin
(KdgMN)
Periplasmic
Alginate Lyase
(AlyABCD)
Symporter
(ToaABC)
Oligoalginate
Lyase
(OalABC)
DEHU
Reductase
(DehR)


Pilot Plant
(Puerto Montt)


Science
AAAS

Bioethanol Optimization

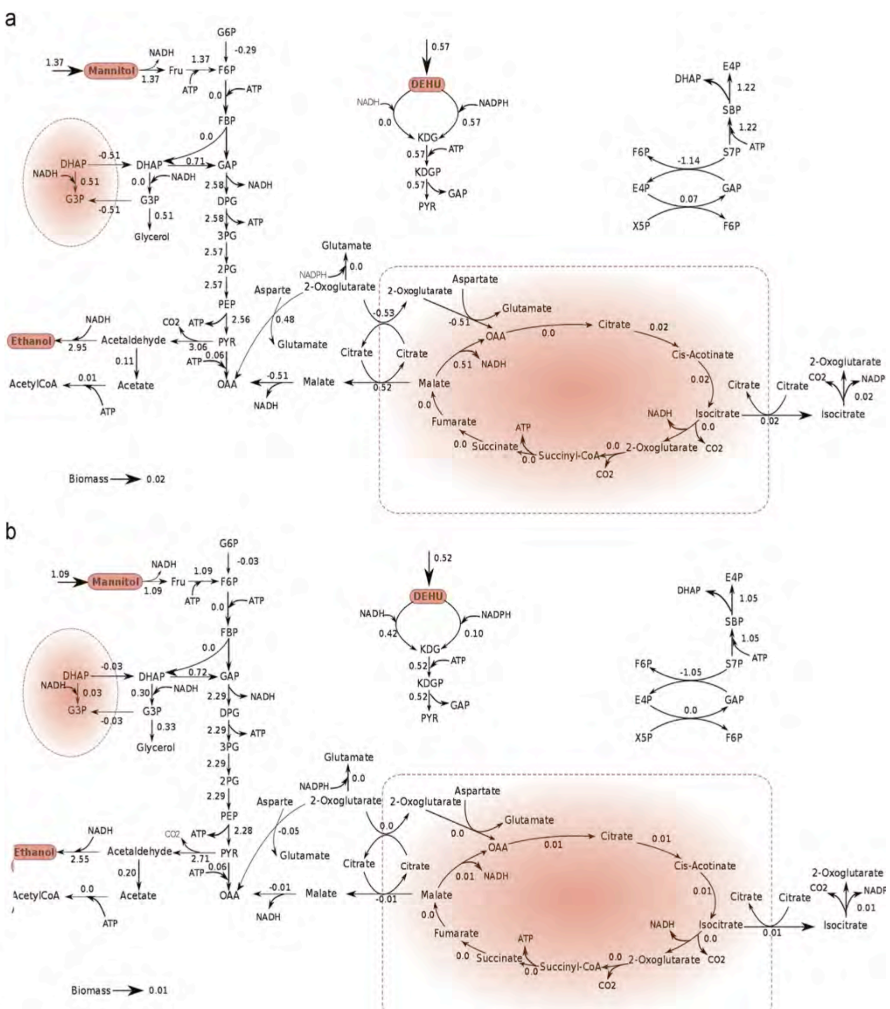
Contents lists available at ScienceDirect

