

See discussions, stats, and author profiles for this publication at: <https://www.researchgate.net/publication/262724898>

Tolerance response of *Lessonia flavicans* from the sub-Antarctic ecoregion of Magallanes under controlled environmental...

Article in *Journal of Applied Phycology* · April 2014

DOI: 10.1007/s10811-014-0294-6

CITATIONS

3

READS

85

7 authors, including:



Silvia Murcia

Montana State University

15 PUBLICATIONS 80 CITATIONS

[SEE PROFILE](#)



Camilo Werlinger

University of Concepción

12 PUBLICATIONS 127 CITATIONS

[SEE PROFILE](#)



Jorge Terrados

Mediterranean Institute for Advanced Studie...

94 PUBLICATIONS 2,608 CITATIONS

[SEE PROFILE](#)

Some of the authors of this publication are also working on these related projects:



Niche modelling, invasion stage and habitat preferences of alien *Vespula* wasps (Hymenoptera: Vespidae) in Navarino island (55°S), southern Chile [View project](#)



HISTORICAL AND RECENT BIOGEOGRAPHIC PATTERNS AND PROCESSES IN SOUTHERN OCEAN MARINE MOLLUSKS WITH CONTRASTING DEVELOPMENTAL MODES [View project](#)

Tolerance response of *Lessonia flavicans* from the sub-Antarctic ecoregion of Magallanes under controlled environmental conditions

Andrés Mansilla · Sebastián Rosenfeld · Javier Rendoll ·
Silvia Murcia · Camilo Werlinger · Nair S. Yokoya ·
Jorge Terrados

Received: 20 December 2013 / Revised and accepted: 4 March 2014
© Springer Science+Business Media Dordrecht 2014

Abstract Environmental heterogeneity plays a key role in spatio-temporal distribution of organisms, their ecology and their evolutionary biology, with their physiological response, or tolerance to the environment defining their distributional range. The macroalgae of the sub-Antarctic ecoregion of Magallanes are subject to a wide range of environments, resulting from geomorphological processes (glacial erosion in the Quaternary), oceanographic gradients, and drastic seasonal variations of photoperiod and irradiance (winter <8 h of light, summer >17 h). We examined the tolerance response of the brown alga *Lessonia flavicans* to contrasting environments (three salinities, two temperatures, and two photoperiods) under controlled laboratory conditions. Our results suggest that *L. flavicans* has limited salinity tolerance that is affected by temperature and photoperiod. Summer temperature ($9\text{ }^{\circ}\text{C}\pm 0.02$) and photoperiod (18:6 h L:D) and salinity 32 psu seem optimal conditions for *L. flavicans* sporophyte development. Results of the present study provide key information for culturing a species of high economic and biological value,

and could aid in predicting the species potential tolerance response to environmental fluctuations in the wake of global changes.

Keywords Phaeophyceae · Environmental heterogeneity · Photoperiod · Salinity · Temperature

Introduction

Understanding the factors that limit geographical distribution of species has been essential for both ecology and evolutionary biology (Sexton et al. 2009). Biotic and abiotic factors might interact synergistically, and physiological response can restrict the range of distribution and abundance of organisms (Bozinovic et al. 2011). There is a need for a better understanding of how environmental factors over time and space may affect the fitness, growth, survival, and reproduction of species (Sexton et al. 2009; Kearney and Porter 2009).

In high-latitude ecosystems, abiotic parameters such as temperature, salinity, and photoperiod are considered key variables affecting the survival, reproduction, and development of macroalgae species (Mansilla et al. 2004; Ramlov et al. 2012) and structuring their geographical distribution (Wiencke and Dieck 1990). Among these variables, temperature is one of the most important factors that condition geographical distribution of macroalgae (Kirst and Wiencke 1995). Temperature affects growth rates, reproductive periods, and survival rates (van den Hoek 1982; Breeman 1988). Photoperiod can also limit the development of macroalgae, as light and dark cycles are responsible for the onset of the different phases of the life cycles (Hay 1981; Gaines and Lubchenco 1982; Dhargalkar 2004) and metabolic processes (Gómez et al. 1998) of many species.

A. Mansilla (✉) · S. Rosenfeld · J. Rendoll · S. Murcia
Laboratorio de Macroalgas Antárticas y Subantárticas, Universidad
de Magallanes, Casilla 113-D, Punta Arenas, Chile
e-mail: andres.mansilla@umag.cl

A. Mansilla · S. Rosenfeld
Instituto de Ecología y Biodiversidad (IEB), Santiago, Chile

C. Werlinger
Departamento de Oceanografía, Universidad de Concepción,
Concepción, Chile

N. S. Yokoya
Núcleo de Pesquisa em Ficologia, Instituto de Botânica, Av. Miguel
Estefano, 3687, 04301-012 São Paulo, SP, Brazil

