Ecosystem Loss and its Implications for Greenhouse Gas Concentration Stabilisation

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Abstract

The objective of the Climate Change Convention requires that atmospheric concentrations of greenhouse gases should be stabilised at a level which allows ecosystems to adapt naturally to climate change. Yet there is substantial and compelling evidence that the degree of climate change which has already occurred is affecting both species and ecosystems, in many cases adversely. It appears very likely that species will increasingly become extinct and ecosystems will be lost as a result of little further change in the climate. In the context of the objective of the Convention, it can thus be reasonably be argued that at least some ecosystems are not "adapting naturally" to climate change and that atmospheric concentrations of greenhouse gases are already too high.

1. Introduction and background

The ultimate objective of the Climate Change Convention is well known for its call for greenhouse gas concentrations in the atmosphere to be stabilised at a level that would "prevent dangerous anthropogenic interference with the climate system". However, a longstanding debate about what constitutes "dangerous interference" has so far proved inconclusive and has not given unambiguous guidance to policy-makers as to the level at which to stablise concentrations. It may thus be wise to pay more attention to the second part of the objective which says that "such a [concentration stabilisation] level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change …". Evidence concerning the impacts of climate change upon both ecosystems and the species that comprise them is fairly clear-cut and likely to be less prone to subjective judgement than attempting to define "dangerous".

Indeed, there is substantial and increasing evidence that some ecosystems are failing to adapt to the degree of climate change that has already occurred, and that both species extinctions and ecosystem loss are likely with further, fairly modest, changes in the climate. In the last decade, a host of evidence been gathered that shows a very strong correlation between changes in species behaviour and changes in the climate. Two recent so-called meta-analyses by Parmesan and Yohe [1] and by Root *et al* [2] are instructive because they combine a broad range of results to test whether or not a coherent pattern of species/climate change correlations exists across different geographical regions and a wide range of species.

The first analysis examined the results of 143 studies of 1,473 species from all regions of the world. Of the 587 species showing significant changes in distribution, abundance, phenology, morphology or genetic frequencies, 82% had shifted in the direction expected if they were climate change-induced, i.e. towards higher latitudes or altitudes, or earlier spring events. The timing of spring events, such as egg-laying by birds or flowering by plants, was shown by 61 studies to have shifted earlier by an average 5.1 days per decade over the last half-century, with changes being most pronounced at higher latitudes. The second analysis reviewed studies of more than 1,700 species, and found similar results: 87% of shifts in phenology and 81% of range shifts were in the direction expected from climate change. These studies give a very high confidence that climate change is already impacting biodiversity. However, simply because species are affected by climate change it does not necessarily mean that the effects will be adverse; some may be beneficial.

In assessing likely species extinctions and ecosystem loss, a particular concern is climate change-induced alteration of species ranges. Individual species can be threatened when their preferred "climate space" moves to an area where they are unable to go or that is fundamentally unsuitable because, for example, the underlying geology is different or because it is utilised by human beings. Species that are likely to be unable to move to their altered climate space include those that currently inhabit islands or mountain ranges.[1]

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[1] It has been argued that because climate has changed considerably in the recent geological past most current species are well adapted to climate-related movement. However, past climate change occurred in the absence of recent large-scale human fragmentation of the landscape which inhibits "natural" movement. Also, past climatic fluctuations did not peak at such high temperatures or rise so rapidly as may occur under the IPCC scenarios. Finally, extinctions are known to have occurred during the recent geological past and there are doubtless many unknown extinctions too. Some or many of these were climate-related (see, for example, Shapiro *et al* (2004), *Science*, 306, pp 1561-1565.)

Ecosystem loss is likely because species will not all move to the same extent or at the same rate as their climate space changes. Any particular ecosystem consists of an assemblage of species, some of which are near the edges of their ranges and others that are not. Those at their range edges will tend to move as their climate space changes whereas those nearer their range centres need not. This differential movement will be exaggerated by opportunistic, robust species tending to move more rapidly and faring better when they do. As mentioned above, impediments to movement may be habitat fragmentation by humans or differences in the underlying geology of the area across which species move. The composition of ecosystems, and hence the ecosystems themselves, will thus change.

