

Marine Science Review - 211

Climate and climate change

In this review:

- A. Recent articles – no abstract available
- B. Recent publications available online
- C. Recent articles with abstracts

A. Recent articles – no abstract available

Patz, J.A., Olson, S.H., and Gray, A.L. **Climate change, oceans, and human health.** *Oceanography* 19(2): 52-59, 2006.

Wang, T. and Overgaard, J. **The heartbreak of adapting to global warming.** *Science* 315(5808): 49-50, 2007.

Kerr, R.A. **US policy: A permanent sea change?** *Science* 315(5813): 756-757, 2007.

Pielke, R., Prins, G., Rayner, S., and Sarewitz, D. **Lifting the taboo on adaptation.** *Nature* 445(7128): 597-598, 2007.

Yang, C.J. and Oppenheimer, M. **A "Manhattan Project" for climate change?** *Climatic Change* 80(3-4): 199-204, 2007.

Kerr, R.A. **Pollutant hazes extend their climate-changing reach.** *Science* 315(5816): 1217, 2007.

Schiermeier, Q. **The new face of the Arctic.** *Nature* 446(7132): 133-135, 2007.

Broecker, W.S. **CO₂ arithmetic.** *Science* 315(5817): 1371, 2007.

Greene, C.H. and Pershing, A.J. **Climate drives sea change.** *Science* 315(5815): 1084-1085, 2007.

B. Recent publications available online

Scientific Expert Group on Climate Change (SEG). 2007. **Confronting Climate Change: Avoiding the Unmanageable and Managing the Unavoidable** [Bierbaum, R.M.; Holdren, J.P., MacCracken, M.C.; Moss, R.H.; and Raven, P.H. (eds.)]. Report prepared for the United Nations Commission on Sustainable Development. Sigma Xi, Research Triangle Park, NC, and the United Nations Foundation, Washington, DC. 144 pp.

Available at: http://www.unfoundation.org/files/pdf/2007/SEG_Report.pdf

Notes: Prepared by an international panel of scientific experts for submission to the UN Commission on Sustainable Development, this report outlines what they consider to be the best measures for mitigating and adapting to global warming. The report summarizes the key aspects of the science of climate change and associated environmental and societal impacts, provides a review of the technological options for slowing climate change by limiting emissions of greenhouse gases, makes recommendations to fulfill the objective set forth in the 1992 UNFCCC, and offers guidance on making society less vulnerable and even more resilient to the changing climate.

Hobday, A.J., Okey, T.A., Poloczanska, E.S., Kunz, T.J. and Richardson, A.J. (eds.) 2006. **Impacts of Climate Change on Australian Marine Life**. Report to the Australian Greenhouse Office, Canberra, Australia.

Available at: <http://www.greenhouse.gov.au/impacts/publications/marinelife.html>

Notes: This report – which comprises three separate parts – provides the first broad synthesis of current knowledge of climate change impacts on Australian marine life. Climate impacts were assessed by (1) reviewing the scientific literature on climate change impacts on Australian marine life in the context of known impacts elsewhere in the world, and (2) developing an indicator-based ranking of the vulnerability of marine life to projected climate changes in the seven Large Marine Domains adjacent to continental Australia. The report concludes that climate change is starting to have a significant impact on Australian marine life, driving fish and seabirds south and threatening coral reefs, and that much more severe impacts could occur in coming decades, affecting sea life, fishing communities and tourism.

C. Recent articles with abstracts

Overpeck, J.T. and Cole, J.E. **Lessons from a distant monsoon**. *Nature* 445(7125): 270-271, 2007.

Notes: The burden of global warming falls most heavily on the developing world. A connection forged between the Indian Ocean climate, Asian monsoons and drought in Indonesia makes for an especially bleak outlook for that nation.

Turner, J., Overland, J.E., and Walsh, J.E. **An Arctic and Antarctic perspective on recent climate change**. *International Journal of Climatology* 27(3): 277-293, 2007.

Notes: We contrast recent climatic and environmental changes and their causes in the Arctic and the Antarctic. There are continuing increases in surface temperatures, losses of sea ice and tundra, and warming of permafrost over broad areas of the Arctic, while most of the major increase in Antarctic temperatures is on the Antarctic Peninsula associated with sea ice loss in the Bellingshausen-Amundsen Seas sector. While both natural atmospheric and oceanic variability, and changes in external forcing including increased greenhouse gas concentrations, must be considered in the quest for understanding such changes, the interactions and feedbacks between system components are particularly strong at high latitudes. For the 1950s to date in the Arctic and for 1957 to date in the Antarctic, positive trends in large-scale atmospheric circulation represented by the Arctic oscillation (AO) and Antarctic oscillations (AAO) and the Pacific North American (PNA) pattern contribute to the long-term temperature trends. However, continuing Arctic trends during the last decade of near neutral AO will require alternate explanations. The trend in the AAO since 1950 is larger than expected from natural variability and may be associated with the decrease in stratospheric ozone over Antarctic. The persistence shown in many Arctic and Antarctic Peninsula components of climate and their influence through possible feedback supports continuation of current trends over the next decade. One can expect large spatial and temporal differences, however, from the relative contributions of intrinsic variability, external forcing, and internal feedback/amplifications. It is particularly important to resolve regional feedback processes in future projections based on modeling scenarios.