J. Terrados
Instituto Mediterráneo de Estudios Avanzados (IMEDEA),
CSIC-UIB), Mallorca, Spain

The macroalgae present in the channels and fjords of the southernmost waters of Chile (from 41°S to 56°S) are subject to diverse and often harsh environmental conditions that result in differences in composition, richness and community structure as compared to other temperate coasts in the Americas (Ojeda 2013). Glacial erosion due to the back and forth movement of ice during the Quaternary drove the geomorphology of these fjords that were proglacial lakes during the Last Glacial Maximum (Kilian et al. 2007). Large differences of current velocity, temperature, salinity, and wave exposure within fjords and channels build strong oceanographic gradients (Silva and Calvete 2002) in a region with an abrupt coastal geomorphology and high local variability of fresh water inputs and substratum types (Valdenegro and Silva 2003). This wide environmental heterogeneity probably plays a fundamental role in the spatial distribution of macroalgae. Another important peculiarity of this ecoregion is the drastic seasonal variations of photoperiod and irradiance. In winter, photoperiod reaches a minimum of 6 h of light and irradiance of 23.2 W m^{-2} , but in the summer the photoperiod reaches a maximum of 18 h of light and an irradiance of 164.7 W m^{-2} (Santana et al. 2010; Ojeda 2013).

One of the most characteristic macroalgae groups of the sub-Antarctic ecoregion of Magallanes, Chile (48°S to 56°S; Rozzi et al. 2006) are those of the family Lessoniaceae (Searles 1978). The genus *Lessonia* Bory 1825 (based on *Lessonia flavicans*) is native to the Falkland Islands or Islas Malvinas (Searles 1978) and includes a group of large tree-like brown algae that live in the lower intertidal and shallow subtidal zones (up to 20 m deep) of rocky shores (Martin and Zuccarello 2012). *Lessonia* spp. have major ecological roles in the structuring of benthic marine communities (Villouta and Santelices 1984; Vásquez and Santelices 1984) and are commercially exploited for the extraction of alginic acid (Steneck et al. 2002).

The ecophysiology of *Lessonia* species in the sub-Antarctic ecoregion of Magallanes is to a large extent unknown. The available information about this genus in the Pacific coast of South America is based on studies of *Lessonia nigrescens* Bory de Saint-Vincent and *Lessonia trabeculata* Villouta and Santelices in northern Chile (Hoffmann et al. 1984; Santelices and Ojeda 1984; Ávila et al. 1985). Research on phycocolloids of *Lessonia* species from the sub-Antarctic region of Chile (Chandía et al. 2005; Chandía and Matsuhiro 2008) show that some species of this brown macroalgae have important carbohydrate compounds with specific properties that make them highly interesting for biotechnology applications, in terms of productivity and nutritional value (Mansilla et al. 2012a; Astorga and Mansilla 2013).

Given the ecological importance and economical potential value that *Lessonia* spp might have in the near future, the study of their biology and ecophysiology is essential to guide cultivation efforts for these species under controlled

laboratory and hatchery conditions. Additionally, the region's vulnerability to environmental changes (Mansilla et al. 2012b) is pressing for the study of the tolerance of *Lessonia* spp to them. The objective of this study was to evaluate the tolerance of sub-Antarctic *L. flavicans* to extreme salinity, temperature, and photoperiod conditions characteristic of the sub-Antarctic Magellanic eco-region.

Materials and methods

Fertile *Lessonia flavicans* thalli were collected from the rocky subtidal areas of the Magallanes's sub-Antarctic ecoregion in June 2012. The foliage was transported in polyethylene bags with sea water to the University of Magallanes's Laboratorio de Macroalgas Antárticas y Subantárticas (LMAS). The blades with sori were treated beforehand using cold freshwater to eliminate epiphytes according to Ávila et al. (2010) recommendations for the cultivation of brown algae. The fertile sections of foliage were carefully rinsed two times with pasteurized (2 h at 70 °C, see Little et al. 1987) sea water, cut off with razor blades and placed on glass slides inside Petri dishes with pasteurized, 0.45 μm -filtered sea water, and kept in semi-darkness ($5 \mu\text{mol photons m}^{-2} \text{ s}^{-1}$ and at 8 °C) for 24 h in order to release the spores (Ávila et al. 1985). Once spores were released, the water with thallus fragments was disposed of. The microscopic phase of *L. flavicans* was kept in a plant growth chamber at 9 ± 1 °C, photoperiod 12:12 h (L:D; Ávila et al. 1985), irradiance of $10 \mu\text{mol photons m}^{-2} \text{ s}^{-1}$ and Provasoli medium (Ávila et al. 2010) that was renewed every 7 days. The growth of the microscopic phase of *L. flavicans* was measured weekly in photographic records acquired with a digital camera Moticam 2000 attached to an OLYMPUS CX31 microscope.

