Presently Atmospheric CO­2 levels are over 400 ppm Dunn *et al.* (2020) well above preindustrial levels of approximately 275 ppm(Macfarling *et al.*, 2006). The world’s oceans absorb as much as one third of annual anthropogenic CO2 (Doney *et al.*, 2009), causing an increase in oceanic pCO2. The increased pCO2  drives a decrease in pH, causing oceanic pH to decline from its pre-industrial revolution level of 8.2 to a current average below 8.1, in a process termed ocean acidification (Caldeira and Wickett, 2003)

Initial studies of the impact of OA on marine organisms focused largely on challenges faced by calcifying organisms(Fabry *et al.*, 2008). However more recently there has been a number of studies that examine how OA impacts the physiology of an array of organisms. Changes in pH have been shown to impact respiratory physiology (Miller, 1985; Bridges, 1995; Widdicombe and Spicer, 2008; Seibel, 2016). Negative impacts to respiratory physiology make it more difficult to obtain oxygen from the environment and may limit aerobic energy production. This has been shown in crab, squid, fish, and sipunculids (Pörtner *et al.*, 1998; Langenbuch and Portner, 2002; Metzger *et al.*, 2007; Rosa and Seibel, 2008; Munday *et al.*, 2009; Walther *et al.*, 2009).

Studies within cephalopods have shown various, and sometimes conflicting, responses to hypercapnia and the resulting low pH. At environmentally relevant ranges of 700-1700 μatm adult Cuttlefish *Sepia officinalis* show no aerobic metabolic response (Gutowska *et al.*, 2008) where as embryonic *S. officinalis* showed an increase in routine metabolism (Rosa *et al.*, 2013). In squid, the vertically migrating epipelagic squid *Dosidicus gigas* showed metabolic depression (Rosa and Seibel, 2008) where as the near-shore reef squid *Sepioteuthis lessoniana* showed no change in metabolism. The benthic octopus *Octopus rubescens* had a short term (24 hour) increase in metabolism which then returned to pre-exposure levels (Onthank *et al.*, 2020).

Because of the relatively few studies of the effect of hypercapnia on cephalopods physiology it is unclear if the variation in response is due to phylogeny, life stage, habitat, or some other factor. The decrease in aerobic metabolism seen in some species of squid has been attributed to limitations of their respiratory pigments (Seibel, 2013). Like other cephalopods, squid rely on hemocyanin for oxygen delivery. This respiratory pigment has comparatively low oxygen carrying capacity (O'Dor and Webber, 1991) and strong Root and Bohr effects (Bridges, 1995; Pörtner, 1995). However Birk et. al., (2018)

Cuttlefish

1. Metabolism shows no response (Gutowska et al 2008, )
2. Increased cuttlebone calcification (very high 2000-4500 uatm) Gutowska 2008, Hu 2014

Squid

1. Show depressed metabolism (Rosa and Seibel 2008)
2. Calcification rates increase in Doryteuthis opalescens
3. Doryteuthis pealii had malformed statoliths with incrased porosity (Very high)
4. Sepioteuthis lessoniana had no change in metabolism at moderate pCO2, but had a decreased metabolism above 4000 uatm (Hu et al 2014)

Octopus

**Birk, M. A., E. L. McLean, and B. A. Seibel. 2018.** Ocean acidification does not limit squid metabolism via blood oxygen supply. *Journal of Experimental Biology* **221**:jeb187443.

**Bridges, C. 1995.** Bohr and root effects in cephalopod haemocyanins‐paradox or pressure in Sepia officinalis? *Marine and Freshwater Behaviour and Physiology* **25**:121-130.

**Caldeira, K., and M. E. Wickett. 2003.** Oceanography: anthropogenic carbon and ocean pH. *Nature* **425**:365-365.

**Doney, S. C., V. J. Fabry, R. A. Feely, and J. A. Kleypas. 2009.** Ocean acidification: the other CO2 problem. *Annual review of marine science* **1**:169-192.