A further concern is that, because species do not act in isolation, changes in one particular species or group of species can affect many others, often in unpredictable ways. In the next section of this paper, a recent example of this type of occurrence is examined. The section after that briefly looks at some forecasts of climate change-induced species movement and the effect that this might have on both species and ecosystems. Finally, the implications that these studies have for concentration levels of atmospheric greenhouse gases are examined.

2. Ecosystem change in the Northeast Atlantic

Seabirds on the North Sea coast of Britain suffered a large-scale breeding failure in 2004 [3]. In Shetland, Orkney and Fair Isle, tens of thousands of seabirds failed to raise any young. The total Shetland population of nearly 7000 pairs of great skuas produced only a handful of chicks, and the 1000 or more pairs of arctic skuas none at all. Shetland's 24,000 pairs of arctic terns and more than 16,000 pairs of kittiwakes have also probably suffered near total breeding failure. This continues a trend (especially in south Shetland) of several years, so much so that some kittiwake colonies are beginning to disappear, despite the fact that the birds are long-lived and can thus survive short-term breeding failures. In Orkney, all of the large arctic tern breeding colonies in the north isles failed. Arctic and great skuas also had a very poor breeding season and numbers of guillemots and kittiwakes were very low.

Whilst the exact cause and extent of the breeding failures is still being investigated, it strongly indicates a widespread food shortage, especially of sandeels, a small fish that forms the staple diet of many UK seabirds. Whilst surface feeders such as terns and kittiwakes might be expected to be disadvantaged by a shortage of sandeels, it is indicative of the probable scale of shortage that deep-diving birds like guillemots (which can dive down to 100m) also failed to breed this year.

A shortage of sandeels is independently indicated by the Danish sandeel fishery which accounts for about 90% of the North Sea catch. In recent years, this fishery has been allocated quotas of around 800,000 to 900,000 tonnes, of which 600,000 to 700,000 tonnes is usually taken. Last year, however, Denmark undershot its quota significantly, catching only 300,000 tonnes and this year's catch is apparently similar [4]. However, whilst the sandeel population has apparently fallen significantly, this does not appear to result solely, or even mainly, from overfishing, in at least some of areas where sea birds' breeding failures have occurred. Shetland has, for example, operated a seabird-friendly sandeel fishing regime for several years. In 2004, the waters around the south of Shetland were closed to sandeel fishing altogether, and a reduced 'Total Allowable Catch' was introduced to the north.

It appears likely that climate change has played a significant part in sandeel declines. Sea surface temperatures in the North Sea in 2003 and 2004 were significantly higher than the 30-year (1961 to 1990) average (see: http://www.met-office.gov.uk/research/hadleycentre/obsdata/MOHSST.html). A study of sandeels in the North Sea indicates that their numbers are inversely proportional to sea temperature during the egg and larval stages, and there is further evidence that this is, in turn, linked to plankton abundance around the time of sandeel egg hatching [5]. The study also indicated that the adverse effect of rising sea temperatures is most marked in the southern North Sea where the lesser sandeel is near the southern limit of its range, leading to the conclusion that the southern limit of sandeel distribution may shift northwards if conditions continue to get warmer.

Plankton populations in the North Sea have certainly changed. Work by the Sir Alister Hardy Foundation, based on continuous plankton recording over more than four decades, has identified a "regime shift" in the plankton composition of the North Sea since about 1986, when an increased influx of warm Atlantic water had major ecological consequences [6]. Indeed, the Foundation has recently shown that across the entire the Northeast Atlantic sea surface temperature change is accompanied by increased phytoplankton abundance in cooler regions and decreased phytoplankton abundance in warmer regions [7]. They conclude that "Future warming is therefore likely to alter the spatial distribution of primary and secondary pelagic production, affecting ecosystem services and placing additional stress on already-depleted fish and mammal populations".