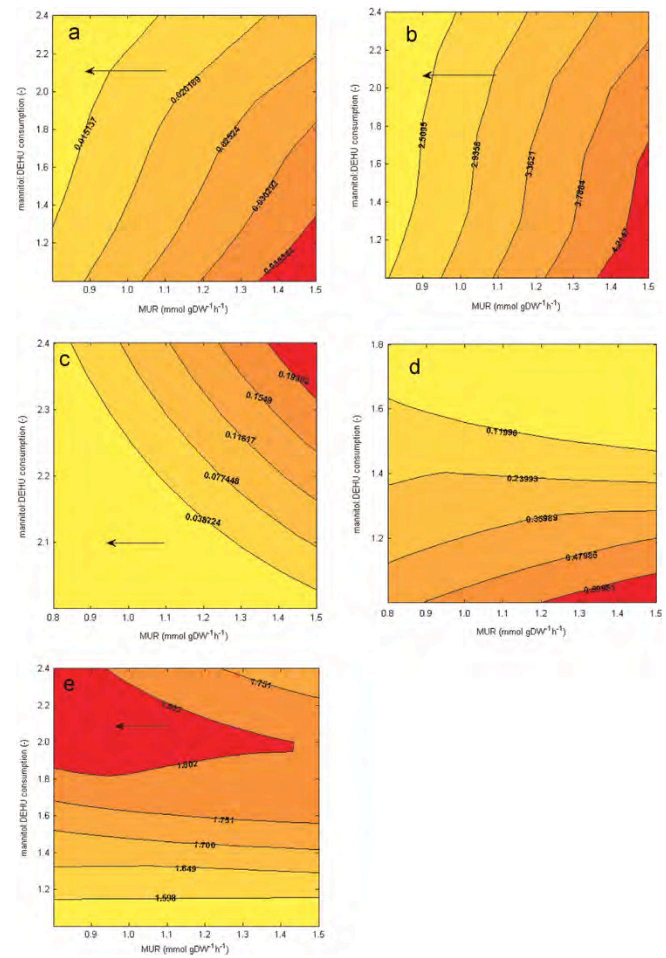
Metabolic Engineering Communications

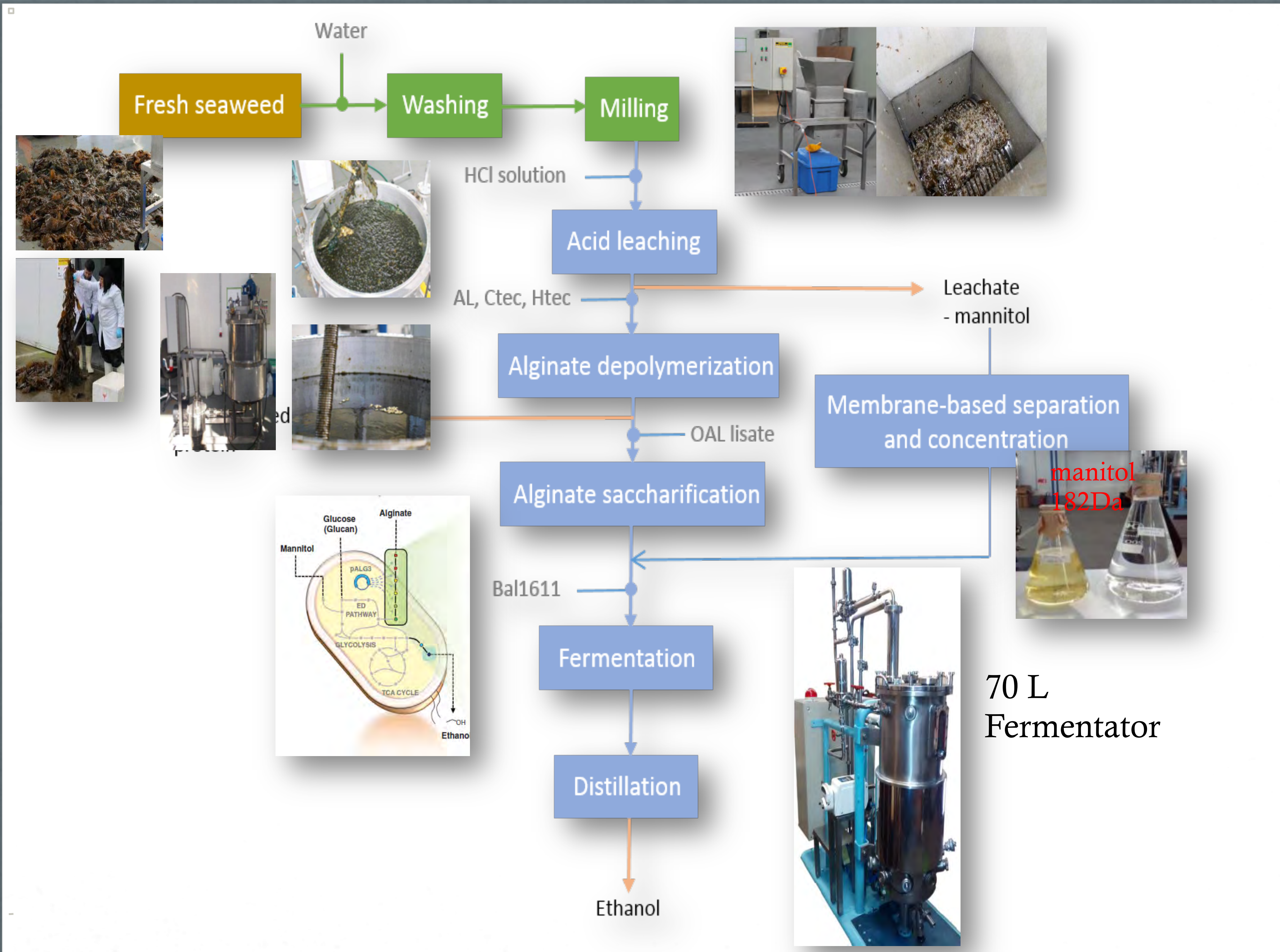
journal homepage: www.elsevier.com/locate/mec

