Marine Environmental Research xxx (2015) 1–9

Contents lists available at ScienceDirect

Marine Environmental Research

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

Effects of thermal stress on the growth of an intertidal population of *Ellisolandia elongata* (Rhodophyta) from N–W Mediterranean Sea

Matteo Nannini [a], [b], [c], [*], [1], Lucia De Marchi [c], [d], [1], [2], Chiara Lombardi [a], Federica Ragazzola [e], [3]

[a] *Environment Research Centre ENEA Via Santa Teresa, 19032 Pozzuolo di Lerici, La Spezia, Italy*
[b] *Department of Biology, University of Pisa, Via Derna 1, 56126 Pisa, Italy*
[c] *Association For-Mare for Applied Ecological Sciences, Via Lovati 33, 27100 Pavia, Italy*
[d] *Istituto di Scienze Marine-Consiglio Nazionale delle Ricerche (CNR-ISMAR), Pozzuolo di Lerici, 19032 Lerici, La Spezia, Italy*
[e] *Department of Earth Sciences, University of Bristol, Bristol BS8 1RJ, UK*

ARTICLE INFO

Article history:
Received 1 December 2014
Received in revised form
11 May 2015
Accepted 13 May 2015
Available online xxx

Keywords:
Climate changes
Coralline algae
Temperature
Linear extension
Calcium carbonate mass
6 month experiment

ABSTRACT

Coralline algae are calcareous algae able to build biogenic structures, thus playing a key-role as marine biodiversity promoters and calcium carbonate producers. The aim was to estimate the growth of *Ellisolandia elongata* under thermal stress. *E. elongata* were cultured for 2, 4 and 6 months under “natural” temperature (Tc) and increased temperature ($Ti = Tc + 3\ ^\circ C$). In order to determine a possible culturing effect, growth in the field was also measured. For the first time, Alizarin Red S dye was used in high energy shallow water environments. Thallus linear extension was higher in the cultured specimens (Tc and Ti) compared to the field specimens. The carbonate mass in the field was higher than in Ti and Tc after 2, 4 months but decreased after 6 months. Partly unknown *in situ* environmental factors could have affected growth and calcification rates in the field while thermal adaptation could explain growth rates in the culturing experiment.

1. Introduction

In marine environments, calcareous algae such as red coralline algae are a significant component of benthic ecosystems, from mesolittoral to the circolittoral zones (Steneck, 1986; Basso, 2012). They play a key-role as “ecosystem engineers” able to build-habitats and promote biodiversity (Jones et al., 1997; Gattie et al., 2003; Kuffner et al., 2008). Being divided into two main morphological forms, geniculated (i.e. articulated, with erected, branched thalli with uncalcified joints between calcified segments) and non-geniculate (i.e. non-articulated, encrusting forms attached to the substratum or free-living forms known as rhodolithes) (Cabioch et al., 1992), coralline algae are able to create endemic biogenic reefs that favour settlement and recruitment of numerous invertebrates and provide habitats for a high diversity of associated organisms (Johansen, 1981). In the Mediterranean Sea, coralline algae biogenic reefs are the second pole of species diversity. Some examples in the mesolittoral zone are: the association of *Lithophyllum papillosum* and *Polysiphonia* spp., the “encorbellement” of *Lithophyllum byssoides* (Lamarck) Foslie (1900) (Laborel et al., 1994) and *L. tortuosum f. crassa* (Lloyd) Me. Lemoine and concretions of *Neogoniolithon brassica-florida* (Harvey) Setchell & L.R. All these habitat are protected by the Habitat Directive-Barcelona Convention 1995.

Due to their wide distribution, coralline algae are important contributors to the global inorganic carbon budgets in shallow water ecosystems (Foster, 2001; Mackenzie et al., 2004; Martin and Gattuso, 2009) by acting as carbon source and sink. Cebrian et al. (2000) estimated a calcimass (animal and algae) of approximately ~1000–2800 g-dw m^{-2} for the shallow infralittoral habitats, with calcareous algae contributing nearly 40% to the total carbonate budget in the shallow water environment. Growth rates of coralline algae depends on their morphology (e.g. geniculated vs non geniculated) and on the environment they live in. With respect to the thallus morphology, marginal extension rates for encrusting corallines are typically <1 mm $month^{-1}$ but may exceed 2–3 mm $month^{-1}$, whereas erect articulated corallines may grow much faster, up to 5 mm $month^{-1}$, with an average growth of

---

[*] Corresponding author. Environment Research Centre ENEA Via Santa Teresa, 19032 Pozzuolo di Lerici, La Spezia, Italy.
E-mail address: mattetametsi@hotmail.it (M. Nannini).

