Response to comments

Reviewer#1

This is an interesting and relevant study that applies a chrono-sequence approach to study carbon accumulation in relation to time since mangrove restoration. The study reports that, based on isotopic signatures, the contribution of mangrove plant material was higher at older sites while younger sites have a higher contribution from riverine inputs. In general the paper is nicely written and uses standard physico-chemical analysis.

My concern is that the sample size is very limited; only 5 cores were used to study the chrono-sequence and no replicate cores were taken. I would agree that this can show some trends and differences between the ages, but a robust statistical quantification or test of the hypothesis is challenging. The study does not report results of statistical tests or uncertainty ranges. In short, I found it difficult to understand heterogeneity and uncertainty and this is really important as it defines the limits of interpretations. In my opinion, the authors should address this basic but critical issue.

Reply*:* Thank you for valuable suggestion regarding statistical validation with uncertainty range. In the revised ms, the 95% confidence interval was added for the Age – C stock relationship (Fig. 8). The results were slightly changed since the previous regression based on exponential function was done with a log-transformation of independent variable, which was not suitable for the comparison with a linear function model. In the present study, the exponential function model was fitted using nonlinear least square method with nls function of R and 95% confidence interval was added using predFit function of investr package of R. Conclusion was not changed but the uncertainty range of the model analysis has been clearly shown in the current ms. Furthermore, MixSIAR model enables to produce uncertainty ranges in contribution % of different end member to OC sources which is another very vital aspect of this research.

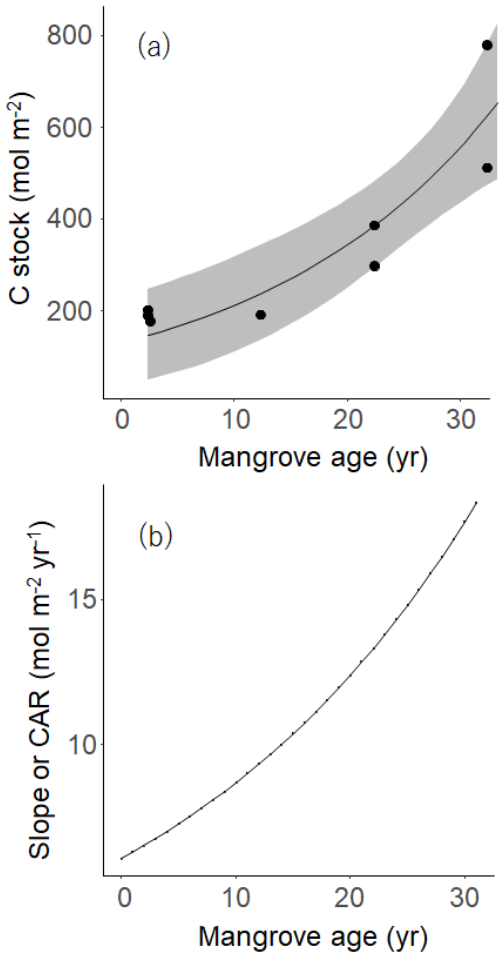

Figure 8: a) The relationship between mangrove age (*Age*) and carbon stock (*OC*), where the curve was drawn based on an exponential function model in Eq. 2: $OC = 171.07\exp(0.03558*Age)$, $R^2 = 0.9873$. The gray band means 95% confidence interval. (b) The relatioinship between mangrove age and carbon accumulation rate (CAR) on the basis of the exponential model (see Eq. 3).

Line 78: could use an additional sentence that links problem statement with hypothesis

Reply: A new sentences on problem statement is added

In this study, we address the question about how chrono-sequential observation in a restored mangrove forest could guide us achieving improved scientific understanding on C sources, stocks and to monitor the changes in accumulation rate at the early development stage and adult stages.

Line 127: This seasonal collection doesn't match with what is shown in Figure 1 and Figure 8(ie BS but not YM?) Please check

Reply: Thank you for the comment. The text is corrected as

A total of 8 cores were retrieved during the survey period with seasonal collection made at BS, AM, and MM site (dry and wet, total cores 6) and wet season collection from PM and YM site (one each).

Line 227: Are this mean values for the whole core? If so, add this to the figure caption.

Reply: Figure 2 caption has been edited by mentioning (mean±SD)

Line 400+: Consider adding an overview table where you summarize literature and your own data

Reply: Thank you for the recommendation. As proposed, a new table on comparative stock (Mg C ha^{-1}) and organic carbon loading (µmol C m^{-2}) has been provided.

Table 2. Comparative results on carbon stock (Mg C ha^{-1}) in restored mangroves of known ages, and organic carbon loading (µmol C m^{-2}) in mangrove with other marine settings.

