Reply to reviewer 1

Review comments shown in black, reply in blue, original text in red and revised text in green. All references to line numbers refer to the original text (the text file as used by reviewer 1).

Krause-Jensen et al. measure pH, temperature and oxygen concentration across several scales where pH is expected to vary naturally due to macrophyte metabolic activity. The measurements in this manuscript are comprehensive and impressive, but while some are not novel (it is well established that pH varies due to macrophyte photosynthesis both on a habitat wide scale and at their thallus surface in the diffusion boundary layer), this manuscript will still be of extreme interest to members of the scientific community who study small-scale coastal biogeochemistry, benthic ecology, macroalgal physiology, ocean acidification, and any combination of these themes. What is particularly significant about the manuscript is the compilation pH variability caused by autotrophs at a variety of scales, and even more so, the investigation of pH variability several heights above the substrate within the kelp bed is particularly novel/interesting. These two aspects of the manuscript are extremely useful to the scientific community. As the authors state, measurements such as these are important for forecasting the effects of ocean acidification on future shallow coastal systems. Most critiques I have of this manuscript are of a relatively minor nature.

Moderate comments:

1) The use of saturation state throughout: If total alkalinity or dissolved inorganic carbon was not measured during specific seasons, then I consider it is inappropriate to calculate saturation states from pH and salinity for these sampling periods, regardless of whether correlations between salinity and total alkalinity are known from this region. Since pH and saturation states are so closely correlated, I do not consider that also mentioning and showing rough estimates of saturation data states adds anything to the manuscript. Furthermore, I consider it somewhat simplistic to imply that saturation states below 1 are "corrosive" (e.g. line 51). There is much evidence that this is not the case.

Reply:

We have now restricted the estimation of saturation states to the periods when we had measured total alkalinity and inorganic carbon concentration (September 2013 and September 2014) and, hence, had the best basis for quantifying saturation states. Consequently, Fig. 3C (fjord scale Ω_{arag} as a function of O_2 for the 3 sampling periods) and Fig. A4 (fjord scale Ω_{arag} during the three sampling periods) are omitted and the ranges of Ω_{arag} are mentioned in the text. We have also reworded the description of corrosive states. The text has been revised as indicated below.

l. 22-23

- ".. and large-scale assessments of pH and the saturation state for aragonite (Ω_{arag}) indicate that it is already close to corrosive states ($\Omega_{arag} < 1$)."

- ".. and large-scale assessments of pH and the saturation state for aragonite have let to the notion that the Arctic Ocean is already close to corrosive state.".

- 'however' added in the following line.

l. 35-37

-"Based on pH-measurements combined with relationships between salinity, total alkalinity and dissolved inorganic carbon we also estimated variability of Ω_{arag}."

-"Based on pH-measurements combined with point samples of total alkalinity, dissolved inorganic carbon and relationships to salinity we also estimated variability of Ω_{arag}."

l. 41-43

- "Overall, Ω_{arag} was favorable to calcification, and pelagic and benthic metabolism was an important driver of pH and Ω_{arag} producing mosaics of variability from low levels in the dark to peak levels at high irradiance."

- "Overall, pelagic and benthic metabolism was an important driver of pH and Ω_{arag} producing mosaics of variability from low levels in the dark to peak levels at high irradiance generally appearing favorable for calcification.

l. 50-52

- "Indeed, large-scale assessments of pH and the saturation state for aragonite (Ω_{arag}) indicate that Arctic Ocean seawaters are already in close proximity to corrosive states ($\Omega_{arag} < 1$, Fabry et al., 2009)."

- "Large-scale assessments of pH in combination with saturation states for aragonite (Ω_{arag}) < 1 have led to the notion that the Arctic Ocean is already in close proximity to corrosive state (Fabry et al., 2009)."

l. 165-167

-"Relationships between A_T and salinity (S) were used to verify the published relationship for the Godthåbsfjord system (TA=159+63S, Meire et al. 2014) which was subsequently applied for calculation of A_T based on salinity data collected in April, July and September."