**Dunn, R. J. H., D. M. Stanitski, N. Gobron, K. M. Willett, M. Ades, R. Adler, R. Allan, R. P. Allan, J. Anderson, A. Argüez, C. Arosio, J. A. Augustine, C. Azorin-Molina, J. Barichivich, J. Barnes, H. E. Beck, A. Becker, N. Bellouin, A. Benedetti, D. I. Berry, S. Blenkinsop, O. Bock, M. G. Bosilovich, O. Boucher, S. A. Buehler, L. Carrea, H. H. Christiansen, F. Chouza, J. R. Christy, E.-S. Chung, M. Coldewey-Egbers, G. P. Compo, O. R. Cooper, C. Covey, A. Crotwell, S. M. Davis, E. de Eyto, R. A. M. de Jeu, B. V. VanderSat, C. L. DeGasperi, D. Degenstein, L. Di Girolamo, M. T. Dokulil, M. G. Donat, W. A. Dorigo, I. Durre, G. S. Dutton, G. Duveiller, J. W. Elkins, V. E. Fioletov, J. Flemming, M. J. Foster, R. A. Frey, S. M. Frith, L. Froidevaux, J. Garforth, S. K. Gupta, L. Haimberger, B. D. Hall, I. Harris, A. K. Heidinger, D. L. Hemming, S.-p. Ho, D. Hubert, D. F. Hurst, I. Hüser, A. Inness, K. Isaksen, V. John, P. D. Jones, J. W. Kaiser, S. Kelly, S. Khaykin, R. Kidd, H. Kim, Z. Kipling, B. M. Kraemer, D. P. Kratz, R. S. La Fuente, X. Lan, K. O. Lantz, T. Leblanc, B. Li, N. G. Loeb, C. S. Long, D. Loyola, W. Marszelewski, B. Martens, L. May, M. Mayer, M. F. McCabe, T. R. McVicar, C. A. Mears, W. P. Menzel, C. J. Merchant, B. R. Miller, D. G. Miralles, S. A. Montzka, C. Morice, J. Mühle, R. Myneni, J. P. Nicolas, J. Noetzli, T. J. Osborn, T. Park, A. Pasik, A. M. Paterson, M. S. Pelto, S. Perkins-Kirkpatrick, G. Pétron, C. Phillips, B. Pinty, S. Po-Chedley, L. Polvani, W. Preimesberger, M. Pulkkanen, W. J. Randel, S. Rémy, L. Ricciardulli, A. D. Richardson, L. Rieger, D. A. Robinson, M. Rodell, K. H. Rosenlof, C. Roth, A. Rozanov, J. A. Rusak, O. Rusanovskaya, T. Rutishäuser, A. Sánchez-Lugo, P. Sawaengphokhai, T. Scanlon, V. Schenzinger, S. G. Schladow, R. W. Schlegel, M. Schmid, Eawag, H. B. Selkirk, S. Sharma, L. Shi, S. V. Shimaraeva, E. A. Silow, A. J. Simmons, C. A. Smith, S. L. Smith, B. J. Soden, V. Sofieva, T. H. Sparks, P. W. Stackhouse, W. Steinbrecht, D. A. Streletskiy, G. Taha, H. Telg, S. J. Thackeray, M. A. Timofeyev, K. Tourpali, M. R. Tye, R. J. van der A, R. van der Schalie, VanderSat B.V., G. van der SchrierW. Paul, G. R. van der Werf, P. Verburg, J.-P. Vernier, H. Vömel, R. S. Vose, R. Wang, S. G. Watanabe, M. Weber, G. A. Weyhenmeyer, D. Wiese, A. C. Wilber, J. D. Wild, T. Wong, R. I. Woolway, X. Yin, L. Zhao, G. Zhao, X. Zhou, J. R. Ziemke, and M. Ziese. 2020.** Global Climate. *Bulletin of the American Meteorological Society* **101**:S9-S128.

**Fabry, V. J., B. A. Seibel, R. A. Feely, and J. C. Orr. 2008.** Impacts of ocean acidification on marine fauna and ecosystem processes. *ICES Journal of Marine Science: Journal du Conseil* **65**:414-432.

