Chapter 2
Anthropogenic Ocean Change: The Consummate Threat to Marine Mammal Welfare

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Abstract Global warming is the consummate conservation and animal welfare challenge of our time. It defies traditional conservation management models and requires we broaden traditional cause and effect time horizons. Continually rising concentrations of CO_2 and other greenhouse gases (GHGs) prolong retention of the sun's energy before it escapes back into space—assuring that global temperatures must rise. Oceans have absorbed ~30% of anthropogenically emitted CO_2 and over 90% of the heat trapped by the world's enhanced greenhouse effect. Sea surface temperature and global ocean heat content have been rising accordingly. Along with rising temperatures, pH, oxygen saturation, salinity, and other aspects of ocean chemistry also are changing. Cumulative interactions among all of these symptoms of anthropogenic ocean change are and will continue to impact ocean biota. In this chapter, we summarize observed and projected anthropogenically driven ocean changes that have been and will continue to compromise marine mammal welfare.

2.1 Introduction

The action required to address global warming stands the traditional model of conservation on its head. In traditional approaches to conservation, we can build a fence, establish a preserve, or hire game wardens, and at the end of the day feel like we have protected the welfare of a particular species. But we cannot build a fence to protect melting sea ice from rising temperatures. Nor can game wardens halt ocean

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acidification. These are the ultimate threats to marine mammal welfare, and only united societal action can combat these challenges. Yet, many in the scientific and public domains continue to be preoccupied with traditional threats, and our focus largely remains on near-term uncertainties rather than the longer-term certainties. Consequently, the understanding needed to inspire timely action often has been lacking.

Current global warming is caused by human interference with earth's energy balance (IPCC 2013). The shortwave radiation coming to earth from the sun ultimately must be balanced by the outgoing long-wave radiation emitted, from the earth and its atmosphere, back into space (Lutgens and Tarbuck 2004, Chap. 2). Without this, the 1.22×10^{17} J of energy earth absorbs from the sun each second would "raise earth's temperature to nearly 800,000 K after a billion years" (Pierrehumbert 2011, p. 33). In other words, if the sun's heat accumulated here and was not reradiated into space, earth long ago would have been reduced to a ball of molten rock or hot gas. Various "climate forcings" can perturb the balance of incoming and outgoing energy (Hansen and Sato 2004). The shading effects of aerosols released into the atmosphere by volcanoes, for example, can provide a temporary negative climate forcing—cooling the earth by reflecting the sun's energy back into space before it gets to the surface. Rising concentrations of CO_2 and other GHGs, on the other hand, provide a positive climate forcing, trapping ever-increasing amounts of the sun's energy and prolonging retention of that heat before it escapes back into space. Simply put, the laws of physics require the world to warm as long as atmospheric GHG concentrations rise (Pierrehumbert 2011).

Naturally occurring events, like volcanic eruptions or El Niño, result in short- and medium-term variation in climate and weather—with some periods cooler than average and some warmer. The important point is that when GHG levels in the atmosphere are stable, the average, or "baseline," around which natural climate fluctuates, can be represented as a level or horizontal line (Fig. 2.1). That level long-term average allows us to use our experiences of the past to plan future actions—like when and where to plant crops and when and how much we will be able to harvest. In no small part, agriculture owes its rise and success over the last several thousand years to a favorable and stable climate (Rockström et al. 2009). When GHG concentrations are steadily increasing, as they are now, the natural variation we always have experienced continues, but it occurs over a higher and rising baseline (Fig. 2.1). Natural climate fluctuations, that surround the rising average, create uncertainty in knowing exactly when particular events will occur. We cannot, for example, confidently predict the first year summer sea ice will disappear from the Arctic, nor when surface temperatures in the Mediterranean Sea will have risen 2 °C. But, without stopping the increase in GHG concentration, it is certain we ultimately will exceed both thresholds. Unlike most predictions, which become less accurate the farther out we project, predicting that various global warming-related thresholds will be exceeded becomes more certain the farther into the future we look. Society's challenge in dealing with anthropogenic climate change is to maintain focus on the ultimate certainty—that without stopping GHG rise, we will exceed all of the thresholds we care about (Steinacher et al. 2013). The only reason we might wish to focus on the near-term uncertainties is if we don't really care about the world we are leaving behind us or for the welfare of future generations.

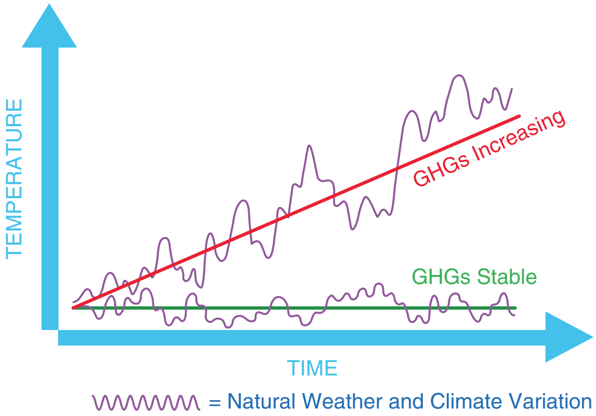

Fig. 2.1 Conceptual diagram of the impact of ever-rising atmospheric GHG concentrations. With GHG levels stable, the average of natural climate fluctuations is a level line. But with chronically rising GHG levels, average temperatures must rise. Despite the chaotic and unpredictable nature of natural variations, it always will be warmer than it would have been without the higher GHG concentrations

2.2 Anthropogenic Ocean Change

Oceans play a critical role in the earth's response to rising atmospheric concentrations of GHGs. About 30% of the CO_2 released by human activity has gone into the oceans, and, 93% of the extra solar energy captured by our enhanced greenhouse effect, has been trapped as heat by the oceans of the world (Hoegh-Guldberg et al. 2014). Climate change can be thought of as the cast of symptoms caused by the anthropogenic changes to the composition of Earth's atmosphere. In the oceans, these symptoms are many and complex. Anthropogenic ocean change includes rising temperatures, altered circulation patterns and temperature stratification, and numerous changes in ocean chemistry. In turn, all of these ocean changes influence the welfare of marine mammals and the other species upon which they depend.