-"Relationships between the point samples of A_T and salinity (S) were used to verify the published relationship for the Godthåbsfjord system (TA=159+63S, Meire et al., 2015) which was subsequently applied for estimation of A_T for the full September data set."

l. 256-258

-"Corresponding Ωarag values ranged from minimum values of 1.5, observed in the bottom waters of the inner part of the fjord in July and September, to

maximum values of 3, observed in the surface and subsurface waters in April and July (Fig. A4)."

-"Ωarag values were closely coupled to pH and ranged from minimum values of 1.6, observed in the bottom waters of the inner part of the fjord to maximum levels of 2.5 in the subsurface waters in September (Krause-Jensen et al. 2015)."

l. 268-270

-"Hence, overall, pH showed much tighter correlation with O2 levels than with water temperature, and the correlation between pH and O2 was matched by a close correlation between Ωarag and O2-levels (Fig. 3C)."

-"Hence, overall, pH showed much tighter correlation with O2 levels than with water temperature, and the correlation between pH and O2 implied a similar close correlation between Ωarag and O2-levels."

l. 435-437

- "Overall, the identified Ω_{arag} conditions were favorable to calcification as they were generally well above 1, particularly in illuminated habitats with intense photosynthesis. "

- "Overall, the identified Ω_{arag} conditions were well above 1, particularly in illuminated habitats with intense photosynthesis and, hence, indicated favorable conditions for calcification. "

2) Microprofile methods: Many details are missing with respect to the measurements in the DBL: How long was the micro-electrodes left before the measurements in the DBL began? I.e. was the DBL in steady state or not? If the DBL was not in a steady state then the pH data obtained could underestimate the true values that can be reached (i.e. as time goes by pH at the surface should constantly increase until the steady state is reached). What were the seawater flow velocities used here? Velocity is one of the most important components that modify the pH within the DBL. What was the dimensions of the chamber used during these measurements of pH, and how was flow velocity modified? How many replicates were conducted with each species? If the aim was to determine what pH likely is at the surface of the different species in the field, then the authors need to demonstrate that environmentally realistic conditions were used. From the details here I cannot judge whether the data collected here reflects processes occurring in the real world - see comments below regarding discussion of these data also.

Reply: After the cut specimen was mounted in the aquarium and the sensor positioned at the lowest point (in itself taking some time), we observed a minimum period of 15 minutes before considering the first reading of the Volt sensor. This should have been long enough for the DBL to reach a steady state. The text has been revised to clarify this period.

We agree flow velocity is important and care should be taken to use flow velocities representative of the outside environment. Unfortunately we were not able to conduct measurements in a flume tank, as that would have complicated logistics. We have

solved this by mounting a plastic pipette tip at the end of a tube coming from a common aquarium air-pump to generate an air current on the surface. This generated a steady flow visible with the USB microscope (drifting particles). We now have analyzed the videos and estimated the flow velocity in our field of vision. We have added this estimate to the paragraph. Ideally we would like to compare with flow velocities in the field through canopies, but we have no field measurements at this scale and have not encountered literature estimates for flow between 0-2mm above a blade surface for this area. The flow velocity was stable, we did not manipulate it to keep conditions comparable among species and replicates. We believe that the fact that there was a steady, slow flow, comparable for all species and replicas enables us to make valid comparisons between species in this study, although maybe not necessarily with cases measured under different circumstances (with other studies). We used three replicates per species. Aquarium dimensions were approximately 25 x 20 x 10 cm.

l. 221-237

- "The set-up was mounted in a room with climate control and temperature was kept at 2-3ºC. We measured pH from a point close to the leaf surface up until out of the diffusive boundary layer (DBL) where the pH was stable. We used UNISENSE micro-pH sensors with 25 or 50 μm tips, connected to a Volt meter with 1 decimal precision for mV measurements (Consort, R362). pH sensors were calibrated with a three point calibration using NIST buffers of pHNBS 4,0; 7,0 and 10,0 allowing at least 5 minutes between every reading for the sensor to stabilize. A USB microscope (Dinocapture) connected to a PC with on-screen visualization software aided in visually establishing the lowest point of the measurements, as close to the macrophyte surface as possible without breaking the tip of the electrode. A scaled picture from this lowest point allowed for back calculating the actual distance to the leaf surface afterwards. We allowed readings at this lowest point to stabilize for >5 min after which the mV value was written down manually. The microsensor was then raised 20 μm with a precise 1D micromanipulator, afterwards 30 μm, after which we continued with 50 μm increments and then 100 and 500 μm increments until a stable pH was obtained for 3 measurements or more and we considered we were outside the DBL. We evaluated 3 replicas of each species at a light intensity of 200 μmol photons m-2 s-1, and calculated the Δ pH across the boundary layer (defined from the tissue surface to where pH was at 0.99* water-column pH)."