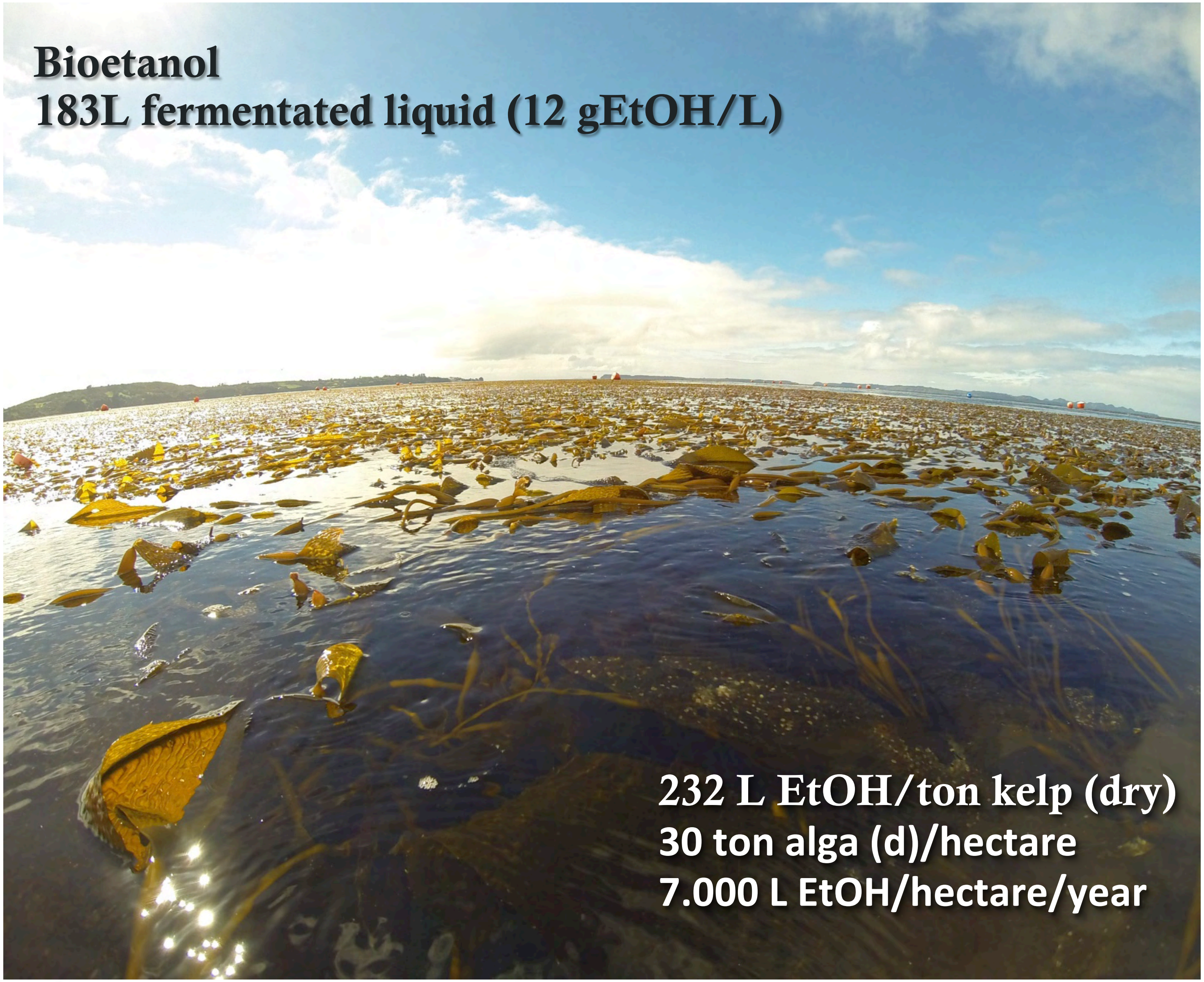
Analyzing redox balance in a synthetic yeast platform to improve utilization of brown macroalgae as feedstock