**Gutowska, M. A., H. O. Pörtner, and F. Melzner. 2008.** Growth and calcification in the cephalopod Sepia officinalis under elevated seawater pCO2. *Marine Ecology Progress Series* **373**:303-309.

**Langenbuch, M., and H. O. Portner. 2002.** Changes in metabolic rate and N excretion in the marine invertebrate Sipunculus nudus under conditions of environmental hypercapnia: identifying effective acid—base variables. *Journal of Experimental Biology* **205**:1153-1160.

**Macfarling, M., D. Etheridge, C. Trudinger, P. Steele, R. Langenfelds, T. Van Ommen, A. Smith, and J. Elkins. 2006.** Law Dome CO2, CH4 and N2O ice core records extended to 2000 years BP. *Geophysical Research Letters* **33**.

**Metzger, R., F. J. Sartoris, M. Langenbuch, and H. O. Pörtner. 2007.** Influence of elevated CO 2 concentrations on thermal tolerance of the edible crab Cancer pagurus. *Journal of Thermal Biology* **32**:144-151.

**Miller, K. I. 1985.** Oxygen equilibria of Octopus dofleini hemocyanin. *Biochemistry* **24**:4582-4586.

**Munday, P. L., D. L. Dixson, J. M. Donelson, G. P. Jones, M. S. Pratchett, G. V. Devitsina, and K. B. Døving. 2009.** Ocean acidification impairs olfactory discrimination and homing ability of a marine fish. *Proceedings of the National Academy of Sciences* **106**:1848-1852.

**O'Dor, R. K., and D. M. Webber. 1991.** Invertebrate athletes: Trade-offs between transport efficiency and power density in cephalopod evolution. *Journal of Experimental Biology* **160**:93-112.

**Onthank, K. L., L. A. Trueblood, T. Schrock-Duff, and L. G. Kore. 2020.** Impact of Short-and Long-Term Exposure to Elevated Seawater Pco2 on Metabolic Rate and Hypoxia Tolerance in Octopus rubescens. *Physiological and Biochemical Zoology* **94**:1-11.

**Pörtner, H.-O. 1995.** Coordination of metabolism, acid‐base regulation and haemocyanin function in cephalopods. *Marine and freshwater behaviour and physiology* **25**:131-148.

**Pörtner, H.-O., A. Reipschläger, and N. Heisler. 1998.** Acid-base regulation, metabolism and energetics in Sipunculus nudus as a function of ambient carbon dioxide level. *The Journal of experimental biology* **201**:43-55.

**Rosa, R., and B. Seibel. 2008.** Synergistic effects of climate-related variables suggest future physiological impairment in a top oceanic predator. *Proceedings of the National Academy of Sciences* **105**:20776.

**Rosa, R., K. Trübenbach, T. Repolho, M. Pimentel, F. Faleiro, J. Boavida-Portugal, M. Baptista, V. M. Lopes, G. Dionísio, and M. C. Leal. 2013.** Lower hypoxia thresholds of cuttlefish early life stages living in a warm acidified ocean. *Proceedings of the Royal Society of London B: Biological Sciences* **280**:20131695.

**Seibel, B. A. 2013.** The jumbo squid, Dosidicus gigas (Ommastrephidae), living in oxygen minimum zones II: Blood–oxygen binding. *Deep Sea Research Part II: Topical Studies in Oceanography* **95**:139-144.

**Seibel, B. A. 2016.** Cephalopod susceptibility to asphyxiation via ocean incalescence, deoxygenation, and acidification. *Physiology* **31**:418-429.

**Walther, K., F.-J. Sartoris, C. Bock, and H.-O. Pörtner. 2009.** Impact of anthropogenic ocean acidification on thermal tolerance of the spider crab Hyas araneus. *Biogeosciences* **6**:2207-2215.

**Widdicombe, S., and J. I. Spicer. 2008.** Predicting the impact of ocean acidification on benthic biodiversity: what can animal physiology tell us? *Journal of Experimental Marine Biology and Ecology* **366**:187-197.