Vol. 22: 1–4, 2014
doi: 10.3354/ab00613

AQUATIC BIOLOGY
Aquat Biol

Published November 20

Contribution to the Theme Section 'Environmental forcing of aquatic primary productivity'

Introduction

F. L. Figueroa[1], J. M. Mercado[2], J. Beardall[3,*], P. J. Neale[4], V. Montecino[5], J. C. Kromkamp[6]

[1]Department of Ecology, Faculty of Sciences, University of Málaga, 29071 Málaga, Spain
[2]Spanish Institute of Oceanography, 29640 Fuengirola, Spain
[3]School of Biological Sciences, Monash University, Clayton, VIC 3800, Australia
[4]Smithsonian Environmental Research Center, Edgewater, Maryland 21037, USA
[5]Departamento de Ciencias Ecológicas, Facultad de Ciencias, Universidad de Chile, Casilla 653, Santiago, Chile
[6]Royal Netherlands Institute for Sea Research, PO Box 140, 4400 AC Yerseke, The Netherlands

ABSTRACT: Earth is currently experiencing rapid changes in climate, associated with anthropogenic activities, which have the potential to have significant effects on aquatic ecosystems. The 9th International Workshop of the Group for Aquatic Primary Productivity (GAP9) assessed the effects of environmental factors on physiological performance and primary productivity of micro- and macroalgae. This Introduction summarizes the activities and main findings of the 4 workgroups of GAP9 as published in this Theme Section of Aquatic Biology.

KEY WORDS: Alboran Sea · Macroalgae · Microalgal mass culture · Nutrients · Ocean acidification · Phytoplankton · Primary productivity · Ultraviolet radiation

Global change involves simultaneous alterations in a range of environmental factors (e.g. temperature, solar radiation, nutrients and CO_2). Increasingly, experimental evidence reveals complex responses of aquatic plant communities to global change, with either synergistic, antagonistic or independent effects that cannot be predicted from the additive responses to each variable alone. The 9th International Workshop of the Group for Aquatic Primary Productivity (GAP9) held at Malaga (Spain; 17–25 September 2012) used a variety of manipulative experiments to improve our understanding of the effects of acidification, changes in UV radiation and nutrient supply on coastal algal communities and isolated strains in mass culture. Most experiments were conducted with species and communities sampled in the northern Alboran Sea, the westernmost basin of the Mediterranean Sea (Fig. 1). This small basin features a complex hydrology strongly influenced by the Atlantic water jet that penetrates the Strait of Gibraltar and shapes east–west permanent gradients in temperature, salinity and nutrients. Furthermore, the coast is densely populated by humans and receives extensive amounts of domestic waste and urban drainage that constitute significant nutrient inputs. Both high biodiversity and strong anthropogenic pressures (Coll et al. 2010) make the Alboran Sea an ideal system to test the resilience of marine ecosystems to global change.

GAP is a working group of the International Society for Limnology (SIL) and the International Association for Ecology (INTECOL). GAP organizes a series of unique experimental workshops designed to foster collaboration between scientists with differing expertise and, especially, to involve graduate students at an early stage in their career. Participants work in groups on a variety of issues under a broad theme, and in disparate environments. They get the opportunity to use state-of-the-art equipment and techniques that are brought to the workshops and made available for all to experience. GAP9 attracted 85 scientists and students. There were 4 workgroups, which focused on coastal phytoplankton (WG1), microalgal mass culture (WG2), experimental studies on macroalgae (WG3) and field measurements on macrophytes (WG4).

