RESPONSE OF VARIOUS MARINE ANIMALS TO OCEAN WARMING

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According to the IPCC, CO_2-induced global warming will be net harmful to the world's marine species. This summary examines this hypothesis for various marine animals, presenting evidence in opposition to the IPCC's point of view.

In prefacing their work, Helmuth *et al.* (2011)[1] begin by noting "virtually every physiological process is affected by the temperature of an organism's body, and ... with the advent of new molecular and biochemical techniques for studying organismal responses to thermal stress ... there has been a renewed interest in the effects of temperature extremes on the ecology and physiology of organisms given the observed and forecasted impacts of global climate change." Against this backdrop and using a simple heat budget model that was ground-truthed with approximately five years of *in situ* temperature data obtained by biomimetic sensors, Helmuth *et al*. "explored the sensitivity of aerial (low tide) mussel body temperature at three tidal elevations to changes in air temperature, solar radiation, wind speed, wave height, and the timing of low tide at a site in central California USA (Bodega Bay)."

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According to the six U.S. scientists, the results suggest "while increases in air temperature and solar radiation can significantly alter the risk of exposure to stressful conditions, especially at upper intertidal elevations, patterns of risk can be substantially reduced by convective cooling such that even moderate increases in mean wind speed (~1 m/sec) can theoretically counteract the effects of substantial (2.5°C) increases in air temperature." They also indicate "shifts in the timing of low tide (+1 hour), such as occur [when] moving to different locations along the coast of California, can have very large impacts on sensitivity to increases in air temperature," noting "depending on the timing of low tide, at some sites increases in air temperature will primarily affect animals in the upper intertidal zone, while at other sites animals will be affected across all tidal elevations." In addition, they report "body temperatures are not always elevated even when low tide air temperatures are extreme," due to "the combined effects of convective cooling and wave splash."

[1] http://www.co2science.org/articles/V14/N33/B1.php.

In concluding their analysis, Helmuth *et al*. say their findings suggest the timing and magnitude of organismal warming "will be highly variable at coastal sites, and can be driven to a large extent by local oceanographic and meteorological processes." Thus, they "strongly caution against the use of single environmental metrics such as air temperature" for "making projections of the impacts of climate change." The results of this study also highlight the caution that should be applied in considering the findings and implications of the thermal effects on organisms that are based on *laboratory*-based studies, which, as illustrated above, are often incapable of mimicking conditions in the *real*-world and can yield results and implications that are quite different than that observed in the real world of nature.

In addressing questions relating to potential future vulnerabilities of the sea urchin *Heliocidaris erythrogramma* along the southeast coast of Australia, where sea surface temperatures (SSTs) have risen by 2.3°C over the last 60 years, Byrne *et al*. (2011)[2] studied the thermotolerance of the urchin's planktonic life phase in experimental treatments ranging from 18 to 26°C, with the latter value representing a 3 to 4°C increase above recent ambient SSTs.

The results of the study revealed "development success across all stages (gastrula, 24 h; larva, 72 h; juvenile, 120 h) decreased with increasing temperature," and they forthrightly acknowledge "significant deleterious effects were evident at +3 to 4°C." However, and quite significantly, they report "larvae that developed through the early bottleneck of normal development at 26°C metamorphosed successfully," and they add that there was a 25% decrease in planktonic larval duration (PLD) of the larvae in the highest of the temperature treatments. In addition, they found in parallel studies with progeny derived from the northern and southern parts of the coastline they studied, "northern embryos had significantly higher thermotolerance."

In discussing their findings, the five researchers say ocean warming may be advantageous to *H. erythrogramma* larvae "through early settlement and reduction of the vulnerable planktonic period." They also state the higher thermotolerance of the species' northern embryos "provides the possibility that *H. erythrogramma* populations might keep up with a warming world through poleward migration of thermotolerant propagules, facilitated by the strong southward flow of the East Australian Current." And thus they conclude "due to its extensive latitudinal distribution, its potential developmental thermotolerance and independence of its lecithotrophic larvae from exogenous food and the need to make a functional skeleton, *H. erythrogramma* may be particularly robust to ocean change."

