

Appendix 3 – An analysis of projected shifts in waterbird assemblages as a result of climate change.

Introduction

Given the importance of climate in driving species distributions, climate change is projected to result in significant shifts in where species occur. Already there is evidence for such changes occurring, with poleward and altitudinal movements in species' ranges (Hickling *et al.* 2006, Maggini *et al.* 2011). As a result, there is concern about the usefulness of protected areas within a changing climate, as protected areas become increasingly unsuitable for the species' for which they have been designated. Not only is this likely to have implications for which protected areas remain important through time, and which species remain adequately covered by the protected area network (covered in Appendix 2), but potential shifts in the importance of different species at sites may have considerable implications for the management of those sites, given their potentially different habitat and management requirements. This is the question examined in this appendix.

There is significant evidence that common bird communities across Europe are changing in response to climate change. In particular, species associated with warmer temperatures are tending to increase in abundance, whilst those associated with cooler temperatures are tending to decline (Devictor *et al.* 2008, Jiguet *et al.* 2010). As these shifts may result in significant changes in particular guilds of species (e.g. Pearce-Higgins 2010), the relative importance of different environmental components may change through time. As evidence for such responses extends to rare species (Green *et al.* 2008), such changes could have considerable implications for the management of individual protected areas. In order to assess the likely magnitude of the potential problem, we use the existing models relating species abundance to climate (Appendix 1) to assess likely future changes in the composition of four different bird communities of conservation importance; breeding seabirds, wintering freshwater waterbirds, wintering coastal waterbirds and wintering marine waterbirds. These were the four groups most comprehensively covered by our models. For each community, we use existing data to assess the current patterns of community composition, and then use our models to infer how those are likely to change as a result of climate change.

Methods

Describing variation in community composition

Current data on the abundance of species across the SPA network were obtained for seabirds from Seabird 2000 and for wintering freshwater, coastal and marine species from WeBS counts. For wintering species, we included relevant passage species also covered by SPA designation, as site management must consider community changes at different times of the year. Species were selected which were listed under Annex 1 of the EU Birds Directive or regarded as migratory, are colonial (either during the breeding season or forming significant aggregations outside of the breeding season) and with high quality data available. A total of 17 seabird, 19 freshwater, 21 coastal and 10 marine species were covered (see Appendix 1 for more details). It was not possible to conduct these analyses for breeding terrestrial or wetland species due to the lack of comprehensive coverage of these species groups. It was necessary to moderate our predictions by information about site-quality for each species by using modelled densities to calculate the likely proportional change in the number of birds

present at each site, and then applying that proportional change to the observed data at each site (Appendix 2). As a result, our models do not allow for significant range expansion and particularly the colonisation of the UK by new species, a topic which is covered in Appendix 4.

Spatial patterns in community composition

Existing patterns in species assemblages were described using the most recent seabird and wintering waterbird data, aggregated at the SPA level. These were summarised using principle components separately for each of the suites of species covered (breeding seabirds, wintering freshwater species, wintering coastal species and wintering marine species), which describe the spatial patterns of species co-occurrence, and identify the sites which contained similar assemblages of species. For wintering species whose abundance was also modelled separately during passage periods, we combined these estimates to produce a maximum count for each site. For the purposes of this analysis, we focus on only the top three components for each of these species suites, as these are generally the most interpretable, accounting for a greater proportion of the variation in the data, labelled SPC_n for seabirds, FPC_n for freshwater waterbirds, CPC_n for coastal waterbirds and MPC_n for marine waterbirds.

Firstly, we use the principal components to describe spatial trends in the existing data, by modelling spatial variation in each principle component as a function of latitude and longitude. For waterbirds, we additionally included site area (km^2) as a covariate. For freshwater species, many of which may also occur on the coast, we included data from both coastal and freshwater SPAs and therefore included habitat (coastal or not) as a two-level factor and tested for the interaction between site area * habitat. For coastal and marine species, only data from coastal sites were included in the analysis. This analysis therefore described the main spatial patterns of community composition across the existing SPA suite.

Projecting temporal patterns in community composition

Secondly, models of projected future changes in species abundance were used to assess likely future changes in community composition for low, medium and high climate change scenarios (as defined by UKCP09) for 2020, 2050 and 2080 time-periods. For species where models had an explanatory power of $> 1\%$ ($r = 0.1$), model predictions were made, but for species where model fit was poorer it was assumed that climate change would not result in significant changes in the abundance of that species as the evidence from the models was that spatial variation in abundance was more strongly driven by other factors (Appendix 2). Given the difficulties of making adequate predictions of spatial variation in abundance because of the lack of information about site quality, which is likely to mediate the abundance of species at that site (Appendix 1), future species abundance was not modelled directly. Instead, the likely proportional change in abundance was calculated and applied to the current abundance data as follows, where P is the predicted abundance at time (t), O is the observed abundance and P_f is the final predicted abundance.

$$P_f = (P_{t2} / P_{t1}) * O_{t1}$$

This means that predictions of abundance adequately reflect spatial variation in site quality for that species, but prevents us from being able to model future colonisations by additional species

The principle components used to describe spatial variation above were then applied to the future projections of abundance (P_i) from the individual models, in order to describe likely future changes in community composition. These were summarised by modelling each of the three principle components for each community as a function of scenario*year combinations, and interactions between scenario*year and latitude, longitude, habitat (for freshwater species) and site size (for all wintering waterbirds), to assess how the spatial variation in these communities are likely to change through time. In order to account for pseudoreplication, models were conducted within a mixed model framework in which site was specified as a random effect, and applying the Kenward Rogers correction for the calculation of the degrees of freedom.

Results

Community composition.

The first three principle components accounted for 42 % of variation in seabird abundance, 50 % in wintering freshwater birds, 63 % in wintering coastal species and 71 % in wintering marine birds (Table 1). For seabirds, the first component distinguished cliff-nesting species (shag, kittiwake, guillemot, razorbill and to a lesser extent shag and puffin), from the remainder. The second separated terns, and to a lesser extent, cormorants, puffins and gulls from the remainder, whilst the third separated herring and lesser-black-backed gulls from other species. For wintering freshwater birds, the first axis largely represented variation from sites with few birds to sites with lots of birds. The second separated diving species (tufted duck, goosander, pochard, little grebe, great crested grebe) from dabbling species (Bewick's swan, whooper swan, wigeon, gadwall, teal, shoveler) whilst the third separated swans from pink-footed goose, teal, cormorant, little egret and little grebe. The first axis for wintering coastal species represented variation from sites with few birds to sites with lots of individuals. The second axis was a gradient from largely shingle or rocky-shore species (turnstone, redshank, curlew, purple sandpiper, ringed plover, oystercatcher) to sandy and estuarine species (dark-bellied brent goose, grey plover, whimbrel and greenshank). The third axis linked grassland and some rocky-shore species ringed plover, golden plover, ruff, snipe, whimbrel and turnstone and contrasted those with three estuarine species of knot, sanderling and bar-tailed godwit. For wintering marine species, the first axis represented a gradient from low to a high abundance of individuals. The second component was a gradient from grebes to common scoter and sandwich tern, whilst the third was a gradient from a number of sea duck (scaup, long-tailed duck and velvet scoter) to red-throated diver.

Spatial variation in community composition

Overall, across all the principal components, spatial variation in 6 of 12 components was significantly correlated with latitude, whilst variation in 2 was significantly correlated with longitude. There was therefore strong evidence for latitudinal gradients in community composition across the UK. As expected, area was also significantly correlated with a number of principal components, particularly the components describing variation from small to large aggregations of individuals for freshwater and coastal species. These patterns are described in more detail below for each community (Table 2).