---

*Corresponding author: john.beardall@monash.edu

Publisher: Inter-Research · www.int-res.com

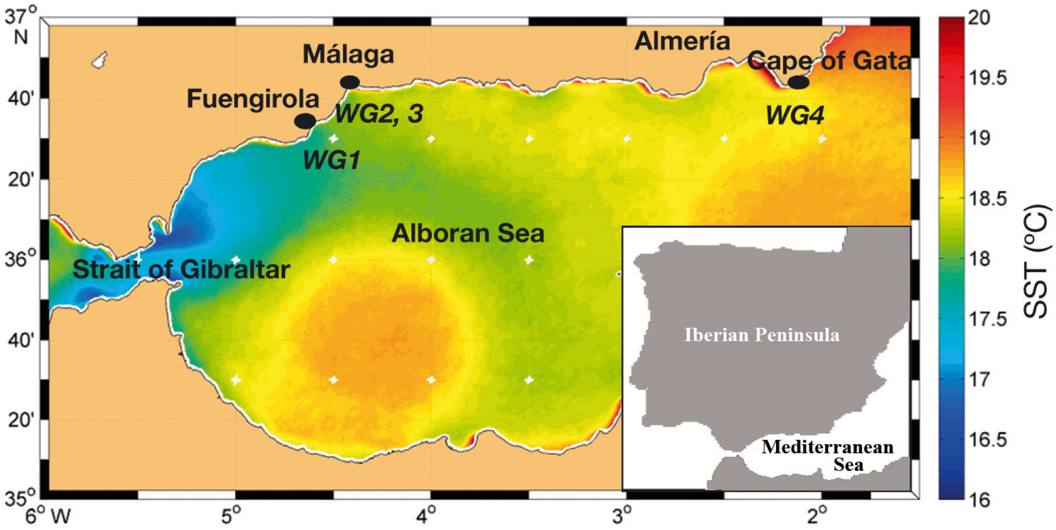

Fig. 1. Sea surface temperature (SST) of the Alboran Sea. Data are based on averaged daily images captured by the satellite MODIS-Aqua from 2002 to 2012 (http://oceancolor.gsfc.nasa.gov/). The location of the sampling and experimention sites of the 4 workgroups (WG) of the GAP9 Workshop are shown

WG1 focused on the interactive effects of altered nutrient supply, increased CO_2 levels and irradiance on coastal phytoplankton physiology, production, composition, size structure, biodiversity and interactions with the microbial community. Phytoplankton responses to each of these global change factors are discussed in the review by Beardall et al. (2014, this and all following studies are part of this Theme Section). The results of a microcosm experiment (Fig. 2a) showing strong effects of nutrient enrichment and interactions between CO_2 and irradiance effects are documented in the 4 companion papers by Neale et al. (2014), Mercado et al. (2014), Reul et al. (2014) and Sobrino et al. (2014).

WG2 investigated the effects of reduction in nutrient supply on the photosynthetic performance and