Laidre and Heide-Jorgensen (2005)[3] used a combination of long-term satellite tracking data, climate data and remotely sensed sea ice concentrations to detect localized habitat trends of the narwhal (*Monodon monoceros*) in Baffin Bay between Greenland and Canada-which is home to the largest numbers of the world's narwhals-to study the species' vulnerability to ongoing and projected climate change. According to the two researchers, "since 1970, the climate in West Greenland has cooled, reflected in both oceanographic and biological conditions (Hanna and Cappelen, 2003)," with the result "Baffin Bay and Davis Strait display

[2] http://www.co2science.org/articles/V14/N20/B2.php.
[3] http://www.co2science.org/articles/V7/N43/C1.php.

strong significant increasing trends in ice concentrations and extent, as high as 7.5% per decade between 1979 and 1996, with comparable increases detected back to 1953 (Parkinson *et al*., 1999; Deser *et al*., 2000; Parkinson, 2000a,b; Parkinson and Cavalieri, 2002; Stern and Heide-Jorgensen, 2003)."

Laidre and Heide-Jorgensen report "cetacean occurrence is generally negatively correlated with dense or complete ice cover due to the need to breathe at the surface," and "lacking the ability to break holes in the ice," narwhals are vulnerable to reductions in open water availability, as has been demonstrated by ice entrapment events "where hundreds of narwhals died during rapid sea ice formation caused by sudden cold periods (Siegastad and Heide-Jorgensen, 1994; Heide-Jorgensen*et al*., 2002)," which events are becoming ever more likely as temperatures continue to decline and sea ice cover and variability increase, which latter two trends were found by them to be "highly significant at or above the 95% confidence level." They thus conclude "with the evidence of changes in sea ice conditions that could impact foraging, prey availability, and of utmost importance, access to the surface to breathe, it is unclear how narwhal sub-populations will fare in light of changes in the high Arctic." Clearly, therefore, warmer temperatures capable of reducing sea ice cover would be beneficial to narwhals, making them less vulnerable to death from the cold.

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Poloczanska *et al*. (2011)[4] resurveyed a historical census of rocky-shore marine fauna that had been conducted in the 1940s and 1950s, in order to determine if there had been subsequent latitudinal changes in the distribution and abundance of intertidal marine species consistent with global climate change along Australia's east coast, which region, as they demonstrate, "has undergone rapid warming, with increases in temperature of ~1.5°C over the past 60 years." Their survey was conducted at 22 rocky-shore sites located between 23 and 35°S latitude, which stretched across 1500 km of coastline.

Results of the analysis indicate, of the 37 species the authors encountered that had distributional data available from both time periods, "only six species showed poleward shifts consistent with predictions of global climate change." Four others actually moved in the opposite direction "inconsistent with expectations under climate change," while the rest "showed no significant changes in range edges."

In discussing the roles of wave exposure, local currents and the presence of large sand islands, the seven scientists state it is the combination of *those* factors-and "not temperature"-"is the primary factor influencing biogeographic distributions along the subtropical east coast of Australia." And supporting this conclusion is the contemporaneous study of Seabra *et al*.

[4] http://www.co2science.org/articles/V14/N34/B1.php.

(2011), which describes how it is that intertidal marine species can easily withstand significant climatic warming without having to migrate poleward.

Specifically, Seabra *et al*. (2011)[5] examined the relative magnitudes of local-scale versus large-scale latitudinal patterns of the intertidal body temperatures of *robolimpets*: autonomous temperature sensor/loggers mimicking the visual aspect and temperature trajectories of real limpets, which were built as described by Lima and Wethey (2009). These temperatures were measured at thirty-minute intervals for recurring periods of 170 days at 13 exposed or moderately exposed rocky shores along 1500 km of the Atlantic coast of the Iberian Peninsula, where they were attached to steep rocky surfaces-both north-facing (typically shaded) and south-facing (sun-exposed)-at three different tidal heights covering the entire vertical range inhabited by real-life limpets.