McNeil, B.I. and Matear, R.J. **Climate change feedbacks on future oceanic acidification**. *Tellus B* 59(2): 191-198, 2007.

Notes: Oceanic anthropogenic CO₂ uptake will decrease both the pH and the aragonite saturation state (Ω_{arag}) of seawater leading to an oceanic acidification. However, the factors controlling future changes in pH and Ω_{arag} are independent and will respond differently to oceanic climate change feedbacks such as ocean warming, circulation and biological changes. We examine the sensitivity of these two CO₂-related parameters to climate change feedbacks within a coupled atmosphere-ocean model. The ocean warming feedback was found to dominate the climate change responses in the surface ocean. Although surface pH is projected to decrease relatively uniformly by about 0.3 by the year 2100, we find pH to be insensitive to climate change feedbacks, whereas Ω_{arag} is buffered by 15%. Ocean carbonate chemistry creates a situation whereby the direct pH changes due to ocean warming are almost cancelled by the pH changes associated with dissolved inorganic carbon concentrations changes via a reduction in CO₂ solubility from ocean warming. We show that the small climate change

feedback on future surface ocean pH is independent to the amount of ocean warming. Our analysis therefore implies that future projections of surface ocean acidification only need to consider future atmospheric CO₂ levels, not climate change induced modifications in the ocean.

McGranahan, G., Balk, D., and Anderson, B. **The rising tide: assessing the risks of climate change and human settlements in low elevation coastal zones.** *Environment & Urbanization* 19(1): 17-37, 2007.

Notes: Settlements in coastal lowlands are especially vulnerable to risks resulting from climate change, yet these lowlands are densely settled and growing rapidly. In this paper, we undertake the first global review of the population and urban settlement patterns in the Low Elevation Coastal Zone (LECZ), defined here as the contiguous area along the coast that is less than 10 metres above sea level. Overall, this zone covers 2 per cent of the world's land area but contains 10 per cent of the world's population and 13 per cent of the world's urban population. A disproportionate number of the countries with a large share of their population in this zone are small island countries, but most of the countries with large populations in the zone are large countries with heavily populated delta regions. On average, the Least Developed Countries have a higher share of their population living in the zone (14 per cent) than do OECD countries (10 per cent), with even greater disparities in the urban shares (21 per cent compared to 11 per cent). Almost two-thirds of urban settlements with populations greater than 5 million fall, at least partly, in the zone. In some countries (most notably China), urbanization is driving a movement in population towards the coast. Reducing the risk of disasters related to climate change in coastal settlements will require a combination of mitigation, migration and settlement modification.

Gilman, E.L., Ellison, J., Jungblut, V., Van Lavieren, H., Wilson, L., Areki, F., Brighthouse, G., Bungitak, J., Dus, E., Henry, M., Kilman, M., Matthews, E., Sauni, L., Teariki-Ruatu, N., Tukia, S., and Yuknavage, K. **Adapting to Pacific Island mangrove responses to sea level rise and climate change.** *Climate Research* 32(3): 161-176, 2006.

Notes: Stresses associated with effects of climate change, including rise in relative mean sea level, present one set of threats to mangroves. Coastal development and ecosystems in the Pacific Islands region are particularly vulnerable to climate change effects. We investigated the capacity of Pacific Island countries and territories to assess mangrove vulnerability to the effects of climate change, and their capacity to adapt to mangrove responses to these forces. Technical and institutional capacity-building priorities include: (1) strengthening management frameworks to conduct site-specific assessment of mangrove vulnerability and incorporate resulting information into land-use plans to prepare for any landward mangrove migration and offsetting anticipated losses; (2) reducing and eliminating stresses on and rehabilitating mangroves, in part, to increase mangrove resilience to climate change effects; and (3) augmenting abilities to establish mangrove baselines, and monitor gradual changes using standardized techniques through a regional network to distinguish local and climate change effects on mangroves. Other priorities are to: (4) assess how mangrove margins have changed over recent decades; (5) determine projections of trends in mean relative sea level and trends in the frequency and elevation of extreme high water events; (6) measure trends in changes in elevations of mangrove surfaces; and (7) incorporate this information into land-use planning processes. Also in (8) some locations require spatial imagery showing topography and locations of mangroves and coastal development. Land-use planners can use information from assessments predicting shoreline responses to projected sea level rise and other climate change effects to reduce risks to coastal development, human safety, and coastal ecosystems. This advanced planning enables coastal managers to minimize social disruption and cost, minimize losses of valued coastal ecosystems, and maximize available options.

Sterman, J.D. and Sweeney, L.B. **Understanding public complacency about climate change: adults' mental models of climate change violate conservation of matter.** *Climatic Change* 80(3-4): 213-238, 2007.