For seabirds, there was a significant positive correlation between latitude and SPC1 ($F_{1,117} = 9.45$, $P = 0.0026$), but negative correlation with SPC2 ($F_{1,117} = 5.90$, $P =$

0.0166). Thus, the greatest abundance of cliff-nesting species was in the north. However, distribution of terns in particular, but also cormorants, gulls and puffins was aggregated towards the south. There was no consistent spatial variation in SPC3 ($P > 0.39$).

FPC1 described variation in few individuals of freshwater species to large aggregations, and as a result, was significantly positively correlated with site size ($F_{1, 74} = 96.79, P < 0.0001$), particularly on non-coastal sites ($F_{1, 74} = 75.74, P < 0.0001$). FPC2 was also negatively correlated with site size ($F_{1, 75} = 18.17, P < 0.0001$), particularly on non-coastal sites ($F_{1, 75} = 30.30, P < 0.0001$), suggesting that large sites support a greater proportion of individuals from diving species, whilst the relationship between FPC3 and site size ($F_{1, 75} = 8.87, P = 0.0039$) was positive, indicating the community of smaller sites tended to support a higher proportion of swans. In addition to these trends, each component was negatively correlated with latitude (FPC1, $F_{1, 74} = 4.90, P = 0.030$; FPC2, $F_{1, 75} = 4.78, P = 0.032$; FPC3, ($F_{1, 75} = 7.39, P = 0.0082$). This indicates that southern sites support greater numbers of individuals (FPC1), particularly of dabbling species (FPC2), little egret and little grebe (FPC3), whilst freshwater SPAs in the north tend to support more diving species (FPC2) and swans (FPC3). Values of FPC3 were reduced on non-coastal sites ($F_{1, 74} = 8.26, P = 0.0053$), reflecting the association of swans with freshwater sites.

As with the freshwater components, the first axis described by CPC1 was also from sites with few individuals to sites with large aggregations. Accordingly, site size was strongly positively correlated with CPC1 ($F_{1, 53} = 93.08, P < 0.001$). Significant longitudinal variation in this component indicated that sites in the east also tended to support higher aggregations of individuals ($F_{1, 53} = 8.79, P = 0.0045$). There was significant positive latitudinal variation in CPC2 ($F_{1, 52} = 4.99, P = 0.029$), indicative of a greater representation of shingle- and rocky-shore species in the north.

There were no significant correlations between any of the marine species principal components and longitude, latitude or site size (all $P > 0.15$).

Temporal variation in community composition

A summary of the models describing likely temporal changes in composition is given in Table 3. Projected changes in seabird abundance are indicative of a significant decline in the relationship between latitude and SPC1, as a result of reductions in the abundance of cliff-nesting species in the north ($F_{11, 1298} = 16.22, P < 0.0001$). Conversely, there is projected to be a significant increase in SPC2 in the south with increasing severity of climate change ($F_{11, 1287} = 6.37, P < 0.0001$), associated with projected increases in the abundance of little tern and herring gull. Climate change is projected to result in significant westward shift in SPC3, with projected increases in herring gulls in the west relative to little and sandwich terns (Figure 1).

Projected changes in FPC1 are indicative of general increases in abundance, particularly in the south ($F_{11, 814} = 7.71, P < 0.0001$) and east ($F_{11, 814} = 2.46, P = 0.005$). Further, the relationship between site size and FPC1 is projected to become less positive through time on freshwater sites, but more positive through time at coastal sites, although even at a high 2080 scenario, the slope for freshwater sites (0.30 ± 0.04) will exceed that for coastal sites (0.22 ± 0.02), as it does now, indicating that for a given area, freshwater sites will support greater numbers of this suite of

species than coastal sites. Similar projected changes in FPC2 are also indicative of general increases in values in the south ($F_{11, 814} = 6.30, P < 0.0001$) and east ($F_{11, 814} = 4.09, P < 0.0001$), reflecting increases in the importance of dabbling species in these regions relative to diving species. This shift is likely to result in a decrease in the relationship between site size and FPC2 on freshwater through increasing magnitude of climate change ($F_{11, 814} = 65.63, P < 0.0001$), potentially linked to reductions in the abundance of diving species whose abundance is currently greater on large sites. Future projections are of increasing values of FPC3 through time, particularly in the south ($F_{11, 814} = 3.73, P < 0.0001$) and east ($F_{11, 814} = 1.83, P = 0.0459$), resulting in an increasing importance of site size through time ($F_{11, 814} = 76.81, P < 0.0001$). These changes are driven by large increases in little egret and teal in particular (Figure 2)

Projected changes in CPC1 suggest that sites in the south are likely to experience significant increases in the abundance of species at these sites through time ($F_{11, 583} = 3.91, P < 0.0001$), associated with a general increase in the slope of the relationship between site area and CPC1 ($F_{11, 583} = 23.07, P < 0.0001$). The current latitudinal gradient in CPC2 of greater numbers of rocky species in the north is projected firstly to become steeper by 2020, but then change in direction, with significant reductions in CPC3 in the north by 2080 under a high emissions scenarios ($F_{12, 583} = 1.90, P = 0.37$), suggestive of declines in the abundance of these species (Figure 3). An increase in CPC3 in the south is projected to be likely ($F_{11, 583} = 3.82, P < 0.0001$) as a result of projected increases in ringed plover, snipe and whimbrel populations.

As a result of climate change there are projected future changes in the MPC1 and MPC2. Values of MPC1 are projected to increase through time and with an increasing severity of climate change ($F_{11, 594} = 5.09, P < 0.0001$), whilst the relationship with latitude is also projected to change through time ($F_{11, 594} = 3.54, P < 0.0001$; Figure 4), such that the current positive relationship is projected firstly to increase in steepness by 2020, but then decline. This suggests that initial increases in the abundance of wintering marine species may occur, but then with increasing severity of climate change, there will be significant reductions in the abundance of such species, particularly in the north (Figure 4). Values of MPC2 are also projected to change through time ($F_{11, 605} = 7.60, P < 0.0001$), with a general increase in grebes by 2080, relative to other species. The relationship between MPC3 and site-size is anticipated as likely to become more positive with increasing severity of climate change and then decline again ($F_{11, 594} = 4.74, P < 0.0001$), indicative first of an increase, and then decline in the relative abundance of some seaduck.

Discussion

Our analysis has highlighted strong gradients in the current assemblage of waterbirds across the UK, with six of the 12 principal components used to describe current variation indicative of strong latitudinal gradients, and three indicative of significant gradients from east to west. Specifically, SPAs in the north tend to support more cliff-nesting seabirds, whilst those in the south support more terns. Wetland SPAs in the south tend to support a higher abundance of most freshwater species, a greater proportion of dabbling species, but fewer swans and more pink-footed geese, teal, little egrets and little grebes. The greatest abundance of coastal species was in the east, whilst species associated with rocky-shore and shingle habitats tended to be more predominant in the north. These gradients are likely to reflect differential effects of habitat and climate across the UK. Thus, the greater abundance of cliff-nesting

seabirds in the north reflects the distribution and abundance of fish prey species, particularly of sandeels, combined with an availability of suitable nest-sites. Higher numbers of wintering freshwater species in the south is likely to be linked to milder temperatures, preventing the freezing of such waterbodies and enabling them to consistently support a greater number of individuals. Southern waterbodies are also likely to be more eutrophic and productive, which may also partially explain this trend, and particularly the distribution of dabbling species. In terms of coastal species, the greater abundance in the east reflects the occurrence of a large number of productive, muddy estuaries which support high densities of invertebrate prey, whilst further north, more shingle- and rocky-shore species tend to predominate. The lack of spatial associations with marine species is likely to reflect the greater variability of the observed data, particularly as the greatest concentrations of these species are likely to be offshore, and dependent upon undersea topography and relatively poorly assessed by the shore-based WeBS counts. The existing patterns identified in the analysis therefore, reassuringly, largely reflect previously described associations.