Subsequent chapters will cover details of how ocean changes affect the welfare of individual species or groups of marine mammals. Here, we focus on four well-documented ocean changes the cumulative effects of which will have increasing influence on the welfare of marine mammals and other ocean biota. We review the observational record of changes already documented. We project future oceanic conditions with which marine mammals will be forced to contend, and compare them to present conditions. Finally, we provide examples of ways in which ocean changes may affect marine mammal welfare.

2.3 Temperature Effects

Sea surface temperatures (SSTs), which have been increasing at least since the middle of the twentieth century (Hoegh-Guldberg et al. 2014), may provide the most readily observed oceanic impact of the anthropogenically enhanced greenhouse effect. Riser et al. (2016) compared data from the HMS Challenger expedition with data collected by the recently deployed and widespread array of Argo profilers. They reported a nearly 0.6 °C increase in near-surface ocean average temperature during this 135-year period. The upward trajectory of SSTs follows the positive trend in surface air temperatures. SSTs, however, show less seasonal and interannual variation than air temperatures, which can respond more rapidly to short-term fluctuations in the climate system (Wijffels et al. 2016).

Ongoing temperature increase is further smoothed at depths below the ocean's surface (Fig. 2.2). Averaged over the top 2000 m of ocean depth, data from the Argo profiler array show a steady rise in ocean heat content during the last 10 years and provide a measure of the earth's growing energy imbalance (Wijffels et al. 2016). The warming of the ocean appears to have recently hastened. Wijffels et al. (2016)

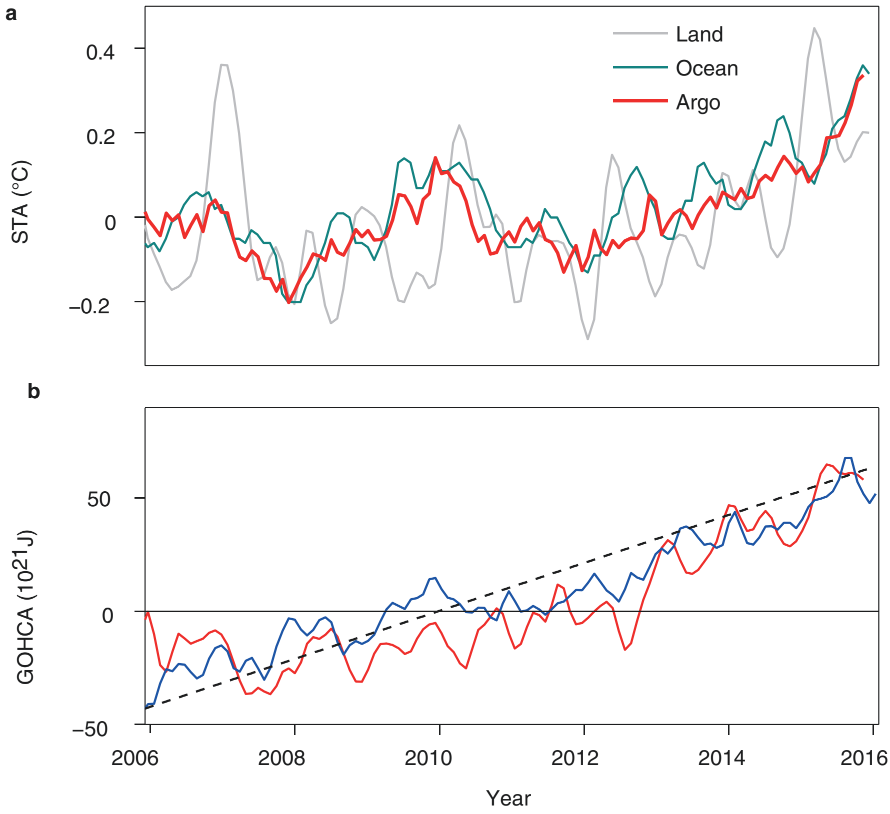

Fig. 2.2 Ocean warming rates excerpted from Fig. 1 in Wijffels et al. 2016. (**a**) Globally averaged surface temperature anomaly (STA, °C), from 5 m Argo temperature (*red*), NOAA (National Oceanic and Atmospheric Administration) global ocean (*turquoise*), and a 6-month running mean of NOAA (NOAA 2015) global land averages (*grey*). (**b**) Global ocean 0–2000 m heat content anomaly. Line plots in **b** are two interpolation methods and a robust linear fit

calculated the rate of near-surface warming at approximately 0.2 °C per decade. Gleckler et al. (2016) estimated the total ocean heat uptake since the 1870s has been 33 (±14) × 10^{22} J and calculated that approximately half of that increase occurred after 1997.

Ocean temperatures are expected to continue to rise, reflecting the guaranteed heating of the earth from increases in anthropogenically emitted GHGs. Figure 2.3 illustrates projected centennial sea surface warming for two different futures.

