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Letter to the Editor

Comment on “Modelling susceptibility of coral reefs to environmental stress-using remote sensing data and GIS models”, authors Maina, Venus, McClanahan, and Ateweberhan

The analysis by Maina et al. is a nice example of applied modeling which could result in real conservation gains for coral reef ecosystems. Models of this type are a critical component for planning future marine protected areas (MPAs) in an age of growing environmental uncertainty. Modeling climate change variables at various spatial and temporal scales is essential if we hope to create future MPAs where corals have the best possible chance of survival. While coral bleaching is a serious and immediate threat to corals globally, the authors did not incorporate one of the most ominous environmental threats coral reefs face in a changing climate. The omitted threat is ocean acidification, a process whereby the oceans are absorbing anthropogenic CO_2 at an unprecedented rate, which reduces the pH of seawater and most importantly the concentration of carbonate ions in seawater. Carbonate ions are the building blocks for calcification and as oceans acidify, corals are expected to build weaker skeletons (a process similar to osteoporosis in humans) and/or grow at slower rates. The threat to coral reefs from ocean acidification has been the subject of numerous peer reviewed research papers and books spanning more than 15 years (Smith and Buddemeier, 1992; Gattuso et al., 1998; Kleypas et al., 1999, 2001, 2006; Langdon et al., 2000, 2003; Leclercq et al., 2000, 2002; Marubini et al., 2001, 2003; Guinotte et al., 2003; Buddemeier et al., 2004; Langdon and Atkinson, 2005; Hoegh-Guldberg et al., 2007; Veron, 2008, and others). Slower growth rates and fragile skeletons are not conducive to reef growth and some estimates predict erosion will outpace net reef accretion as early as 2050 in some regions of the world’s oceans (Hoegh-Guldberg et al., 2007).

The direct threat of reduced calcification in corals is not the only challenge to reefs posed by ocean acidification. There is widespread concern about the potential for major ecosystem changes (reviewed by Guinotte and Fabry, 2008; and others) and Kuffner et al. (2007) have shown that the recruitment of crustose coralline algae is dramatically reduced by elevated pCO_2. This finding illustrates not only that other important components of coral reef ecosystems are at risk, but also that the effects of acidification on processes such as recruitment may be even more important than direct effects on calcification.

Planning future MPAs in the face of climate change will be complicated in the Western Indian Ocean because the negative effects of ocean acidification will first be felt in the areas Maina et al. identified as ‘not susceptible’ and ‘low susceptibility’ with respect to coral bleaching. Fig. 1 shows the projected spatial expansion of decreasing levels of surface ocean aragonite saturation state (Ω_a) through the year 2049 (aragonite saturation state data from the modeled data set reported on by Guinotte et al., 2003). These aragonite saturation state projections are based on a conservative IPCC CO_2 scenario (B2) and probably underestimate the change in carbonate saturation state. An example of present day coral locations occurring in the ‘marginal’ classification is the corals of the Galapagos Islands. The coral communities of the Galapagos are poorly cemented, susceptible to storm damage and bioerosion, and are not considered “reefs” by many definitions of the term (Kleypas et al., 2001)—a good example of ‘marginal’ coral communities occurring in a “marginal reef” environment. The aragonite saturation state conditions that are present today in the waters off the Galapagos will appear in South African waters as early as 2020 and off the coasts of Mozambique and Madagascar by the year 2030. The southern regions of the Maina et al. study area may be the least susceptible to coral bleaching, but will be the first areas to experience the negative consequences of ocean acidification.

This comment is not meant to degrade or downplay the utility and/or importance of the Maina et al. research. Rather it is intended to draw attention to the need for models designed to incorporate the synergistic effects of numerous environmental changes occurring in concert (e.g. higher ocean temperatures plus lower aragonite saturation states). Research into the synergistic effects of higher ocean temperatures and reduced carbonate saturation state are in their

