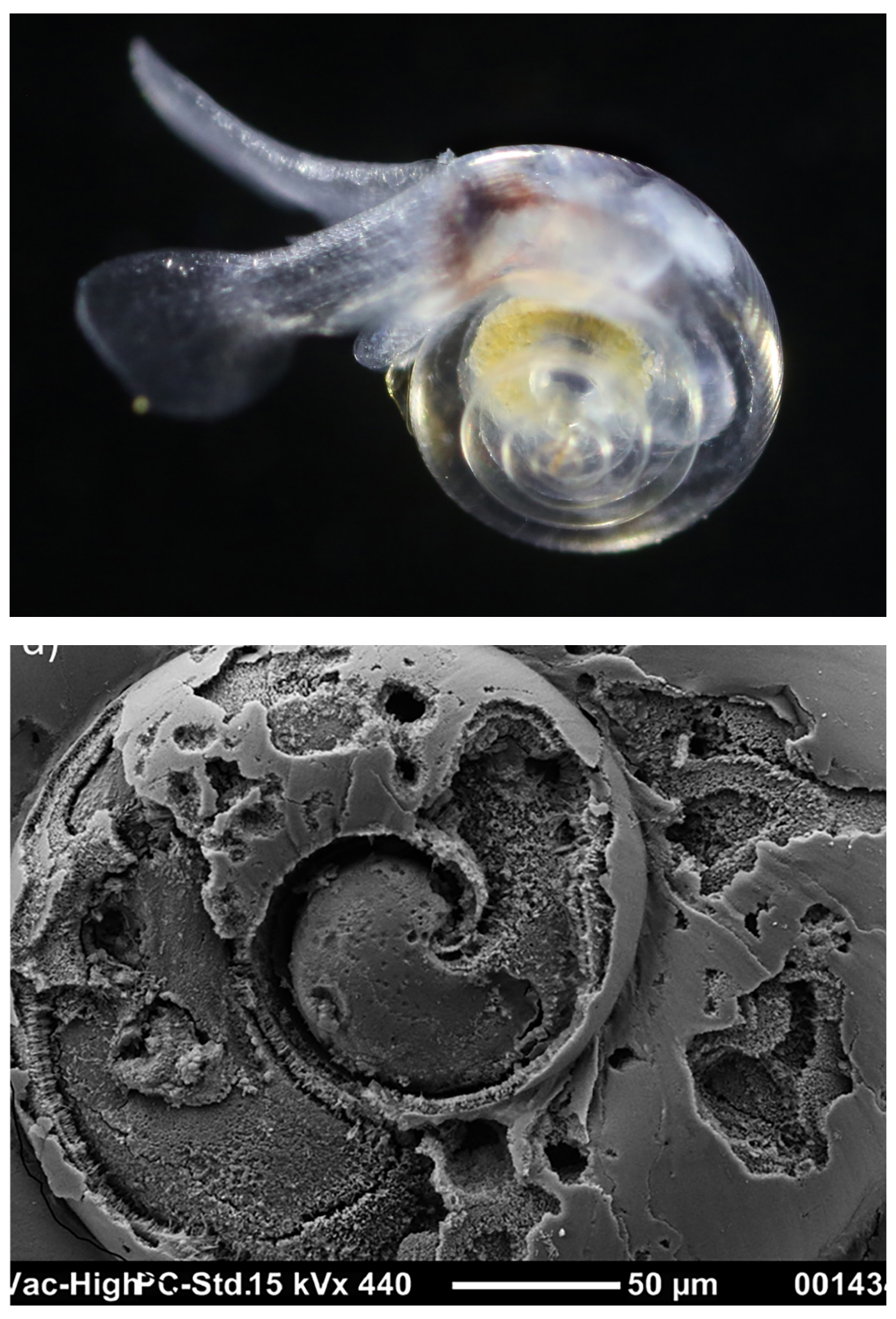
POLAR OCEANS AS A CARBON SINK

Permanent ecosystem and fisheries loss due to polar ocean acidification



Top :Image of healthy pteropods courtesy Dr. Nina Bednarsek. Bottom: Niemi et al., 2020, Frontiers in Marine Science

The Arctic and Southern Oceans have absorbed the lion's share of excess CO2 in the Earth's atmosphere. By some estimates, polar waters have absorbed up to 60% of the carbon taken up by the world's oceans thus far. This makes them an important carbon sink, limiting global warming, despite sharp increases in human carbon emissions.