The "most relevant finding" of the study, in the words of the four researchers, was "sunny versus shaded differences were consistently larger than the variability associated with [a] the seasons, [b] shore-specific characteristics (topography, orientation, wave exposure, etc.) and [c] shore level." Seabra *et al*. say these findings emphasize the importance of analyzing temperature variability at scales relevant to the organisms being studied, "since the usage of sea surface temperature (SST) derived from remotely sensed data to model the distribution of intertidal species may be missing key environmental features," especially since their results "clearly show that other factors than SST play a much stronger role in determining the body temperatures of these organisms." They also suggest "the observed temperature variability may explain the weak correlations found in many studies modeling the distribution of intertidal species using SST data (e.g. Lima*et al*., 2007b), which negatively impacts attempts of forecasting distributional changes in response to predicted climate warming."

Thermal heterogeneity within habitats must be fully understood in order to interpret patterns of biogeographic response to climate change.

And if that is done correctly, it would appear that predictions of species extinctions may in reality be a lot less likely than presently presumed.

Seabra *et al*. further state "habitat heterogeneity as determined by surface orientation and, to a lesser extent, height on the shore may provide thermal refugia allowing species to occupy habitats apparently inhospitable when considering only average temperatures," and they note "this may be important for understanding range shifts contrary to global warming predictions (e.g. Lima *et al*., 2007a, 2009; Hilbish *et al*., 2010)." Thus, they emphasize once again "thermal heterogeneity within

[5] http://www.co2science.org/articles/V14/N34/B2.php.

habitats must be fully understood in order to interpret patterns of biogeographic response to climate change." And if that is done correctly, it would appear that predictions of species extinctions may in reality be a lot less likely than presently presumed.

In introducing their study, Webster *et al*. (2011)[6] note sponges comprise a major component of coral reef macrofauna and that they play key ecological roles, including providing habitat for other invertebrates and complex microbial symbioses, citing Bell (2008). Concerned that projected increases in air and sea surface temperatures of up to 4°C by 2100, as suggested in the IPCC (2007) report, will have a direct and significant impact on them and their holobionts, Webster *et al*. "assessed the effect of elevated seawater temperature on bacterial communities in larvae of the Great Barrier Reef sponge, *Rhopaloeides odorabile*," in a series of laboratory experiments in order to be able to "compare the thermal thresholds for the different life history phases of this model sponge species."

Although *R. odorabile* adults had previously been observed to experience significant negative repercussions above 32°C, the four researchers found their larvae exhibited "a markedly higher thermal tolerance," with no adverse health effects detected at temperatures up to 36°C, while their microbial communities "were conserved at temperatures up to 34°C." Given such findings, the Australian scientists conducting the study state, "we demonstrated that sponge larvae maintain highly stable symbioses at seawater temperatures exceeding those that are predicted under current climate change scenarios." And given the high likelihood that both the sponge and its holobionts would experience considerable adaptive evolution between now and the end of the twenty-first century, it is safe to say predicted global warming would have little to no impact on them in terms of their survival and normal functioning.

Introducing their study, Weber *et al*. (2012)[7] write "temperature has a profound effect on hatching success, embryonic development and sex in marine turtles," which effects have logically led to "growing concerns regarding the impacts of climate warming on their reproductive success." Against this backdrop, Weber *et al*. conducted a test for "local adaptation in an island-nesting population of green turtles (*Chelonia mydas*) where incubation temperatures vary dramatically among closely adjacent nesting beaches," one with pale sand (Long Beach, LB) and one with dark sand (Northeast Bay, NEB), which was consistently 2-3°C warmer than the pale sand beach only 6 km distant from it. This they did using "a combination of *in situ* and common-garden approaches to compare survival (as a measure of fitness), developmental rates and size at hatching for offspring of LB and NEB females at different incubation temperatures, while simultaneously accounting for egg-mediated maternal effects."

