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Interactive comment on "Macroalgal metabolism and lateral carbon flows create extended atmospheric CO_2 sinks" *by* Kenta Watanabe et al.

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GENERAL COMMENTS

This study documents the exchange of dissolved carbon between a macroalgal habitat and adjacent waters. The study highlights that macroalgal metabolism and excretion of dissolved organic carbon (DOC) during the productive phase of the vegetation create low CO2 concentration and high DOC concentration that, via water exchange, propagates from the macroalgal habitat to waters beyond the habitat. The low CO2 concentrations created by macroalgae thereby contribute to increased air-sea CO2 uptake both at the habitat and beyond, and export of DOC beyond the habitat suggests a potential of this carbon to reach oceanic sinks. These findings add significantly

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to the limited field evidence of the effect of macroalgal metabolism on dissolved carbon concentrations and the size of macroalgal-associated carbon fluxes and potentials for C-sequestration. Such evidence is important to underpin the recent notion that macroalgae contribute significantly to global C-sequestration, with the majority of the sequestration being supported by dissolved organic carbon reaching oceanic C-sink. The combination of in-situ measurements and flux studies, degradation experiments and modeling strengthen the findings. The study can be improved by adding detail in the method description, presentation and discussion of results and reference to earlier findings.

SPECIFIC COMMENTS

Methods

Field surveys (l. 76-80): - Please specify that the field studies were conducted during a diurnal cycle in February and March, respectively, and please underline the timing of sampling as well as the timing of sunrise/sunset so that the reader knows how the diurnal cycle was represented. Please also mention that February /March is the local winter time.

Field bag experiments: - (l. 93) Was the ambient seawater for the macroalgal bags and control bags taken from the macroalgal site?

Biomass, cover and species composition (l. 100-106): - How long were the transect lines? While cover was assessed every 10 m (in 1 x 1 m quadrates) it is not clear how biomass assessments relate to cover assessments. Were the five 0.5 x 0.5 m biomass samples taken within quadrates assessed for cover and where cover estimates documented dominance by sargassaceous algae? Or were the biomass samples placed e.g. randomly within the belt dominated by sargassaceous algae? Please add detail.

Degradation experiment - Why were the samples stored at room temperature (22 ïĆřC)? Did this correspond to the in situ temperature? Were the samples aerated

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or did they turn anoxic during the incubation? How were degradation rates calculated?

Mass balance modeling - It is not entirely clear how this modeling was conducted - please expand the explanation. As far as I understand, the modeling was conducted solely for the macroalgal site (and not for the off shore site), please state this clearly. - L. 154: Are the initial values for the macroalgal site estimated to be diurnal averages measured at the off shore site? (Please indicate in the text that the initial values are denotated "0" in the formula). (To clarify, I suggest moving the sentence (l. 163) "The values of DICO, TAlkO, and DOCO were the mean values at station H5." to follow l. 154.) L. 160-162: Please explain in more detail how the central parameters GCP, R and CC were determined (based on start/end and light/dark and macroalgal/control measurements) and which day length was applied. Regarding the calculation of calcification – please also see e.g. Wahl et al. 2018. - Please make it clear in the methods section how the two different model scenarios (i.e. with and without considering water exchange, blue line and black line of Fig 5) were calculated.

Results

(3.1) Carbonate system and DOC - Net community calcification: Did your study allow calculating potential differences in calcification between light and dark settings? - Fig. 2: Are the two lines significantly different?

(3.2) Biomass/cover - Fig. 3: Relationships between cover and biomass (relates to the question on how biomass samples were taken): How come that the highest biomass in panel a corresponds to the lowest coverage in panel b? And that the lowest biomass of sargassaceous algae (and highest relative biomass of "others" in panel c corresponds to a high (absolute and relative) cover of sargassaceous algae in panel d? Are there any significant biomass-cover relationships?