This "ecosystem service" however has come at a high cost: increasing rates of acidification of polar waters, because when dissolved into seawater, CO2 forms carbonic acid. Acidification levels today are higher than at any point in the past three million years.

In addition to acidification, the polar and many near-polar ocean ecosystems face additional threats due to global warming: marine heatwaves and generally warming waters, which also sometimes decreases oxygen levels; freshening of these waters, from increasing amounts of meltwater pouring off the Greenland and Antarctic ice sheets, which also can affect ocean currents and mixing between surface and deeper waters; invasion by more southerly species; and especially in the Arctic, loss of multi-year sea ice.

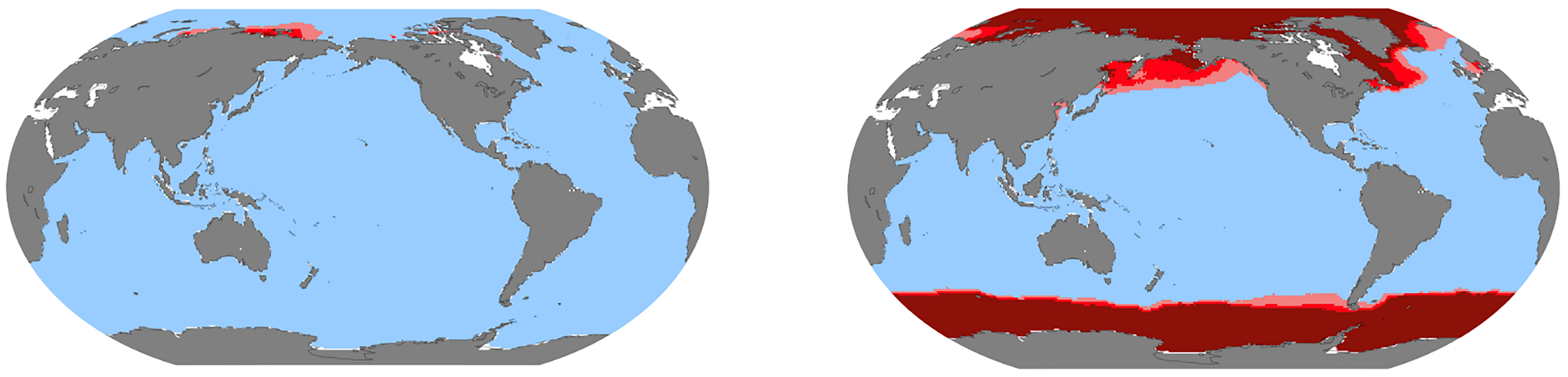
Together, these threats are stressing polar and near-polar ecosystems already today, with impacts such as marine die-off events and apparent difficulty in some regions for animals to build shells. Both polar oceans already appear to be nearing a critical ocean acidification chemical threshold. There is high likelihood that these changes are a harbinger of much worse to come; until, and unless, CO2 levels begin to fall sharply.

There is currently no practical way for humans to reverse ocean acidification, and these more acidic conditions will persist for tens of thousands of years. This is because processes that buffer the acidity from the ocean occur very slowly, over nearly geologic time scales. CO2 "only" lasts for 800–1000 years in the atmosphere, but ocean processes are much slower.

It will take some 50–70,000 years to bring acidification and its impacts back to pre-industrial levels…making this one of the most permanent impacts of climate change in our polar regions.