[1] These two authors contributed equally.

[2] Current address: Departamento de Biologia, Universidade de Aveiro, 3810-193 Aveiro, Portugal.

[3] Current address: Institute of Marine Sciences, University of Portsmouth, Ferry Road, Eastney Portsmouth PO4 9LY, UK.

http://dx.doi.org/10.1016/j.marenvres.2015.05.005

Please cite this article in press as: Nannini, M., et al., Effects of thermal stress on the growth of an intertidal population of *Ellisolandia elongata* (Rhodophyta) from N–W Mediterranean Sea, Marine Environmental Research (2015), http://dx.doi.org/10.1016/j.marenvres.2015.05.005

1.5–2 mm $month^{-1}$ (Andrake and Johansen, 1980; Steneck, 1985). Martone (2010) observed that the growth rate and the deposition of $CaCO_3$ of the individual meristems of *Calliarthron cheilosporioides* decreases as the fronds size increase (fronds <5 cm^2 grew 2.3–3.3 mm $month^{-1}$; fronds >15 cm^2 instead 0.8–1.6 mm $month^{-1}$); moreover the individual meristems of the small fronds (<5 cm^2) grew 0.1–0.15 cm^2 $month^{-1}$, depositing 5.6–8.6 mg $CaCO_3$ and for the larger fronds (>15 cm^2) the growth rate was 0.02–0.04 cm^2 $month^{-1}$, with a deposition of 1.2–2.2 mg $CaCO_3$.

Even if some species can be potentially resilient, coralline algae have general characteristics that make them potentially vulnerable to climate changes, such as the mineralogical composition of their thalli (high Mg-calcite (HMC)), the most soluble $CaCO_3$ polymorph. This feature makes coralline algae highly susceptible to temperature (the substitution of Mg in calcite is endothermic, and therefore is facilitated at high temperatures) and to the saturation state of the seawater with respect to calcium carbonate polymorphs (Porzio et al., 2011), and thus makes them a model organism in climate change studies (Kamenos et al., 2008; Noisette et al., 2013).

Global average temperature at the Earth's surface has risen by 0.7 °C during the last century and is expected to rise by 3 °C by 2100 (Solomon et al., 2007). Brodie et al. (2014) demonstrated that each calcified alga has a thermal optimum, so their distributions are probably already changing due to global warming and are expected to shift significantly as global sea surface temperatures continue to rise. For example, previous studies have shown how *Corallina officinalis,* with a thermal optimum between 12 °C (2.89 ± 0.63 mm) (mean ± s.d.) and 18 °C (2.79 ± 0.62) (mean ± s.d.), is unable to grow at higher temperature (Colthart and Johansen, 1973). Furthermore, calcified algae may not benefit from the increasing availability of inorganic carbon for photosynthesis, as ocean acidification also increases the metabolic costs of calcification and can corrode their skeletons when seawater becomes undersaturated with respect to high Mg calcite (Nelson, 2009). Previous studies have shown a negative effect of global warming on recruitment (Kuffner et al., 2008), growth (Jokiel et al., 2008), and calcification (Gao et al., 1993; Semesi et al., 2009) of coralline algae leading to an increasing susceptibility to grazing by bioeroders (Steneck, 1986). Thus, global warming and ocean acidification could have a dramatic consequence on species distributions (Harley et al., 2012; Bijma et al., 2013) with a shift in their abundance and geographical boundaries (Díez et al., 2012).

The focus of our study was to look at growth response of a Mediterranean ecosystem engineer from the mesolittoral fringe when exposed to thermal stress expected for the near future (2100).