(3.3) Degradation of DOC - l. 211-212 "Degradation rates (k) estimated by exponential fitting were 0.0044 d^{-1} and 0.0018 d^{-1} in February and March, respectively." Please clarify how degradation rates were calculated by e.g. chnagingt he sentence to "Degra-

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dation rates (k) estimated by exponential fitting of XXX vs XXX were 0.0044 d−1 and 0.0018 d−1 in February and March, respectively." and specify XXX. Fig. 4: - It is notable that DOC concentrations of the control bags were similar between Feb and Mar while DOC concentrations of macroalgal bags differed considerably, with final concentrations being about 140 ïA■M in Feb and <100 ïA■M in Mar. Please discuss this in the discussion section.. - The 4th control sampling for March has high variability – might one sample be contaminated and should be omitted? - Panel c: Should the line-fit not be exponential? - How were degradation rates calculated. Based on fits of data in panel c? Why not based on fitting an exp decline curve to the macroalgal data of panel a and b?

(3.4) Carbon budgets - L. 214. "The mass balance models simulated the temporal changes in carbonate chemistry and DOC concentration (Fig. 5)." It is not clear how the mass balance models did this - please expand in the methods section and also elaborate a bit more here. Please explain that the model simulations represent both the situation when water exchange is taken into account (blue lines in Fig. 5) and the situation when it is not (black lines in Fig. 5). - I also suggest adding more detail to the legend of Fig. 5 to specify the significance of the blue line (in contrast to the black line), which is not mentioned in the current version of the legend. l. 216: How were the spans in hourly exchange rates calculated (35-48% and 50-76%) and why is the range not reported in Table 3 (35% and 50% is reported without any range). - It follows from the modeling approach (l. 223-224) that "DIC budgets driven by water exchange indicated a net input of DIC from offshore to the macroalgal bed (Fig. 6 and Table 3.)", - because otherwise the DIC levels at the macroalgal site would have been considerably lower that what was measured (as shown in Fig 5). However, the abstract says "The exported water lowered CO2 concentrations in the offsite surface water and enhanced atmospheric CO2 uptake.", and I think this statement needs be better underpinned by results and discussion.

Discussion

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- Net calcification (NCC): Please discuss /mention what may constitute the NCC: calcareous algae in the algal bed, mussels... ? Did you identify any variation in NCC between light and dark incubations? – please mention/discuss. For these discussions I suggest referring/comparing to e.g. Wahl et al 2018 & Duarte & Krause-Jensen 2018.

- L. 276-8: Please elaborate a bit on this in relation to the differences observed between the Feb and Mar measurements. Regarding "growth phase", please mention that the study took place during the productive period.

- L. 305-307: Regarding the comparation between DOC turnover times: Were the experimental conditions similar?

- Please discuss reasons for the big difference in the residual concentrations of DOC in the degradation of material from Feb and March.

- C-sequestration. L. 322-323: I suggest mentioning that a first-order assessment suggested that almost 70% of global macroalgal C-sequestration is attributable to DOC export to the deep sea (Krause-Jensen & Duarte 2016).

Figs/Tables (in addition to what is mentioned above) Fig 5 legend: Please mention that details regarding rates are available in Table 1. I suggest moving Table 1 to supplementary material as the data are already presented in Fig 5.

Fig 6 & Legend: Please change "Carbon flows.." to "Dissolved carbon flows.." Please add explanation of RDOCm. Unclear what is the difference between NDR and DOC. The legend says that (107) and (88) represents DOC flows; then why are the numbers at the DOC arrows different? Please mention how the data were generated (model, degradation exp, bag exp – maybe using different colors). Mention that the same calcification rates are reported both as calcification rates and as inorganic biomass growth. Mention if the NCP is the sum of macroalgal and planktonic NCP.. Mention that details regarding rates of C-metabolism are available in Table 2 and details on water exchange rates are available in Table 3.

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References

- It would be appropriate to mention the pioneer study by Smith 1981 suggesting that lowering of CO2 concentrations by macroalgae leads to increased CO2 uptake and to highlight that the current study not only confirms that this is the case but also takes the finding further by documenting that the effect extends beyond the macroalgal habitat.