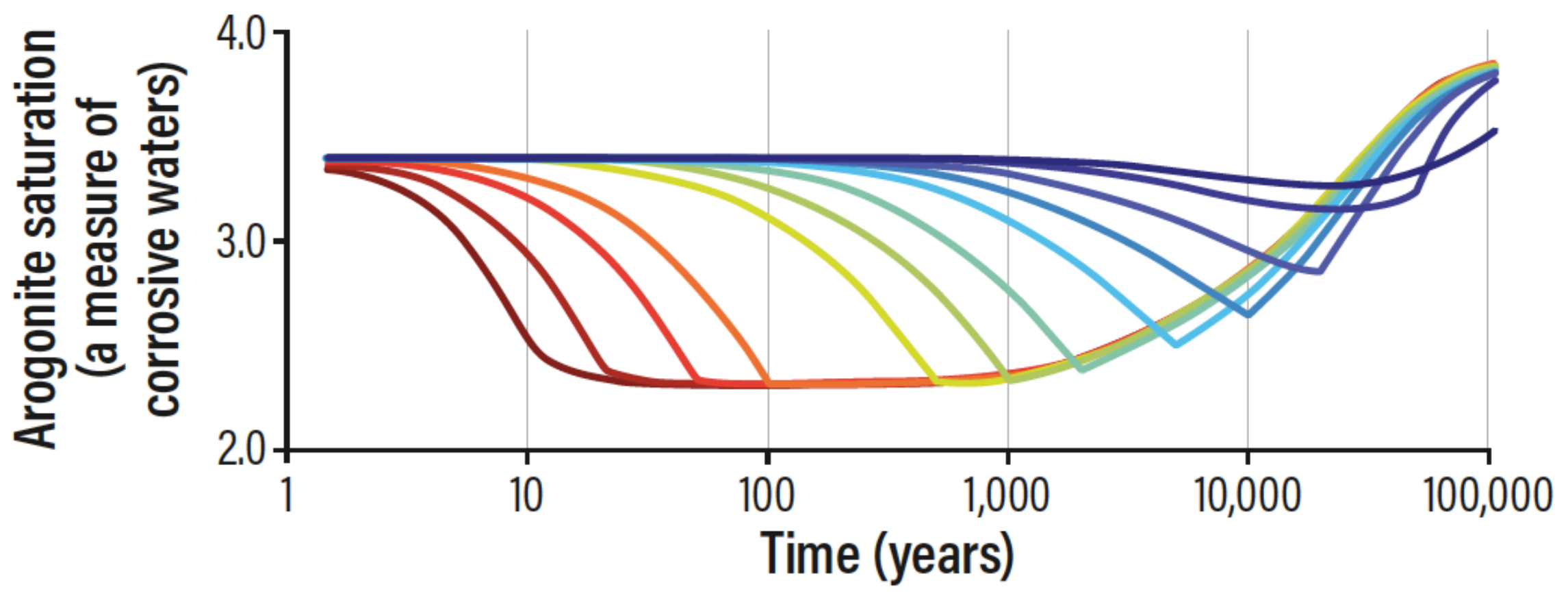
This very long lifetime of acidification in the oceans is one reason why mitigation efforts focused on "solar-radiation management," as opposed to decreasing atmospheric CO2, represent a special threat to the health of the world's oceans, especially those at the poles.

Acidification with Low Emissions (left) and Very High Emissions (right)



Difference between acidification levels in a 1.5° world (RCP2.6) (left map), and a 3–4° world (RCP8.5) (right map) by 2100. Red shows "undersaturated aragonite conditions," a measure of ocean acidification meaning that shelled organisms will have difficulty building or maintaining their shells, leading to potential decline of populations and dietary sources for fish, with loss of biodiversity towards simplified food webs. Image source: IPCC SROCC (2019).

For ocean species, acidification is essentially permanent.
Recovery time from acidification: 50,000–70,000 years



Adapted from Honisch et al (2012)

Scenario	CO2 concentration (ppm)	Impacts for marine life and ocean circulation
Low emissions	**440–460** Peak assuming 50% reductions by 2030, depending on the scale of permafrost emission feedbacks Temperature peak 1.6-1.8°C and declining	• In large portions of the Arctic and Southern Oceans, this will lead to prolonged ocean acidification: very long-term (tens of thousands of years) corrosive conditions that stress all marine organisms, especially those unable to build or maintain their shells. • Isolated marine heat waves and related marine die-off events are likely to occur each year, until temperatures decrease to at least today's levels sometime after 2200. • Freshening from polar glacier and ice sheet melt may decrease the availability of needed nutrients in surface waters, causing changes in the food web. • In the Arctic, food web impacts will be exacerbated by frequent loss of summer sea ice, and complete loss of multi-year ice at these peak temperature levels.Once temperatures return to below 1.5°C, these ice-free summers will be more occasional. • The AMOC (Atlantic Meridional Overturning Circulation) is likely to slow further, but not collapse.
Optimistic fulfillment of all current pledges	**>500** Temperature peak 1.9°C	• With the disappearance of sea ice for several months each summer, Arctic and near-Arctic waters will warm significantly faster, and hold heat longer. Marine heatwaves will be more frequent. • Harmful long-term acidification levels spreading throughout much of the Arctic and Southern Oceans, as well as important fisheries in the Barents, Bering, Beaufort and Amundsen Seas. • Such conditions, which will persist for several thousand years, may also begin to appear seasonally in other "hot spots" further from the poles, such as the North Sea and waters off western Canada, Iceland and the Canadian Maritimes. • The impact of multiple stressors – increased acidification, marine heat waves, and greater freshening from meltwater off both polar ice sheets – on food webs and fisheries in these regions could be significant. • Impacts on the AMOC and other ocean currents will be greater than at low emissions.
Current implemented NDCs	**>600** Temperature peak 3.1°C	• Ocean acidification and multiple stressors will spread southward, and persist for longer periods each year. Significant extinctions of cold-water polar species will become more likely, as waters both warm and become more corrosive for tens of thousands of years. • With acceleration of Greenland melt, severe slowing and even shutdown of the AMOC cannot be ruled out. This would lead to severe and unpredictable disturbances to global weather patterns, which at this temperature level would already be more extreme from a warmer and wetter atmosphere.
Current emissions growth	**>800** by 2100 Temperature peak 4-5°C and rising	• Few of today's polar species, especially shell-building species, are likely to survive the radical change in environment caused by such a rapid and extreme rise in acidification, which will last 50–70,000 years. • This low-pH environment would occur in combination with much warmer, and also fresher, waters from extensive and accelerating ice sheet melt, including potentially rapid West Antarctic Ice Sheet collapse. • Mass extinction of many sea ice associated polar and near-polar species will be the result. Fish such as cod, herring and salmon are extremely unlikely to survive in the wild, with food webs overall less diverse and resilient. Ocean currents, and related weather impacts from this rapid incursion of ice sheet meltwater, will likely be extreme and unpredictable.