Location	Age (year)	Dominant species	Soil C stock Mg C ha^{-1}	OC loading µmol C m^{-2}	Reference
Philippines, Panay					
Bakhanwan EP	0	No vegetation	3.1-24.3	4-58	This study
Bare sediment					
Pioneer	0.25	*Avicennia marina, Rhizophora spp*	21.4	-	This study
Young	10	*Rhizophora apiculata*	23.1	-	This study
Adult	20	*Rhizophora apiculata*	36.9-46.4	42-148	This study
Mature	30	*Rhizophora apiculata*	61.3-93.5	68-380	This study
Planted	-	*Rhizophora sp.*	-	310-1140	Unpublished data, Miyajima et al.
Naturally recovered	-	*Avicennia Rumphiana*	-	57-640	Unpublished data, Miyajima et al.
North-central Vietnam	0 - 27	*Kandelia obovata*	54 - 84	-	Van Hieu et al., 2017
Pichavaram, India	12-21	*Rhizophora spp*	41-94	-	Gnanamoorthy et al., 2019
Bhitarkanika, India	5	*Kandelia candel*	38	-	Bhomia et al., 2016
Sulawesi, Indonesia	>10	*Rhizophora apiculata*	150-300	-	Cameron et al., 2019
Continental margin	-	-	-	40-80	Mayer, 1994
Vegetated marine sediment	-	-	-	56-67	Miyajima and Hamaguchi, 2017
Floodplain	-	-	-	16-42	Goni et al., 2014

Line 450: I like this section as it justifies the chronosequence approach. This could be presented a bit earlier in the ms?

Reply: We agreed on that recommendation, and accordingly moved section 4.4.1 as 4.1 and stat the discussion by giving justification of chrono sequence approach.

Reviewer#2

Overarching comments: The study investigates the carbon dynamics in mangrove stands of differing ages. This study provides useful information on the differences in carbon stocks and potential source of input throughout a mangrove stand's maturation. In general the study is well thought out and presented. Authors frame the study well and provide sound reasoning for various data collected. My main concern is the number of soil cores taken from different mangrove stand ages. A total of eight samples are used to compare between 4 different age classes and between 2 seasons. This is only one sample per unique experimental condition. That is not enough to perform the rigorous statistical comparison this study deserves. Also, the English language has many minor grammatical errors and should be edited by a native speaker.

Reply: Thank you for the comment. We agree that sample sizes are small, and we did not take replication of soil samples at each site, and can't evaluate uncertainty for carbon stocks at each individual condition, however, we calculated the uncertainty of the predicted CAR which is one of the main items to be evaluated in the present study.

The results were slightly changed since the previous regression based on exponential function was done with a log-transformation of independent variable, which was not suitable for the comparison with a linear function model. In the present study, the exponential function model was fitted using nonlinear least square method with nls function of R and 95% confidence interval was added using predFit function of investr package of R. Conclusion was not changed but the uncertainty range of the model analysis has been clearly shown in the current ms.

Furthermore, MixSIAR model enables to produce uncertainty ranges in contribution % of different end member to OC sources which is another very vital aspect of this research.

We are thankful to our BlueCARES colleague and ocean science expert Dr. Charissa Ferrera for supporting in language edits throughout the manuscript.

Line 21: Drop the word "the". It should read "estuary in Panay Island, Philippines" Done

Line 21: I have never come across the term "endmember source apportionment." What does it mean?

Reply: Its rewritten as "…source apportionment of multiple endmembers in the"

Source apportionment is a practice to identify different endmembers as a tracer. For instance, a coastal sedimentary OC pool can be mixture sources like phytoplankton, C3 plant, C4 plant and so on, each of which are endmember and contributor to the total pool.

Lines 27 to 29: This sentence does not convey the importance of the study or the wider implications of the findings well.

Change to “Hence, sediment of relatively young mangrove forest appears to be significant C sink, and short term chrono-sequence based method can efficiently define the importance of mangrove restoration program as potential carbon sequestration pathway.”

Line 32: Drop the word “the”. It should read “Mangroves, located around tropical and…” Done

Line 34: Should be plural when referring to “carbon stocks”. Please change here and throughout.

Done as suggested throughout the manuscript

Line 35: The proportion of sediment organic carbon found in mangroves can vary much more widely than 73-79%. I suggest the authors use a few more citations for this sentence to clarify this to the readers.

Added two new citations in support of the statement (Alongi, 2020; Hatje et al., 2020; Walcker et al., 2018).