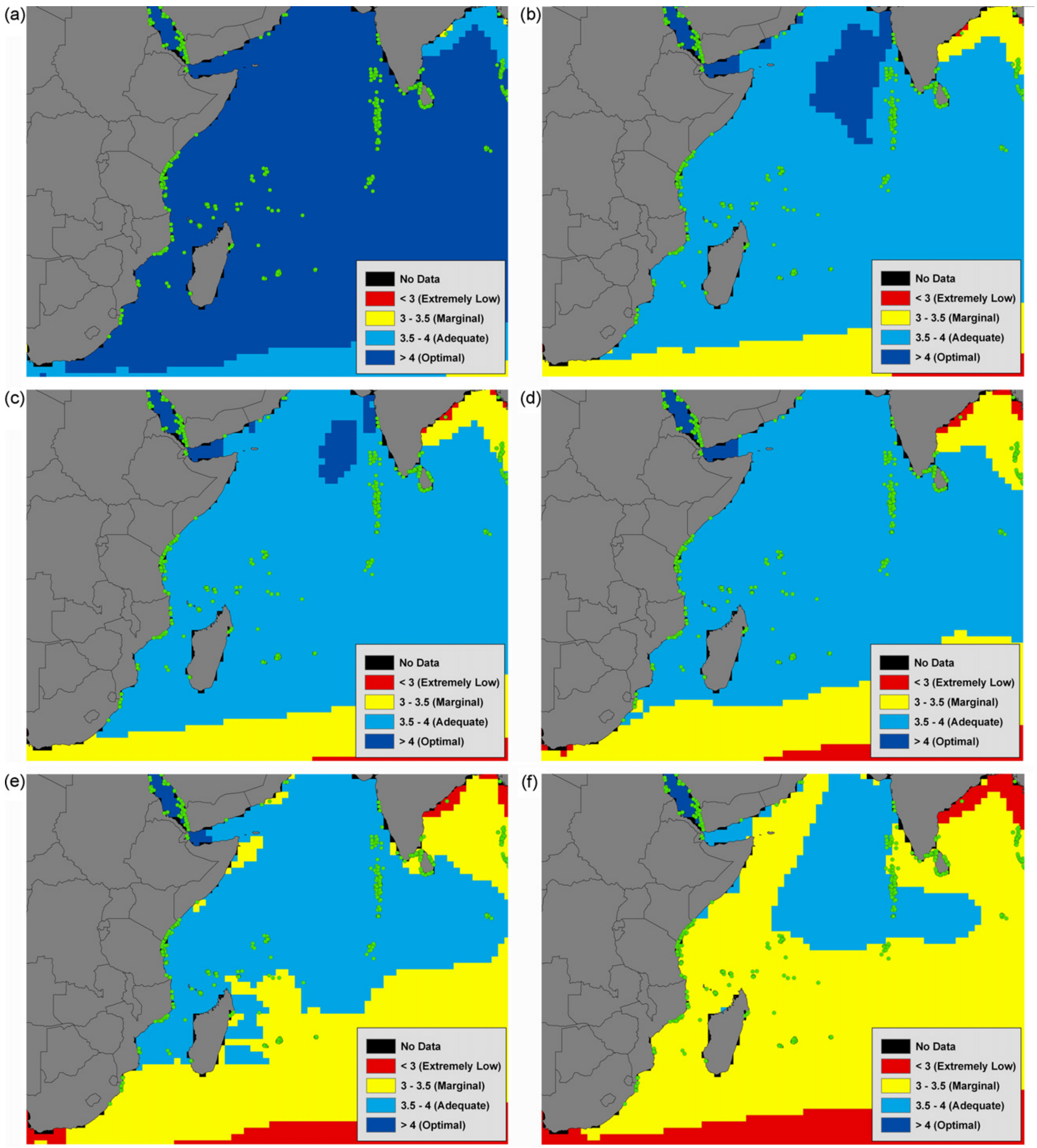

Fig. 1 – (a) Surface ocean aragonite saturation state (Ω_a), calculated preindustrial (1870) values; $p\mathrm{CO_2}$ = 280 ppm. Green dots are Reefbase coral reef locations. Worldwide, almost all present day reef locations were in the "optimal" range two centuries ago, (b) projected (Ω_a) values, 2000–2009; $p\mathrm{CO_2}$ = 375 ppm, (c) projected (Ω_a) values, 2010–2019; $p\mathrm{CO_2}$ = 387 ppm, (d) projected (Ω_a) values, 2020–2029; $p\mathrm{CO_2}$ = 415 ppm, (e) projected (Ω_a) values, 2030–2039; $p\mathrm{CO_2}$ = 437 ppm and (f) projected (Ω_a) values, 2040–2049; $p\mathrm{CO_2}$ = 465 ppm.

infancy, but if we are to determine areas where corals have the best chance for survival over the long term, we must incorporate all of the large-scale environmental stressors into the models, including decreasing carbonate saturation states (ocean acidification). In the East African case, integration of aragonite saturation state data depicted in the figures below with data illustrated in Fig. 4 of Maina et al. might suggest that some of the reef sites in their "low" and "medial" susceptibility categories (Madagascar, the Seychelles, Tanzania, northern Mozambique) could be candidates for conservation and preservation. These areas could be as good as or better than the "not susceptible" reefs farther to the south.