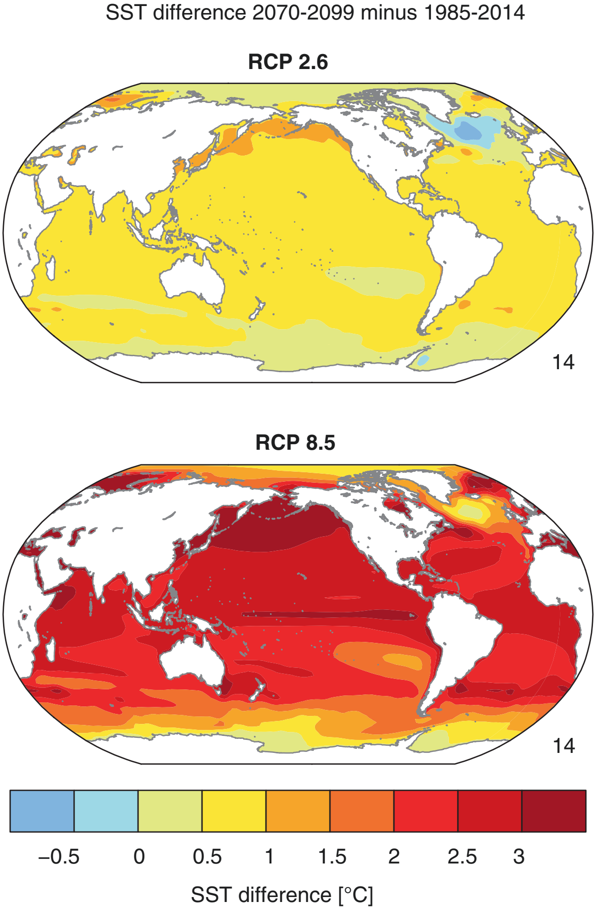

Fig. 2.3 Sea surface temperature (SST) maps showing the projected warming of the world's ocean between now and the end of this century under two greenhouse gas emissions scenarios or representative concentration pathways (RCPs). RCP 2.6 represents aggressive mitigation of emissions leading to <2 °C atmospheric warming through this century. RCP 8.5 represents a continuing path of unabated emissions and ~5 °C atmospheric warming. Climate model data used in Figs. 2.3–2.7 are taken from the CMIP5 archive (Taylor et al. 2012, BAMS). The number of different models used to form each multi-model mean map is given in the bottom right corner of each map

These are based on so-called Representative Concentration Pathways (RCPs), which provide possible future trajectories of GHG emissions and concentrations. Each RCP is tied into a coherent socioeconomic story line (Wayne 2013). Based on these GHG pathways, climate models then calculate to what extent GHG concentrations perturb earth's energy balance and what implications this forcing has for temperature and other climate variables. RCPs therefore provide a range of standardized inputs into modeling efforts around the world, focused on studying the effects of a range of future emissions choices dependent upon societal decisions. Here, we focus on two pathways, RCP 8.5, which assumes continuation of the GHG emissions path that world societies have been following, and RCP 2.6, which assumes dramatically mitigated emissions. Following RCP 2.6 would likely limit annual global mean air temperature increase to <2 °C above preindustrial levels by the end of the century, and it would allow mean air temperature to decline slightly thereafter. In contrast, if we continue to follow RCP 8.5, annual mean temperature increases are projected to reach 5 °C by the end of this century (Wayne 2013). Following our current path of unabated GHG rise (RCP 8.5) also would mean annual temperatures over the world's ocean surface are likely to increase by 2.4 °C between now and the end of this century. Average temperatures in some regions will be far higher, but few areas will warm less than 0.5 °C (Fig. 2.3). Rahmstorf et al. (2015) reported that the subpolar North Atlantic is one of the very few areas of the world to have cooled in recent decades. This apparently is due to a slowing of the Atlantic Ocean overturning currents that brings warm surface water into the region. This slowdown is possibly triggered by increased buoyancy due to warming and freshening (e.g., by meltwater from the Greenland ice sheet) of surface waters. If we maintain business-as-usual emissions (RCP 8.5), ocean cooling in the North Atlantic will be overwhelmed by this century's end, as a result of the warming of the atmosphere above, but warming there still will be less than most other areas of the ocean.

In contrast to continuing along the RCP 8.5 emissions pathway, following RCP 2.6 would take ocean temperatures on a far cooler path, with end-of-century SST increasing only 0.6 °C. That is, average SST warming on our current path will be four times what it could be if society adopted the RCP 2.6 pathway. Committing to the RCP 2.6 mitigation scenario would also minimize stratification of the upper ocean. The Bering Sea is on the other end of the temperature trend spectrum from the North Atlantic. Currently among the most productive seas of the world, the Bering Sea is projected to warm more than most other regions regardless of which emissions path we take (Figs. 2.3 and 2.4). Such warming is sure to impact the welfare of marine mammals and other marine biota.