Tolerance experiment

We performed a set of four consecutive experiments with young sporophytes (diameter, 10–16 mm; fresh weight, 10–20 mg) to evaluate the effect of salinity, temperature, and photoperiod on the growth of *L. flavicans* plantings. We used young sporophytes to avoid the artifacts involved in the fragmentation of larger thalli and the consequent disruption of physiological processes. Further, sporophytes might be also the plant units to use in future culturing of the species. The sporophytes were grown in Provasoli medium inside an incubation chamber (BioRef 19 L) with temperature and photoperiod control. Considering the salinity variations present in the ecoregion's natural environment (Valdenegro and Silva 2003; Kilian et al. 2007; Ríos et al. 2007), three salinity levels (14, 23, and 32 psu) were evaluated in each of the four experiments. The salinity levels were obtained following Yokoyama et al. (1999) protocol, and confirmed with an ATAGO S/Mill

refractometer. The water was filtered through 0.45 μm and then pasteurized to reduce the number of micro-organisms. Five replicated 500-mL glass jars containing two young *L. flavicans* sporophytes were set at each of the three salinity levels. A different combination of temperature and photoperiod levels was used in each of the four experiments. These levels corresponded to maximum and minimum temperature and photoperiod values measured in shallow benthic ecosystems of the sub-Antarctic ecoregion of Magallanes (Ríos et al. 2007; Ojeda 2013): 9 °C and 5 °C, and 18:6 and 6:18 h L:D, respectively. All the experiments were performed using an irradiance of $70 \pm 2 \mu\text{mol photons m}^{-2} \text{s}^{-1}$, an illumination level considered optimum for cultivation of sporophytes of *L. nigrescens* (Ávila et al. 1985).

The cultures were kept for 25 days, and every 4 days, the growth medium was changed and the sporophyte biomass (fresh weight) inside each jar was measured. The biomasses of the two sporophytes inside each jar were summed thus obtaining five independent replicas for each salinity level. Prior to weighing, the excess of water from the sporophytes was removed using absorbent paper, and the fresh weight was assessed using an analytical RADWAG AS 220/C/2 scale.

Data analysis

Repeated-measures ANOVA was used to evaluate the effect of salinity on the biomass of *L. flavicans* sporophytes during the cultivation period in each of the four combinations of temperature and photoperiod tested. Biomass (fresh weight) of sporophytes inside each culture jar and date of measurement was standardized by the initial biomass. The sphericity

assumption was checked using the Mauchly test and, if violated, the Greenhouse–Geisser and Huynh–Feldt adjusted probabilities are provided. All data analysis was performed with the STATISTICA 7.1 software, using a 95 % confidence interval ($p < 0.05$).

Results

Development of gametophytes in laboratory

Spores of *L. flavicans* settled to their growth substratum, and during the first 48 h, the formation of the germination tube was observed (Fig. 1a, b). The differentiation of male and female gametophytes started on day 11 of cultivation (Fig. 1c), and gametophytes with an average diameter of $45 \pm 10 \mu\text{m}$ were observed on day 15 (Fig. 1d). At approximately 18 days of culture, the fertilization of the female gametophytes was observed (Fig. 1e). Rhizoids were observed and the longitudinal and periclinal divisions commenced on day 24. A polystromatic layer with a prolonged morphology was differentiated, which corresponds to a young *L. flavicans* sporophyte (Fig. 1f).

Effects of salinity on sporophyte biomass

Salinity of 14 psu led to a reduction of the biomass of *L. flavicans* sporophytes in the four combinations of temperature and photoperiod tested (Fig. 2, Table 1). Sporophyte biomass was reduced to zero after 17 days (at 5 °C) and 13 days (at 9 °C) of culture in the 6:18 h L:D

Fig. 1 Initial development stages (microscopic) of *Lessonia flavicans* under laboratory conditions: i) spores; ii) spores with a developed germination tube; iii) appearance of male and female gametophytes; iv) mature male and female gametophytes; v) mature female sporophyte; vi) young sporophyte