Line 39: Organic matter mangrove soil depths can extend much deeper than 3m. I suggest the authors include that information here with a citation

Reply: New sentence added “Sediment depth in the undisturbed mangrove forest sites can often exceed 3 m (Elwin et al., 2019).”

Line 44: “2 to 8 times lower” doesn’t make sense. It should be one eighth or one half.

Reply: Corrected as “…$1/8^{th}$ to $1/2^{th}$ lower…”

Line 58: SFT has already been defined one line previously, the authors don’t need to do it again

Reply: Simplified as

In this study, an evaluation based on a type of ‘natural experiment’ or chrono-sequence (a.k.a. “space-for-time-substitution" or SFT; Pickett, 1989) is made to a relatively younger site (e.g., Bakhawan Ecopark, Philippines, examined in this study) where to fulfill conditions for chrono-sequence, all environmental and biological conditions of the experimental sites must be identical except for the age, and species diversity is low (Nilsson and Wilson, 1991; Walker et al., 2010).

Line 75: I’ve never come across the term “end-member” what does it mean?

Reply: As mentioned before, endmembers are used as a tracer for source apportionment in OC pool. For instance, a coastal sedimentary OC pool can be mixture sources like phytoplankton, C3 plant, C4 plant and so on, each of which are endmember and contributor to the total pool.

References are:

https://en.wikipedia.org/wiki/Endmember

https://www.sciencedirect.com/topics/engineering/endmembers

Lines 114-116: Are the authors assuming that all the trees in each section of mangrove (PM, YM, AM and MM) are the same? If so I suggest they are explicit with that assumption.

Reply: With respect to species diversity, its mentioned in the text as:

Rhizophora apiculata is the dominant species at YM, AM and MM, while mixed mangroves (*Avicennia* and *Rhizophora* sp.) are found at PM.

With respect to age they are different as also mentioned in the beginning

Sediment sampling locations were categorized according to mangrove ageing as bare sediment (BS, 0-yr), pioneer mangroves (PM, 0.25-yr), young mangrove (YM, 10-yr), adult mangrove (AM, 20-yr) and mature mangroves (MM, 30-yr).

Lines 124 to 134: It is not clear what these cores were taken for. Was it to perform isotopic analysis or to measure soil C stocks? I suggest the authors mention the purpose of these cores like they have on line 135 for porewater sampling cores.

Reply: The purpose of sediment collection is clarified now

Within 3-4 hours after collection, sediment samples were kept in styrofoam box and brought to the laboratory for analyzing of bulk density, specific surface area (SSA), concentrations and isotope ratios of carbon and nitrogen, and carbon stock. Analyses took place normally within a month or maximum two after the collection.

Lines 125 to 127: Is my understanding correct that one core was taken from each forest age type during each season? This is not enough replication to conduct adequate statistical comparison between forest age groups. Especially as the soil thickness is only 50cm, OM and C concentrations are known to vary significantly in shallower soil horizons.

Reply: We agree that sample sizes are small, and we did not take replication of soil samples at each site, and can't evaluate uncertainty for carbon stocks at each individual condition, however, we calculated the uncertainty of the predicted CAR which is one of the main items to be evaluated in the present study.

The results were slightly changed since the previous regression based on exponential function was done with a log-transformation of independent variable, which was not suitable for the comparison with a linear function model. In the present study, the exponential function model was fitted using nonlinear least square method with nls function of R and 95% confidence interval was added using predFit function of investr package of R. Conclusion was not changed but the uncertainty range of the model analysis has been clearly shown in the current ms.

Furthermore, MixSIAR model enables to produce uncertainty ranges in contribution % of different end member to OC sources which is another very vital aspect of this research.

Line 127: what about BS and PM sites?

Reply: Corrected as: A total of 8 cores were retrieved during the survey period with seasonal collection made at BS, AM, and MM site (dry and wet, total cores 6) and wet season collection from PM and YM site (one each).

Line 130: Average depth and soil depth in all sites should be reported in the results section.

Reply: Total sediment depth for each site has been explicitly mentioned now in the M&M so that we don't repeat same value in the result section:

Total sample depth at BS, AM and MM were always 50 cm, while for PM and YM they were 20 cm and 25 cm, respectively.

Line 178: Why did authors only measure soil C stocks in the top 50cm depth?

Reply: Sediment coring was easier till 50cm at BS, AM, and MM, however, after that it was hard to penetrate further, where as at PM and YM, sediment was even harder to reach to 50 cm.

Line 190: Where are a and b derived from? Are they coefficients from calculating a line of best fit? If so, I suggest the authors make that clear.