Perhaps as important as the rise in annual average temperatures is the range of extremes that will be experienced. In some areas, like the Arabian Sea where SSTs historically have fluctuated little, seasonal and interannual variation is expected to continue to be small. In other geographic regions, seasonal or single year natural fluctuations will result in temporary periods during which high temperatures are well above the long-term mean trends. In the Bering Sea, for example, under RCP

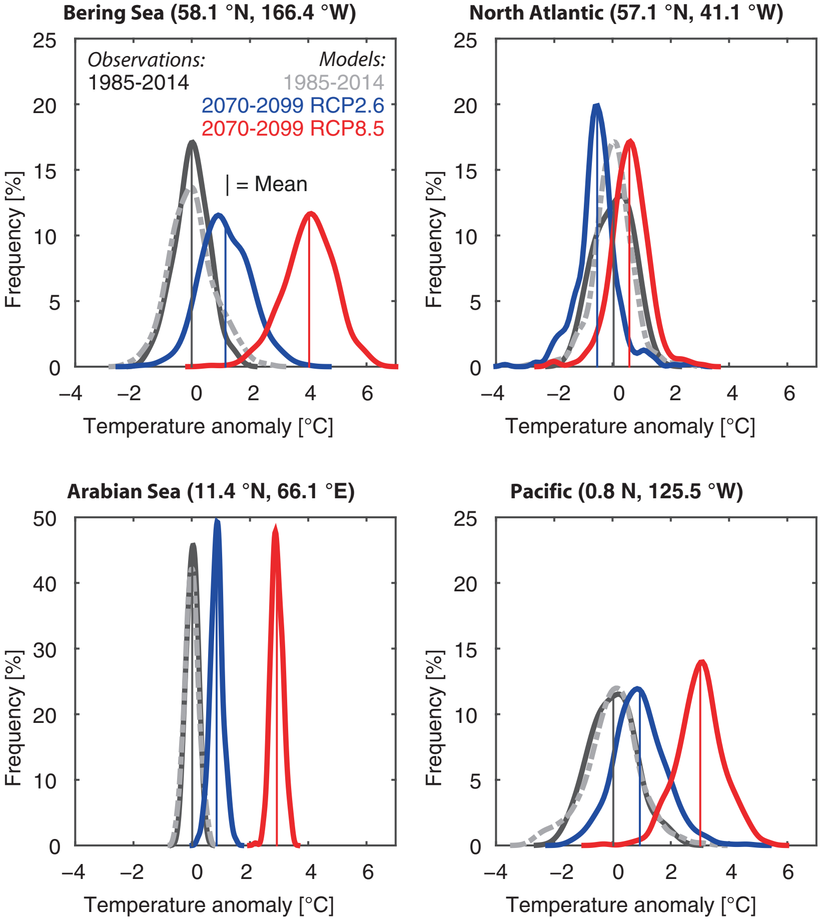

Fig. 2.4 Distribution of observed and projected sea surface temperature anomalies for four disparate oceanic regions. Frequency of occurrence (%) expressed as kernel-smoothed histograms of the distribution of sea surface temperature from each 30-year period. Note the different *y*-axis scale for the Arabian Sea, a tropical basin with little interannual variability in temperature. The climate models, emissions scenarios, and time periods used are the same as in Fig. 2.3

8.5, future annual mean temperatures are projected to be 4 °C warmer than at present, while an individual year might be 6 °C warmer than present norms (Fig. 2.4). Recent observations illustrate how seasonal and annual temperature extremes, on top of already warmer average conditions, could have major impacts on biota. In early 2016, unusually high, in historic terms, surface water temperatures caused coral bleaching across 93% of the Australian Great Barrier Reef. Investigators concluded that reaching those high water temperatures would have been nearly impossible without the chronic warming associated with rising GHG concentrations (King et al. 2016).

Regardless of societal actions, the world's oceans will continue to warm through the century. Even with the aggressive mitigation required to follow the RCP 2.6 emissions pathway, sea surface warming during the next 85 years will match or exceed the reported 0.6 °C surface warming (Riser et al. 2016) of the past 135 years. Because it tracks SST (Wijffels et al. 2016), we expect global ocean heat content to continue to rise as well, meaning all ocean depths will be warming. Indeed, Mathesius et al. (2015) showed that even after a complete removal of all anthropogenic CO_2 from the atmosphere, it will take several hundred years for SSTs to return to preindustrial levels. As with terrestrial regions, continuing on our present GHG emissions path will mean a largely unrecognizable ocean world by this century's end (Figs. 2.3 and 2.4). For example, the average SST increase of over 4 °C, with some years as much as 6 °C warmer than the current mean, projected under RCP 8.5, would totally transform the Bering Sea. Figures 2.3 and 2.4 also emphasize that the rate at which ocean temperatures continue to rise, will be highly dependent on the mitigation pathway society chooses to adopt.

2.4 Changes in Salinity

Secondary effects of climate change include altered precipitation and circulation patterns. These changes have a direct bearing on ocean chemistry, including salinity patterns. Salinity patterns, in turn, influence stratification of water masses and vary regionally (Hoegh-Guldberg et al. 2014). Rising temperatures affect both evaporation and rainfall and will further alter salinity patterns. The observed salinity pattern has been amplifying at a rate of 16% $°C^{-1}$ over the last roughly 50 years (Durack et al. 2012). This pattern of amplification reveals the clear fingerprint of an intensifying hydrological cycle, which in turn, tends to make dry regions drier and wet regions wetter (Held and Soden 2006). In oceans, this has led to enhancement of historic salinity patterns, with evaporation-dominated midlatitudes becoming more saline, while relatively fresh surface waters in rainfall-dominated tropical regions and polar regions have become fresher (Durack et al. 2012). We can anticipate even more dramatic exaggeration of ocean salinity patterns in the future. Much of the surface area of the Atlantic Ocean and large swaths in the southern Pacific are expected to become much more saline by the end of the century, while most of the Pacific Ocean and high-latitude areas will freshen (Fig. 2.5). The contrast between profound freshening in the North Atlantic and Arctic Ocean and salinity increases in most of the rest of the Atlantic will undoubtedly have major ramifications for biota. Also, because models historically have underestimated the observed rate of salinity changes (Durack et al. 2012), the scale and regional contrasts of future salinity patterns may be far greater than shown in Fig. 2.5. If society adopts an emissions pathway similar to RCP 2.6, globally averaged freshening of surface waters would only be 1/3 of what it would be under RCP 8.5.