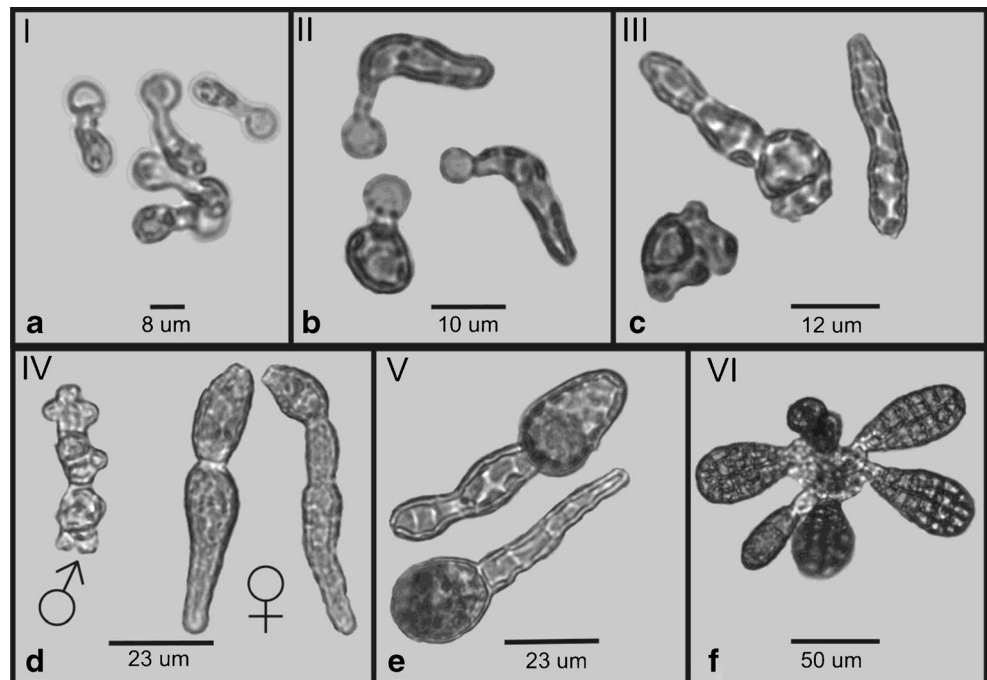
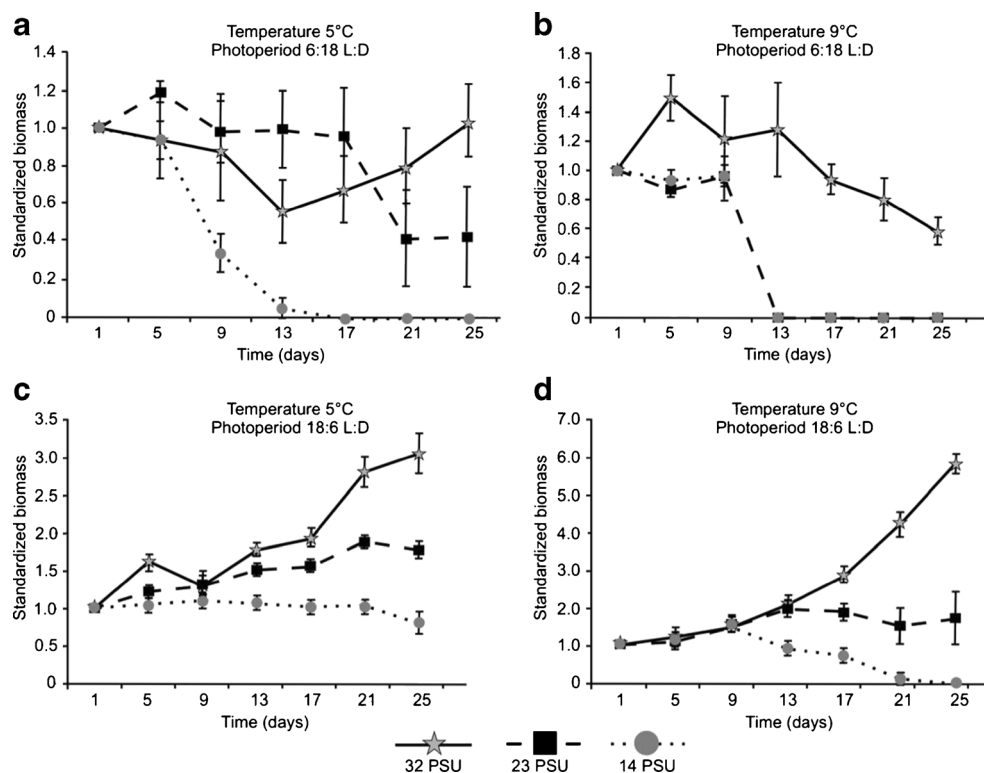


Fig. 2 Standardized average fresh biomass (relative to initial value) of *L. flavicans* sporophytes subjected to four combinations of temperature and photoperiod and three salinities during 25 days of culture. Circles represent salinity: 14 psu, Squares 23 psu, Stars 32 psu. Error bars represent ± 1 standard error ($n=5$)



photoperiod, and after 25 days of culture at 9 °C in the 18:6 h L:D photoperiod. However, the reduction of sporophyte biomass was minimal at 5 °C and 18:6 h L:D photoperiod.

The biomass of *L. flavicans* sporophytes cultured at 5 °C and photoperiod of 6:18 h L:D was reduced to half of the

initial value at salinity of 23 psu, but did not show a net change at a salinity of 32 psu (Fig. 2a). When temperature was set to 9 °C, the reduction of sporophyte biomass in this photoperiod was higher because it was zero after 13 days of culture at salinity of 23 psu and 40 % lower than initial values at salinity of 32 psu (Fig. 2b).