The six scientists report their study found the offspring of female turtles nesting on the naturally hot (black sand) beach "survived better and grew larger at hot incubation temperatures" compared with the offspring of females nesting on the cooler (pale sand) beach, which differences, in their words, were due to "shallower thermal reaction norms in the hot beach population, rather than shifts in thermal optima, and could not be explained by egg-

[6] http://www.co2science.org/articles/V15/N11/B3.php.
[7] http://www.co2science.org/articles/V15/N27/C3.php.

mediated maternal effects." And they also conclude "the results of the common-garden experiment suggest that the increased heat-tolerance of NEB turtles has a genetic basis."

Weber *et al*. also say their results suggest "marine turtle nesting behavior can drive adaptive differentiation at remarkably fine spatial scales," and they therefore opine "previous studies may have underestimated the extent of adaptive structuring in marine turtle populations that may significantly affect their capacity to respond to environmental change." In their concluding paragraph, therefore, they state whereas "global warming is predicted to have multiple deleterious effects on the reproductive success of marine turtles, including the loss of nesting beaches to rising sea levels, increasingly feminized populations and reduced hatching success," their results suggest "in at least one of these respects, marine turtles have the capacity to adapt to warmer temperatures."

According to Doonan *et al*. (2012)[8], "*Katharina tunicata*, commonly known as the Black Katy Chiton, is an abundant intertidal grazer with a limited pelagic larval stage of approximately six days (Paine, 1992)," which is distributed along the Pacific coast of North America from Alaska's Aleutian Islands to southern California, where they say it is "an important regulator of intertidal ecosystems." Nevertheless, they say the species "has recently suffered declines in localized parts of its range as a result of exploitation by humans and sea otters." And noting that it is also "under threat from the effects of climate change," they sought to determine "whether local-scale barriers to gene flow could potentially compromise the dispersal capacity of the species in the face of climate change." To assess this possibility, Doonan *et al*. "used nuclear single-nucleotide polymorphisms and mitochrondrial DNA sequencing to elucidate fine-scale patterns of genetic variation between populations of the Black Katy Chiton separated by 15-150 km in southwest Vancouver Island."

Based on their analysis, the four UK researchers from Queen's University in Belfast report "both the nuclear and mitochondrial data sets revealed no genetic differentiation between the populations studied," as well as the fact "an isolation-with-migration analysis indicated extensive local-scale gene flow, suggesting an absence of barriers to dispersal." In addition, they say "population demographic analysis also revealed long-term population stability through previous periods of climate change associated with the Pleistocene glaciations," and-more particularly-at the Pleistocene-Holocene transition of approximately ten thousand years ago, as discussed by Fields *et al*. (1993). In light of such findings, Doonan *et al*. conclude, "taken together, the current evidence of high dispersal and a lack of biogeographic barriers to gene flow, coupled with the signature of long-term population stability through previous periods of climate change, suggest that this dispersal potential may act as a lifeline for *K. tunicata* as their southerly habitats rapidly warm, and a poleward migration is required for survival," additionally citing the work of Graham *et al*. (2010) in this regard.

In an ecosystem level study, Stuart-Smith *et al*. (2010)[9] preface their work by stating, "despite increasing scientific and public concerns [about] the potential impacts of global ocean warming on marine biodiversity, very few empirical data on community-level responses to rising water

[8] http://www.co2science.org/articles/V15/N48/B2.php.
[9] http://www.co2science.org/articles/V13/N17/B1.php.

temperatures are available." In an effort designed to help fill this important data void, the authors undertook, as they describe it, "a study of sub-tidal reef communities over a decadal time scale, comparing data on fishes, macroinvertebrates and macroalgae collected at 136 sites, spanning hundreds of kilometers around the island of Tasmania (southeastern Australia) in the early to mid 1990s, with data from the same sites in 2006/2007." This region, in their words, "has experienced relatively rapid warming during the last century as a consequence of a strengthening of the warm East Australian Current (Ridgway, 2007)," such that there has been "an increase in sea surface temperature of 2.28 ± 0.35°C per century for the period 1944-2002 (Ridgway, 2007), which is considerably more rapid than the global mean of 0.6 ± 0.2°C per century estimated by Smith and Reynolds (2003), and a mean increase in surface air temperature of 0.6-0.8°C (Salinger, 2005; Hansen *et al*., 2006)." In fact, the warming around this part of Tasmania has been more than three times greater than that of the global mean, making this region a prime location to examine the impacts of rising temperature on marine species in the real-world of nature.