- "The set-up was mounted in an aquarium in a climate-controlled room with temperature kept at 2-3ºC. By gently blowing the water surface above the mounted slide with air supplied by an aquarium pump, we generated a stable, low, current velocity of approximately 0.28 ± 0.02 (SE) mm s^{-1} in our observational area. We measured pH from a point close to the leaf surface up until out of the DBL where the pH was stable. We used UNISENSE micro-pH sensors with 25 or 50 μm tips, connected to a Volt meter with 1 decimal precision for mV measurements (Consort, R362). pH sensors were calibrated with a three point calibration using NIST buffers of pH_{NBS} 4,0; 7,0 and 10,0 before each series of measurements. After each change in species or replica a resting period of >15 minutes was observed to allow the DBL to be fully developed before measurements. A USB microscope (Dinocapture) connected to a PC with on-screen visualization software aided in visually establishing the lowest point of the measurements, as close to the macrophyte surface as possible

without breaking the tip of the electrode. A scaled picture from this lowest point allowed for back calculating the actual distance to the leaf surface afterwards. We allowed readings at this lowest point to stabilize for >15 min after which the mV value was written down manually. The microsensor was then raised 20 μm with a precise 1D micromanipulator, afterwards 30 μm, after which we continued with 50 μm increments and then 100 and 500 μm increments until a stable pH was obtained for 3 measurements or more and we considered we were outside the DBL, between subsequent points the sensor was allowed to stabilize for at least 5 minutes. We evaluated 3 replicas of each species at a light intensity of 200 μmol photons m^{-2} s^{-1}, and calculated the Δ pH across the DBL (defined from the tissue surface to where pH was at 0.99* water-column pH)."

Minor comments:

Introduction:

3) Line 78: The sentence that kelp modify pH "as demonstrated for subtropical and tropical vegetated habitats" is a little odd, as this manuscript deals with colder climates, but the introduction does not mention the fact that these types of measurements have been conducted before in colder ecosystems. Given that this manuscript is investigating the ability of macrophytes to modify pH in colder waters, and that the sentence itself is referring to the ability of kelp to modify pH (which predominately live in temperate and sub-polar ecosystems), I would add citations to two papers that deal specifically with the capacity of kelp to modify pH in a sub-Antarctic and temperate ecosystems (e.g. Cornwall et al. 2013a - referenced below, Delille et al. 2009), both papers which found large variability over a diel cycle. This is strange that the Delille paper is not cited here, as it is cited and discussed in the discussion.

Reply: We agree and have added the suggested references.

l. 78

- "as demonstrated for subtropical and tropical vegetated habitats (e.g. Hofmann et al. 2011, Hendriks et al. 2014)"

- "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)."

4) line 106: The term "thallus boundary layer" should be changed to diffusion boundary and a citation that describes what this is and how it is formed is needed, as not all readers will be familiar with this.

Reply: We agree and have changed the text.

l. 106

- "..the thallus boundary layer of key macrophyte species"

- "..the diffusive boundary layer (i.e. the layer in which molecular diffusion is the dominant transport mechanism for dissolved material, see e.g. de Beer and Larkum 2001) of key macrophyte species"

Methods:

5) Study area: Kelp habitats are mentioned here and throughout the methods, but the specific species that are dominant in the study area should be given here; are they the same species investigated in the micro-scale pH measurements? The same comment applies for the macroalgal-dominated intertidal regions. The same comment applies to the figure legends containing photographs of seaweed, these need to have species names on them.