Table 1 Repeated-measures (ANOVA) analysis, evaluating the effect of salinity, on the biomass gain of sporophytes of *L. flavicans* under four combinations of temperature and photoperiod

Temperature 5 °C	Degrees of freedom	MS	F	p	Temperature 9 °C	Degrees of freedom	MS	F	p
	Photoperiod 6:18 L:D					Photoperiod 6:18 L:D			
Intercept	1	34.75	50.56	0.000	Intercept	1	27.93	87.93	0.000
Salinity	2	3.56	5.19	0.023	Salinity	2	5.53	17.42	0.000
Error	12	0.68			Error	12	0.31		
Time	5	0.75	9.64	0.000	Time	5	2.46	75.77	0.000
Time*Salinity	10	0.31	4.04	0.004	Time*Salinity	10	0.20	6.30	0.001
Error	60	0.07			Error	60	0.03		
	Photoperiod 18:6 L:D					Photoperiod 18:6 L:D			
Intercept	1	216.84	1379.97	0.000	Intercept	1	281.41	474.82	0.000
Salinity	2	7.62	48.49	0.000	Salinity	2	37.12	62.64	0.000
Error	12	0.15			Error	12	0.59		
Time	5	1.20	26.99	0.000	Time	5	3.07	13.66	0.000
Time*Salinity	10	0.96	21.50	0.000	Time*Salinity	10	7.31	32.58	0.000
Error	60	0.04			Error	60	0.22		

Sporophytes cultured at a temperature of 5 °C and a 18:6 h L:D photoperiod increased biomass by more than 50 % at salinity 23 psu and triplicated it at salinity of 32 psu (Fig. 2c). The increase of the culturing temperature to 9 °C led also to an increase of sporophyte biomass at salinity 23 psu, and particularly, at salinity of 32 psu where sporophyte biomass at the end of the experiment was six times more than that at the beginning (Fig. 2d).

Discussion

Developmental characteristics of *L. flavicans* microscopic phases meet those described for the order Laminariales (Kain 1979; Lüning 1980; Ávila et al. 1985). Some differences between *L. flavicans* and the congeneric *L. nigrescens* were observed because the first young sporophytes of *L. flavicans* were obtained after 24 days of culture; whereas in *L. nigrescens*, this occurs on day 18 (Ávila et al. 1985). The presence of species-specific differences highlights the importance of identifying the optimal cultivation conditions for gametophytes and sporophytes of *L. flavicans* and other species if culture protocols for Laminariales of sub-Antarctic regions are to be provided. Additionally, knowledge of the optimal growth conditions allows for a better understanding of adaptive processes, survival and development, reproductive cycles and spatial distribution of the species (Hoffmann and Santelices 1982; Hoffmann et al. 1984; Yokoya et al. 1999). For example, the recent studies suggests different tolerance to temperature among two cryptic species of the genus *Lessonia*, where gametophytes of *Lessonia berteriana* Montagne (northern Chile distribution) are more tolerant to higher temperatures than gametophytes of *Lessonia spicata* (Suhr) Santelices (southern Chile distribution; Oppliger et al. 2012).

Net increase of *L. flavicans* biomass occurred only in sporophytes cultured in the photoperiod characteristic of summer (18:6 h L:D) whereas biomass gain was none or minimal in sporophytes cultured in the winter photoperiod (6:18 h L:D). The combination of the photoperiod and temperature characteristic of summer (9 °C) lead to the highest increase of sporophyte biomass but this temperature did not promote biomass increase of sporophytes cultured in the winter photoperiod. The biomass gain of sporophytes cultured at 5 °C, and the 18:6 L:D

photoperiod was lower than that of sporophytes cultured at 9 °C and same photoperiod. Hence, the length of day seems to be a primary environmental condition to consider when culturing *L. flavicans* sporophytes followed by temperature. This seems not to be the case for the sporophytes of *L. nigrescens* that show maximum growth at 10 °C independently of photoperiod (Ávila et al. 1985; Martínez 1999). The gametophytic and sporophytic phases of *Lessonia* populations at high latitudes have lower tolerance to high temperatures than populations at low latitudes (Martínez 1999; Oppliger et al. 2012).

Field experiments with *Macrocystis pyrifera* (Linnaeus) C. Agardh performed in Southern California have shown that temperature and irradiance are key environmental conditions for sporophyte development because at very high temperatures or very low irradiance their growth was inhibited (Dean and Jacobsen 1984). Other species of “kelp” such as *Pterygophora californica* and *Eisenia arborea* present in California have a different behavior compared to *M. pyrifera*, since the sporophytes of those species can tolerate high temperatures (Matson and Edwards 2007). Additionally, while *E. arborea* can produce embryonic sporophytes at high temperatures, *P. californica* cannot (Matson and Edwards 2007). Likewise, recent studies show that seasonal changes of temperature and light had an effect on the early survival and growth of *Ecklonia radiata* (C. Agardh) J Agardh. Gametophyte growth rates of this species were positively related to day length, with the fastest growing zoospores released when the days were long. The survival was greatest in the coolest temperature, while optimum growth was achieved in higher temperatures (Mohring et al. 2013).

Assessing the influence of environmental conditions on the development of kelps seems to be a complex task considering the high variability introduced by species-specific and stage of life cycle effects, the possible seasonality of the responses and the effects of adaptation to local environmental conditions. Our results provide evidence of photoperiod and temperature effects on *L. flavicans* sporophyte growth, although only winter and summer minimum and maximum temperatures were tested. Thus, we consider essential to do further evaluations of the effects of a wider range of photoperiods and temperatures on the development of the gametophytic and sporophytic phases of *L. flavicans*.