Reply: Clarified as "…where *a* and *b* are constants determined from the best-fit exponential relationship"

Equations 2 and 3: Do the authors have figures for these curves that were fit? It would be good for this info to be included somewhere in the supplementary info for readers to see.

Reply: In Fig. 8 shows the best-fit curve for both the equations.

Lines 230 to 240: This paragraph is very data dense and mentions a lot of ranges of data between forest age groups, hence is difficult to follow. I suggest the authors create a summary table for the data explained in this paragraph, it will be much clearer and condense the text in the results section.

Reply: Since these data are captured already in Fig. 2, we believe showing them again in tabulated form would be redundant. However, the paragraph is streamlined.

Line 245: Doe this value carry any uncertainty? How many measurements was this based off?

Reply: Edited as

Minimum pH was recorded at the top 10cm depth of the mature mangroves in the wet season (5.41±0.26)

Lines 284 to 285: I would not call the BD values in this study different to those reported by Donato et al. 2011. To me these are comparable, especially as in some other (low OC) mangroves BD can reach up to 2.00 g cm-3.

Reply: Agreed. Revised as

Bulk densities (BD) at the sampling sites (0.3 to 1.3 g cm^{-3}) were comparable with the reported BD values across mangrove soils of the Indo-Pacific regions (0.20 to 0.92 g cm^{-3}, Donato et al., 2011), with sand fractions dominating the lower intertidal zone

Line 785, Fig. 2: The information in the upper left most panel is a repeat of what was explained in the text. I don't think it is needed. Also it is interesting that pioneer and young mangrove have comparable OC

stocks. How many replicates was this data based on? Does the YM for this panel have any error bars? Was it just one replicate?

Reply: Although mangrove development with age has been mentioned before in the text, we believe showing that trend in Fig 2 which is otherwise very much result oriented would help interpreting data from chrono-sequence perspective. Furthermore, removing that would break compositeness of the fig. 2.

Reply: Single core was collected from each of PM and YM site. Hence stock data does not have uncertainty range.

A total of 8 cores were retrieved during the survey period with seasonal collection made at BS, AM, and MM site (dry and wet, total cores 6) and wet season collection from PM and YM site (one each).

Line 790, Fig. 4: Do these values carry any uncertainty? It should be included in this figure. Also, why are there only 3 mangrove categories in this fig, what about pioneer and young mangrove?

Reply: As the vertical profile shown in Fig. 4 captures each depth-wise seasonal results, uncertainty ranges could not be shown for this figure.

Also, because of laboratory logistical reasons, SSA were measured only for BS, AM and MM.

However, this is now explicitly mentioned:

Specific surface areas were measured only for BS, AM and MM cores.

I suggest the authors have a native English speaker red the manuscript and make edits. There are many minor grammatical errors throughout.

Furthermore, MixSIAR model enables to produce uncertainty ranges in contribution % of different end member to OC sources which is another very vital aspect of this research.

Autor's own edits

In addition to the corrections based on reviewer's comments, we have recognized few others corrections to make for better refinement of the manuscript. Below is the details of changes made from author's side:

Delete- "..due to their role in climate change mitigation"

Corrected- "…oxidation reduction potential (ORP, Pt-electrode)", also ORP is consistently used, not Eh

Corrected - Within 3-4 hours after collection, sediment samples were kept in styrofoam box and brought to the laboratory for analyzing bulk density, specific surface area (SSA), concentrations and isotope ratios of carbon and nitrogen, and carbon stock

Corrected – In Fig 2. We have added labels (a, b, c,...) to individual panels in Fig. 2 and identify a specific panel in the text using such labels (e.g. "Fig. 2b"), also, marked by "nd" where no data are available, so that atleast they are not misunderstood as zero

Corrected: Sediment thickness unit in Fig 2 is corrected to cm

Corrected: SSA unit is corrected as $m^2\ g^{-1}$ (or m^2/g) in text and in Fig. 2. (it was already good in Fig. 4)

Added in text: "….mean $\delta^{15}N$ became more positive with mangrove age ($\delta^{15}N$ = –1.15 at the BS to 1.06 ‰ at AM, figure not shown).

Added: Fig S2 caption- Solid and dashed lines represent Mean and SD, respectively.

Correction- We recognize that Fig. 7 is not very straightforward than table S3 while both have same message. Hence we decided to show Table S3 in the main text and move Fig. 7 as Supplementary Information. In the revised ms, table S3 becomes Table 2 and Fig 7 becomes Fig S3. The caption of Fig. S3 is revised as

Source apportionment of sedimentary organic matter at different mangrove stages by applying bayesian mixing model with $\delta^{13}C$ and OC:TN. This is a density plot against proportion of sources. Here, the total area in each curve exceeds 1.0 since this is Scaled-Density adjusted for a maximum peak of 1.0. MixSIAR outputs the Scaled-Density instead of original density. The Scaled-Density shows a same visual pattern as original density plot.