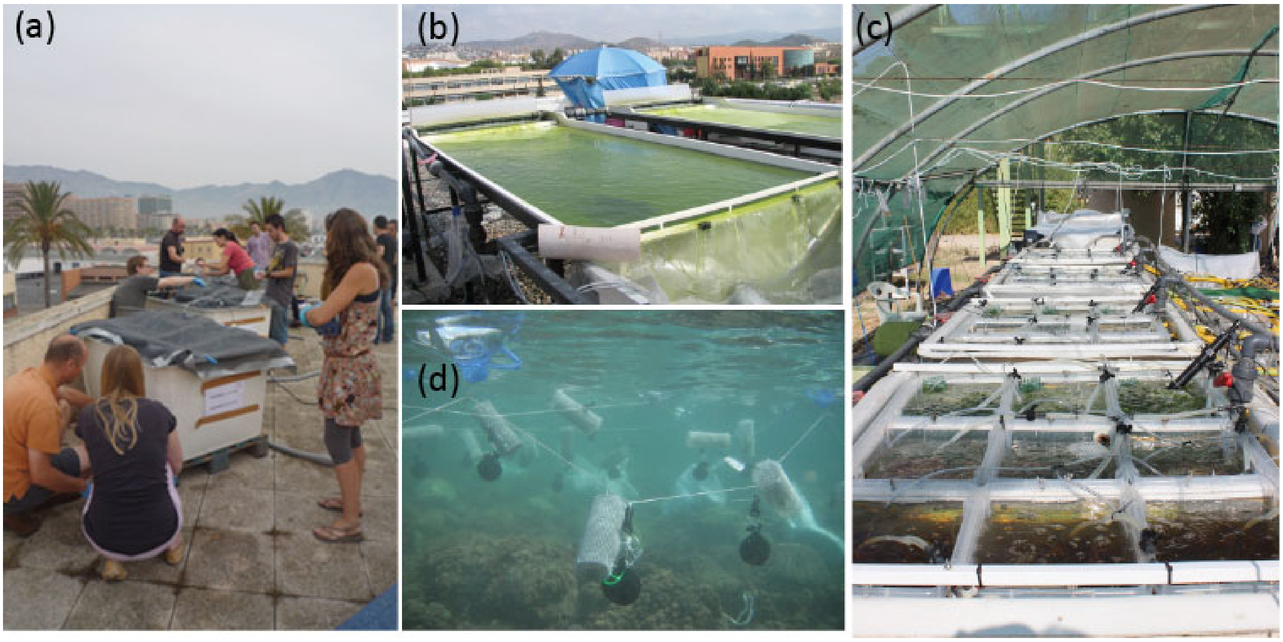

Fig. 2. Experimental set-up used in the different workgroups (WG). (a) Tanks in which 20 l microcosms were incubated for the experiments conducted by WG1. (b) Thin-layer cascade pond used by WG2. (c) Detail of one of the outdoor mesocosms used by WG3. (d) Detail of the *in situ* incubator system used by WG4

biochemical composition of the microalga *Chlorella fusca*. Ihnken et al (2014) investigated the interrelationship between pH and photosynthetic performance in *C. fusca*, and Jerez et al (2014) describe the photosynthetic performance of this species in different parts of the thin-layer cascade (Fig. 2b). A practical guide was worked out on how fluorescence can be used in monitoring photosynthetic activity of mass cultures (Malapascua et al. 2014). Malpartida et al. (2014) report on the synergies between UV radiation and nutrient limitation in photobioreactors.

WG3 investigated the interactive effects of solar UVR and temperature on 3 species of macroalgae (*Cystoseira tamariscifolia*, *Ulva rigida* and *Ellisolandia elongata*) with different bio-optical characteristics grown under modified CO_2 and nutrient regimes, using a complex outdoor mesocosm set-up (Fig. 2c). The experimental conditions simulated climate change scenarios expected at the end of this century. The effects of nutrients, pH, temperature and irradiance on the diurnal and daily responses of *in vivo* chlorophyll *a* fluorescence in the 3 algae are presented in Stengel et al. (2014). Figueroa et al. (2014b) reports continuously measured fluorescence yields in *U. rigida* during both light and dark periods. The effects of C and N regimes on biochemical composition (pigments, proteins, lipids and photoprotectors) are analyzed in Figueroa et al. (2014a). Finally, Parages et al. (2014) describe environment-induced changes in the phosphorylation of MAPK-like proteins in the 3 algal species.

WG4 conducted field studies in the Natural Park of Cape of Gata (Fig. 1) with key macroalgae as model species. A novel *in situ* incubator system (Fig. 2d) to study the impact of increased CO_2 on macroalgae was tested. Celis-Plá et al. (2014) report the short-term ecophysiological and biochemical responses of *C. tamariscifolia* and *E. elongata* to changes in solar irradiance and nutrient levels. Korbee et al. (2014) describe the results of short-term high CO_2 experiments with one non-calcifying (*C. tamariscifolia*) and 2 calcifying (*E. elongata* and *Padina pavonica*) macroalgae. The physiological responses of these species to elevated pCO_2 were different, possibly due to anatomical and physiological features, suggesting that ocean acidification could induce a shift in the relative dominance of a species. Similarly, Hofmann & Bischof (2014), in their review on calcification in macroalgae, conclude that ocean acidification could decrease the competitive performance of the coralline algae that deposit high-Mg calcite. In contrast, some dolomite depositing species may be able to acclimate to high pCO_2.

The experiments conducted during the GAP9 workshop, with both microalgae and macroalgae, have shown interactive effects of CO_2 and temperature on photosynthesis and biochemical composition, modulated by nutrient availability. Furthermore, a high capacity of macroalgae for acclimation to environmental stress factors was observed in field studies. Further investigations on the impact of climate change, using both experimental physiology and ecology, are necessary to provide more accurate predictions of the effects of climate change on algae in the natural environment or in aquaculture systems.

