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Interactive Comment

Interactive comment on "Projected pH reductions by 2100 might put deep North Atlantic biodiversity at risk" *by* M. Gehlen et al.

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Anonymous Referee #1

Review of Gehlen et al.

We thank the reviewer for his comments and suggestions. We reply to each point below.

This manuscript uses a suite of climate models to predict future changes in pH in deep waters of the North Atlantic. These are then superimposed on the distribution of seamounts and canyons to predict biodiversity threats in 2100. Approximately 17% of the seafloor below 500 m is predicted to experience pH declines of 0.2 pH units. The tremendous stability of conditions in deep water and historical changes recorded in the

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Interactive Discussion

Discussion Paper

geologic record, suggest this amount of pH decline is potentially dangerous to deep-ocean biodiversity. The modeling component of this paper seems sound, although this is not my area of expertise.

1) Work by others including some of the co-authors have predicted seafloor changes in temperature, pH, POC flux and oxygen (Bopp et al. 2013, and pointed out impacts on deep biodiversity (Mora et al. 2013). This paper might want to devote more space to acknowledging and reviewing that earlier work.

We acknowledge the study by Mora et al. (2013) in the introduction section by adding a sentence on p8611, line 16: "The study complements assessments by Bopp et al. (2013) and Mora et al. (2013) which evaluated large-scale average pH reductions in response to the same RCP pathways, but without a detailed discussion of spatial patterns and their link to circulation."

2) Has a similar approach been taken with warming or oxygen?

Mora and co-workers took a multiple stressors approach including temperature and oxygen. Cocco et al. (2013) investigated changes in CO2 and O2 in response to a high emission scenario in a set of Earth System Models. We chose to focus on pH only. The North Atlantic is an area of deep water formation and the water column is well oxygenated at present and, according to model projections, will remain so in the future.

Please consider the following issues and suggestions:

3) Please provide the justification for selection of a 500 m upper limit of analysis. This is not an upper limit for deep-water corals or sponges is it?

The selection of 500 m as an upper limit for analysis follows from model considerations. This study uses output from coarse resolution global ocean models that do not fully resolve processes on the shelf or upper slope. Digitised topographies as used in general circulation models usually average over fine resolution digital data sets by averaging the fine resolution data for use in the coarse grid. Therefore, along the continental shelf break model topographies at around 500 m depth would include also shallower areas, but these cannot be resolved as such.

4) It seems that a significant component of deep biodiversity may fall between 200-500 m.

We agree that there is significant biodiversity between 200 and 500m. However, we wish to maintain the upper limit due to the reasons as outlined above.

5) Do the effects of a 0.2 or 0.3 pH unit decline depend on the baseline or starting point?

We thank the reviewer for raising this issue. Please refer to the uploaded pdf document for our reply.

6) What are the absolute pH values at 500, 1000, 2000 m in the deep Atlantic Ocean?

The absolute mean values of pH in the deep Atlantic: 500 m = 8.015Âă; 1000 m = 7.999; 2000 m = 7.994 We add a figure illustrating the observed mean profile of pH for present day conditions derived from GLODAP alkalinity and DIC, along with WOA nutrient data to the supplementary material.

7) Is anything known about natural pH variability in the deep Atlantic and how this changes with water depth, latitude or region?

To our best knowledge, the only published time-series data resolving seasonal variability of pH at different depths across the water column (from 10 m to 3500 m) is by González-Dávila et al. (2010).

8) There is limited discussion of the mechanisms by which pH might affect biodiversity. Is it through effects on calcification? Acid-base regulation? Energetics (which are discussed somewhat)?

We amended this section of the discussion (p8621, lines 13 to 29) so it is more spe-

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cific and saysÂă: “Our knowledge of the ecology of deep benthic communities is still limited and impacts of pH changes on these communities are difficult to evaluate owing to lack of experimental and observational data. Rapid changes in pH will likely lead to disruption of extracellular acid-base balance, impedance of calcification and other physiological effects in deep-water organisms, and whatever acclimation is required may have increased energetic costs (Widdicombe and Spicer, 2008) – e.g. for metabolism/maintenance, growth, reproduction – and could extend to increases in mortality of both adults and juveniles. Changes at the individual and population level will inevitably lead to more widespread ecosystem and community level changes and potential shifts in biodiversity (Hendriks et al., 2010) and ecosystem functioning (Danovaro et al., 2008). Biodiversity reductions could arise from a loss of species, functional, or even taxonomic groups sensitive to pH change. The ecological implications of pH change could be more severe if keystone or habitat-forming species are impacted (Widdicombe and Spicer, 2008), which seems likely (Guinotte et al., 2006). These effects may be likely exacerbated in the presence of other stressors (Walther et al., 2009), such as global warming and projected reductions in deep-sea food supply (Bopp et al., 2013), as well as elevated resource exploitation and pollution. In particular, reductions in food supply to deep benthic communities are projected to result in a decrease in biomass and a shift towards smaller sized organisms (Jones et al., 2013). These changes will modify energy transfer rates through benthic food webs and may leave communities more susceptible to pH reductions. We propose these and future model projections to be taken into account when defining long-term preservation and management approaches to deep-sea ecosystems.”