Deleted: "deposition of pollen" as we know Pollen does not affect SSA, because most of organic matter is removed in advance of measurement. Revised the sentence as : The latter might have been a result of sediment-stabilizing function of mangroves or influenced by weathering process that transforms sand and silt fractions into clay fractions

Changed: " A sizeable contribution of MPB…" to "A sizeable fraction of OC at the tidal flat was contributed by the marine and benthic algae"

New text: under section 4.3 **Vertical profile of organic carbon**;

" The variation in OC content from the bottom to the top of sediment cores also reflected the change in the proportion of mangrove-derived materials and allochthonous (e.g., benthic algae) organic carbon sources in the sediments and the mineralization of organic matter in mangrove sediment (Tue at al., 2011). "

"This has been shown in other studies that root-derived carbon tends to be accumulated more efficiently as aggregate in SOM pool and contribute largely as potential C source (Xia et al., 2005)."

"Low surface DOC might be the reason of higher mixing and dilution with overlying water of low DOC concentration (Table S1)."

New Text: under 4.4**. Increase of organic carbon with mangrove development**

"and roots generally have lower decomposition rates than leaves favoring C storage partly because of the composition relatively rich in recalcitrant material such as suberin and lignin root-derived C (Rasse et al., 2005)."

Revision: Organic carbon burial part under the section "Accumulation of organic carbon" is merged with the section "Increase of organic carbon with mangrove development", while "Relevance of chrono-sequence approach" has been moved up in the discussion as separate section 4.1 (as suggested by Reviewer).

Next text: For the section **Implication of blue carbon chrono-sequence,** we recognized that we only discussed blue carbon in soils, but we have not mentioned this fact explicitly, e.g. for the case of Bakhawan

Ecopark, what would be the estimate total OC stock and accumulation rate including both soil and biomass OC using literature review? Then may be it is worthwhile to mention them and compare them with, e.g., IPCC default values. Based on this argument, we revised the section by adding below text

"For Bakhawan Ecopark, mangrove coverage of 121 ha, total organic carbon stock and accumulation rate in the vegetated soil was estimated to be 2795 to 11500 Mg C ha^{-1}, and 72 to 304 Mg C yr^{-1}, respectively. Carbon stock in above ground biomass was 2744 to 5499 Mg C ha^{-1} for the younger and adult sites (derived from the literature data by Salmo et al., 2014, and biomass to C conversion factor of 45%, IPCC 2013). However, if IPCC default values are plugged-in to compute total C stock in soil and above ground biomass (386, and 92-192 Mg C ha-1, respectively), significant differences between observed and computed results are observed (computed: 46700, and 5009 to 10454 Mg C ha^{-1}, respectively). Given IPCC default values are derived from the intact forest while our observed data were taken from restored sites, such direct comparison has potential biases."

Newly added citations

Elwin A., Bukoski, J.J., Jintana, V., Robinson, E.J.Z., Clark, J.M.: Preservation and recovery of mangrove ecosystem carbon stocks in abandoned shrimp ponds. Sci Rep. 4, 9:18275. doi: 10.1038/s41598-019-54893-6, 2019

Hatje, V., Masqué, P., Patire, V.F., Dórea, A., and Barros, F.: Blue carbon stocks, accumulation rates, and associated spatial variability in Brazilian mangroves, Limnol. Oceanogr., 9999: 1–14, doi: 10.1002/lno.11607, 2020.

Rasse, D.P., Rumpel, C., Dignac, M.-F. Is soil carbon mostly root carbon? Mechanisms for a specific stabilisation. Plant, 269, 341–356, 2005

Tue, N.T., Dung, L.V., Nhuan, M.T., Omori, K.: Carbon storage of a tropical mangrove forest in Mui Ca Mau National Park, Vietnam. Catena, 121: 119–126, 2011

Xia M, Talhelm AF, Pregitzer KS.: Fine roots are the dominant source of recalcitrant plant litter in sugar maple-dominated northern hardwood forests. New Phytol. 208: 715– 726, 2015.

Deleted citation

Jiménez-Arias, J.L., Morris, E., Rubio-de-Inglés, M.J., Peralta, G., García-Robledo, E., Corzo, A., and Papaspyrou, S.: Tidal elevation is the key factor modulating burial rates and composition of organic matter in a coastal wetland with multiple habitats, Sci. Total Environ., 724: 138205, doi: 10.1016/j.scitotenv.2020.138205, 2020.