REFERENCES

Buddemeier, R.W., Kleypas, J.A., Aronson, R., 2004. Coral Reefs and Global Climate Change. Potential Contributions of Climate Change to Stresses on Coral Reef Ecosystems. Pew Center for Global Climate Change, Arlington, VA, p. 42.

Gattuso, J.-P., Frankignoulle, M., Bourge, I., Romaine, S., Buddemeier, R.W., 1998. Effect of calcium carbonate saturation of seawater on coral calcification. Global Planet Change 18, 37–46.

Guinotte, J.M., Buddemeier, R.W., Kleypas, J.A., 2003. Future coral reef habitat marginality: temporal and spatial effects of climate change in the Pacific basin. Coral Reefs 22, 551–558.

Guinotte, J.M, Fabry, V.J., 2008. Ocean acidification and its potential effects on marine ecosystems. In: Ostfeld, R.S., Schlesinger, W.H. (Eds.), The Year in Ecology and Conservation Biology 2008, Annals of the New York Academy of Sciences, pp. 320–342.

Hoegh-Guldberg, O., et al., 2007. Coral reefs under rapid climate change and ocean acidification. Science 318, 1737–1742.

Kleypas, J.A., Buddemeier, R.W., Archer, D., Gattuso, J.-P., Langdon, C., Opdyke, B.N., 1999. Geochemical consequences of increased atmospheric carbon dioxide on coral reefs. Science 284, 118–120.

Kleypas, J.A., Buddemeier, R.W., Gattuso, J.-P., 2001. The future of coral reefs in an age of global change. Int. J. Earth Sci. 90, 426–437.

Kleypas, J.A., et al., 2006. Impacts of Ocean Acidification on Coral Reefs and Other Marine Calcifiers: A Guide for Future Research, report of a workshop held April 18–20, 2005, St. Petersburg, FL, sponsored by NSF, NOAA, and the U.S. Geological Survey, 88 pp.

Kuffner, I.B., et al., 2007. Decreased abundance of crustose coralline algae due to ocean acidification. Nat. Geosci. 1, 114–117.

Langdon, C., Atkinson, M.J., 2005. Effect of elevated pCO_2 on photosynthesis and calcification of corals and interactions with seasonal change in temperature/irradiance and nutrient enrichment. J. Geophys. Res. 110, C09S07, doi:10.1029/2004JC002576.

Langdon, C., et al., 2000. Effect of calcium carbonate saturation state on the calcification rate of an experimental coral reef. Global Biogeochem. Cy. 14, 639–654.

Langdon, C., et al., 2003. Effect of elevated CO_2 on the community metabolism of an experimental coral reef. Global Biogeochem. Cy. 17 (1), 1011, doi:10.1029/2002GB001941.

Leclercq, N., Gattuso, J.-P., Jaubert, J., 2000. CO_2 partial pressure controls the calcification rate of a coral community. Global Change Biol. 6, 329–334.

Leclercq, N., Gattuso, J.-P., Jaubert, J., 2002. Primary production, respiration, and calcification of a coral reef mesocosm under increased CO_2 partial pressure. Limnol. Oceanogr. 47, 558–564.

Marubini, F., Barnett, H., Langdon, C., Atkinson, M.J., 2001. Dependence of calcification on light and carbonate ion concentration for the hermatypic coral *Porites compressa*. Mar. Ecol. -Prog. Ser. 220, 153–162.

Marubini, F., Ferrier-Pagés, C., Cuif, J.P., 2003. Suppression of skeletal growth in scleractinian corals by decreasing ambient carbonate-ion concentration: a cross family comparison. Proc. R. Soc. Lond. B 270, 179–184.

Smith, S.V., Buddemeier, R.W., 1992. Global change and coral reef ecosystems. Ann. Rev. Ecol. Syst. 23, 89–118.

Veron, J.E., 2008. A Reef in Time: The Great Barrier Reef from Beginning to End. Harvard University Press, Cambridge, Massachusetts.

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