Notes: Public attitudes about climate change reveal a contradiction. Surveys show most Americans believe climate change poses serious risks but also that reductions in greenhouse gas (GHG) emissions sufficient to stabilize atmospheric GHG concentrations can be deferred until there is greater evidence that climate change is harmful. US policymakers likewise argue it is prudent to wait and see whether climate change will cause substantial economic harm before undertaking policies to reduce emissions. Such wait-and-see policies erroneously presume climate change can be reversed quickly should harm become evident, underestimating substantial delays in the climate's response to anthropogenic forcing. We report experiments with

highly educated adults - graduate students at MIT - showing widespread misunderstanding of the fundamental stock and flow relationships, including mass balance principles, that lead to long response delays. GHG emissions are now about twice the rate of GHG removal from the atmosphere. GHG concentrations will therefore continue to rise even if emissions fall, stabilizing only when emissions equal removal. In contrast, most subjects believe atmospheric GHG concentrations can be stabilized while emissions into the atmosphere continuously exceed the removal of GHGs from it. These beliefs - analogous to arguing a bathtub filled faster than it drains will never overflow - support wait-and-see policies but violate conservation of matter. Low public support for mitigation policies may arise from misconceptions of climate dynamics rather than high discount rates or uncertainty about the impact of climate change. Implications for education and communication between scientists and nonscientists (the public and policymakers) are discussed.

Atrill, M.J., Wright, J., and Edwards, M. **Climate-related increases in jellyfish frequency suggest a more gelatinous future for the North Sea.** *Limnology and Oceanography* 52(1): 480-485, 2007.

Notes: Data obtained since 1958 from the continuous plankton recorder show an increasing occurrence of jellyfish in the central North Sea that is positively related to the North Atlantic Oscillation (NAO) and Atlantic inflow to the northern North Sea. Since 1970, jellyfish frequency has been also significantly negatively correlated with mean annual pH, independent of NAO trends. Jellyfish frequency increased in the mid-1980s, coincident with the reported regime shift in the North Sea and tracking trends in phytoplankton color. As models produced under all climate-change scenarios indicate a move toward a positive NAO, and pH of the oceans is predicted to decrease with rising CO₂, we suggest that jellyfish frequency will increase over the next 100 yr.

Levitan, O., Rosenberg, G., Setlik, I., Setlikova, E., Grigel, J., Klepetar, J., Prasil, O., and Berman-Frank, I. **Elevated CO₂ enhances nitrogen fixation and growth in the marine cyanobacterium *Trichodesmium*.** *Global Change Biology* 13(2): 531-538, 2007.

Notes: The increases in atmospheric pCO₂ over the last century are accompanied by higher concentrations of CO₂(aq) in the surface oceans. This acidification of the surface ocean is expected to influence aquatic primary productivity and may also affect cyanobacterial nitrogen (N)-fixers (diazotrophs). No data is currently available showing the response of diazotrophs to enhanced oceanic CO₂(aq). We examined the influence of pCO₂ [preindustrial ~ 250 ppmv (low), ambient ~400, future ~900 ppmv (high)] on the photosynthesis, N fixation, and growth of *Trichodesmium IMS101*. *Trichodesmium* spp. is a bloom-forming cyanobacterium contributing substantial inputs of 'new N' to the oligotrophic subtropical and tropical oceans. High pCO₂ enhanced N fixation, C : N ratios, filament length, and biomass of *Trichodesmium* in comparison with both ambient and low pCO₂ cultures. Photosynthesis and respiration did not change significantly between the treatments. We suggest that enhanced N fixation and growth in the high pCO₂ cultures occurs due to reallocation of energy and resources from carbon concentrating mechanisms (CCM) required under low and ambient pCO₂. Thus, in oceanic regions, where light and nutrients such as P and Fe are not limiting, we expect the projected concentrations of CO₂ to increase N fixation and growth of *Trichodesmium*. Other diazotrophs may be similarly affected, thereby enhancing inputs of new N and increasing primary productivity in the oceans

Kouwenberg, J.H.M. and Lantoine, F. **Effects of ultraviolet-B stressed diatom food on the reproductive output in Mediterranean *Calanus helgolandicus* (Crustacea; Copepoda).** *Journal of Experimental Marine Biology and Ecology* 341(2): 239-253, 2007.

Notes: Recent predictions anticipate a solar ultraviolet-B increase of 5-10% over temperate latitudes within the next 15 years. As Mediterranean waters are clear, enabling deep UVB penetration, we used controlled experiments to test the effects of equivalent levels of UVB on trophic plankton interactions. We grew the diatom *Skeletonema costatum* in the laboratory under daily 4 h UVB exposure in doses of 10% higher than today in contrast to control cultures (no UVB). UVB-exposed algae showed modification in cell structure, volume increase and delay in cell division, eventually leading to lysis and cell death after five days of daily 4 h exposure. Both control and UVB-stressed *S. costatum* cultures were used as food for wild *Calanus helgolandicus* females collected in the NW Mediterranean. Those fed on control diatoms produced three times more eggs, healthier offspring with fewer lethal naupliar deformities than females fed on UVB-exposed diatoms. Our results provide the first experimental evidence of indirect UVB effects on reproductive output through trophic response in marine plankton. The

sensitivity of the *S. costatum* strain is discussed as well as the reduced reproductive output of the female copepods. We suggest that the low egg numbers and high naupliar deformity ratios are possibly a consequence of UVB-induced deficiency of essential components in the UVB-stressed maternal diet.

Blackford, J.C. and Gilbert, F.J. **pH variability and CO₂ induced acidification in the North Sea.** *Journal of Marine Systems* 64(1-4): 229-241, 2007.

