Reply to reviewer 2

Review comments shown in black, reply in blue, original text in green and revised text in red. Page numbers refer to the original version (the pdf file as used by the reviewer)

Krause-Jensen et al. measured the inorganic carbon chemistry in a Greenlandic fjord, and by measuring O2 as well, they are able to evaluate and distinguish tidal and photoautotrophic influences. They examined the inorganic carbon chemistry from the planktonic community down to surface of macroalgae and they also examined seasonal differences. It should be pointed out that some previous studies, already measured the fluctuations in inorganic carbon concentrations in coastal habitats (Delille et al. 2000, Middelboe and Hansen 2007) and related them to photoautotrophic activity, but the detailed analysis of this study is completely new. Furthermore, the Arctic with its particularities has in this context never been examined before. The methods are timely and well explained.

Thank you!

Concerning the presentation of the results I would suggest to provide also pCO2-data in the text, to allow an easier comparison with previous works from photosynthesis researchers. For researcher focusing on aquatic photosynthesis the pCO2-value is of particular relevance (This might be a very personal point of view, but still I would like to give this advice).

Reply: We agree that pCO_2 data are of interest and we have added the ranges. As the main point in this paper is the changes in pH we prefer not to enter a detailed description of pCO2. We are providing such detailed description of gas exchange in sub-Arctic and Arctic kelp forests in a separate paper (not yet published)

- p. 14918, l. 4 (fjordscale): Corresponding pCO_2 levels ranged from 162 to 325 µatm in the surface layer across the fjord in September.

- p. 4919, l. 30 (small-scale and diurnal pH variability): Corresponding pCO2-levels ranged from 238 to 536 µatm at the kelp sites and from 258 to 515 µatm at the microalgal/filamentous algal sites.

Generally, but in the discussion I would suggest to pay more attention to the effects of ocean acidication on non-calcifying algae/ animals. These are often overlooked and receive too little attention compared to calcifying species. However, in your study, where you focus on Arctic fjords, where kelps are the most important keystone species you should mention the known OA-effects on kelp and in my opinion even highlight it in your discussion.

Reply: We have added information on OA effects on kelp as specified in the responses below.

The paper is very well written and beside the mentioned suggestions for improvements I only have some minor remarks, which potentially might help to improve the paper and broaden its audience. I hope that you consider them constructive. In Summary, I enjoyed reading the paper and recommend the publication after a minor revision.

Thank you for the constructive criticism.

Page 4909 Line 5: Why do you limit yourself to calcifyers? Also non-calcifying organisms will, in particular photoautotrophs will be strongly influenced by lowered pH? I recommend mentioning them.

Reply: We did the following change of text:

- As most calcifiers occupy coastal habitats, the assessment of risks from OA to these vulnerable organisms cannot be derived from extrapolation of current and forecasted offshore conditions

- Effects of OA on calcifiers and non-calcifying phototrophs occupying coastal habitats cannot be derived from extrapolation of current and forecasted offshore conditions,

Page 4910 Line 20: Gordillo and Mercado 2011 named this problematic in 2011, consider citing them.

Gordillo and Mercado2011, Inorganic carbon acquisition in algal communities:are the laboratory data relevant to the natural ecosystems? Photosynth Res (2011) 109:257–267

Reply: Reference added (it is Mercado and Gordillo 2011) and a line included:

- , the same is true regarding potential effects of OA on coastal phototrophs (calcifying or non-calcifying) (Mercado and Gordillo, 2011).
- L. 24: vulnerability changed to sensitivity

Page 4911 Line 8: A reference to Delille et al. 2000 and Middelboe and Hansen et al. 2007 is much more appropriate.

Reply: We have added references and modified the text:

"Such effects have been demonstrated for Antarctic and temperate kelp/macroalgal ecosystems (Middelboe & Hansen 2007, Delille et al. 2009, Cornwall et al. 2013a) as well as for subtropical and tropical seagrass meadows (e.g. Hofmann et al. 2011, Hendriks et al. 2014)."

Line 14: What about non calcifying organisms, such as the kelp, the key-species of the ecosystem you are investigating. Kelps growth can be stimulated by OA (Olischläger et al. 2012), but its reproduction can be OA-insensitive (Olischläger et al. 2012), or hampered by OA (Roleda et al. 2011, Xu et al. 2015). Furthermore OA affects the competition between understory red algae and kelps (Connell and Russell 2010) You are examining kelp habitats, in my opinion you should mention the known pH-effects on kelp, in particular of species with the Arctic distribution.