Table 2 Reports of *Lessonia flavicans* for the sub-Antarctic ecoregion of Magallanes

Localities	Latitude S	Longitude W	Salinity (psu)	Reference
Trinidad Channel	49° 53.2'	75° 13.0'	30.69	Searles (1978)
Punta Santa Ana	53° 38'	70° 55'	31	Chandía et al. (2005); Martin and Zuccarello (2012)
Ocasion Channel	54° 33.4'	71° 59.7'	31.15	Searles (1978)
Beagle Channel	55° 0'	69° 02.2'	32.17	Searles (1978)

Salinity values for each site were obtained from Silva and Calvete (2002) and Valdenegro and Silva (2003)

Salinity seemed also a determining factor of *L. flavicans* sporophyte growth, with salinities of 23 psu and 14 psu leading to a reduction of biomass gain, or even resulting fatal to sporophytes. The salinity of 32 psu, typical of Magellanic channels with low freshwater influence, was conducive to the best growth. In this regard, most of the reports about the presence of *L. flavicans* within the sub-Antarctic ecoregion of Magallanes correspond to areas with salinity between 30.7 and 32.2 psu (Table 2). Hence, salinity might be another crucial variable determining the spatial distribution of the species. In contrast, young sporophytes of the kelp *Saccharina latissima* (Linnaeus) Lane, Mayes, Druehl and Saunders can tolerate very low levels of salinity (6 psu; Peteiro and Sánchez 2012). The gametophytic and sporophytic phases of *Macrocystis pyrifera* in the sub-Antarctic ecoregion of Magallanes have a wider range of tolerance to salinity than those distributed on the northern Chilean coastline (Buschmann et al. 2004). This wide salinity tolerance allows *M. pyrifera* to live in very heterogeneous habitats in the region (Mansilla et al. 2009). Salinity is known to affect the development of several macroalgal species, for example in some species of kelps as *Alaria esculenta* (L.) Greville, the microscopic stages were shown to be more sensitive to salinity changes than the macroscopic stages (Fredersdorf et al. 2009). Likewise, in other species of macroalgae, low salinities inhibited the formation of erect axis and the carposporeling developed only a basal disc in *Hydropuntia caudata* (J. Agardh) Gurgel and Fredericq (Miranda et al. 2012).

In conclusion, our results suggest that *L. flavicans* has a limited salinity tolerance range, which seems closely linked to salinity of its natural habitats in the sub-Antarctic ecoregion of Magallanes. In addition to salinity, photoperiod and temperature have also an effect on the growth of the sporophytic phase of *L. flavicans*. Summer temperature and photoperiod and a salinity of 32 psu seem to provide optimal conditions for *L. flavicans* sporophyte development. This is key information for culturing of a species of high commercial value. Further, these results could aid in predicting the species potential tolerance response to imminent environmental fluctuations in the wake of global changes.

Acknowledgments The authors thank the support and funding of CONICYT–Chile (Program FONDECYT 1110875) for the collection of samples and the materials for experiments. Author SR would like to thank the Scholarship provided by the Institute of Ecology and Biodiversity (www.ieb.cl; Chile) (code ICM P05-002) and The Master of Science Program in Conservations and Management of Natural Resources in Sub-Antarctic Ecosystems of the University of Magallanes (www.umag.cl/postgrados/magister-ciencias/). Also the students of Magister program in Statistics at the University of Concepción, Mr. Geovanni Moreno, José Salcedo and Alex Pereira for their help in the statistical analysis of experimental data. Finally the author would like to thank the AM Millennium Scientific Initiative (grant no. P05-002 ICM, Chile) and the Basal Financing Program of the Comisión Nacional de Investigación Científica y Tecnológica (grant no. PFB-23, Chile).