Notes: A coupled carbonate system-marine ecosystem-hydrodynamic model is used to simulate the temporal and spatial variability in pH across the southern North Sea as it relates to the environmental and biological processes affecting CO₂, namely, photosynthesis and respiration, riverine boundary conditions and atmospheric CO₂ concentrations. Annual pH ranges are found to vary from < 0.2 in areas of low biological activity to > 1.0 in areas influenced by riverine signals, consistent with observations and previous studies. It is shown that benthic, as well as pelagic, activity is an important factor in this variability. The acidification of the region due to increased fluxes of atmospheric CO₂ into the marine system is calculated and shown to exceed, on average, 0.1 pH units over the next 50 years and result in a total acidification of 0.5 pH units below pre-industrial levels at atmospheric CO₂ concentrations of 1000 ppm. The potential for measurable changes in biogeochemistry are demonstrated by simulating the observed inhibition of pelagic nitrification with decreasing pH. However, we conclude that there is a lack of knowledge of how acidification might affect the complex interaction of processes that govern marine biogeochemical cycles and a consequent need for further research and observations.

Miles, H., Widdicombe, S., Spicer, J.I., and Hall-Spencer, J. **Effects of anthropogenic seawater acidification on acid-base balance in the sea urchin *Psammechinus miliaris*.** *Marine Pollution Bulletin* 54(1): 89-96, 2007.

Notes: The purple-tipped sea urchin, *Psammechinus miliaris*, was exposed to artificially acidified seawater treatments (pH_w 6.16, 6.63 or 7.44) over a period of 8 days. Urchin mortality of 100% was observed at pH_w 6.16 after 7 days and coincided with a pronounced hypercapnia in the coelomic fluid producing an irrecoverable acidosis. Coelomic fluid acid-base measures showed that an accumulation of CO₂ and a significant reduction in pH occurred in all treatments compared with controls. Bicarbonate buffering was employed in each case, reducing the resultant acidosis, but compensation was incomplete even under moderate environmental hypercapnia. Significant test dissolution was inferred from observable increases in the Mg²⁺ concentration of the coelomic fluid under all pH treatments. We show that a chronic reduction of surface water pH to below 7.5 would be severely detrimental to the acid-base balance of this predominantly intertidal species, despite its ability to tolerate fluctuations in pCO₂ and pH in the rock pool environment. The absence of respiratory pigment (or any substantial protein in the coelomic fluid), a poor capacity for ionic regulation and dependency on a magnesium calcite test, make echinoids particularly vulnerable to anthropogenic acidification. Geological sequestration leaks may result in dramatic localised pH reductions, e.g. pH 5.8. *P. miliaris* is intolerant of pH 6.16 seawater and significant mortality is seen at pH 6.63.

Helmuth, B., Mieszkowska, N., Moore, P., and Hawkins, S.J. **Living on the edge of two changing worlds: Forecasting the responses of rocky intertidal ecosystems to climate change.** *Annual Review of Ecology, Evolution, and Systematics* 37: 373-404, 2006.

Notes: Long-term monitoring shows that the poleward range edges of intertidal biota have shifted by as much as 50 km per decade, faster than most recorded shifts of terrestrial species. Although most studies have concentrated on species-range edges, recent work emphasizes how modifying factors such as regional differences in the timing of low tide can overwhelm large-scale climatic gradients, leading to a mosaic of environmental stress. We discuss how changes in the mean and variability in climatic regimes, as modified by local and regional factors, can lead to complex patterns of species distribution rather than simple range shifts. We describe how ecological forecasting may be used to generate explicit hypotheses regarding the likely impacts of different climatic change scenarios on the distribution of intertidal species and how related hindcasting methods can be used to evaluate changes that have already been detected. These hypotheses can then be tested over a hierarchy of temporal and spatial scales using coupled field and laboratory-based approaches.

Parmesan, C. **Ecological and evolutionary responses to recent climate change.** *Annual Review of Ecology, Evolution, and Systematics* 37: 637-669, 2006.

Notes: Ecological changes in the phenology and distribution of plants and animals are occurring in all well-studied marine, freshwater, and terrestrial groups. These observed changes are heavily biased in the directions predicted from global warming and have been linked to local or regional climate change through correlations between climate and biological variation, field and laboratory experiments, and physiological research. Range-restricted species, particularly polar and mountain top species, show severe range contractions and have been the first groups in which entire species have gone extinct due to recent climate change. Tropical coral reefs and amphibians have been most negatively affected. Predator-prey and plant-insect interactions have been disrupted when interacting species have responded differently to warming. Evolutionary adaptations to warmer conditions have occurred in the interiors of species' ranges, and resource use and dispersal have evolved rapidly at expanding range margins. Observed genetic shifts modulate local effects of climate change, but there is little evidence that they will mitigate negative effects at the species level.

Konopka, P., Engel, A., Funke, B., Müller, R., Groß, J., Günther, G., Wetter, T., Stiller, G., von Clarmann, T., Glatthor, N., Oelhaf, H., Wetzell, G., López-Puertas, M., Pirre, M., Huret, N., and Riese, M. **Ozone loss driven by nitrogen oxides and triggered by stratospheric warmings can outweigh the effect of halogens.** *Journal of Geophysical Research* 112(D5): art. D05105, 2007.