Reply: We have added species names (except for the brown filaments in the photo, which we did not identify to species), and yes, the dominant species of the study area were investigated in the micro-scale experiment.

l. 20-26

- "..subtidal macroalgae form productive benthic habitats along the shores to water depths of ca. 40 m (Krause-Jensen et al., 2012) interspaced with communities of benthic microalgae (Glud et al., 2010, Attard et al. 2014) as well as with scattered eelgrass meadows at 1-3 meters depth (Olesen et al., 2015). Communities of intertidal macroalgae are prominent in the intertidal zone where they form an important habitat for e.g. blue mussel (Blicher et al., 2013)."

- "..subtidal macroalgae, dominated by *Saccharina longicruris* and *Agarum clathratum* form productive benthic habitats along the shores to water depths of ca. 40 m (Krause-Jensen et al., 2012) interspaced with communities of benthic microalgae (Glud et al., 2010, Attard et al. 2014) as well as with scattered eelgrass (*Zostera marina*) meadows at 1-3 meters depth (Olesen et al., 2015). Communities of intertidal macroalgae dominated by *Fucus spp*. and *Ascophyllum nodosum* are prominent in the intertidal zone where they form an important habitat for e.g. blue mussel (Blicher et al., 2013)."

l. 207

- pH-variation in vegetated tidal pools and adjacent intertidal habitats on the shore were quantified

- pH-variation in vegetated tidal pools dominated by *Ascophyllum nodosum* and adjacent intertidal habitats on the shore also dominated by *A. nodosum* and *Fucus spp*. were quantified

Fig. 1 legend

- ".. C: Photopanel of benthic habitats: A typical kelp forest habitat and habitat colonized by microalgae/scattered filamentous algae (example from site #1, representative of sites #1-3 in map) and a vegetated intertidal pool and the adjacent vegetated shore (site #4 in map)."

- "..C: Photopanel of benthic habitats: A typical kelp forest habitat (dominated by *Saccharina longicruris*) and habitat colonized by microalgae/scattered brown filamentous algae (example from site #1, representative of sites #1-3 in map) and a vegetated intertidal pool and the adjacent vegetated shore dominated by *Ascophyllum nodosum* and *Fucus spp*. (site #4 in map)."

Fig. A1. Legend

- "..kelp forest"

- "..*Saccharina longicruris*-dominated kelp forest"

6) The study describes the general study area well, but specific details of the deployment area of diurnal variation in the kelp bed are needed, in particular with respects to depth and species composition where the deployments took place, as both would likely influence pH. Also, the description of the deployments within and outside kelp beds are somewhat ambiguous as to whether there is spatial pseudo-replication occurring, i.e. are the 3 kelp bed deployments closer to each other than the 3 non-kelp bed deployments? If the deployment locations of pH sensors within and outside of the kelp forests are segregated spatially, then I question whether it is appropriate to test for differences between them. 3 different kelp beds in different locations should have been used, rather than 3 locations within the same bed (as it is written currently).

Reply: We did indeed use three kelp beds situated in three different locations of the fjord and we did kelp bed vs. non-kelp bed deployments in each of the three locations. All kelp beds were dominated by *S. longicruris* with co-occurrence of *A. clathratum*. The water depth was 2-5 m (apparent from Fig. 4). We reworded to make this clear:

l. 178-182

- 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.

Very minor changes were added in the surrounding text to improve coherence.

7) Micro-scale pH variability: Not all readers will know what each of the six species of macrophytes are. Mentioning what each are (i.e. Ochrophyta, Rhodophyta etc.) would be helpful.

Reply: Done

l. 216-221

- “pH-variations at a millimeter scale were measured in the laboratory on 6 different species of macrophytes (Ascophyllum nodosum, Fucus vesiculosus, Saccharina longicruris, Agarum clathratum, Ulva lactuca, Zostera marina) occurring in Kobbefjord and collected either there or, for logistic reasons, in another branch of the Godthåbsfjord system.

- “pH-variations at a millimeter scale were measured in the laboratory on 6 different species of macrophytes (the intertidal brown macroalgae *Ascophyllum nodosum* and *Fucus vesiculosus*, the kelps *Saccharina longicruris* and *Agarum clathratum*, the green alga *Ulva lactuca*, and the seagrass *Zostera marina*) occurring in Kobbefjord and collected either there or, for logistic reasons, in another branch of the Godthåbsfjord system.

8) Were there any effects of cutting the macroalgae on the pH data measured? It is known that leached substances from some, but not all, kelp species after they are wounded can reduce pH.