References

- Astorga MS, Mansilla A (2013) Sub-Antarctic macroalgae: opportunities for gastronomic tourism and local fisheries in the Region of Magallanes and Chilean Antarctic Territory. *J Appl Phycol* 1–6
- Ávila M, Merino C, Guissen K, Piel MI (2010) Manual de cultivo de macroalgas pardas. Desde el Laboratorio al océano. Universidad Arturo Prat 33 pp. http://www.ficologia.cl/manual_cultivo_pardas.pdf
- Ávila M, Hoffmann AJ, Santelices B (1985) Interacciones de temperatura, densidad de flujo fotónico y fotoperiodo sobre el desarrollo de etapas microscópicas de *Lessonia nigrescens* (Phaeophyta, Laminariales). *Rev Chil Hist Nat* 58:71–82
- Bozinovic F, Calosi P, Spicer JI (2011) Physiological correlates of geographic range in animals. *Annu Rev Ecol Syst* 42:155–179
- Breeman AM (1988) Relative importance of temperature and other factors in determining geographic boundaries of seaweeds: experimental and phenological evidence. *Helgol Meeresunters* 42:199–241
- Buschmann AH, Vásquez JA, Osorio EP, Reyes E, Filun L, Hernández-González MC, Vega A (2004) The effect of water movement, temperature and salinity on abundance and reproductive patterns of *Macrocystis* spp. (Phaeophyta) at different latitudes in Chile. *Mar Biol* 145:849–862
- Chandía NP, Matsuhiro B (2008) Characterization of a fucoidan from *Lessonia vadosa* (Phaeophyta) and its anticoagulant and elicitor properties. *Int J Biol Macromol* 42:235–240
- Chandía NP, Matsuhiro B, Ortiz J, Mansilla A (2005) Carbohydrates from sequential extraction of *Lessonia vadosa* (Phaeophyta). *J Chil Chem Soc* 2:501–504
- Dean TA, Jacobsen FR (1984) Growth of juvenile *Macrocystis pyrifera* (Laminariales) in relation to environmental factors. *Mar Biol* 83:301–311
- Dhargalkar VK (2004) Effect of different temperature regimes on the chlorophyll a concentration in four species of Antarctic macroalgae. *Seaweed Res Utiln* 26:237–243
- Fredersdorf J, Müller R, Becker S, Wiencke C, Bischof K (2009) Interactive effects of radiation, temperature and salinity on different life history stages of the Arctic kelp *Alaria esculenta* (Phaeophyceae). *Oecologia* 160:483–492
- Gaines SD, Lubchenco J (1982) A unified approach to marine plant herbivore interactions. II. Biogeography. *Annu Rev Ecol Syst* 13:111–138
- Gómez I, Weykam G, Wiencke C (1998) Photosynthetic metabolism and major organic compounds in the marine brown alga *Desmarestia menziesii* from King George Island (Antarctica). *Aquat Bot* 60:105–118
- Hay ME (1981) Herbivory, algal distribution and maintenance of between habitat diversity on a tropical fringing reef. *Am Nat* 118:520–540
- Hoffmann AJ, Santelices B (1982) Effects of light intensity and nutrients on gametophytes and gametogenesis of *Lessonia nigrescens* Bory (Phaeophyta). *J Exp Mar Biol Ecol* 60:77–89
- Hoffmann AJ, Avila M, Santelices B (1984) Interactions of nitrate and phosphate on the development of microscopic stages of *Lessonia nigrescens* Bory (Phaeophyta). *J Exp Mar Biol Ecol* 78:177–186
- Kain J (1979) A view of the genus *Laminaria*. *Oceanogr Mar Biol Annu Rev* 17:101–161
- Kearney M, Porter W (2009) Mechanistic niche modelling: combining physiological and spatial data to predict species ranges. *Ecol Lett* 12:334–350
- Kilian R, Baeza O, Steinke T, Arevalo M, Rios C, Schneider C (2007) Late Pleistocene to Holocene marine transgression and thermohaline control on sediment transport in the western Magallanes fjord system of Chile (53°S). *Quat Int* 161:90–107
- Kirst G, Wiencke C (1995) Ecophysiology of polar algae. *J Phycol* 31:181–199