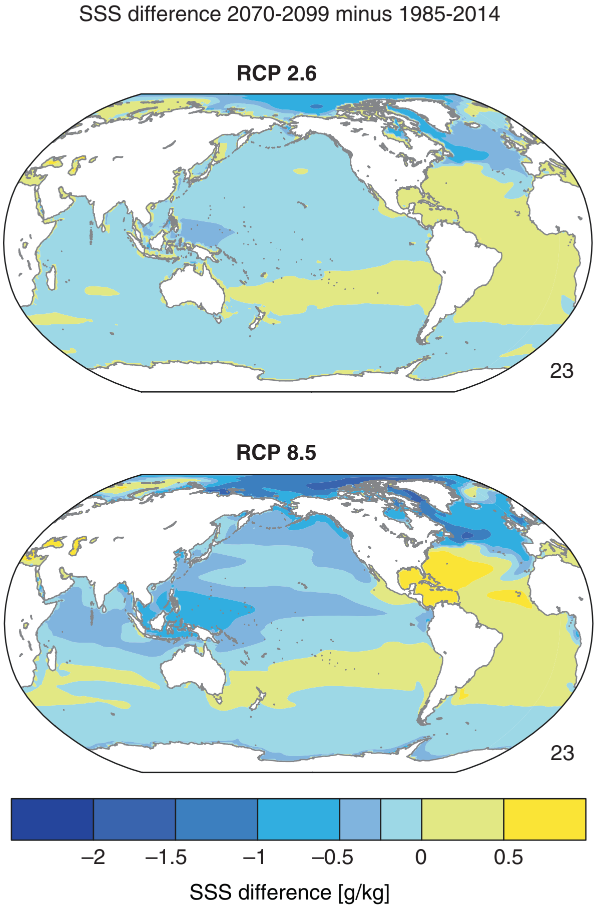

Fig. 2.5 As Fig. 2.3, but for sea surface salinity (SSS). Most of the ocean surface is projected to freshen as a consequence of an intensifying hydrological cycle and changes in ocean currents. Increased freshwater runoff from the melting of large ice sheets is typically not yet included in these climate models and would lead to additional discharge of freshwater (also contributing to sea level rise)

2.5 Changes in Oxygen Concentrations

The mean dissolved oxygen concentration in global oceans currently is ~162 µmol kg^{-1} (~162 mmol m^{-3}). This concentration varies widely among oceanic regions, with some Antarctic waters supersaturated at over 500 µmol kg^{-1}, while some coastal sediments and deep layers in the Black Sea and Cariaco Basin are essentially depleted of oxygen (Pörtner et al. 2014). Warmer water holds less oxygen and oceans globally are projected to see dramatic declines in oxygen content

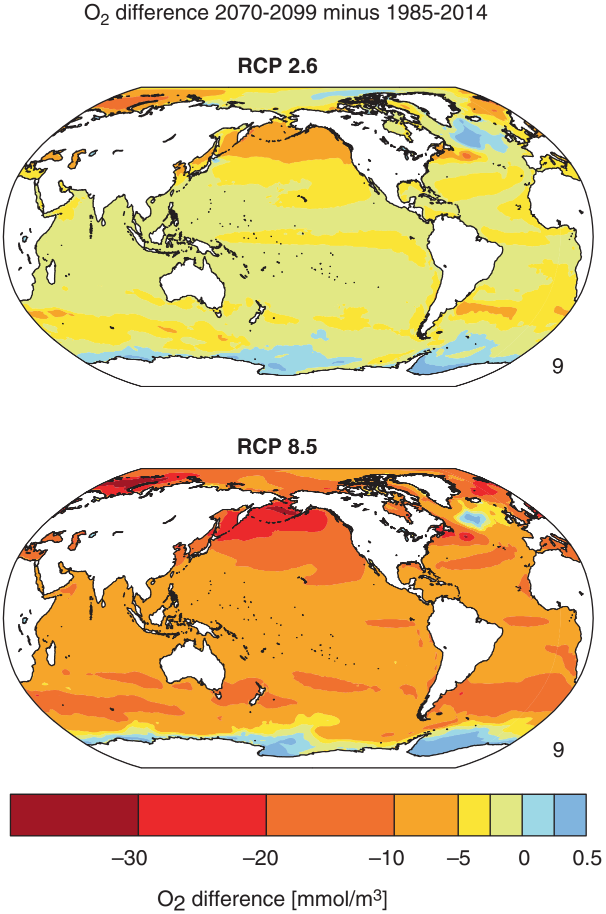

Fig. 2.6 As Fig. 2.3, but for oxygen (O_2) concentration at the ocean surface. As climate change leads to a warmer and more stratified ocean, O_2 concentrations will decline almost everywhere. O_2 reductions are also expected below the surface, leading to an expansion of so-called oxygen minimum zones, where O_2 concentrations are too low for most aerobic biota

regardless of our emissions path (Fig. 2.6). As global ocean oxygenation declines, regional contrasts also will be enhanced. The highly productive waters of the North Pacific, Bering, and Barents seas will see strong declines in oxygen available in the water column, while the subpolar North Atlantic and Antarctic seas will continue to become oxygen enriched.