Notes: Ozone loss in the lower and middle stratosphere in spring and summer, in particular over polar regions, is driven mainly by halogens and nitrogen oxides (NO_x). Whereas the stratospheric chlorine levels are expected to decrease in the future, the role of NO_x for the O₃ budget in a changing climate is not well quantified. Here we combine satellite measurements and model simulations to diagnose the accumulated O₃ loss during winter and spring 2002-2003 in the Arctic polar stratosphere. We show that in a winter stratosphere strongly disturbed by warmings, O₃ loss processes driven by halogens and NO_x can significantly overlap within the polar column and become comparable in magnitude even if a significant, halogen-induced O₃ loss has occurred. Whereas, until the beginning of March 2003, polar column O₃ loss was mainly caused by the halogen chemistry within the vortex at an altitude around 18 km, the chemical O₃ destruction in March and April was dominated by the NO_x chemistry in O₃-rich air masses transported from the subtropics and mixed with the polar air above the region affected by the halogens. This NO_x-related O₃ loss started around mid-December 2002 in subtropical air masses above 30 km that moved poleward after the major warming in January, descended to 22 km with an increasing magnitude of O₃ loss and reached surprisingly high values of up to 50% local loss around the end of April. To some extent, the NO_x-driven O₃ loss was enhanced by mesospheric air trapped in the vortex at the beginning of the winter as a layer of few km in the vertical and transported downward within the vortex. The effect of NO_x transported from the subtropics dominated the O₃ loss processes in the polar stratosphere in spring 2003, both relative to the effect of the halogens and relative to the contribution of the mesospheric NO_x sources. A comparison with the 1999/2000 Arctic winter and with the Antarctic vortex split event in 2002 shows that wave events triggered by stratospheric warmings may significantly enhance O₃ loss driven by NO_x when O₃- and NO_x-rich air masses from the subtropics are transported poleward and are mixed with the vortex air.

Greally, B.R. and et al. **Observations of 1,1-difluoroethane (HFC-152a) at AGAGE and SOGE monitoring stations in 1994-2004 and derived global and regional emission estimates.** *Journal of Geophysical Research* 112(6): art. D06308, 2007.

Notes: Ground-based in situ measurements of 1,1-difluoroethane (HFC-152a, CH₃CHF₂) which is regulated under the Kyoto Protocol are reported under the auspices of the AGAGE (Advanced Global Atmospheric Gases Experiment) and SOGE (System of Observation of halogenated Greenhouse gases in Europe) programs. Observations of HFC-152a at five locations (four European and one Australian) over a 10 year period were recorded. The annual average growth rate of HFC-152a in the midlatitude Northern Hemisphere has risen from 0.11 ppt/yr to 0.6 ppt/yr from 1994 to 2004. The Southern Hemisphere annual average growth rate has risen from 0.09 ppt/yr to 0.4 ppt/yr from 1998 to 2004. The 2004 average mixing ratio for HFC-152a was 5.0 ppt and 1.8 ppt in the Northern and Southern hemispheres, respectively. The annual cycle observed for this species in both hemispheres is approximately consistent with measured annual cycles at the same locations in other gases which are destroyed by OH. Yearly global emissions of HFC-152a from 1994 to 2004 are derived using the global mean HFC-152a observations and a 12-box 2-D model. The global emission of HFC-152a has risen from 7 Kt/yr to 28 Kt/yr from 1995 to 2004. On the basis of observations of above-baseline elevations in the HFC-152a record and a consumption model,

regional emission estimates for Europe and Australia are calculated, indicating accelerating emissions from Europe since 2000. The overall European emission in 2004 ranges from 1.5 to 4.0 Kt/year, 5-15% of global emissions for 1,1-difluoroethane, while the Australian contribution is negligible at 5-10 tonnes/year, <0.05% of global emissions.

Rahmstorf, S. **A semi-empirical approach to projecting future sea-level rise.** *Science* 315(5810): 368-370, 2007.

Notes: A semi-empirical relation is presented that connects global sea-level rise to global mean surface temperature. It is proposed that, for time scales relevant to anthropogenic warming, the rate of sea-level rise is roughly proportional to the magnitude of warming above the temperatures of the pre-Industrial Age. This holds to good approximation for temperature and sea-level changes during the 20th century, with a proportionality constant of 3.4 millimeters/year per degrees C. When applied to future warming scenarios of the Intergovernmental Panel on Climate Change, this relationship results in a projected sea-level rise in 2100 of 0.5 to 1.4 meters above the 1990 level.

Portner, H.O. and Knust, R. **Climate change affects marine fishes through the oxygen limitation of thermal tolerance.** *Science* 315(5808): 95-97, 2007.

Notes: A cause-and-effect understanding of climate influences on ecosystems requires evaluation of thermal limits of member species and of their ability to cope with changing temperatures. Laboratory data available for marine fish and invertebrates from various climatic regions led to the hypothesis that, as a unifying principle, a mismatch between the demand for oxygen and the capacity of oxygen supply to tissues is the first mechanism to restrict whole-animal tolerance to thermal extremes. We show in the eelpout, *Zoarces viviparus*, a bioindicator fish species for environmental monitoring from North and Baltic Seas (Helcom), that thermally limited oxygen delivery closely matches environmental temperatures beyond which growth performance and abundance decrease. Decrements in aerobic performance in warming seas will thus be the first process to cause extinction or relocation to cooler waters.

Schrag, D.P. **Preparing to capture carbon.** *Science* 315(5813): 812-813, 2007.