As expected from previous analyses, climate change is projected to result in significant shifts in the distribution of these community gradients across the country, with significant shifts in the latitudinal distribution of 9/12 of the components projected, and longitudinal shifts in five. In relation to seabirds, significant interactions between SPC1 and SPC2 and latitude are indicative of likely reductions in the abundance cliff-nesting seabirds in the north, and increases of other species, particularly some tern and gull species, in the south. Already there is increasing evidence for northern seabird colonies suffering declines in productivity as a result of increases in sea surface temperature and subsequent knock-on effects via plankton on food (largely sandeel) availability (e.g. Frederiksen *et al.* 2005, 2006). These changes have previously been shown to affect guillemot (Frederiksen *et al.* 2006), Kittiwake (Frederiksen *et al.* 2005, 2006), puffin (Frederiksen *et al.* 2006) and shag (Frederiksen *et al.* 2006), all species strongly positively correlated with SPC1 (Table 1a). Our projections are therefore supported by detailed ecological information and reflect currently observed trends, and therefore may be associated with a high degree of confidence. These projected shifts may have a number of management implications. Firstly, they emphasise the importance of properly managing the fisheries which these seabirds rely upon, which may have detrimental additive effects on seabird populations additional to those caused by climate changes (Frederiksen *et al.* 2004). Secondly, as seabird colonies may be vulnerable to disturbance, appropriately managing visitor pressure on potentially expanding coastal tern colonies in the south, or increasingly vulnerable cliff-nesting seabirds in the north (e.g. Beale *et al.* 2004), may also be important.

Turning to freshwater species, our models predict increases in the abundance of many species in the south, driven in many cases by reductions in the severity of winter weather. Large freshwater sites in the south are likely, therefore, to become increasingly important for wintering waterbirds through time. It is therefore important that such sites are managed adequately so that such potential increases are not compromised by potentially detrimental effects of disturbance on carrying capacity. Such wetland sites are under increased pressure from eutrophication associated with diffuse pollution (e.g. MacDonald *et al.* 2006), and again, care should be taken that this does not detrimentally reduce the ability of freshwater sites in southern England to support increasing numbers of wildfowl. Associated with these changes are

projected increases in the likely abundance of dabbling and grazing duck species on these sites, particularly teal. Therefore not only is the protection of open water important, but also the appropriate management and protection of surrounding margins and vegetation. Conversely, changes in the distribution of piscivorous species may have implications for potential conflict between anglers and bird conservation. Projected declines in the abundance of northerly distributed diving wildfowl may be associated with milder winters, with potentially fewer individuals migrating to the UK to winter.

Significant shifts in the distribution of coastal wintering waterbirds have already been detected and linked to increases in temperature (Austin & Rehfish 2005, MacLean *et al.* 2008). Thus, the distribution of a number of estuarine species have shifted north and east as increases in winter temperature have enabled them to remain in more productive eastern coastal estuaries, either in the UK, or on continental Europe. Our models suggest that significant future shifts in the latitudinal distribution of species are likely, although project further increases in the abundance of wintering individuals in the south, largely as a result of milder winters. There is also projected to be a significant shift in the relative distribution of shingle / rocky shore and estuarine species as a result of climate change. There is currently an increasing preponderance of the former group in the north, which is projected first to increase, presumably linked to milder winters, but then decline, potentially as individuals are increasingly able to overwinter in Scandinavia, reflecting recent shifts in these species. Models also project an increase in largely grassland associated waders (e.g. snipe) in the south, again, presumably linked to milder winters which reduce the need for such species to migrate further south.

The distribution of marine species is not well described by the WeBS data at some sites, as they are based upon shore-counts, and therefore only count those individuals which are close inshore and countable. However, our models do suggest that increasing severity of climate change may reduce the abundance of some species which are currently concentrated in the north, and also result in a shift in the importance of grebes and divers, relative to other species.

It is worth emphasising for many of the species covered, particularly the wintering waterbirds, that the size of the wintering populations in the UK, or even across the flyway, is not just dependent upon climate on the wintering grounds, important though that is, but also climate on the breeding grounds, and on migration. Many of the species covered in this paper breed further north and east in the Arctic and High Arctic. Projected increases in the wintering abundance of these species as a result of climatic amelioration in the UK will only occur if there are sufficient birds across the flyway to respond to such increases. Given projected reductions in the breeding range of many of these species as a result of climate warming (e.g. Huntley *et al.* 2007), and likely negative effects of increasing temperature upon productivity in these areas (e.g. Beale *et al.* 2006, Pearce-Higgins *et al.* 2010), it is possible that our projected increases in the abundance of wintering waders and waterfowl will not be realised, as breeding productivity and populations decline. Indeed, it is likely that for many of these species, the current limit which winter weather imposes is likely to reduce, and be replaced by an increasing importance of productivity, as illustrated recently for golden plover breeding in the UK (Pearce-Higgins *et al.* 2010).

To conclude, our analysis suggests that significant shifts in the distribution of both breeding seabirds and wintering waterbirds will occur across the UK over the course of this century as a result of climate change, reflecting existing trends. Managing these shifts will be an increasingly important consideration for site managers, with some groups of species, such as cliff-nesting seabirds, diving freshwater birds and some marine waterbirds likely to suffer significant large-scale reductions in abundance. The analysis presented here provides some broad trends which such managers may wish to consider, although we suggest that they also consider the more detailed species-specific trends for individual sites presented on the website, which will provide more detail for individual sites and species. However, irrespective of climate change, a key result from the study is also that large sites will largely continue to support high numbers of species, even in a changing climate. Therefore, a key adaptation principal will continue to be the protection and designation of large sites, in addition to focussing habitat creation and restoration on the boundaries of sites, as these will not only support the highest numbers of birds now (as exemplified by positive correlations between both FPC1 and CPC1 and site area), but will continue to do so in the future, with continued positive relationships between site area and these components. Indeed, for coastal birds, future projections suggest that larger sites will become increasingly important through time. These findings therefore support one of the principles of Hodgson *et al.* (2009), that focussing on the protection of large sites is a priority climate change adaptation principle, and matching the suggestions of Lawton *et al.* (2010).

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Table 1a. Principal components describing spatial variation in the abundance of breeding seabirds across SPAs.

Species	SPC1	SPC2	SPC3	SPC4	SPC5
Fulmar	0.25	-0.20	0.15	-0.10	0.49
Gannet	0.20	0.19	-0.31	-0.08	0.00
Cormorant	0.16	0.19	-0.09	-0.15	-0.07
Shag	0.42	0.13	-0.06	-0.16	-0.04
Kittiwake	0.37	-0.21	0.20	0.17	-0.23
Black-headed gull	-0.08	0.21	0.21	0.37	0.16
Common Gull	-0.02	-0.03	-0.02	-0.05	-0.08
Lesser Black-backed Gull	0.06	0.12	-0.39	0.53	0.19
Herring Gull	0.24	0.16	-0.40	0.41	0.06
Great Black-backed Gull	0.14	-0.12	0.03	-0.19	0.74
Little Tern	-0.07	0.27	0.38	0.27	0.15
Sandwich tern	0.06	0.47	0.38	0.03	0.05
Common Tern	0.04	0.42	0.23	-0.02	-0.03
Arctic Tern	0.19	0.26	-0.02	-0.31	-0.12
Guillemot	0.43	-0.22	0.22	0.16	-0.13
Razorbill	0.37	-0.23	0.21	0.19	-0.14
Puffin	0.32	0.30	-0.17	-0.23	0.03
Eigenvalue	3.56	2.30	1.68	1.43	1.13
Proportion variation	0.21	0.14	0.10	0.08	0.07

Table 1b. Principal components describing spatial variation in the abundance of waterbirds across freshwater SPAs.