Reply: We do not expect a direct, measurable, effect of possible leached substances on the pH as we used a central measurement spot on the surface that was removed from the cut edges. Also the volume of the water in the aquarium should have diluted any possible effects and we have not visually observed leaching. However we cannot completely exclude the algae affecting aquarium pH in this way. However we think this effect should be negligible compared to the photosynthetic effect on pH.

9) Lines 219 - 221: In nature the macroalgal blades do not exist in isolation, yet here they are examined in this way. Kelp canopies can attenuate water (as mentioned by the authors in the discussion), is it not likely that this could further increase the DBL thickness, leading to larger changes in pH at the thallus surface? Some discussion of how this set-up could influence the results should be mentioned.

Reply: We agree and have expanded the comment already made on this in the discussion:

l. 420-422

- Reduced flows as present in dense vegetation increase the boundary layer thickness and consequently the pH range (Hurd et al., 2011, Cornwall et al., 2013)

- Reduced flows as present in dense vegetation increase the DBL thickness and consequently the pH range (Hurd et al., 2011, Cornwall et al., 2013). The current experiment was, hence, conducted at reduced flow, and, importantly, with the same flow conditions for all species.

10) Line 236: The term "DBL" is defined previously and should be used throughout rather than the more colloquial "boundary layer".

Reply: Done.

11) Line 216: Some mention of how the different species of macrophytes' blade varied in morphology might be useful here, as DBL thickness can be altered by even small undulations (Hurd and Pilditch 2011).

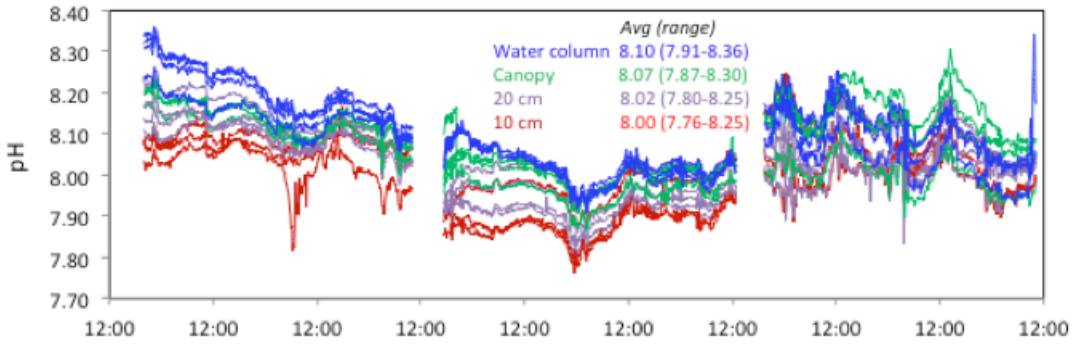
Reply: Done.

- We deleted the following sentence in the results section (l. 329-331) "There were important differences among species, which likely related to their photosynthetic rates and variations in the thickness of their boundary layer."

- and added the following line to the discussion (l. 415): "The interspecific differences likely related to the species' photosynthetic rates as well as to their morphology, which affect the thickness of the DBL (Hurd and Pilditch 2011)."

Results: 12) Figure 7: I consider this the most novel aspect of the study, but it is hard to see the exact differences the authors mention in the results. Is it possible to break this figure down in a second panel that displays the mean of each day, say every hour or so, so that the mean and variability of pH at each time of the day in each location can be observed?

Reply: We have played with various additional presentations of the data and found that the best solution was to provide information on the average and range of pH (after transferring to H+ concentrations and subsequently backtransferring) and provide these in the original figure. We hope you like this solution.



13) Lines 329 - 331. This is more a discussion point, but begs the question of why the DBL thickness is not presented, or why photosynthetic rates were not measured? DBL thickness should have been easy to calculate with the methods used here to determine pH within the DBL.

Reply: We did not measure photosynthesis. However, we did measure the thickness of the DBL and also measured the DBL at various light intensities. As the focus of this paper is on pH variability at different scales, we found that this information would be too detailed in the context of this paper. We will instead present this information in a separate paper.