Notes: Carbon sequestration from large sources of fossil fuel combustion, particularly coal, is an essential component of any serious plan to avoid catastrophic impacts of human-induced climate change. Scientific and economic challenges still exist, but none are serious enough to suggest that carbon capture and storage will not work at the scale required to offset trillions of tons of carbon dioxide emissions over the next century. The challenge is whether the technology will be ready when society decides that it is time to get going.

O'Connor, M.I., Bruno, J.F., Gaines, S.D., Halpern, B.S., Lester, S.E., Kinlan, B.P., and Weiss, J.M. **Temperature control of larval dispersal and the implications for marine ecology, evolution, and conservation.** *Proceedings of the National Academy of Sciences [USA]* 104(4): 1266-1271, 2007.

Notes: Temperature controls the rate of fundamental biochemical processes and thereby regulates organismal attributes including development rate and survival. The increase in metabolic rate with temperature explains substantial among-species variation in life history traits, population dynamics, and ecosystem processes. Temperature can also cause variability in metabolic rate within species. Here, we compare the effect of temperature on a key component of marine life cycles among a geographically and taxonomically diverse group of marine fish and invertebrates. Although innumerable lab studies document the negative effect of temperature on larval development time, little is known about the generality versus taxon-dependence of this relationship. We present a unified, parameterized model for the temperature dependence of larval development in marine animals. Because the duration of the larval period is known to influence larval dispersal distance and survival, changes in ocean temperature could have a direct and predictable influence on population connectivity, community structure, and regional-to-global scale patterns of biodiversity.

Tanhua, T., Körtzinger, A., Friis, K., Waugh, D.W., and Wallace, D.W.R. **An estimate of anthropogenic CO₂ inventory from decadal changes in oceanic carbon content.** *Proceedings of the National Academy of Sciences [USA]* 104(9): 3037-3042, 2007.

Notes: Increased knowledge of the present global carbon cycle is important for our ability to understand and to predict the future carbon cycle and global climate. Approximately half of the anthropogenic carbon released to the atmosphere from fossil fuel burning is stored in the ocean, although distribution and regional fluxes of the ocean sink are debated. Estimates of anthropogenic carbon (*C_{ant}*) in the oceans remain prone to error arising from (i) a need to estimate preindustrial reference concentrations of carbon for different oceanic regions, and (ii) differing behavior of transient ocean tracers used to infer *C_{ant}*. We introduce an empirical approach to estimate *C_{ant}* that circumvents both problems by using measurement of the decadal change of ocean carbon concentrations and the exponential nature of the atmospheric *C_{ant}* increase. In contrast to prior approaches, the results are independent of tracer data but are shown to be qualitatively and quantitatively consistent with tracer-derived estimates. The approach reveals more *C_{ant}* in the deep ocean than prior studies; with possible implications for future carbon uptake and deep ocean carbonate dissolution. Our results suggest that this approach applied on the unprecedented global data archive provides a means of estimating the *C_{ant}* for large parts of the world's ocean.

Ammann, C.M., Joos, F., Schimel, D.S., Otto-Bliesner, B.L., and Tomas, R.A. **Solar influence on climate during the past millennium: Results from transient simulations with the NCAR Climate System Model.** *Proceedings of the National Academy of Sciences [USA]* 104(10): 3713-3718, 2007.

Notes: The potential role of solar variations in modulating recent climate has been debated for many decades and recent papers suggest that solar forcing may be less than previously believed. Because solar variability before the satellite period must be scaled from proxy data, large uncertainty exists about phase and magnitude of the forcing. We used a coupled climate system model to determine whether proxy-based irradiance series are capable of inducing climatic variations that resemble variations found in climate reconstructions, and if part of the previously estimated large range of past solar irradiance changes could be excluded. Transient simulations, covering the published range of solar irradiance estimates, were integrated from 850 AD to the present. Solar forcing as well as volcanic and anthropogenic forcing are detectable in the model results despite internal variability. The resulting climates are generally consistent with temperature reconstructions. Smaller, rather than larger, long-term trends in solar irradiance appear more plausible and produced modeled climates in better agreement with the range of Northern Hemisphere temperature proxy records both with respect to phase and magnitude. Despite the direct response of the model to solar forcing, even large solar irradiance change combined with realistic volcanic forcing over past centuries could not explain the late 20th century warming without inclusion of greenhouse gas forcing. Although solar and volcanic effects appear to dominate most of the slow climate variations within the past thousand years, the impacts of greenhouse gases have dominated since the second half of the last century.

Kossin, J.P., Knapp, K.R., Vimont, D.J., Murnane, R.J., and Harper, B.A. **A globally consistent reanalysis of hurricane variability and trends.** *Geophysical Research Letters* 34(4): art. L04815, 2007.

Notes: Recently documented trends in the existing records of hurricane intensity and their relationship to increasing sea surface temperatures suggest that hurricane intensity may be increasing due to global warming. However, it is presently being argued that the existing global hurricane records are too inconsistent to accurately measure trends. As a first step in addressing this debate, we constructed a more homogeneous global record of hurricane intensity and found that previously documented trends in some ocean basins are well supported, but in others the existing records contain trends that may be inflated or spurious.

Kwok, R. **Near zero replenishment of the Arctic multiyear sea ice cover at the end of 2005 summer.** *Geophysical Research Letters* 34(5): art. L05501, 2007.