	FPC1	FPC2	FPC3	FPC4	FPC5
Bewick's Swan	0.20	0.29	-0.42	-0.15	-0.07
Whooper Swan	0.27	0.19	-0.40	-0.20	-0.05
Pink-footed goose	0.04	0.12	0.30	-0.10	0.06
Greylag Goose (Icelandic)	-0.05	-0.02	-0.06	-0.12	0.19
Wigeon	0.23	0.38	0.12	-0.13	0.18
Gadwall	0.26	0.25	-0.11	0.34	-0.25
Teal	0.20	0.33	0.28	0.00	0.14
Mallard	0.06	-0.01	0.04	-0.13	0.14
Pintail	0.09	0.17	0.13	0.01	0.46
Shoveler	0.22	0.38	0.08	0.04	-0.18
Pochard	0.38	-0.26	-0.17	-0.20	-0.08
Tufted Duck	0.36	-0.33	-0.01	-0.06	-0.03
Goldeneye	0.13	-0.04	-0.09	0.62	0.23
Goosander	0.32	-0.35	0.05	-0.16	0.03
Cormorant	0.27	-0.08	0.23	-0.20	0.45
Little Egret	0.02	0.11	0.46	-0.06	-0.40
Little Grebe	0.26	-0.13	0.35	-0.06	-0.36
Great Crested Grebe	0.17	-0.18	0.04	0.42	0.12
Coot	0.29	-0.06	-0.15	0.29	-0.08
Eigenvalue	4.46	3.19	1.89	1.78	1.45
Proportion variation	0.23	0.17	0.10	0.09	0.08

Table 1c. Principal components describing spatial variation in the abundance of estuarine species across coastal SPAs.

	CPC1	CPC2	CPC3	CPC4	CPC5
Dark-bellied Brent Goose	0.22	-0.37	0.00	0.07	-0.30
Shelduck	0.29	0.02	-0.09	0.15	0.06
Oystercatcher	0.19	0.40	-0.15	0.16	0.01
Avocet	-0.03	-0.15	0.06	0.26	0.45
Ringed Plover ¹	0.25	0.04	0.26	-0.23	-0.02
Golden Plover	0.19	-0.04	0.25	-0.29	0.30
Grey Plover	0.27	-0.24	-0.15	-0.04	-0.17
Lapwing	0.27	0.03	0.00	-0.05	0.31
Knot	0.29	0.09	-0.24	-0.04	0.02
Sanderling ¹	0.19	0.02	-0.32	-0.31	0.17
Purple Sandpiper	0.00	0.36	0.07	-0.25	-0.48
Dunlin	0.25	0.02	-0.01	0.25	-0.04
Ruff	0.13	-0.09	0.43	-0.34	0.27
Snipe	0.09	0.02	0.33	0.44	-0.05
Black-tailed Godwit (Icelandic)	0.27	-0.09	-0.13	0.09	0.05
Bar-tailed Godwit	0.25	-0.12	-0.37	-0.21	0.00
Whimbrel ^a	0.21	-0.24	0.30	0.11	-0.14
Curlew	0.23	0.37	0.03	0.23	0.12
Greenshank	0.24	-0.30	0.07	0.10	-0.28
Redshank	0.23	0.30	0.04	0.17	0.02
Turnstone	0.19	0.27	0.31	-0.21	-0.21
Eigenvalue	9.00	2.32	1.82	1.53	1.14
Proportion variation	0.43	0.11	0.09	0.07	0.05

Table 1d. Principal components describing spatial variation in the abundance of marine species across coastal SPAs

	MPC1	MPC2	MPC3	MPC4	MPC5
Scaup	0.02	-0.12	0.57	0.78	-0.21
Eider	0.41	-0.13	0.03	-0.11	-0.22
Long-tailed Duck	0.42	0.08	0.27	-0.21	-0.17
Common Scoter	0.21	0.62	-0.19	0.27	0.20
Velvet Scoter	0.41	0.04	0.29	-0.23	-0.19
Red-breasted Merganser	0.31	-0.14	0.14	-0.01	0.68
Red-throated Diver	0.23	-0.19	-0.65	0.34	-0.35
Great-crested Grebe	0.26	-0.42	-0.15	0.26	0.45
Slavonian Grebe	0.39	-0.21	-0.13	-0.07	-0.15
Sandwich Tern ^a	0.27	0.56	-0.07	0.16	0.05
Eigenvalue	4.68	1.38	1.04	1.00	0.75
Proportion variation	0.47	0.14	0.10	0.08	0.05

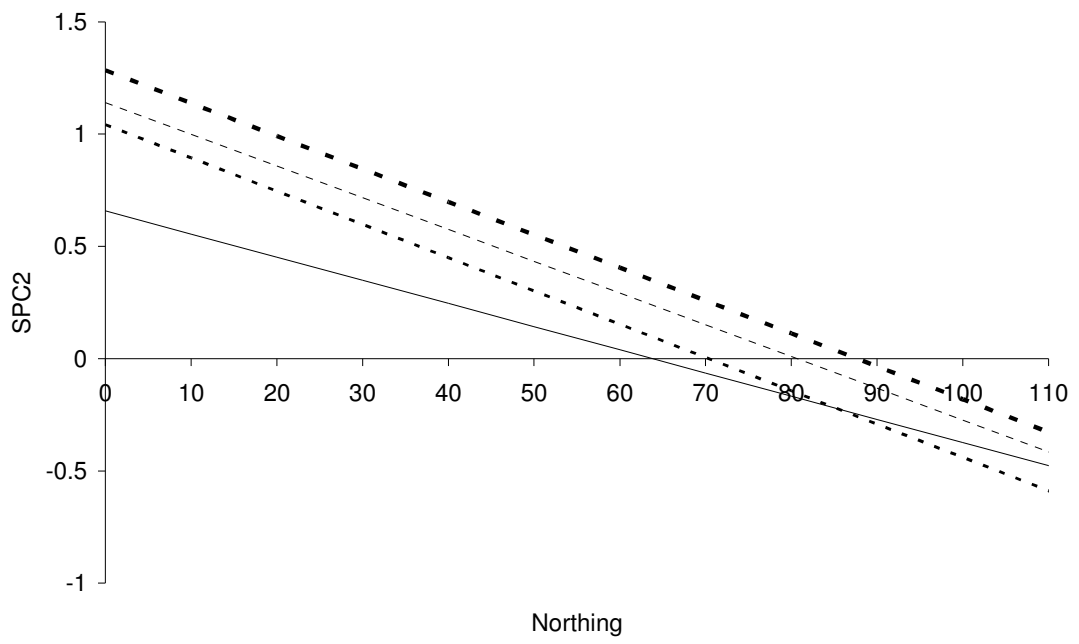
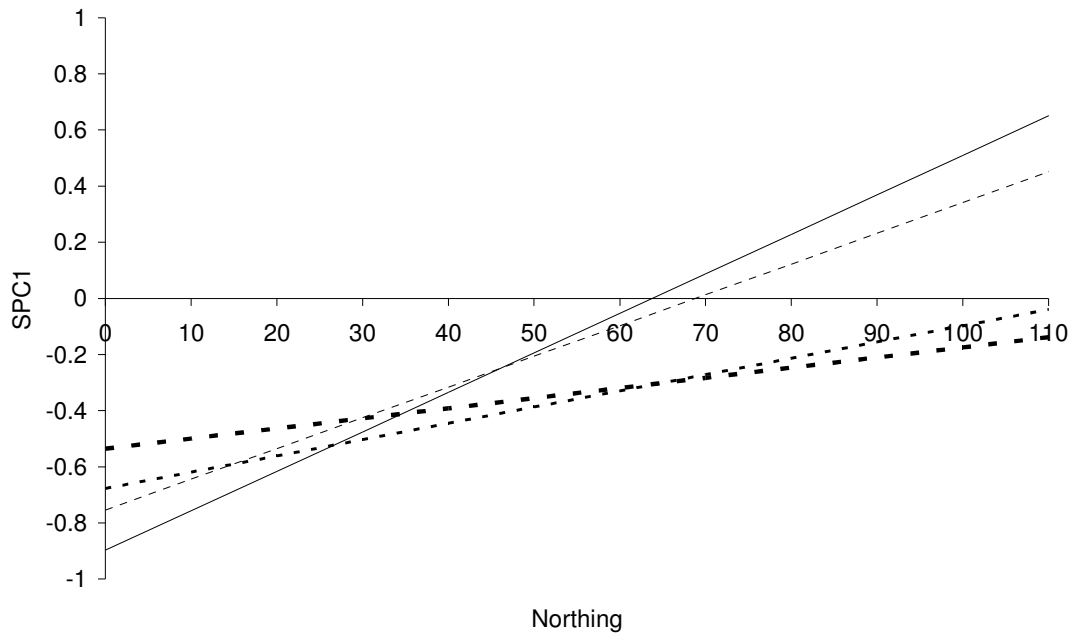
^a Autumn passage peak,