The “bourrelet” or “corniche” of *Ellisolandia elongata* Ellis and Solander (1786) (Laborel et al., 1994) is an example of foliose habit characterizing the upper mesolittoral fringe with a high variation in physical parameters and pressure of herbivores (Underwood and Jernakoff, 1984). This species is typical of transitional environments, growing on vertical rocks, occupying the lower portion of the intertidal to the upper limit of the infralittoral zone, and emerging only for short periods of the year due to the low mean tidal range in the Mediterranea Sea (<50 cm) (Cerrano et al., 2004; El Haïkali et al., 2004). It has been shown that plasticity increases in highly fluctuating environments (Schaum and Collins, 2014), therefore the species living in such environments are more likely to adapt better to climatic changes. Here, we discuss variability in growth (i.e. linear extension and calcium carbonate mass) of *E. elongata* due to exposure to natural (Field) and controlled conditions (Tc) and to thermal stress (Ti) following the expected conditions by 2100 (IPCC, 2007).

The reduction and eventual disappearance of “ecosystem engineers” may undermine the functioning of ecological systems thus leading to the disappearance and/or fragmentation of populations and communities associated with them (Airoldi et al., 2008), thus a loss in Mediterranean marine biodiversity.

2. Materials and methods

2.1. *E. elongata J. Ellis and Solander 1786*

E. elongata (Rhodophyta) belongs to the order Corallinales, family Corallinaceae. It is a geniculated algae with flexible pinnate fronds (5–7 mm) and a crustose base. *E. elongata* fronds appear less resilient to physical disturbances (i.e. thermal stress, exsiccation and crumpling, grazing) compared to the crustose parts. The structure of the frond is composed of flexible uncalcified joints called genicula, located between calcified segments (Babbini and Bressan, 1997), which grow as individual plants on rocks or granular substrates, but also as epiphytes on shells or on other algae (Cerrano et al., 2004). *E. elongata* is the most common species in the Mediterranean Sea with a distribution from North-West Mediterranean Sea (from southern coast of the Spain to Greece) to South-East Mediterranean Sea (from Lebanon to Algeria, with the highest concentration in Tunisia) (Bressan and Babbini, 2003). The species is dioecious and it is reproductive between February–March to June (Bressan and Babbini, 2003) and is also present in transitional environments such as tidal pools where it has to cope with rapid pCO_2 and salinity fluctuations (Morris and Taylor, 1983; Huggett and Griffiths, 1986).

2.2. *Study area*

The Gulf of La Spezia is located in the Ligurian Sea (North-Western Mediterranean Sea) (Fig. 1). Being delimited to the west by Tino Island and to the east by Punta Bianca, the Gulf has an extension of 5 km in width and 10 km in length. The depth of the Gulf ranges between 10 m in the inner part of the dam and 25 m near Palmaria Island and Tino Island. The dominant winds are North-east and North (Bordone, 2013), whereas the direction of waves is mainly from 180°N to 270° N, with the peak at 240°N (Buzzolino, 2011). Chemical and physical parameters of the water column within the Gulf are regularly monitored with by ENEA observatory and campaigns since 1973 (Ciuffardi et al., 2013; MOIS).

The biological components of the Gulf have been subject to long term monitoring studies conducted by ENEA in the last 20 years on bioconstructor organisms such as bryozoans (Cocito and Sgorbini, 2014), the symbiotic coral *Cladocora caespitosa* forming extensive beds (Peirano et al., 2004, 2005; Rodolfo-Metalpa et al., 2005), and structuring key species of coralligenous reefs such as *Paramuricea clavata* (Cocito et al., 2002; Cupido et al., 2008, 2009, 2012).

The coralline alga *E. elongata,* extensively distributed within the Gulf, has been relatively poorly studied in the area despite its important contribute in forming mesolittoral reefs. The selected experimental area was Baia Blu (44°4′58.35″N, 009°53′2.05″E) (Fig. 1), a bay located at the eastern end of the Gulf of La Spezia and provided with ENEA *in situ* monitoring stations.

2.3. *Experiment set-up*

2.3.1. *Field*

The experiment was performed between April to October 2014 in both the field and laboratory. Within the experimental area of Baia Blu, four sites (25 × 25 cm) with *E. elongata* were chosen randomly on hard horizontal rocky substrate at a depth of approximately 80–90 cm. The samples of *E. elongata* were stained in the field with Alizarin Red S dye to monitor algal growth

Please cite this article in press as: Nannini, M., et al., Effects of thermal stress on the growth of an intertidal population of *Ellisolandia elongata* (Rhodophyta) from N–W Mediterranean Sea, Marine Environmental Research (2015), http://dx.doi.org/10.1016/j.marenvres.2015.05.005