C.A. Contador[a,b], C. Shene[a,c], A. Olivera[a,b], Y. Yoshikuni[d], A. Buschmann[a,e], B.A. Andrews[a,b], J.A. Asenjo[a,b,*]






Water
Fresh seaweed
Washing
Milling
HCl solution
Acid leaching
Leachate
- mannitol
AL, Ctec, Htec
Alginate depolymerization
OAL lisate
Membrane-based separation
and concentration
manitol
182Da
Alginate saccharification
Glucose
(Glucan)
Alginate
Mannitol
pALG3
ED
PATHWAY
GLYCOLYSIS
TCA CYCLE
OH
Ethano
Bal1611
Fermentation
Distillation
Ethanol
70 L
Fermentator


Bioetanol
183L fermentated liquid (12 gEtOH/L)
232 L EtOH/ton kelp (dry)
30 ton alga (d)/hectare
7.000 L EtOH/hectare/year

Kelp Phlorotannins

Phloroeckol

Tetrameric phloroglucinol

Table 2. Independent variable and work levels

	Levels		
Independent variables	**1**	**2**	**3**
Extraction Time (h)	2	3	4
Extraction Temperature (°C)	25	40	55
Ratio solid/liquid (S:L)	1:10	1:15	1:20
Particle size (mm)	<1.4	2-1.4	>2

Leyton, Pezoa-Conte, Barriga, Buschmann, Mäki-Arvela, Mikkola, Lienqueo 2016. Algal Research (accepted)