Contrary to what they had expected to find, the four researchers discovered "Tasmanian shallow rocky reef communities have been relative stable over the past decade," in spite of the "substantial rise in sea surface temperature over this period" and the "continuation of a considerable warming trend in oceanographic conditions over the last 50 years." Indeed, they report "the northeast and southeast bioregions, which are most influenced by the East Australian Current and hence have experienced the greatest warming over the last century, appeared to have actually changed very little," adding "not only were Tasmanian reef communities remarkably similar between 1994 and 2006 in a multivariate sense, but univariate community characteristics such as species richness and total fish abundance were also consistent." Thus, the Australian scientists found very little evidence to support the scenarios of the IPCC, who foresee continued global warming decimating Earth's highly productive costal marine ecosystems.

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Poloczanska *et al*. (2013)[10] "investigated the peer-reviewed literature that addresses the question of whether or not climate change impacts marine ecological phenomena, and found 208 studies of 857 species and assemblages." And

[10] http://www.co2science.org/articles/V17/N6/B2.php.

from these reports they say they extracted "1,735 observations of the following types of response: distribution, phenology, abundance, community change, calcification and demography," for which "either regional or global climate change was considered as a driver."

In discussing their findings, first of all, the twenty researchers say "from this database, 81-83% of all observations for distribution, phenology, community composition, abundance, demography and calcification across taxa and ocean basins were consistent with the expected impacts of climate change." And they add "of the species responding to climate change, rates of distribution shifts were, on average, consistent with those required to track ocean surface temperature changes." In light of the findings of this massive review of the relevant scientific literature, it would appear that Earth's marine life is well equipped to deal with predicted changes in the global ocean environment, and that they are, in fact, already doing so.

Linares *et al*. (2013)[11] preface their work by writing "several studies have provided evidence that thermal stress affects the growth, survival and physiology of tropical and temperate macro-invertebrate species." But they note "few studies have focused on sub-tidal temperate species and the potential differential thermal tolerances of populations dwelling under contrasting temperature conditions." Hoping to help fill this data void by focusing their attention on *gorgonians* (sessile colonial cnidarians found throughout the oceans of the world that are closely related to corals), Linares *et al*. assessed "the role that environmental history plays in the response of the temperate gorgonian *Eunicella singularis* to thermal stress," comparing populations dwelling in the coldest and warmest areas of the NW Mediterranean Sea.

The four researchers report "*E. singularis* populations from both areas exhibited a high resistance to thermal stress." However, they found "populations from warmer areas had an increased tolerance to thermal stress," such that "the upper thermal limits found for cold and warm populations were 28 and 29°C, respectively." Linares *et al*. conclude their study by noting their results "agree with results for other Mediterranean anthozoans (Rodolfo-Metalpa *et al*. 2006; Torrents *et al*., 2008) and tropical corals (Middlebrook *et al*., 2008), demonstrating thereby that shallow populations (acclimated to warm temperature conditions) have a higher tolerance to thermal stress than deep populations."

References

Bell, J.J. 2008. The functional roles of marine sponges. *Estuarine, Coastal and Shelf Science* **79**: 341-353.

Byrne, M., Selvakumaraswamy, P., Ho, M.A., Woolsey, E. and Nguyen, H.D. 2011. Sea urchin development in a global change hotspot, potential for southerly migration of thermotolerant propagules. *Deep-Sea Research II* **58**: 712-719.

Deser, C., Walsh, J.E. and Timlin, M.S. 2000. Arctic sea ice variability in the context of recent atmospheric circulation trends. *Journal of Climatology* **13**: 617-633.

[11] http://www.co2science.org/articles/V17/N12/B2.php.

Doonan, J., Beatty, G.E., Sigwart, J.D. and Provan, J. 2012. Extensive local-scale gene flow and long-term population stability in the intertidal mollusk *Katharina tunicata* (Mollusca: Polyplacophora). *Biological Journal of the Linnean Society* **106**: 589-597.