In summary, it would appear that a large-scale change in marine ecosystems is occurring in the North Sea, caused in large part by climate change. The plankton regime has certainly changed and it is hard to find an explanation other than sea temperature rise that adequately accounts for it. Sandeel numbers have declined and a change in sea temperature coupled with a change in the plankton population (also induced by temperature change) seems a likely explanation. Sea bird breeding success was certainly low in 2004, most probably due to the fall in sandeel numbers.

3. Some forecast of species and ecosystem changes

In the wake of the large numbers of publications reporting strong correlations between climate change and alterations in species ranges, many workers have modelled species responses to future climate change. Such models typically work on the basis of defining the climate "space" or "envelope" for particular species and then employing climate models to forecast where that space will be in the future. Whilst species will not necessarily move to fill their future climate space, the models give a good picture of possible future movement and hence of where movement might be difficult, for example where the climate space for a land-based species moves entirely to a marine area [8, 9]. Recently, a number of workers have focussed upon species that are endemic to limited areas that that have few, if any, options for movement [10].

For example, Williams *et al* conducted a study of the Australian Wet Tropics World Heritage Area which is the most biologically rich area in Australia [11]. They assessed the effects of increases in temperature of between 1°C and 7°C on species distribution using bioclimatic modelling based on over 220,000 records. Estimates were made of the change in the core range of each species under different climate scenarios, assuming that species continued to occupy the climate space they currently use. Models for 62 endemic montane (greater than 600m altitude) species indicated that 1°C warming will result in an average of 40% loss of potential core range, 3.5°C warming a 90% loss and 5°C warming a 97% loss. Warming of 7°C resulted in the loss of all potential core range for all species.

Early in 2004, a number those that had conducted studies that modeled species responses to climate change produced a joint paper that assessed the extinction risks for sample regions covering about 20% of the Earth's terrestrial surface, including parts of Australia, Brazil, Europe, Mexico and South Africa [12]. They concluded that '15 to 37% of species in our sample of regions and taxa will be "committed to extinction" as a result of mid-range climate warming scenarios for 2050. Taking the average of the three methods and two dispersal scenarios, minimal climate warming scenarios produce lower projections of species committed to extinction (~18%) than mid-range (~24%) and maximum change (~35%) scenarios.'

4. Implications for concentration stabilsation

There is substantial and compelling evidence that the degree of climate change which has already occurred has affected both species and ecosystems, in many cases adversely. Indeed, there is evidence that at least one species has become extinct due to climate change: the golden toad of Costa Rica [13]. It appears very likely that species will increasingly become extinct and ecosystems will be lost with little further change in the climate. In terms of the ultimate objective of the Climate Change Convention, it can thus be reasonably argued that some ecosystems are not "adapting naturally" to climate change and that atmospheric concentrations of greenhouse gases are already too high.[2]

However, given that further climate change will necessarily occur, a realistic aim would be to keep further mean global temperature rise to less than 2°Celsius above pre-industrial levels, as the EU has proposed. The concentration stabilisation level corresponding to this goal is debatable, particularly in light of increasing indications that climate sensitivities are higher than previously though, see for example [14]. The value of 550 ppmv previously proposed by the EU in conjunction with their two degree limit was always high and now seems unrealistically so; 450 ppmv, or even lower, would be more appropriate.

References

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3 The numerical estimates included in this paragraph are provisional figures provided by Euan Dunn of the Royal Society for the Protection of Birds.

4 Proffitt F. (2004), Reproductive failure threatens bird colonies on north sea coast, *Science*, **305,** no 5687, 1090, 20 August 2004.

[2] A counterargument is that extinctions and ecosystem loss have occurred frequently over geological timescales and are thus natural, but if this view were shared by those that drew up Article 2 of the Convention then they would clearly have had no need to include the text on ecosystems

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