Roleda et al. 2012. Ocean acidification and seaweed reproduction: increased CO2 ameliorates the negative effect of lowered pH on meiospore germination in the giant kelp Macrocystis pyrifera (Laminariales, Phaeophyceae) Global Change Biology, 18, *pages 854–864*

Olischläger et al. (2012) Effects of ocean acidification on differ- ent life-cycle stages of the kelp Laminaria hyperborea (Phaeophyceae) Bot Mar 55, 5, 511–525, DOI: 10.1515/bot-2012-0163,

Xu et al. (2015) Effects of CO2 and Seawater Acidification on the Early Stages of Saccharina japonica Development, Environ. Sci. Technol., 2015, 49 (6), pp 3548–3556, DOI: 10.1021/es5058924

Connell S, Russell BD (2010) The direct effects of increasing CO2 and temperature on non-calcifying organisms: increasing the potential for phase shifts in kelp forests, Proc. R. Soc. B 2010 277, 1409-1415

Reply: We agree and have modified the section to also include mentioning of potential effects of OA on the phototrophs:

p. 4911, l. 8-14

- Calcifiers such as bivalves, brittle stars and sea urchins are ecologically important as they contribute significantly to carbon cycling in both sub-Arctic and high-Arctic areas of Greenland where their distribution range from the intertidal zone to >300 m depth (Sejr et al. 2002; Blicher et al. 2007, 2009, 2013 Blicher & Sejr 2011). Calcifiers, especially bivalves are also important prey items for marine mammals (Born et al. 2003) and sea birds (Blicher et al. 2011).

- Calcifiers such as bivalves, brittle stars and sea urchins, which are potentially vulnerable to OA, are ecologically important as they contribute significantly to carbon cycling in both sub-Arctic and Arctic Greenland where their distribution range from the intertidal zone to >300 m depth (Sejr et al., 2002; Blicher et al., 2007, 2009, 2013 Blicher and Sejr, 2011). Phototrophs such as kelps, while being able to affect the pH regime, may also respond to OA, which has been shown to stimulate their growth (Olischläger et al. 2012) and affect the competition between kelps and understory red algae (Connell and Russell 2010).

Page 4915 Line 1: Can you define kelp habitats, species depth, density? Species would be most important

Reply: yes – we have now added a specification as also requested by reviewer 1. Old and new text are indicated below.

- We conducted 3 parallel deployments of two frames in kelp habitats and two frames in habitats colonized by microalgae and scattered filamentous algae, with each deployment lasting about 48 h. The typical distance between the frames in each habitat was 10-20 m and between kelp forests and habitats colonized by microalgae and scattered filamentous algae approximately 100 m.

- We selected dense (close to 100% cover) three kelp beds located in shallow water (average depth 2-5 m) in different sites of the fjord. All kelp beds were dominated by *S. longicruris* with co-occurrence of *A. clathratum* and were surrounded by habitats colonized by microalgae and varying amounts of scattered filamentous algae. We conducted parallel deployments of frames with loggers in kelp beds vs. surrounding non-kelp habitats in each of the three sites, with each deployment lasting about 48 h. The typical distance between kelp and non-kelp habitats at each site was approximately 100 m.

Page 4916 Line 14: Saccharina longicruris or Saccharina latissima? See figure 8, where you write latissima,

Reply: It is *S. longicruris*. We have corrected the legend of Fig. 8 accordingly.

Page 4918 Line 27: Could you describe the light attenuation underwater, in my experience in Arctic fjords in summer the underwater light regime is strongly influence by melting river plums. You describe a river flowing into your fjord, therefore I asked myself if there were pronounced river sediments plums above your algae habitats? Sometime, kelp algae can even be densely covered by sediments, which might affect their photosynthesis and thereby influence on the local pH.

Reply: The river did not cause pronounced sediment plumes above the algal habitat. K_d at the central station of Kobbefjord has been reported at 0.135 m^{-1} in September (Sejr et al. 2014). This information is now added in the description of the study area.

p. 4912, l. 19

- Light attenuation in the water column has been reported to range from 0.083 in February over 0.197 in May to 0.135 in September (Sejr et al. 2014).