- Little B, Gerchakov S, Udey L (1987) A method for sterilization of natural seawater. *J Microbiol Methods* 7:193–200
- Lüning K (1980) Critical levels of light and temperature regulating the gametogenesis of three *Laminaria* species (Phaeophyceae). *J Phycol* 16:1–15
- Mansilla A, Palacios M, Aguilar S (2004) Efecto de la salinidad en el desarrollo en *Sarcothalia crispata* (Bory) Leister bajo condiciones de laboratorio. *Ann Inst de la Pat Ser Cs Nat* 32:13–33
- Mansilla A, Ávila M, Caceres J, Palacios M, Navarro N, Cañete I, Oyarzún S (2009) Diagnóstico bases biológicas explotación sustentable *Macrocystis pyrifera*, (Huiro), XII Región Código BIP N° 30060262-0. Gobierno Regional de Magallanes y Antártica Chilena. Informe de Proyecto, Universidad de Magallanes, Chile, 345pp
- Mansilla A, Ávila M, Yokoya NS (2012a) Current knowledge on biotechnological interesting seaweeds from the Magellan Region, Chile. *Rev Bras Farmacogn* 22:760–767
- Mansilla A, Ojeda J, Rozzi R (2012b) Cambio climático global en el contexto de la Ecoregión subantártica de Magallanes y la reserva de biosfera Cabo de Hornos. *Ann Inst de la Pat Ser Cs Nat* 40:69–76
- Martin P, Zuccarello GC (2012) Molecular phylogeny and timing of radiation in *Lessonia* (Phaeophyceae, Laminariales). *Phycol Res* 60:276–287
- Martinez EA (1999) Latitudinal differences in thermal tolerance among microscopic sporophytes of the kelp *Lessonia nigrescens* (Phaeophyta: Laminariales). *Pac Sci* 53:74–81
- Matson PG, Edwards MS (2007) Effects of ocean temperature on the southern range limits of two understory kelps, *Pterygophora californica* and *Eisenia arborea*, at multiple life-stages. *Mar Biol* 151:1941–1949
- Miranda GEC, Yokoya NS, Fuji MT (2012) Effects of temperature, salinity and irradiance on carposporeling development of *Hydropuntia caudata* (Gracilariales, Rhodophyta). *Rev Bras Farmacogn* 22:818–824
- Mohring MB, Kendrick GA, Wernberg T, Rule MJ, Vanderklift MA (2013) Environmental influences on kelp performance across the reproductive period: an ecological trade-off between gametophyte survival and growth? *PLoS ONE* 8(6):e65310
- Ojeda J (2013) Dinámica estacional de macroalgas y moluscos intermareales y su relación con el conocimiento tradicional ecológico yagán, en canales subantárticos del Cabo de Hornos: una aproximación biocultural desde la filosofía ambiental de campo. Postgraduate Thesis, Universidad de Magallanes, Punta Arenas, Chile, 145 pp
- Oppliger LV, Correa JA, Engelen AH, Tellier F, Vieira V et al (2012) Temperature effects on gametophyte life-history traits and geographic distribution of two cryptic kelp species. *Plos One* 7(6):e39289
- Peteiro C, Sánchez N (2012) Comparing salinity tolerance in early stages of the sporophytes of a non-indigenous kelp (*Undaria pinnatifida*) and a native kelp (*Saccharina latissima*). *Russ J Mar Biol* 38:197–200
- Ramlov F, de Souza J, Farias A, Maraschin M, Horta PA, Yokoya NS (2012) Effects of temperature, salinity, irradiance, and nutrients on the development of carposporelings and tetrasporophytes in *Gracilaria domingensis* (Kütz.) Sonder ex Dickie (Rhodophyta, Gracilariales). *Bot Mar* 55:253–259
- Ríos C, Arntz WE, Gerdes D, Mutschke E, Montiel A (2007) Spatial and temporal variability of the benthic assemblages associated to the holdfasts of the kelp *Macrocystis pyrifera* in the Straits of Magellan, Chile. *Polar Biol* 31:89–100
- Rozzi R, Massardo F, Anderson CB, Heidinger K, Silander JA (2006) Ten principles for biocultural conservation of the southern tip of the Americas: the approach of the Omora Ethnobotanical Park. *Ecol Soc* 11:43
- Santana A, Olave C, Butorovic N (2010) Estudio climatológico con registros de alta resolución temporal en campamento posesión (ENAP) Magallanes, Chile. *Ann Inst de la Pat* 38:5–34
- Santelices B, Ojeda P (1984) Recruitment, growth and survival of *Lessonia nigrescens* (Phaeophyta) at various tidal levels in exposed habitats of central Chile. *Mar Ecol Prog Ser* 14:165–173
- Searles RB (1978) The genus *Lessonia* Bory (Phaeophyta, Laminariales) in Southern Chile and Argentina. *Br Phycol J* 13:361–381
- Sexton JP, Mcintyre PJ, Angert AL, Rice RJ (2009) Evolution and ecology of species range limits. *Annu Rev Ecol Evol Syst* 40:415–436
- Silva N, Calvete C (2002) Características oceanográficas físicas y químicas de canales australes chilenos entre el golfo de penas y el Estrecho de Magallanes (Crucero CIMAR-FIORDOS 2). *Cienc Tecnol Mar* 25:23–88
- Steneck RS, Graham MH, Bourque BJ, Corbett D, Erlandson JM, Estes JA, Tegner MJ (2002) Kelp forest ecosystems: biodiversity, stability, resilience and future. *Environ Conserv* 29:436–459
- Valdenegro C, Silva N (2003) Caracterización oceanográfica física y química de la zona de canales y fiordos australes de Chile entre el estrecho de Magallanes y Cabo de Hornos (Cimar 3 fiordos). *Cienc Tecnol Mar* 26:19–60
- van den Hoek C (1982) The distribution of benthic marine algae in relation to the temperature regulation of their life histories. *Biol J Linn Soc* 18:81–144
- Vásquez JA, Santelices B (1984) Comunidades de macroinvertebrados en discos adhesivos de *Lessonia nigrescens* Bory (Phaeophyta) en Chile central. *Rev Chil Hist Nat* 57:131–154
- Villouta E, Santelices B (1984) Estructura de la comunidad submareal de *Lessonia* (Phaeophyta, Laminariales) en Chile norte y central. *Rev Chil Hist Nat* 57:111–122
- Wiencke C, Dieck IT (1990) Temperature requirements for growth and survival of macroalgae from Antarctica and southern Chile. *Mar Ecol Prog Ser* 59:157–170
- Yokoya NS, Kakita H, Obika H, Kitamura T (1999) Effects of environmental factors and plant growth regulators on growth of the red alga *Gracilaria vermiculophylla* from Shikoku Islands, Japan. *Hydrobiologia* 398/399:339–347