Discussion: 14) Lines 363-366: The differences in pH between kelp, and non-kelp, dominated habitats recorded here were small in the paired measurements. In addition,

no data is provided showing that the density of kelp influences pH in a particular habitat, nor do the authors conduct manipulative experiments that separated out the effects of kelp and phytoplankton on pH variability. Therefore, I would not consider that the manuscript can support the statement that "mosaics of pH reflected that the density of primary producers...were key drivers of pH variability".

Reply: This summarizing statement on the effect of primary producer density on pH range and variability is aimed broader that at the small difference between pH in the two neighboring submerged benthic habitats (which are both directly, and through advection, affected by the productivity of benthic vegetation). It is certainly also aimed at the much steeper pH gradients/variability in the dense benthic communities (subtidal, intertidal, and in vegetation DBL) as opposed to the less dense pelagic communities. Hence, a pH-variability of e.g. 0.2 units operates over a 10-100 m scale in the planktonic community where the density of primary producers is low while it operates over a cm-m scale in communities of benthic primary producers, which have a much higher density. Further, within each of these communities, the highest pH levels were recorded in the surface layers representing highest concentration of phytoplankton (chl) and the most productive layers of the kelp. The same is true on a temporal scale where the diurnal pH variation in the benthic vegetation matches the seasonal variability of pH in the planktonic community. We have modified the text a bit to strengthen this meaning.

l. 363-368

- The mosaics of pH reflected that the density of the primary producers, and the spatio-temporal separation of photosynthesis and ecosystem respiration in combination with mixing of water masses were key drivers of the variability in both planktonic and benthic communities. Thus, the vertical gradient of declining pH from upper illuminated to lower shaded habitats varied from the 10-100 m scale in the planktonic community to the m scale in the dense kelp forest.

- The mosaics of pH reflected that the density of the primary producers, and the spatio-temporal separation of photosynthesis and ecosystem respiration in combination with mixing of water masses were key drivers of the variability in both planktonic and benthic communities. Hence, the vertical gradient of declining pH from upper illuminated to lower shaded habitats varied from the 10-100 m scale in the planktonic community where the density of primary producers is relatively low to the cm-m scale in dense kelp forests. The same is true on a temporal scale where the diurnal pH variation in the benthic vegetation matches the seasonal variability of pH in the planktonic community.

15) Page 16, 2nd paragraph: Comparing pH variability here with that in other systems is really like comparing apples and oranges unless a multitude of factors are examined. Different depths, seawater retention times, densities of macroalgae, light regimes, species, etc could all play important roles, making comparisons difficult. The start of this paragraph needs an overhaul, there are a number of unreferenced points, the studies the authors compare their data to are not fully inclusive, and overall I consider that the paragraph should make more of an effort to compare the data here to points I have mentioned here, rather than speculating on why there was a slight difference (0.03 units) between the filamentous and kelp habitats.

Reply: We see your point and have revised the text with this in mind.

l. 372-382

- The diel variability in kelp beds was in range with that reported from a Californian kelp forest (Frieder et al., 2012), while greater than reported for Mediterranean seagrass beds (Hendriks et al. 2014), and below the range of up to 1 pH unit reported for dense algal mats (Middelboe and Hansen, 2007). The diel variability in pH in the kelp forest was subjected to a stronger direct biological control than that of the microalgae/filamentous algae, as reflected in stronger pH vs. O2 relationships and steeper pH vs. light relationships, because of the larger density of the kelps and associated faster rates of metabolic activity per unit volume in combination with reduced flow in the dense habitat. The habitat colonized by microalgae/filamentous algae carried a less distinct biological signal reflecting the benthic primary producers at the site in combination with a signal from the planktonic community and the nearby kelp forests in the water masses exchanged with tidal currents.

- Though a multitude of factors including water depth, light regime, season, seawater retention time, density and plant species may all affect pH variability in vegetated habitats, our results match evidence from other latitudes of strong pH variability in macroalgal forests and seagrass meadows. Hence, marked diel pH variability has also been reported from a Californian kelp forest (Frieder et al., 2012), a Mediterranean seagrass bed (Hendriks et al. 2014), and in extreme case for a temperate shallow dense algal bed (diel range ca. 1 unit, Middelboe and Hansen, 2007) and kelp forest (diel range: ca. 0.6-0.8 pH units, Cornwall et al. 2013a). Our pH measurements in benthic habitats neighboring the kelp forest also carried a biological signal, though less distinct, likely reflecting the combined signal of the benthic primary producers at the site, of the neighboring kelp forests and of the planktonic community in the water masses exchanged with tidal currents.