The mean surface ocean oxygen concentration, between now and the end of the century, is projected to decline by 3.7% if we continue along the RCP 8.5 emissions path. On top of general declines in oxygen content with rising temperatures, increased stratification and other factors are expected to expand near shore and pelagic hypoxic zones. Oxygen concentrations below 60 $\mu M\ kg^{-1}$ are lethal to >50% of benthos. These hypoxic areas currently include ~5% of global ocean volume (Deutsch et al. 2011). As surface layers warm, and in some areas become less saline, stratification can enhance hypoxic conditions (Deutsch et al. 2011). Assuming we continue to follow RCP 8.5, Bopp et al. (2013) projected up to 30% increase in suboxic (low oxygen carrying) waters by 2100 as a result of various global warming influences on ocean water structure and chemistry. Following RCP 2.6 through the century, however, mean global oxygen concentrations would decline by only 1% from present values, with far less drastic regional gradients (Fig. 2.6).

2.6 Changes in Ocean Acidity

Atmospheric concentrations of carbon dioxide (CO_2) have been rising, and ~30% of anthropogenically derived CO_2 has been absorbed by the ocean (Hoegh-Guldberg et al. 2014). Rising concentrations of CO_2 increase carbonic acid concentrations and acidify the ocean. Globally, the surface ocean pH declined 0.1 points (from 8.25 to 8.14) between 1751 and 2004 (Jacobson 2005). The current ocean pH ranges from 7.8 to 8.4 (Pörtner et al. 2014) and has been decreasing at a rate of −0.0013 to −0.0024 pH units per year (Pörtner et al. 2014). The observed ocean acidification (OA) rate varies greatly on a regional basis and, for example, is 50% greater in the northern Atlantic than the subtropical Atlantic (Olafsson et al. 2009). Reduced salinities due to freshwater from ice melt or precipitation can exacerbate OA by reducing availability of buffers occurring in more saline waters (Jacobs and Giulivi 2010; Vélez-Belchí et al. 2010). OA also is more severe in cold regions, which have a higher sea-air flux rate for CO_2, and because cold waters have a lower buffer capacity than warmer waters, although, both factors can vary greatly on a seasonal basis (Olafsson et al. 2009). If we continue to follow our current emissions pathway (RCP 8.5), mean surface ocean pH is projected to decline by ~0.28, from the present global mean of 8.08 to 7.80. This 3.5% decline in less than a century dwarfs the rate of pH decline Jacobson (2005) reported for the previous 250 years. Observed regional gradients also will be further enhanced (Fig. 2.7), with ramifications for large segments of ocean biota.

Of all the changing ocean chemistries, the CO_2 impact may be most significant. Higher aqueous CO_2 concentrations result in decreased carbonate ion concentrations and make it more difficult for marine organisms to form biogenic calcium carbonate ($CaCO_3$). Increasing solubility of the forms of calcium carbonate (calcite, magnesium calcite, and aragonite) that are critical components of marine organisms' shells and skeletons has important ramifications for ocean biota (Orr et al. 2005). Numerous studies have attempted to evaluate impact of various levels of OA on oceanic biota. Olafsson et al. (2009) concluded, as a result of ongoing OA, aragonite solubility has increased. Large areas of benthos that historically lived in an environment where aragonite was supersaturated, are becoming undersaturated. Controlled measurements of the impact of that undersaturation, however, are still needed. Hoegh-Guldberg et al. (2014) and Pörtner et al. (2014) provide extensive examples of the complications

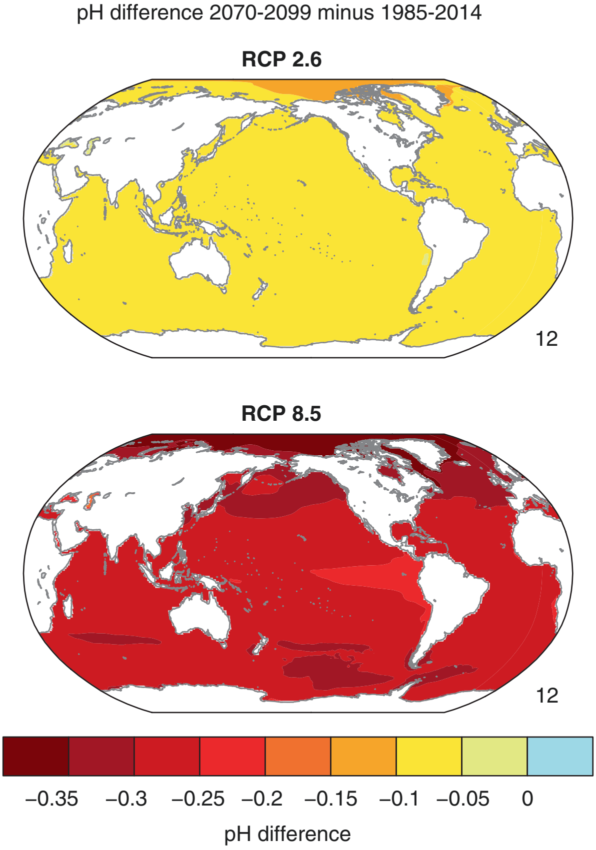

Fig. 2.7 As Fig. 2.3, but for pH at the ocean surface. The lower the pH, the more acidic the water. The projected decrease of pH in all basins is a direct consequence of the increased uptake of CO_2 by the ocean. Indeed, this is one of the most robust features of climate change, as it is a well-understood chemical process. Note that the seemingly small change under emissions scenario RCP 2.6 in fact already constitutes a significant stress for some calcifying ocean organisms

involved in such assessments, reporting a mixture of effects. Some species appeared unaffected by observed or experimental levels of OA, some showed negative impacts, and some appeared to benefit. In the long run, however, if OA continues, negative impacts on marine calcifiers are expected to dominate. Ridgwell and Schmidt (2010) calculated that we currently are on an OA path unmatched in the last 65 million years and that impacts on marine calcifiers are likely to be severe. Our projections (Fig. 2.7) make it clear that overall pH declines will be exacerbated at higher latitudes, and Orr et al. (2005) projected that detrimental effects, in those cooler, less buffered, regions, could be noticeable within decades. As with the other variables we have examined, the benefits of GHG mitigation are clear. Following RCP 2.6 would result in only 0.06

(0.76%) decline in global ocean pH, with much less amplification of regional gradients (Fig. 2.7). The potential for dramatically lowered pH to have major negative impacts on ocean productivity, and the ability of society to avoid the most profound declines, provide strong incentive to mitigate GHG rise.