Table 2. Summary of the models describing spatial variation in the principle components for seabirds (SPC), freshwater(FPC), coastal (CPC) and marine (MPC) waterbirds as a function of geographical location, site-size and habitat.

	SPC1	SPC2	SPC3	FPC1	FPC2	FPC3	CPC1	CPC2	CPC3	MPC1	MPC2	MPC3
Latitude	++++	----		-	-	-		+				
Longitude		+	+++				+					
Area				++++	----	++	++++					
Coast	N/A	N/A	N/A			+++	N/A	N/A	N/A	N/A	N/A	N/A
Coast*Area	N/A	N/A	N/A	----			N/A	N/A	N/A	N/A	N/A	N/A

Table 3. Summary of the models describing temporal variation in the principle components for seabirds (SPC), freshwater(FPC), coastal (CPC) and marine (MPC) waterbirds as a function of geographical location, site-size and habitat. Presented are the interactions between each of these variables and year.

	SPC1	SPC2	SPC3	FPC1	FPC2	FPC3	CPC1	CPC2	CPC3	MPC1	MPC2	MPC3
Latitude	----	----		----	----	----	----	nnnn	----	nnnn		
Longitude		++	++++	++++	++++	++++						
Area	+	+	--	----	----	++++	++++					nnnn
Coast	N/A	N/A	N/A				N/A	N/A	N/A	N/A	N/A	N/A
Coast*Area	N/A	N/A	N/A	++++	++++		N/A	N/A	N/A	N/A	N/A	N/A