Fields, P.A., Graham, J.B., Rosenblatt, R.H. and Somero, G.N. 1993. Effects of expected global climate change on marine faunas. *Trends in Ecology and Evolution* **8**: 361-367.

Graham, C.H., VanDerWal, J., Philips, S.J., Moritz, C. and Williams, S.E. 2010. Dynamic refugia and species persistence: tracking spatial shifts in habitat through time. *Ecography* **33**: 1062-1069.

Hanna, E. and Cappelen, J. 2003. Recent cooling in coastal southern Greenland and relation with the North Atlantic Oscillation. *Geophysical Research Letters* **30**: 32-1-32-3.

Hansen, J., Sato, M., Ruedy, R., Lo, K., Lea, D.W. and Medina-Elizade, M. 2006. Global temperature change. *Proceedings of the National Academy of Sciences USA* **103**: 14,288-14,293.

Heide-Jorgensen, M.P., Richard, P., Ramsay, M. and Akeeagok, S. 2002. In: *Three recent Ice Entrapments of Arctic Cetaceans in West Greenland and the Eastern Canadian High Arctic*. Volume 4, NAMMCO Scientific Publications, pp. 143-148.

Helmuth, B., Yamane, L., Lalwani, S., Matzelle, A., Tockstein, A. and Gao, N. 2011. Hidden signals of climate change in intertidal ecosystems: What (not) to expect when you are expecting. *Journal of Experimental Marine Biology and Ecology***400**: 191-199.

Hilbish, T.J., Brannock, P.M., Jones, K.R., Smith, A.B., Bullock, N.B. and Wethey, D.S. 2010. Historical changes in the distributions of invasive and endemic marine invertebrates are contrary to global warming predictions: the effects of decadal climate oscillations. *Journal of Biogeography* **37**: 423-431.

IPCC. 2007. *Climate Change 2007: The Physical Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. IPCC, Geneva, Switzerland.

Laidre, K.L. and Heide-Jorgensen, M.P. 2005. Arctic sea ice trends and narwhal vulnerability. *Biological Conservation* **121**: 509-517.

Lima, F.P., Queiroz, N., Ribeiro, P.A., XSavier, R., Hawkins, S.J. and Santos, A.M. 2009. First record of *Halidrys siliquosa* (Linnaeus) Lyngbye in the Portuguese coast: counter-intuitive range expansion? *Marine Biodiversity Records* **2**: 10.1017/S1755267208000018.

Lima, F.P., Ribeiro, P.A., Queiroz, N., Hawkins, S.J. and Santos, A.M. 2007a. Do distributional shifts of northern and southern species of algae match the warming pattern? *Global Change Biology* **13**: 2592-2604.

Lima, F.P., Ribeiro, P.A., Queiroz, N., Xavier, R., Tarroso, P., Hawkins, S.J. and Santos, A.M. 2007b. Modeling past and present geographical distribution of the marine gastropod *Patella rustica* as a tool for exploring responses to environmental change. *Global Change Biology* **13**: 2065-2077.

Lima, F.P. and Wethey, D.S. 2009. Robolimpets: measuring intertidal body temperatures using biomimetic loggers. *Limnology and Oceanography: Methods* **7**: 347-353.

Linares, C., Cebrian, E., Kipson, S. and Garrabou, J. 2013. Does thermal history influence the tolerance of temperate gorgonians to future warming? *Marine Environmental Research* **89**: 45-52.

Middlebrook, R., Hoegh-Guldberg, O. and Leggat, W. 2008. The effect of thermal history on the susceptibility of reef-building corals to thermal stress. *Journal of Experimental Biology* **211**: 1050-1056.

Paine, R.T. 1992. Food-web analysis through field measurement of per capita interaction strength. *Nature* **355**: 73-75.

Parkinson, C.L. 2000a. Variability of Arctic sea ice: the view from space, and 18-year record. *Arctic* **53**: 341-358.