9) If corals are of major concern, please discuss what a 0.2 or 0.3 pH decline corresponds to with regard to aragonite saturation state.

We chose to mention corals as merely an example group of interest among many, and deliberately chose not to assess changes in aragonite saturation state to maintain an ecosystem-wide focus. Several studies have addressed decreases in saturation state and impacts on cold-water corals. We intend, with this study, to broaden the discussion on impacts of ocean acidification to other communities than calcifiers. The tight control of pH at the cellular scale is an important prerequisite of proper cell functioning and mechanisms of pH control are ubiquitous across many taxa. pH is thus a master variable for biological systems.

10) It would be appropriate to also calculate and map changes in Omega (aragonite) and determine what fraction of the seamounts or canyons will be exposed to specific omega decline levels. It may be that we have more knowledge of saturation state requirements than pH tolerances.

As stated above, impacts of decreasing aragonite saturation states on calcifiers were the focus of numerous previous studies. From the point of view of biological conservation, pH is the more universal environmental variable as it is not specific to a particular group of organisms.

11) Several assumptions seem to be made: One is that there is no adaptation potential. . .. Over the next 85 years – is this what the authors believe?

To our knowledge, there is very little (if any information) available on the adaptation potential of deep sea fauna to ocean acidification. There is a pressing need for further biological studies. We do not want to speculate, but rather answer a precise question that is 'likelihood of pH changes affecting deep seafloor'

12) Do they expect any synergistic interaction with declining oxygen?

This study focuses on the deep North Atlantic, a well-ventilated sub-region of the world ocean. Despite a projected increase in stratification, the region will remain well-oxygenated in the future. This is explicitly stated in the revised version by adding "The North Atlantic is a well-ventilated region of the world ocean and, despite a projected increase in stratification, will remain well-oxygenated in the future (Bopp et al., 2013)." (p8611, line 16)

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Additional points and considerations that could enhance this work.

13) Are there actual biodiversity data to show that seamount and canyon biodiversity is higher than other settings (continental slope, mid-ocean ridges, vents, basins, fjords, carbonate mounds, or other features).

We do not infer that the biodiversity of seamounts and canyons is higher than in other settings. We assess pH reductions over the seafloor without discrimination of particular habitats first. We then selected these features as representative examples of specific deep sea environments. We modified the last sentences of the final paragraph of the introduction section (p8611, lines 18 to 23) to: “Future multi-model projections of pH changes over the seafloor are analysed with reference to this threshold and without discrimination of particular habitats first. Next, model results are put into the perspective of ecosystem conservation by evaluating changes in pH against the distribution of seamounts and deep-sea canyons. These features are known as sites of high-biodiversity deep-sea ecosystems, such as cold-water corals and sponge communities (ICES, 2007; Clark MR et al., 2010; De Leo et al., 2010) and are selected as representative examples of deep sea environments. “

14) What fraction of the deep-ocean corals occur on canyons and seamounts as opposed to other features (slopes, mounds, mid ocean ridges etc.)?

We did not detail the distribution of cold water corals, as they were not the focus of this study.

15) Would the major messages change if these other settings were considered?

It is unlikely that major messages would change given that the ecosystem level response at canyons and seamounts was the focus of the present work rather than the coral group specifically. However, we already assessed impacts on the global deep sea floor as well, which should provide relevant information for the curious reader.

16) The beginning of the paper could do more to justify why the focus is on biodiversity

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and not, for example on fisheries? Habitat support or other ecosystem services? Is biodiversity being used as a proxy for something else?

While we appreciate the importance of fisheries as a critical sector of living marine resource sciences, biodiversity is a value by itself and one of the seven criteria retained for the identification of ÂńÂăecologically or biologically significant areasÂăÂż (EBSA) by the 10th Convention of the Parties (COP) to the Convention on Biological Diversity (CBD) (see Annex 1 to CBD CoP Decision IX/20Âă; CBD, 2008a). These criteria are proposed as a framework for identifying Marine Protected Areas.