16) Page 17, 2nd paragraph: The first half of this paragraph begins to discuss points of extreme importance to those scientists who study macroalgal habitats. This should be expanded and a separate paragraph should deal with the variability in rockpools, which is a phenomenon that is well known and of less importance to the readers.

Reply: We split the paragraph in two as suggested and added the following sentence in extension of the macroalgal paragraph (l. 398): The fast rates of metabolic activity in combination with reduced flow in such densely vegetated habitats make these 3-D patterns appear in spite of the marked exchange of water masses resulting from the 1-4.5 m tidal range.

17) Line 418: Regarding pH measurements of Sporolithon durum, the review of Roleda and Hurd (2012) should not be cited here, they reproduce the exact figures from Hurd et al. (2011) which is the original source.

Reply: OK. We omitted the Roleda and Hurd (2012) reference.

18) Line 419: The citation to Cornwall et al. (2013) is not in the bibliography, but rather the paper in the bibliography is Cornwall et al. (2012). I suspect that Cornwall et al. (2013b -referenced below) is required in the bibliography. Please check all other references are correct.

Reply: Thank you. We substituted Cornwall et al 2012 by Cornwall et al 2013b.

19) Line 407-408 & Figure 8: I question why pH did not reach a high value for Ulva here, when it is known that Ulva has some of the most efficient CO2 concentrating mechanisms known, and is capable of elevating pH to very high levels in enclosed habitats – as mentioned by the authors. The authors should discuss the possible reasons why pH elevation in the DBL was not high in subsequent sections.

Reply: True. We added this comment in line 419: The pH-range across the DBL of Ulva was surprisingly low considering Ulvas ability to elevate pH to high levels (Björk et al. 2004) but probably the combination of low water temperature and limited nutrient supply limited Ulvas photosynthetic rate.

20) Page 19, 1st paragraph: Though high pH could be an important refuge from potential impacts of ocean acidification in the future during the day, what about at night when pH is even more reduced?

Reply: Yes during night the opposite may certainly be the case. We address this on p. 19, 2nd paragraph.

References cited in this review:

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Cornwall CE, Hepburn CD, Pilditch CA, Hurd CL. 2013b. Concentration boundary layers around complex assemblages of macroalgae: Implications for the effects of ocean acidification on understorey coralline algae. Limnol. Oceanogr. 58:121-130.

Cornwall CE, Hepburn CD, Pritchard DW, McGraw CM, Currie KI, Hunter KA, Hurd CL. 2012. Carbon-use strategies in macroalgae: differential responses to lowered pH and implications for ocean acidification. J. Phycol. 48:137-144.

Delille B, Borges AV, Delille D. 2009. Influence of giant kelp beds (Macrocystis pyrifera) on diel cycles of pCO2 and DIC in the Sub-Antarctic coastal area. Estuar. Coast. Shelf Sci. 81:114-122.

Hurd CL, Cornwall CE, Currie KI, Hepburn CD, McGraw CM, Hunter KA, Boyd P. 2011. Metabolically-induced pH fluctuations by some coastal calcifiers exceed projected 22nd century ocean acidification: a mechanism for differential susceptibility? Glob. Change Biol. 17:3254-3262.

Hurd CL, Pilditch CA. 2011. Flow-induced morphological variations affect diffusion boundary-layer thickness of Macrocystis pyrifera (Heterokontophyta, Laminariales). J. Phycol. 47:341-351.

Roleda MY, Hurd CL. 2012. Seaweed responses to ocean acidification. Pages 407-431 in Wiencke C, Bischof K, eds. Seaweed Biology: Novel insights into Ecophysiology, Ecology and Utilization. Berlin: Springer Berlin Heidelberg.

Additional changes

p. 4910, l. 9: omitted "comprising about 35% of the World's coastline (Krause-Jensen and Duarte 2014) as approximately the same meaning appears in l. 26.