Contacts/reviewers

Nina Bednaršek, National Institute of Biology, Slovenia/Oregon State University, USA
NinaB@sccwrp.org

Richard Bellerby, East China Normal University/Norwegian Institute for Water Research
richard.bellerby@niva.no

Rolf Rødven, Arctic Monitoring and Assessment Programme
rolf.rodven@amap.no

Emma Needham, International Cryosphere Climate Initiative
emma@iccinet.org

For more information, see the 2021 State of the Cryosphere Report: iccinet.org/statecryo21

NATIONAL INSTITUTE OF BIOLOGY

Oregon State University

EAST CHINA NORMAL UNIVERSITY

Norwegian Institute for Water Research

International Cryosphere Climate Initiative

Literature

AMAP, 2018. AMAP Assessment 2018: Arctic Ocean Acidification. Arctic Monitoring and Assessment Programme (AMAP), Tromsø, Norway. vi+187pp (https://www.amap.no/documents/doc/amap-assessment-2018-arctic-ocean-acidification/1659)

Bednaršek N, Tarling GA, Bakker DCE, Fielding S, Feely RA. Dissolution Dominating Calcification Process in Polar Pteropods Close to the Point of Aragonite Undersaturation. Ross P, ed. PLoS ONE. 2014;9(10):e109183. doi:10.1371/journal.pone.0109183.

N. Bednaršek, R. A. Feely, J. C. P. Reum, B. Peterson, J. Menkel, S. R. Alin, B. Hales (2014). Limacina helicina shell dissolution as an indicator of declining habitat suitability owing to ocean acidification in the California Current Ecosystem. Proc. R. Soc. B 281:20140123. DOI: 10.1098/rspb.2014.0123

Bednarsek et al., 2021- accepted for frontiers

Cantoni, C., Hopwood, M., Clarke, J., Chiggiato, J., Achterberg, E., & Cozzi, S. (2020). Glacial Drivers of Marine Biogeochemistry Indicate a Future Shift to More Corrosive Conditions in an Arctic Fjord. Journal of Geophysical Research Biogeosciences.

Cummings, Vonda et al. "Ocean Acidification at High Latitudes: Potential Effects on Functioning of the Antarctic Bivalve Laternula Elliptica." Ed. Jack Anthony Gilbert. PLoS ONE 6.1 (2011): e16069. PMC. Web. 22 Nov. 2015.

Dupont, S. & P.rtner, H. (2013). Get ready for ocean acidification, Nature, 498, 429.

Dupont et al (2008). Near-future level of CO2-driven acidification radically affects larval survival and development on the brittle star Ophiothrix fragilis . Vol. 373: 285–294, 2008 MARINE ECOLOGY PROGRESS SERIES doi: 10.3354/meps07800

Frolicher, T. L., J. L. Sarmiento, D. J. Paynter, J. P. Dunne, J. P. Krasting, and M. Winton, 2015: Dominance of the Southern Ocean in anthropogenic carbon and heat uptake in CMIP5 models. J. Climate, 28, 862–886, https://doi.org/10.1175/JCLI-D-14-00117.1.