Notes: The remarkably low Arctic multiyear (MY) sea ice coverage following the summer of 2005 is placed in the context of its variability over the past seven years (2000-2006). Annual cycles of MY ice coverage, from QuikSCAT and satellite passive

ice motion, show that the replenishment of MY ice area at the end of this summer is near zero ($0.1 \times 10^6 \text{ km}^2$) compared to the previous five summers of 1.0, 1.2, 0.4, 0.4, and $0.9 \times 10^6 \text{ km}^2$. This is examined in terms of anomalies in ice export and the record of freezing (*FDD*) and melting degree-days (*MDD*). The 2005 summer (Jun-Sep) saw the highest Fram Strait ice export ($>0.25 \times 10^6 \text{ km}^2$) compared to the 7-year mean of $0.14 \times 10^6 \text{ km}^2$. This directly explains $\sim 40\%$ of the decrease in MY coverage of $0.6 \times 10^6 \text{ km}^2$ between Jan 2005 and Jan 2006. The cumulative effects of the recent warmer winters and summers, relative to the longer-term record since 1958, explain the balance. For this short record, the combination of spatially averaged *FDD* and *MDD* anomalies of the preceding year explain $\sim 63\%$ of the variance in the replenishment areas.

Stearns, L.A. and Hamilton, G.S. **Rapid volume loss from two East Greenland outlet glaciers quantified using repeat stereo satellite imagery.** *Geophysical Research Letters* 34(5): art. L05503, 2007.

Notes: The coastal portions of Kangerdlugssuaq and Helheim glaciers in southeast Greenland lost at least $51 \pm 8 \text{ km}^3 \text{ yr}^{-1}$ of ice between 2001-2006 due to thinning and retreat, according to an analysis of sequential digital elevation models (DEMs) derived from stereo ASTER satellite imagery. The dominant contribution to this ice loss was dynamic thinning caused by the acceleration in flow of both glaciers. Peak rates of change, including thinning rates of $\sim 90 \text{ m yr}^{-1}$, coincided with the rapid increases in flow speed. Extrapolation of the measured data to the ice divides yields an estimated combined catchment volume loss of $\sim 122 \pm 30 \text{ km}^3 \text{ yr}^{-1}$, which accounts for half the total mass loss from the ice sheet reported in recent studies. These catchment-wide volume losses contributed $\sim 0.31 \pm 0.07 \text{ mm yr}^{-1}$ to global sea level rise over the 5-year observation period with the coastal regions alone contributing at least $0.1 \pm 0.02 \text{ mm yr}^{-1}$.

Rintoul, S.R. **Rapid freshening of Antarctic Bottom Water formed in the Indian and Pacific oceans.** *Geophysical Research Letters* 34(6): art. L06606, 2007.

Notes: Repeat hydrographic sections occupied in 1995 and 2005 reveal a rapid decline in the salinity and density of Antarctic Bottom Water throughout the Australian Antarctic Basin. The basin-wide shift of the deep potential temperature-salinity ($\theta - S$) relationship reflects freshening of both the Indian and Pacific sources of Antarctic Bottom Water. The $\theta - S$ curves diverge for waters cooler than -0.1°C , corresponding to a layer up to 1000 m thick over the Antarctic continental slope and rise. Changes over the last decade are in the same direction but more rapid than those observed between the late 1960s and the 1990s. When combined with recent observations of similar freshening of North Atlantic Deep Water, these results demonstrate that dense water formed in both hemispheres is freshening in response to changes in the high latitude freshwater balance and rapidly transmitting the signature of changes in surface climate into the deep ocean.

Gazeau, F., Quiblier, C., Jansen, J. M., Gattuso, J.-P., Middelburg, J.J., and Heip, C.H.R. **Impact of elevated CO_2 on shellfish calcification.** *Geophysical Research Letters* 34(7): art. L07603, 2007.

Notes: Ocean acidification resulting from human emissions of carbon dioxide has already lowered and will further lower surface ocean pH. The consequent decrease in calcium carbonate saturation potentially threatens calcareous marine organisms. Here, we demonstrate that the calcification rates of the edible mussel (*Mytilus edulis*) and Pacific oyster (*Crassostrea gigas*) decline linearly with increasing $p\text{CO}_2$. Mussel and oyster calcification may decrease by 25 and 10%, respectively, by the end of the century, following the IPCC IS92a scenario ($\sim 740 \text{ ppmv}$ in 2100). Moreover, mussels dissolve at $p\text{CO}_2$ values exceeding a threshold value of $\sim 1800 \text{ ppmv}$. As these two species are important ecosystem engineers in coastal ecosystems and represent a large part of worldwide aquaculture production, the predicted decrease of calcification in response to ocean acidification will probably have an impact on coastal biodiversity and ecosystem functioning as well as potentially lead to significant economic loss.

Reist, J.D., Wrona, F.J., Prowse, T.D., Power, M., Dempson, J.B., Beamish, R.J., King, J.R., Carmichael, T.J., and Sawatzky, C.D. **General effects of climate change on Arctic fishes and fish populations.** *Ambio* 35(7): 370-380, 2006.