17) What is the support for extracting thresholds from the paleoceanographic literature? The time scales seem wrong for comparison with current change. Why wouldn't a 0.1 pH decline over 100 years be more significant than a 0.2 pH decline over thousands or tens of thousands of years?

Thank you for pointing out some ambiguities in the original text. We explicitly state now the implication of paleoceanographic pH data. We modified the text to point out that we consider time scales from multi-annual to millions of years. We do not suggest that a 0.1 pH decline over 100 years is more significant/relevant than a 0.2 pH decline over thousands of years. The text reads now (p8616, line 26 to p8617, line 8: "Many past episodes of climate change occurred over significantly longer time-scales than the current anthropogenic perturbation of the climate system, allowing carbonate compensation to keep deep-water pH close to constant (Hönisch et al., 2008). This is corroborated by computing pH reduction over glacial-interglacial cycles for a North Atlantic site. Decadal-to-centennial changes are addressed by fresh-water hosing model experiments to simulate effects of circulation changes associated with rapid Heinrich and Dansgaard Oeschger events. In both cases, pH reductions are below 0.15 pH units. Similarly, a small amplitude of natural temporal pH variability at depth emerges from a multi-annual time series stations (González-Dávila et al., 2010) and the analysis of the long pre-industrial simulation "piControl" (Fig. S1 in the Supplement). In summary, natural pH variations on multi-annual, decadal-to-century, and longer time

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scales were likely smaller than 0.2 pH units on the regional-to-basin scale in the deep Atlantic and at least for the past million years. This suggests that small pH variations of up to 0.2 pH units do not present a risk for marine life."

Summary: This paper addresses issues relevant to Biogeosciences, and presents original data, although the general concept of predicting change and superimposing this on bathymetry is not entirely novel. The writing is generally clear and the authors provide a strong case to substantiate their interpretations. The methods are valid but the assumption that a 0.2 unit decline in pH will alter deep-sea biodiversity remains to be tested broadly.

We agree with the reviewer.

Technical Corrections: Technical corrections have been taken into account while preparing the revised manuscript.

Pg 8609 line 9 the deep benthic environment; also. . .You don't actually report real consequences. We agree and modified the sentence to: "We report on major pH reductions over the deep North Atlantic seafloor (depth > 500 m) and deep-sea biodiversity hotspots, such as seamounts and canyons."

Pg 8610 line 4 – Mora et al. 2013 should be cited as considering consequences of OA in deep water. Done

Pg 8610 line 7 deep sea is only hyphenated when used as a double adjective. Corrected

Pg 8610 line 9 I question whether mineral extraction is dominant in the deep-sea – it has not really happened yet. We agree with the reviewer that at present only few leases have been granted for mining. One example is the lease granted to Nautilus Minerals Inc. for the exploitation of polymetallic massive sulphide deposits in the territorial waters of Papua New Guinea. We have modified the sentence to "While waste disposal, fishing and, in the future, mineral extraction are well-recognized as human pressures

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...".

Pg 8610 line 18. Need a citation after. . . taxa. Done

Pg 8618 line 18 please define what depths are mean by 'deep water' Throughout all of the manuscript, pH reductions are reported for depths exceeding 500 m below sea surface. I is stated on p8612, line 15.

Pg 8619 line 16 please define what is meant by 'climate change' – is this warming? We added the definition to line 5 "... physical (climate change, defined here as physical changes in response to warming) ..."

Pg 8620 line 26. Other good citations include Buhl-Mortensen et al. 2010 (Marine Ecology) and other papers by that author. Done

Pg 8621 line 10. So given the threat to deep protected areas – what do the authors recommend be done? Set aside larger protected areas? Avoid climate change-impacted areas? The only appropriate reaction would be to curb down CO2 emissions.

Fig. 4 Can you comment on the biology in the regions shown in orange with greatest pH change? The area with the greatest pH change (in orange) extends around much of the Atlantic margin. This covers a range of depths and climatic zones and has a highly variable biology. Coupled to this, we have very limited data on the fauna of large areas of the deep sea. This means that we would not like to make any generalising statement about the biology of the area with greatest change. To do this properly would be a new study (or serveral) in its own right.

Please also note the supplement to this comment:
http://www.biogeosciences-discuss.net/11/C5728/2014/bgd-11-C5728-2014-supplement.pdf

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Interactive comment on Biogeosciences Discuss., 11, 8607, 2014.