Gattuso, J.P., Magnan, A., Bill., R., Cheung, W.W.L., Howes, E.L., Joos, F., Allemand, D., Bopp, L., Cooley, S.R., Eakin, C.M., Hoegh-Guldberg, O., Kelly, R.P., P.rtner H.O., Rogers, A.D., Baxter, J.M., Laffoley, D., Osborn, D., Rankovic, A., Rochette, J., Sumaila, U.R., Treyer, S. & Turley, C. (2015). Contrasting futures for ocean and society from different anthropogenic CO2 emissions scenarios. Science, 349, DOI: 10.1126/science.aac4722.

Green HL, Findlay HS, Shutler JD, Land PE and Bellerby RGJ (2021) Satellite Observations Are Needed to Understand Ocean Acidification and Multi-Stressor Impacts on Fish Stocks in a Changing Arctic Ocean. Front. Mar. Sci. 8:635797. doi: 10.3389/fmars.2021.635797

Hauri et al., 2021- accepted IAP Statement on Ocean Acidification, 2009. See: http://www.interacademies.net/File.aspx?id=9075

IPCC, 2014: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada,

R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1132 pp.

IPCC, 2014: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 688 pp.

IPCC, 2018: Global warming of 1.5ÅãC. An IPCC Special Report on the impacts of global warming of 1.5ÅãC above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [V. Masson-Delmotte, P. Zhai, H. O. P.rtner, D. Roberts, J. Skea, P.R.Shukla,A. Pirani, W. Moufouma-Okia, C.P.an, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, T. Waterfield(eds.)].

IPCC, 2019: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. In press.

IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S. L. Connors, C. P.an, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J. B. R. Matthews, T. K. Maycock, T. Waterfield, O. Yelek.i, R. Yu and B. Zhou (eds.)]. Cambridge University Press. In Press.

Kikuchi et al. 2021. Status and trends of Arctic Ocean environmental change and its impacts on marine biogeochemistry: Findings from the ArCS project. Polar Science, 27: 100639. https://doi.org/10.1016/j. polar.2021.100639

Mathis, J.T., J.N. Cross, W. Evans, and S.C. Doney. 2015. Ocean acidification in the surface waters of the Pacific-Arctic boundary regions. Oceanography 28(2):122–135, http://dx.doi.org/10.5670/oceanog.2015.36

McNeil BI, Matear RJ. Southern Ocean acidification: A tipping point at 450-ppm atmospheric CO2. Proceedings of the National Academy of Sciences of the United States of America. 2008;105(48):18860–18864. doi:10.1073/pnas.0806318105.

Riebesell, U. & Gattuso, J.P. (2015). Lessons learned from ocean acidification research. Nature Climate Change, 5, 12–14.

Sasse TP, McNeil BI, Matear RJ, Lenton A (2015) Quanitfying the influence of CO2 seasonality on future aragonite undersaturation onset. Biogeosciences, 12: 6017–6031, doi:10.5194bg-12-6017-2015

Terhaar, J., Torres, O., Bourgeois, T., and Kwiatkowski, L.: Arctic Ocean acidification over the 21st century co-driven by anthropogenic carbon increases and freshening in the CMIP6 model ensemble, Biogeosciences, 18, 2221–2240, https://doi.org/10.5194/bg-18-2221-2021, 2021.

Vargas C, Lagos N, Lardies M, Duarte C, Manr.quez P, Aguilera V, Broiman B, Widdicombe S & Dupont S (2017) Species-specific responses to ocean acidification should account for local adaptation and adaptive plasticity. Nature Ecology and Evolution. 1:84.

Vehmaa, Anu and Marko Reinikainen. Ocean Acidification in the Baltic Sea. AIR POLLUTION AND CLIMATE SERIES 40 ISBN: 978-91-984717-2-4

Wilson TJB, Cooley SR, Tai TC, Cheung WWL, Tyedmers PH (2020) Potential socioeconomic impacts from ocean acidification and climate change effects on Atlantic Canadian fisheries. PLoS ONE 15(1): e0226544. https://doi.org/10.1371/journal.pone.022654

Wittmann, A.C. & P.rtner, H.O. (2013). Sensitivities of extant animal taxa to ocean acidification. Nature Climate Change, 3, 995–1001.