2.7 Cumulative Effects

As with pH, biological ramifications of change in temperature, oxygen concentration, and salinity are individually varied and complicated and are yet to be fully understood. A full understanding of all of the complications, however, is not necessary to hypothesize a future negative trend for ocean biota. On our current emissions path, oceans will be profoundly different places than they are today. The cumulative effects of end-of-century pH decreases, along with anticipated reductions in oxygenation, changes in salinity, and warmer temperatures, are most likely to be negative with regard to forms of ocean life that we value and to which we have become accustomed (Hoegh-Guldberg et al. 2014; Pörtner et al. 2014). Bopp et al. (2013) summarized these ongoing ocean changes and projected they would result in an ~8% decline in ocean net primary productivity by 2100, if we continue to follow current emissions pathways. However, changes in all of the parameters we examined would be far less severe if society were to adopt significant and sustained emissions reductions. Bopp et al. (2013) estimated that following the RCP 2.6 path would mean only a ~2% decline in net primary productivity by the end of the century.

2.8 Impacts on Marine Mammals

Because subsequent chapters will describe examples of observed and expected impacts on individual marine mammal species, or groups of species, we provide only a few examples here. It is clear, however, that the anthropogenic ocean changes described in previous sections can affect marine mammal welfare in multiple ways. Most impacts on marine mammals will likely reflect biological productivity and food availability as mediated by changing temperatures, ocean structure, and productivity. We cannot, however, rule out more direct impacts of rising temperatures, especially in regions where the greatest water temperature rise is projected. The observed distribution of marine mammal pursuit predators may be a harbinger of direct effects of rising temperature. Because fish are ectotherms and can swim faster at warmer temperatures, ocean warming could increase energetic costs of underwater pursuits for marine mammals. Cairns et al. (2008) concluded that marine mammal (and bird) predators are limited, by the metabolic expense of pursuit, to waters cooler than ~20 °C. Similarly, McIntyre et al. (2011) noted that southern elephant seals (*Mirounga leonina*) consistently dove deeper and stayed down longer in areas where waters were warmer. Early impacts of warming on marine mammals may therefore include range contractions to higher latitudes, as well as altered and presumably less efficient vertical stratification of foraging efforts.

Polar bears (*Ursus maritimus*) are largely restricted to catching their seal prey from the surface of the sea ice (Amstrup 2003), and there is a linear relationship between sea ice extent and global mean temperature (Amstrup et al. 2010). Declining availability of sea ice has been linked to reduced body condition, survival, and population size (Rode et al. 2010; Regehr et al. 2007). Although some species may respond positively to changes in Arctic marine productivity as sea ice cover is reduced (Crawford et al. 2015), polar bears will not have access to that productivity without the sea ice platform. And, given ongoing ocean changes, any improvements in productivity are likely to be only temporary. Also, polar bears are not likely to compensate for lost sea ice access by taking advantage of terrestrial food sources (Rode et al. 2015). Their dependence on the surface of the ice for catching prey, therefore, translates into a direct relationship between rising temperatures and polar bear food availability, regardless of potential changes in marine productivity.

Marine mammals that are tied to specific haul-out sites or rookeries could encounter higher foraging costs if altered prey distributions require longer foraging trips (Péron et al. 2012; Hazen et al. 2013). On the other hand, if prey distributions become constrained by thermal stratification or hypoxic zones, marine mammal foraging may, temporarily be enhanced by localized concentrations of prey (Hazen et al. 2009). Sea level rise (from thermal expansion and freshwater ice melt—direct consequences of rising temperatures), combined with altered prey availability, will, in the long run, negatively affect most species with high fidelity to specific locales (e.g., haul-out sites and rookeries).

Warming of ice-covered waters will alter species distributions, which could make alternate prey available but also could increase competition and even introduce new predation risks for high-latitude species adapted to ice-covered seas. Moore and Huntington (2009) hypothesized that subarctic cetaceans will move north as sea ice extent declines and open water seasons lengthen. As a result of recent declines in the spatial and temporal extent of sea ice in Hudson Bay and Hudson Strait, killer whale (*Orcinus orca*) sightings in Hudson Bay are on the increase (Oosthoek 2012), exposing resident marine mammals (and their prey) to a new predation risk. Polar bears in the Davis Strait region of Eastern Canada maintained high numbers into the early 2000s despite declining sea ice availability. There, polar bears appear to have offset some of their dependence on ringed seals (*Phoca hispida*), which themselves depend on relatively solid ice cover, with harp seals (*Pagophilus groenlandicus*) which prefer a more broken ice edge habitat. This may reflect a shift of harp seal distribution in response to northerly movement of the sea ice conditions they require for whelping (Peacock et al. 2013). Also it is likely to be a temporary condition with the harp seals following remaining ice as it continues a northerly retreat.