Notes: Projected shifts in climate forcing variables such as temperature and precipitation are of great relevance to arctic freshwater ecosystems and biota. These will result in many direct and indirect effects upon the ecosystems and fish present therein. Shifts projected for fish populations will range from positive to negative in overall effect, differ among species and also among populations within species depending upon their biology and tolerances, and will be integrated by the fish within their local aquascapes. This results in a wide range of future possibilities for arctic freshwater and diadromous fishes. Owing to a dearth of basic knowledge regarding fish biology and habitat interactions in the north, complicated by scaling issues and uncertainty in future climate projections, only qualitative scenarios can be developed in most cases. This limits preparedness to meet challenges of climate change in the Arctic with respect to fish and fisheries.

Reist, J.D., Wrona, F.J., Prowse, T.D., Power, M., Dempson, J.B., King, J.R., and Beamish, R.J. **An overview of effects of climate change on selected Arctic freshwater and anadromous fishes.** *Ambio* 35(7): 381-387, 2006.

Notes: Arctic freshwater and diadromous fish species will respond to the various effects of climate change in many ways. For wide-ranging species, many of which are key components of northern aquatic ecosystems and fisheries, there is a large range of possible responses due to inter- and intra-specific variation, differences in the effects of climate drivers within ACIA regions, and differences in drivers among regions. All this diversity, coupled with limited understanding of fish responses to climate parameters generally, permits enumeration only of a range of possible responses which are developed here for selected important fishes. Accordingly, in-depth examination is required of possible effects within species within ACIA regions, as well as comparative studies across regions. Two particularly important species (Arctic char and Atlantic salmon) are examined as case studies to provide background for such studies

Reist, J.D., Wrona, F.J., Prowse, T.D., Dempson, J.B., Power, M., Kock, G., Carmichael, T.J., Sawatzky, C.D., Lehtonen, H., and Tallman, R.F. **Effects of climate change and UV radiation on fisheries for Arctic freshwater and anadromous species.** *Ambio* 35(7): 402-410, 2006.

Notes: Fisheries for arctic freshwater and diadromous fish species contribute significantly to northern economies. Climate change, and to a lesser extent increased ultraviolet radiation, effects in freshwaters will have profound effects on fisheries from three perspectives: quantity of fish available, quality of fish available, and success of the fishers. Accordingly, substantive adaptation will very likely be required to conduct fisheries sustainably in the future as these effects take hold. A shift to flexible and rapidly responsive 'adaptive management' of commercial fisheries will be necessary; local land- and resource-use patterns for subsistence fisheries will change; and, the nature, management and place for many recreational fisheries will change. Overall, given the complexity and uncertainty associated with climate change and related effects on arctic freshwaters and their biota, a much more conservative approach to all aspects of fishery management will be required to ensure ecosystems and key fished species retain sufficient resiliency and capacity to meet future changes.

Wrona, F.J., Prowse, T.D., Reist, J.D., Hobbie, J.E., Levesque, L.M.J., and Vincent, W.F. **Climate change effects on aquatic biota, ecosystem structure and function.** *Ambio* 35(7): 359-369, 2006.

Notes: Climate change is projected to cause significant alterations to aquatic biogeochemical processes, (including carbon dynamics), aquatic food web structure, dynamics and biodiversity, primary and secondary production; and, affect the range, distribution and habitat quality/quantity of aquatic mammals and waterfowl. Projected enhanced permafrost thawing is very likely to increase nutrient, sediment, and carbon loadings to aquatic systems, resulting in both positive and negative effects on freshwater chemistry. Nutrient and carbon enrichment will enhance nutrient cycling and productivity, and alter the generation and consumption of carbon-based trace gases. Consequently, the status of aquatic ecosystems as carbon sinks or sources is very likely to change. Climate change will also very likely affect the biodiversity of freshwater ecosystems across most of the Arctic. The magnitude, extent, and duration of the impacts and responses will be system- and location-dependent. Projected effects on aquatic mammals and waterfowl include altered migration routes and timing; a possible increase in the incidence of mortality and decreased growth and productivity from disease and/or parasites; and, probable changes in habitat suitability and timing of availability.

Wrona, F.J., Prowse, T.D., Reist, J.D., Hobbie, J.E., Levesque, L.M.J., Macdonald, R.W., and Vincent, W.F. **Effects of ultraviolet radiation and contaminant-related stressors on Arctic freshwater ecosystems.** *Ambio* 35(7): 388-401, 2006.

Notes: Climate change is likely to act as a multiple stressor, leading to cumulative and/or synergistic impacts on aquatic systems. Projected increases in temperature and corresponding alterations in precipitation regimes will enhance contaminant influxes to aquatic systems, and independently increase the susceptibility of aquatic organisms to contaminant exposure and effects. The consequences for the biota will in most cases be additive (cumulative) and multiplicative (synergistic). The overall result will be higher contaminant loads and biomagnification in aquatic ecosystems. Changes in stratospheric ozone and corresponding ultraviolet radiation regimes are also expected to produce cumulative and/or synergistic effects on aquatic ecosystem structure and function. Reduced ice cover is likely to have a much greater effect on underwater UV radiation exposure than the projected levels of stratospheric ozone depletion. A major increase in UV radiation levels will cause enhanced damage to organisms (biomolecular, cellular, and physiological damage, and alterations in species composition). Allocations of energy and resources by aquatic biota to UV radiation protection will increase, probably decreasing trophic-level productivity. Elemental fluxes will increase via photochemical pathways.