Parkinson, C.L. 2000b. Recent trend reversals in Arctic Sea ice extents: possible connections to the North Atlantic oscillation. *Polar Geography* **24**: 1-12.

Parkinson, C.L. and Cavalieri, D.J. 2002. A 21-year record of Arctic sea-ice extents and their regional, seasonal and monthly variability and trends. *Annals of Glaciology* **34**: 441-446.

Parkinson, C., Cavalieri, D., Gloersen, D., Zwally, J. and Comiso, J. 1999. Arctic sea ice extents, areas, and trends, 1978-1996. *Journal of Geophysical Research* **104**: 20,837-20,856.

Poloczanska, E.S., Brown, C.J., Syderman, W.J., Kiessling, W., Schoeman, D.S., Moore, P.J., Brander, K., Bruno, J.F., Buckley, L.B., Burrows, M.T., Duarte, C.M., Halpern, B.S., Holding, J., Kappel, C.V., O'Connor, M.I., Pandolfi, J.M., Parmesan, C., Schwing, F., Thompson, S.A. and Richardson, A.J. 2013. Global imprint of climate change on marine life. *Nature Climate Change* **3**: 919-925.

Poloczanska, E.S., Smith, S., Fauconnet, L., Healy, J., Tibbetts, I.R., Burrows, M.T. and Richardson, A.J. 2011. Little change in the distribution of rocky shore faunal communities on the Australian east coast after 50 years of rapid warming. *Journal of Experimental Marine Biology and Ecology* **400**: 145-154.

Ridgway, K.R. 2007. Long-term trend and decadal variability of the southward penetration of the East Australian current. *Geophysical Research Letters* **34**: 10.1029/2007GL030393.

Rodolfo-Metalpa, R., Richard, C., Allemand, D. and Ferrier-Pages, C. 2006. Growth and photosynthesis of two Mediterranean corals, *Cladocora caespitosa* and *Oculina patagonica*, under normal and elevated temperatures. *Journal of Experimental Biology* **2009**: 4546-4556.

Salinger, M. 2005. Climate variability and change: past, present and future-an overview. *Climatic Change* **70**: 9-29.

Seabra, R., Wethey, D.S., Santos, A.M. and Lima, F.P. 2011. Side matters: Microhabitat influence on intertidal heat stress over a large geographical scale. *Journal of Experimental Marine Biology and Ecology* **400**: 200-208.

Siegstad, H. and Heide-Jorgensen, M.P. 1994. Ice entrapments of narwhals (*Monodon monoceros*) and white whales (*Delphinapterus leucas*) in Greenland. *Meddeleser om Gronland Bioscience* **39**: 151-160.

Smith, T.M. and Reynolds, R.W. 2003. Extended reconstruction of global sea surface temperatures based on COADS data (1854-1997). *Journal of Climate* **16**: 1495-1510.

Stern, H.L. and Heide-Jorgensen, M.P. 2003. Trends and variability of sea ice in Baffin Bay and Davis Strait, 1953-2001. *Polar Research* **22**: 11-18.

Stuart-Smith, R.D., Barrett, N.S., Stevenson, D.G. and Edgar, G.J. 2010. Stability in temperate reef communities over a decadal time scale despite concurrent ocean warming. *Global Change Biology* **16**: 122-134.

Torrents, O., Tambutte, E., Caminiti, N. and Garrabou, J. 2008. Upper thermal thresholds of shallow vs. deep populations of the precious Mediterranean red coral *Corallium rubrum* (L.): assessing the potential effects of warming in the NW Mediterranean. *Journal of Experimental Marine Biology and Ecology* **357**: 7-19.

Weber, S.B., Broderick, A.C., Groothuis, T.G.G., Ellick, J., Godley, B.J. and Blount, J.D. 2012. Fine-scale thermal adaptation in a green turtle nesting population. *Proceedings of the Royal Society B* **279**: 1077-1084.

Webster, N.S., Botte, E.S., Soo, R.M. and Whalan, S. 2011. The larval sponge holobiont exhibits high thermal tolerance. *Environmental Microbiology Reports* **3**: 756-762.

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