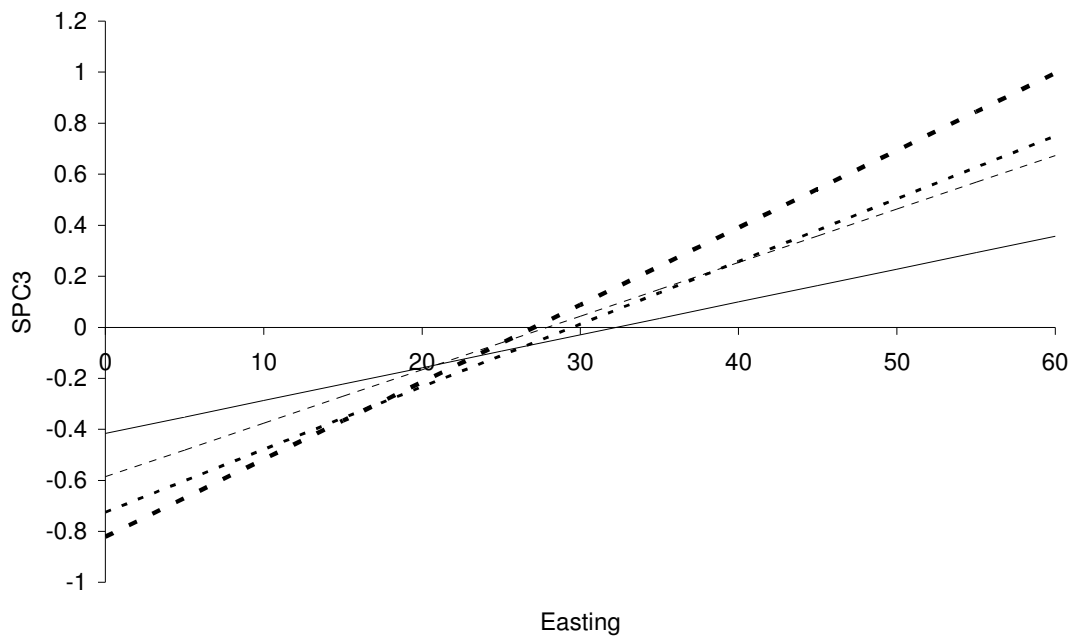
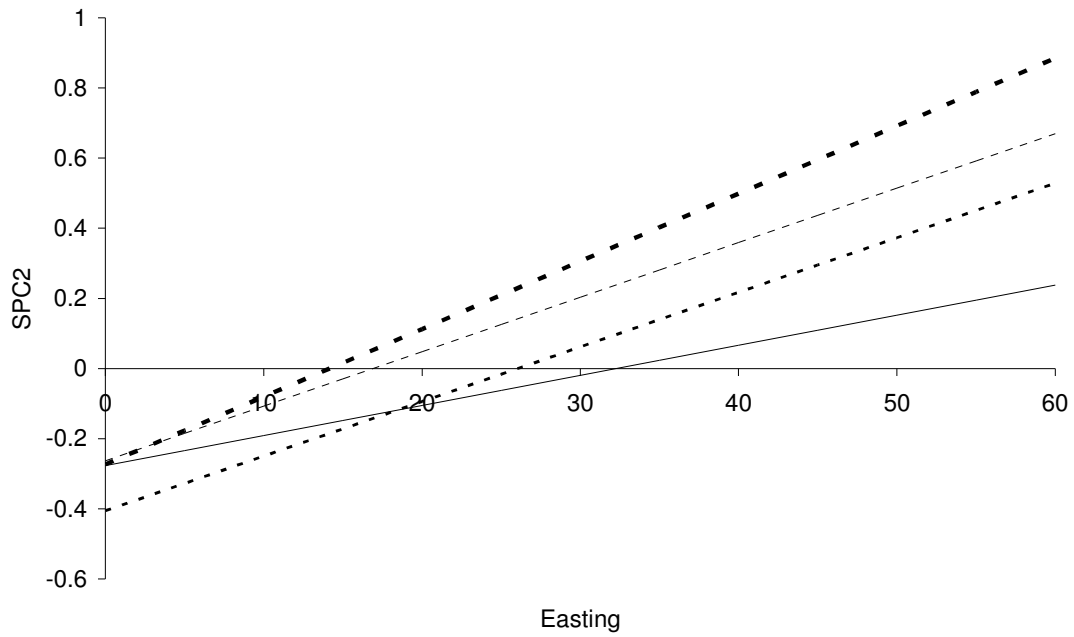
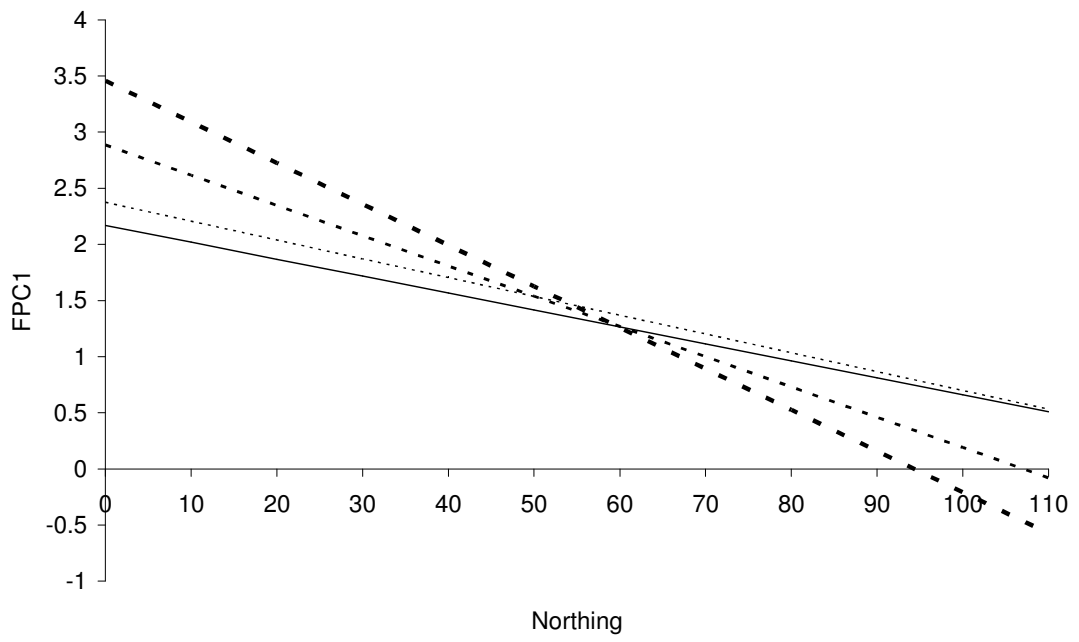
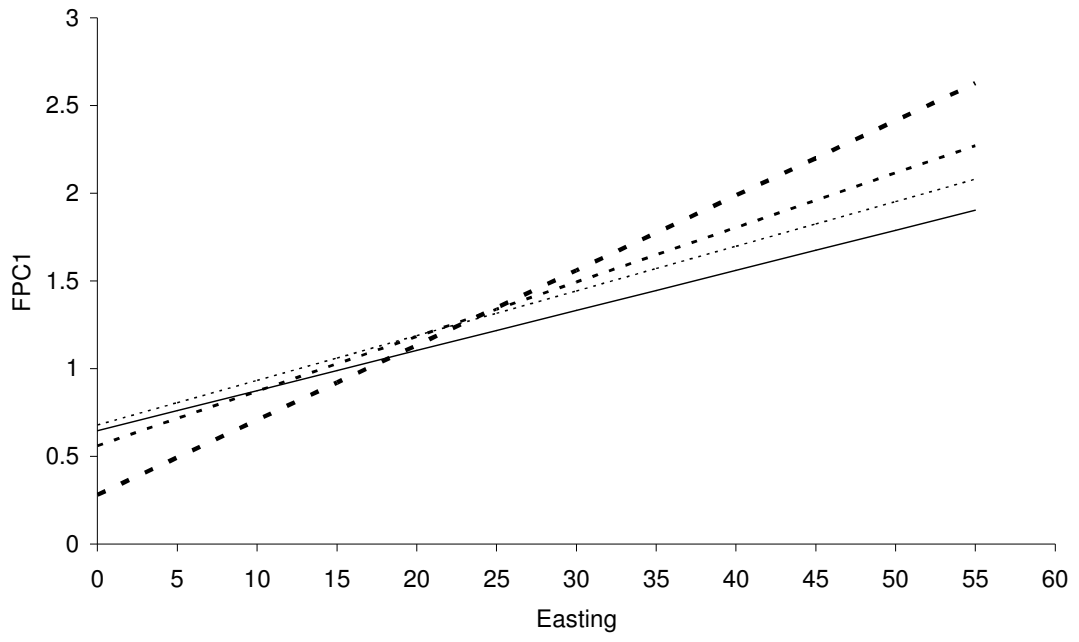
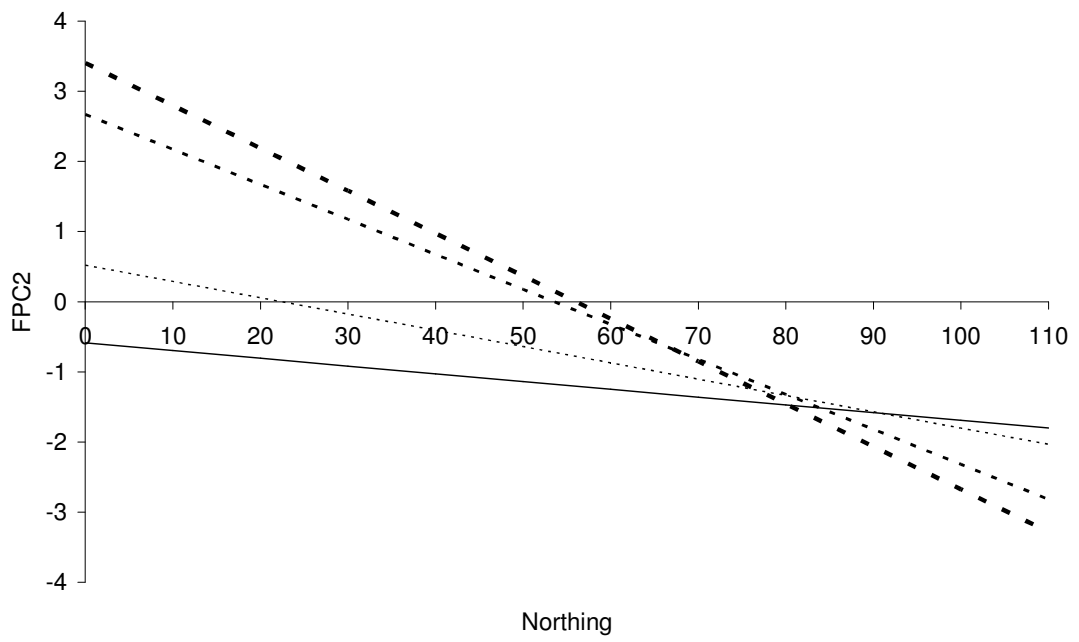
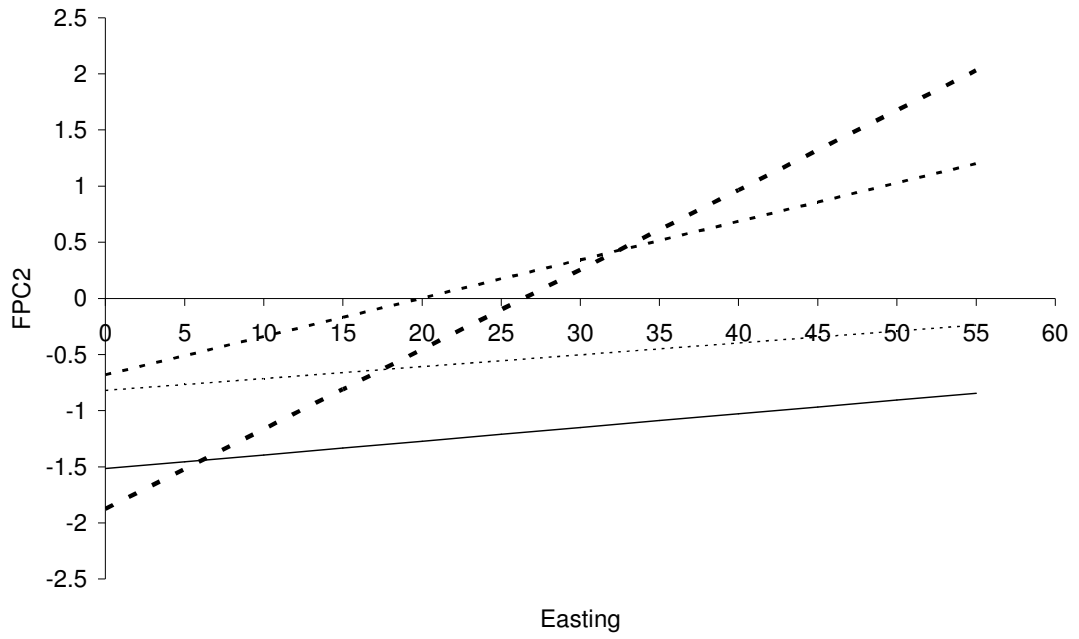