- Line 60-61: “However, the effects of macroalgal metabolism on the carbonate system in both macroalgal beds and adjacent water bodies have not been quantified”: Please consider rephrasing to say e.g. that there is limited field evidence on this.. Earlier studies have documented effects of macroalgal metabolism on the carbonate system (e.g. Wahl et al. 2018, Middelboe et al. 2007, Krause-Jensen et al. 2015 & 2016, Duarte & Krause-Jensen 2018), and some of these provide evidence of how diurnal/temporal variations in macroalgal metabolism affect calcification. You may also want to mention that there are recent studies on particulate organic carbon (POC) fluxes from macroalgae (e.g. Filbee-Dexter et al. 2018, Pedersen et al. 2019, Queirós et al. 2019...) but less information on DOC fluxes despite the expected major importance of macroalgal DOC fluxes for carbon sequestration.

Duarte, C. M., & Krause-Jensen, D. (2018). Greenland Tidal Pools as Hot Spots for Ecosystem Metabolism and Calcification. Estuaries and coasts, 41(5), 1314-1321.

Filbee-Dexter, K., Wernberg, T., Norderhaug, K. M., Ramirez-Llodra, E., & Pedersen, M. F. (2018). Movement of pulsed resource subsidies from kelp forests to deep fjords. Oecologia, 187(1), 291-304.

Krause-Jensen, D., Marbà, N., Sanz-Martin, M., Hendriks, I. E., Thyrring, J., Carstensen, J., ... & Duarte, C. M. (2016). Long photoperiods sustain high pH in Arctic kelp forests. Science advances, 2(12), e1501938.

Middelboe, A. L., & Hansen, P. J. (2007). High pH in shallow-water macroalgal habitats. Marine Ecology Progress Series, 338, 107-117.

Pedersen, M. F., Filbee-Dexter, K., Norderhaug, K. M., Fredriksen, S., Frisk, N. L., & Wernberg, T. (2019). Detrital carbon production and export in high latitude kelp forests. Oecologia, 1-13.

Smith, S. V. (1981). Marine macrophytes as a global carbon sink. Science, 211(4484), 838-840.

Queirós, A. M., Stephens, N., Widdicombe, S., Tait, K., McCoy, S. J., Ingels, J., ... & Cazenave, P. (2019). Connected macroalgalâĂŘsediment systems: blue carbon and food webs in the deep coastal ocean. Ecological Monographs, e01366.

Wahl, M., Schneider Covachã, S., Saderne, V., Hiebenthal, C., Müller, J. D., Pansch, C., & Sawall, Y. (2018). Macroalgae may mitigate ocean acidification effects on mussel calcification by increasing pH and its fluctuations. Limnology and Oceanography, 63(1), 3-21.

TECHNICAL CORRECTIONS

l. 17-18: I suggest adding field measurements of carbon species to the set of applied methods. l. 22: Please change “offsite” to “offshore” l. 36: “is more labile” – I suggest rephrasing to underline the variable lability of macroalgal carbon. l. 39: “is comparable to..” – or larger than? l. 40-41: “Macroalgal beds therefore have the potential to sequester substantial amounts of carbon in marine systems”: This does not follow logically from the previous sentences – please rephrase. l. 49-50: please mention also the estimated contribution of DOC to macroalgal C-sequestration in this previous study to highlight the hypothesis that macroalgal DOC is of major importance. l. 67: “..this macroalgae is the dominant group in temperate regions”: should it be e.g.“. . .the Sargassaceae family of macroalgae is a dominant group in temperate regions”? l. 74: “at a water depth..” –> “at water depths..” l. 188 and 193: Please add “(Table 1)” at the end of the sentence. l. 236: Please add after “(Table 2)” e.g.: “.., the rest being attributable to planktonic NCP.” l. 241: please substitute “known” by “shown”. l. 275/6: I suggest changing “The inhibition of macroalgal R by low water temperatures during the

winter can explain the relatively high NCP values during the productive period at our study site (Table 1 and 2).” to “The inhibition of macroalgal R by low water temperatures during the productive winter can explain the relatively high NCP values observed at our study site (Table 1 and 2).” - should “irradiation” be “irradiance”?

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