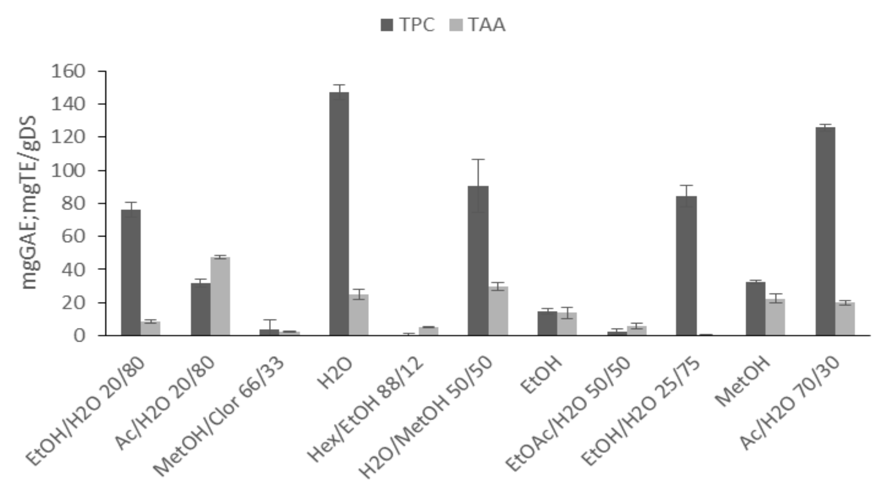


Figure 3. Evaluation of the best extractant for total polyphenols (TPC) and total antioxidant activity (TAA) in *Macrocystis pyrifera*

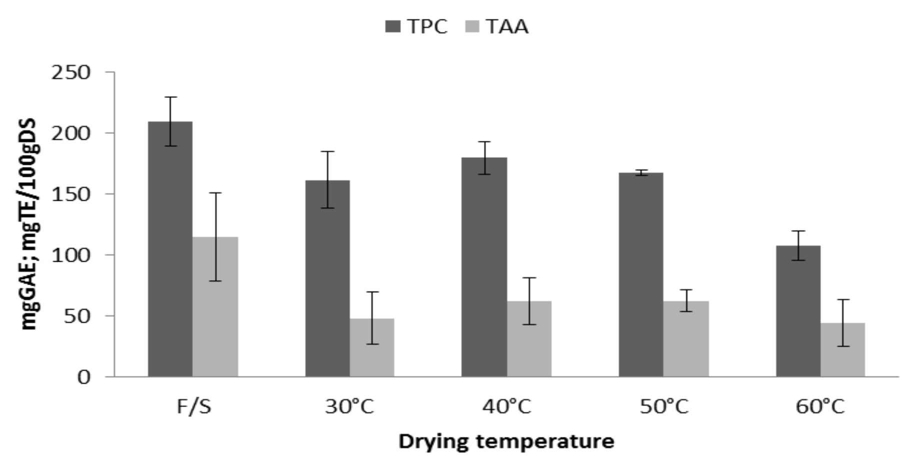


Figure 2. Evaluation of the different drying temperatures for *Macrocystis pyrifera* in total polyphenols (TPC) and total antioxidant activity (TAA)

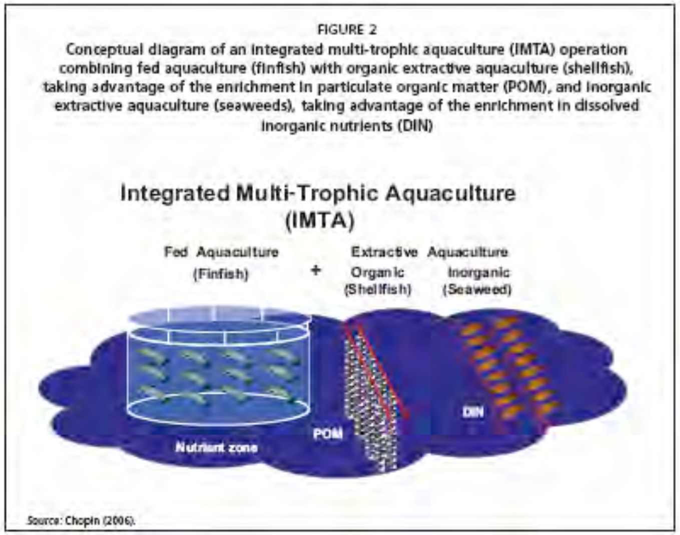
Products

- Agronomic Uses

- Food Products

- Abalone Feed

Ecosystem Services



Challenges

- Increasing predictability of production systems (e.g. pest control; avoiding stress periods; genetic improvements …..)
- Development of the industrialization process
- Development of novel aquaculture regulations (environmental, sanitary, etc.)
- Increasing seaweed biomass value (including environmental services; IMTA) and the development of processing technologies

Kelp Team

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Kelp Physiology and Ecology

THANK YOU!!!

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InnovaChile
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