Figure 1. Projected geographical shifts in the composition of the seabird community under a medium emissions scenario by 2020 (thin dash), 2050 (medium dash) and 2080 (thick dash), compared to the present (thin solid). For descriptions of SPC1, SPC2 and SPC3 see Table 1a.





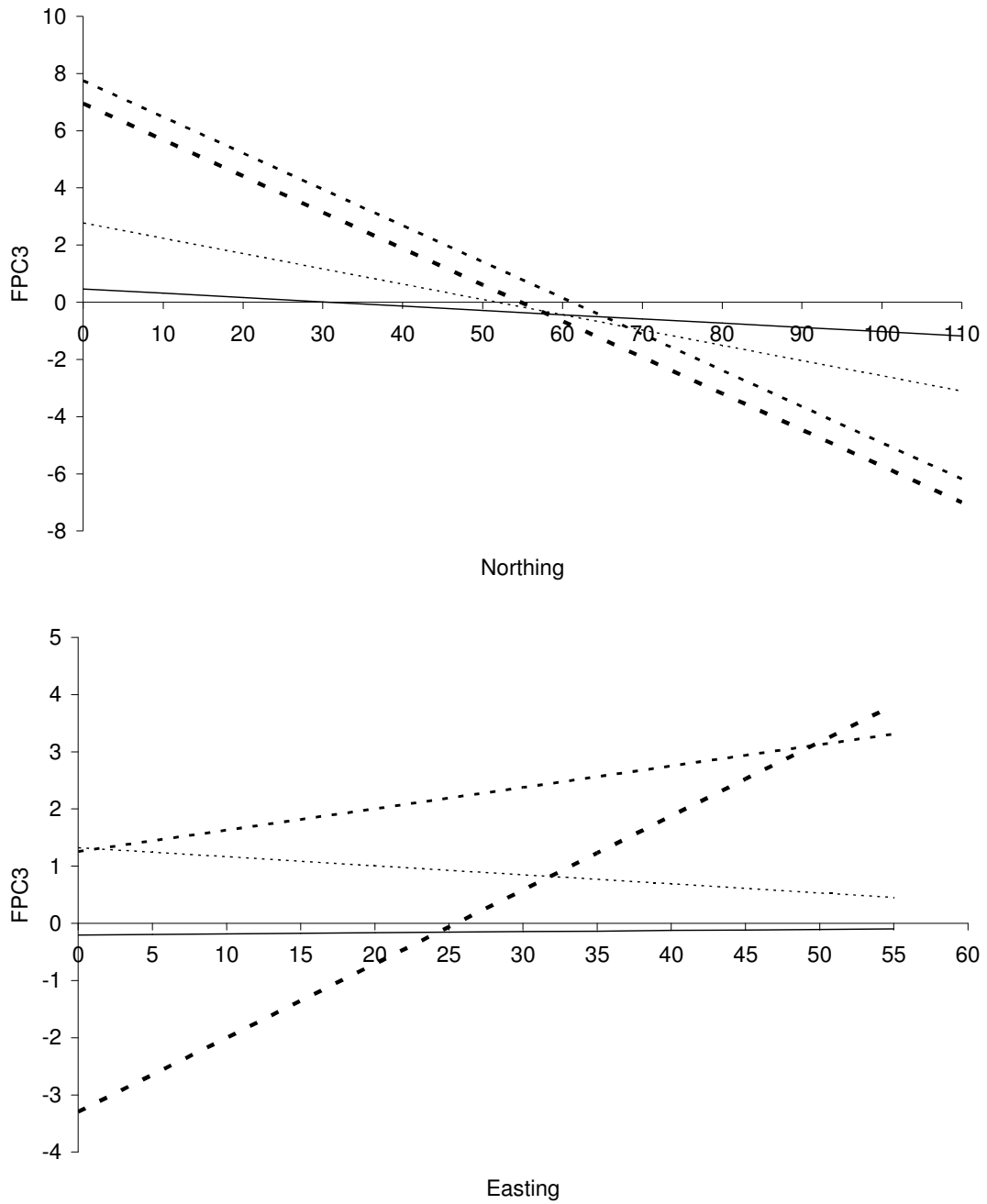
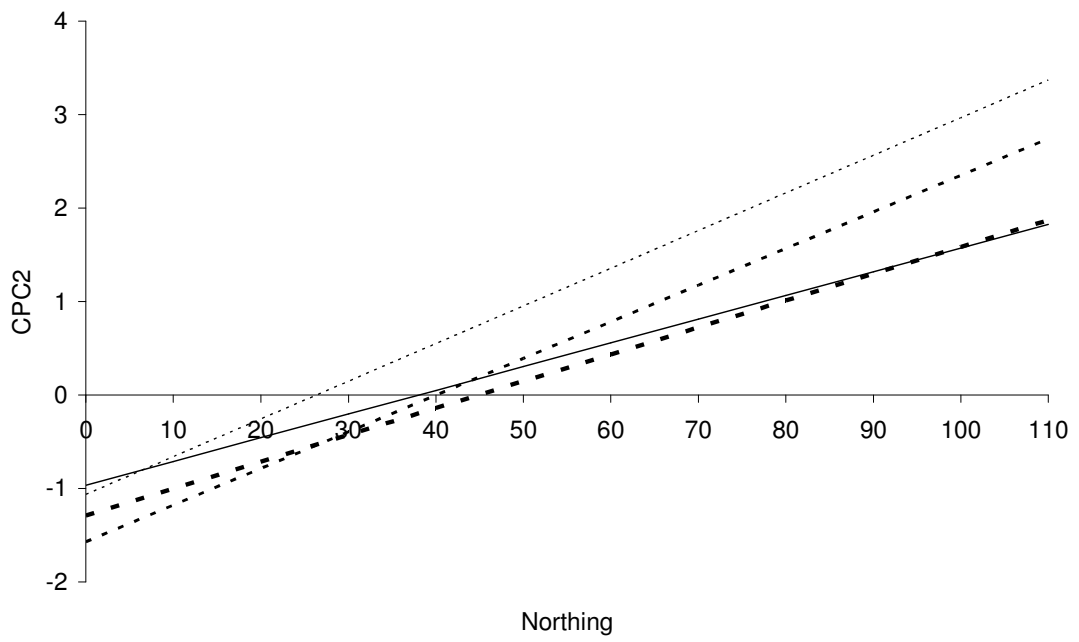
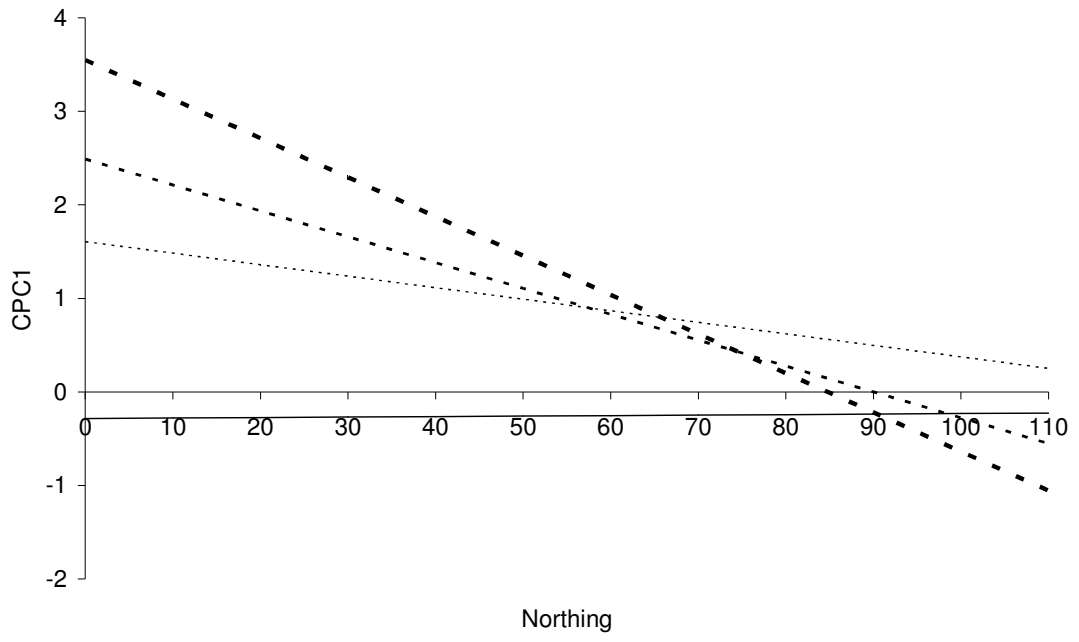