2.9 Conclusions

Here, we have examined ongoing ocean changes that will profoundly affect the future welfare of marine mammals and the marine environments that support them. We increasingly are aware of how climate change already has altered environments on land and at sea, with cascading impacts on welfare of the animals those environments support. Different climate models, as well as different simulations from the same model, provide a number of possible futures for any given GHG path society may take. It is important to recognize that although models project a wide range of possible future paths, we will get to realize only one path in real life. If we are lucky, our actual realization may be similar to models on the low end of the projected severity scale. All model outcomes, however, that do not include a halt to the increase in atmospheric GHG concentrations, predict a future ocean system that will be continually changing in unfavorable ways. As long as GHG concentrations increase, we will not see stability return to ocean temperatures, sea ice extent, oxygen concentrations, or pH, and marine mammals as well as other ocean biota will continually struggle to keep pace with an environment changing faster than it has in millennia. In other words, there will be no sustainable future—ocean biota and human lives depending on it, always, will be shooting at a moving target.

Although we can point to specific examples of marine mammal response to individual climate drivers, the ultimate threat anthropogenic ocean change poses for marine mammal welfare will be changes in their supporting food web caused by the cumulative effects of changing ocean temperature and chemistry. As a result of rising temperatures, lowered pH, and reduced oxygen concentration, Bopp et al. (2013) projected strong declines in global ocean net primary productivity through this century. Because these negative trends will persist over multi-centennial time frames (Mathesius et al. 2015), the impact of anthropogenic ocean change must be recognized as the consummate challenge to future welfare of all marine mammals and the ocean habitats supporting them.

The good news is that the most significant contributor to future uncertainty is in our hands. We cannot control the natural variation in the climate system (Fig. 2.1). We can, however, control the slope of the rising baseline. We can choose to keep our climate in "runaway" mode, we can choose a more gradual slope, or ideally we can choose a path (like RCP 2.6) that stops the rise in GHG emissions and bends our current upward slope to a new level baseline. Following RCP 2.6 rather than RCP 8.5 would mean less than one quarter of the global ocean SST increase toward which we are now heading. It also would result in one third of the change in ocean salinity, one quarter of the pH decline, and less than one third of the decline in ocean oxygenation. In other words, we could avoid the worst of oceanic changes that future global warming has to offer. Perhaps most importantly, following RCP 2.6 does not just reduce near-term impacts. On multi-centennial time scales, temperatures, pH, and oxygen saturation will stabilize on the RCP 2.6 emissions scenario (Mathesius et al. (2015); (Fig. 2.8)). But the urgency of action cannot be overstated. Procrastination now will assure catastrophe later. If society waits to address

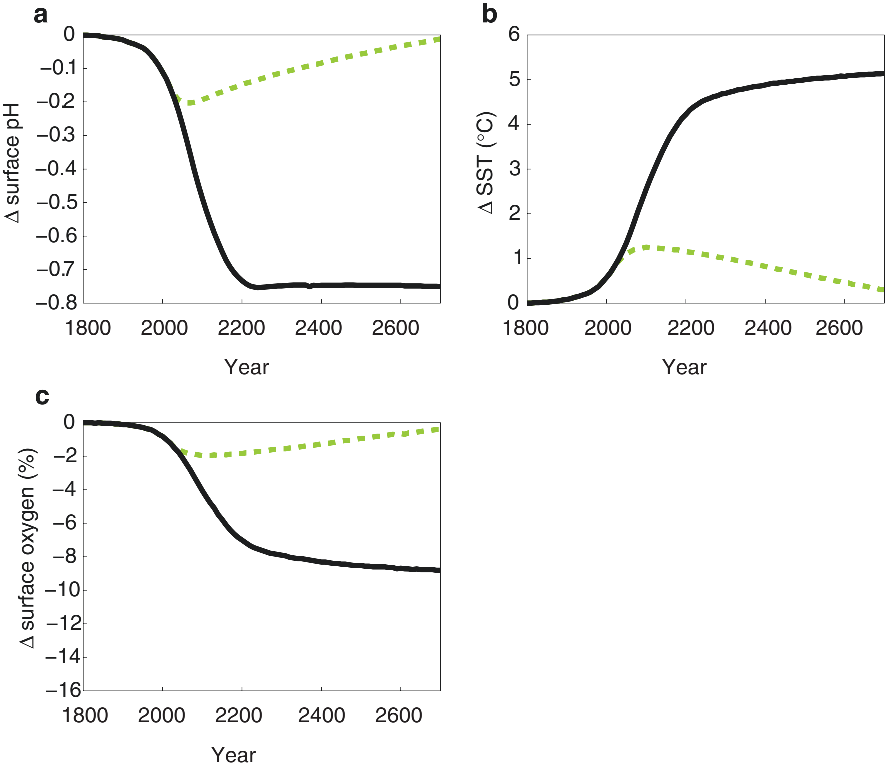

Fig. 2.8 Anomalies of globally averaged ocean variables (excerpted from Fig. 2 in Mathesius et al. 2015). Trajectories for RCP 8.5 (*black*) and RCP 2.6 (*green*), showing globally averaged anomalies of: (**a**) surface pH, (**b**) sea surface temperature (SST), and (**c**) surface dissolved oxygen. All anomalies were calculated with respect to year 1800

emissions challenges until the summer sea ice disappears, or other thresholds critical to marine mammals are exceeded, it is unlikely policy makers will have time or resources to think about, or prioritize, the welfare of marine mammals. By then, food and water shortages, refugee crises, and other human welfare challenges may trump all conservation concerns. Our current path clearly is not in the best interest of marine mammal welfare. We can assure a better future for marine mammals and the rest of us, but, time is of the essence!

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