LITERATURE CITED

Beardall J, Stojkovic S, Gao K (2014) Interactive effects of nutrient supply and other environmental factors on the sensitivity of marine primary producers to ultraviolet radiation: implications for the impacts of global change. Aquat Biol 22:5–24

Celis-Plá PSM, Martínez B, Quintano E, García-Sánchez M and others (2014) Short-term ecophysiological and biochemical responses of *Cystoseira tamariscifolia* and *Ellisolandia elongata* to environmental changes. Aquat Biol 22:227–244

Coll M, Piroddi C, Steenbeeck J, Kaschner K and others (2010) The biodiversity of the Mediterranean Sea: estimates, patterns, and threats. PLoS ONE 5:e11842

Figueroa FL, Bonomi Barufi J, Malta EJ, Conde-Álvarez R and others (2014a) Short-term effects of increasing CO_2, nitrate and temperature on three Mediterranean macroalgae: biochemical composition. Aquat Biol 22:177–193

Figueroa FL, Conde-Álvarez R, Bonomi Barufi J, Celis-Plá PSM and others (2014b) Continuous monitoring of *in vivo* chlorophyll *a* fluorescence in *Ulva rigida* (Chlorophyta) submitted to different CO_2, nutrient and temperature regimes. Aquat Biol 22:195–212

Hofmann LC, Bischof K (2014) Ocean acidification effects on calcifying macroalgae. Aquat Biol 22:261–279

Ihnken S, Beardall J, Kromkamp JC, Serrano CG and others (2014) Light acclimation and pH perturbations affect photosynthetic performance in *Chlorella* mass culture. Aquat Biol 22:95–110

Jerez CG, Navarro E, Malpartida I, Rico RM, Masojídek J, Abdala R, Figueroa FL (2014) Hydrodynamics and photosynthesis performance of *Chlorella fusca* (Chlorophyta) grown in a thin-layer cascade (TLC) system. Aquat Biol 22:111–122

Korbee N, Navarro NP, García-Sánchez M, Celis-Plá PSM and others (2014) A novel *in situ* system to evaluate the effect of high CO_2 on photosynthesis and biochemistry of seaweeds. Aquat Biol 22:245–259

Malapascua JRF, Jerez CG, Sergejevová M, Figueroa FL, Masojídek J (2014) Photosynthesis monitoring to optimize growth of microalgal mass cultures: application of chlorophyll fluorescence techniques. Aquat Biol 22: 123–140

Malpartida I, Jerez CG, Morales MM, Nascimento P and others (2014) Synergistic effect of UV radiation and nutrient limitation on *Chlorella fusca* (Chlorophyta) cultures grown in outdoor cylindrical photobioreactors. Aquat

Biol 22:141–158

➤ Mercado JM, Sobrino C, Neale PJ, Segovia M and others (2014) Effect of CO_2, nutrients and light on coastal plankton. II. Metabolic rates. Aquat Biol 22:43–57

➤ Neale PJ, Sobrino C, Segovia M, Mercado JM and others (2014) Effect of CO_2, nutrients and light on coastal plankton. I. Abiotic conditions and biological responses. Aquat Biol 22:25–41

➤ Parages ML, Figueroa FL, Conde-Álvarez RM, Jiménez C (2014) Phosphorylation of MAPK-like proteins in three intertidal macroalgae under stress conditions. Aquat Biol 22:213–226

➤ Reul A, Muñoz M, Bautista B, Neale PJ and others (2014) Effect of CO_2, nutrients and light on coastal plankton. III. Trophic cascade, size structure and composition. Aquat Biol 22:59–76

➤ Sobrino C, Segovia M, Neale PJ, Mercado JM, García-Gómez C and others (2014) Effect of CO_2, nutrients and light on coastal plankton. IV. Physiological responses. Aquat Biol 22:77–93

➤ Stengel DB, Conde-Álvarez R, Connan S, Nitschke U and others (2014) Short-term effects of CO_2, nutrients and temperature on three marine macroalgae under solar radiation. Aquat Biol 22:159–176