Page 4922 Line 25: The growth season of kelp in the Arctic is difficult to address, since Arctic brown algae accumulate C-storage metabolites during spring summer and grow in winter (Dunton and Schell 1986). In peak summer many adult species do not show vegetative growth and tend to fuel their reproduction. At least in the high Arctic this reproduction phase is decreasing or has already ended in September (Olischläger and Wiencke 2013). Furthermore, arctic kelps tend to store more of their photosynthates in preparation for the polar night. This potentially might affect their respiration rates (Olischläger et al. 2014) and be relevant for your data. Hence algae might be already preparing for the overwintering and growth season, showing reduced metabolic activity. In my opinion you should consider discuss these informations in relation to your pH/O2- profiles.

Dunton KH, Schell DM (1986) Seasonal carbon budget and growth of Laminaria solidungula in the Alaskan High Arctic. Mar Ecol Prog Ser 31:57–66

Olischläger M, Wiencke C (2013a) Seasonal fertility and combined effects of temperature and UV- radiation on Alaria esculenta and Laminaria digitata (Phaeophyceae) from Spitsbergen. Polar Biol 36:1019–1029

Olischläger M, Iniguez C, Gordillo FJL , Christian Wiencke (2014) Biochemical composition of temperate and Arctic populations of Saccharina latissima after exposure to increased pCO2 and temperature reveals ecotypic variation. Planta Volume 240: 1213-1224, DOI 10.1007/s00425-014-2143-x

Reply: Delille et al (2009) whom we refer to here state in the abstract “Daily variations of pCO_2 and DIC are significant in the spring and summer, but absent in the winter, reflecting the seasonal cycle of biological activity in the kelp beds." So, even though blade extension takes place in winter, the main C-assimilation and, hence, the main effect on pH, occurs during the spring and summer when irradiance is highest. For clarity we have changed "productive season" to "spring and summer".

Page 4925 Line 10: I remember a talk from Frank Melzner, where he showed that mussels grow at very low pH-conditions, but were in good physiological conditions with well-calcified shells as long as they had enough to eat. This was different when the mussels were starving. I hope this is correct in the way I explained it. Consider, have a look at Frank Melzners papers or contact him.

Reply: Good point! We have expanded the sentence and added the reference:

- "Blue mussels have indeed been observed to abound in intertidal macroalgal habitats (Blicher et al. 2013) and along with other calcifiers to be trophically linked with habitat-forming algae such as *Ascophyllum* (Riera et al., 2009), and have also been reported to tolerate high pCO_2 concentrations when food is abundant (Thomsen et al., 2013)."

Page 4926: Increased primary production? In my eyes depending on the habitat, Fucus, subjected to high pCO_2 showed a negative growth response (Gutow et al. 2014). Laminaria hyperborea responded with increased growth (Olischläger et al. 2012). Potentially, this statement is too general. Consider being more specific and provide references. Furthermore, the response is apparently dependent on the influence of further environmental factors, such as light, nutrients temperature.

Gutow et al. (2014) Ocean acidification affects growth but not nutritional quality of the seaweed Fucus vesiculosus (Phaeophyceae, Fucales) Journal of Experimental Marine Biology and Ecology, 453 , pp. 84-90 . doi:10.1016/j.jembe.2014.01.005

Olischläger et al. (2012) Effects of ocean acidification on different life-cycle stages of the kelp Laminaria hyperborea (Phaeophyceae) Bot Mar 55, 5, 511–525, DOI: 10.1515/bot- 2012-0163

Reply: Rereading the sentence I see that it can be misunderstood as a discussion of OA effects on the vegetation, which is not the intention. The aim was to point to the vegetation as a potential niche of high pH in summer. To avoid this misunderstanding we have now rephrased:

- Under scenarios of ocean acidification such coastal environments of increased primary production should gain increased importance as local refuges for calcifyers.

- Under scenarios of ocean acidification such vegetated habitats may gain increased importance as local refuges for calcifyers.

We have also rephrased the final sentence, which could also be misunderstood:

- Similarly, increased pelagic primary production has been forecasted for parts of the Arctic Ocean (Arrigo et al., 2008; Slagstad et al., 2011, Popova et al., 2012) and may also gain increased importance as local niches of high pH.

- Similarly, increased pelagic primary production as forecasted for parts of the Arctic Ocean (Arrigo et al., 2008; Slagstad et al., 2011, Popova et al., 2012) may also create local niches of high pH.