Figure 2. Projected geographical shifts in the composition of the freshwater community under a medium emissions scenario by 2020 (thin dash), 2050 (medium dash) and 2080 (thick dash), compared to the present (thin solid). For descriptions of FPC1, FPC2 and FPC3 see Table 1b.



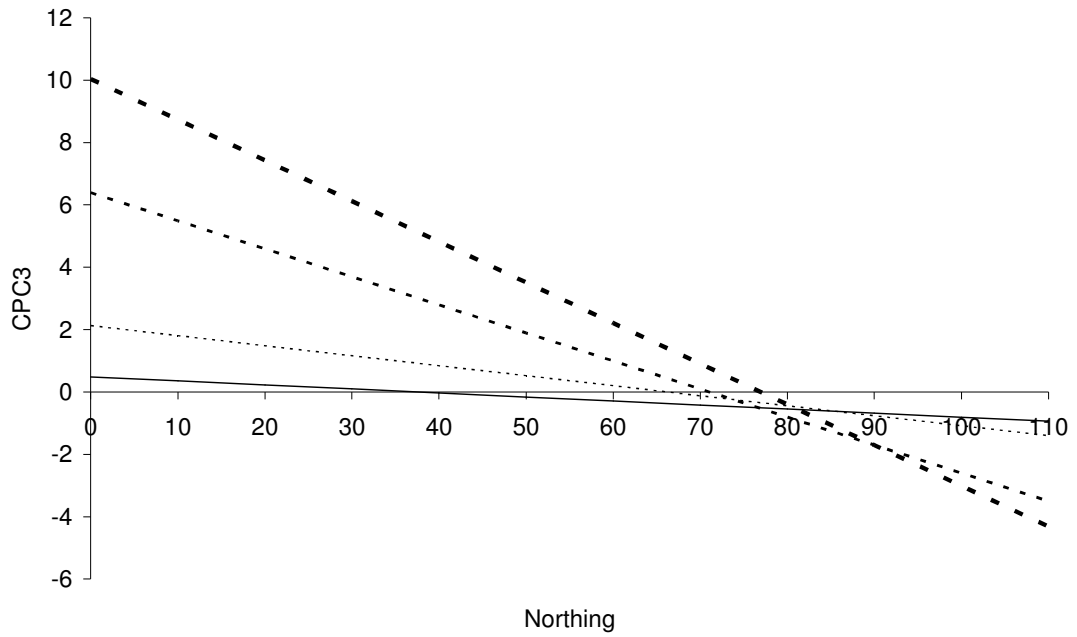


Figure 3. Projected geographical shifts in the composition of the coastal community under a medium emissions scenario by 2020 (thin dash), 2050 (medium dash) and 2080 (thick dash), compared to the present (thin solid). For descriptions of CPC1, CPC2 and CPC3 see Table 1c.

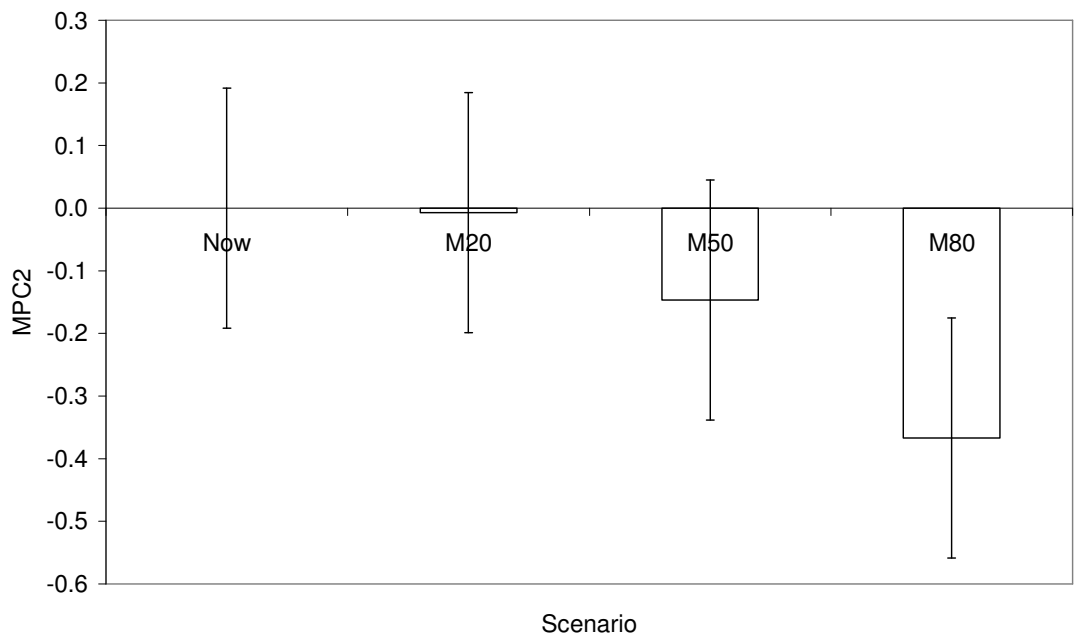
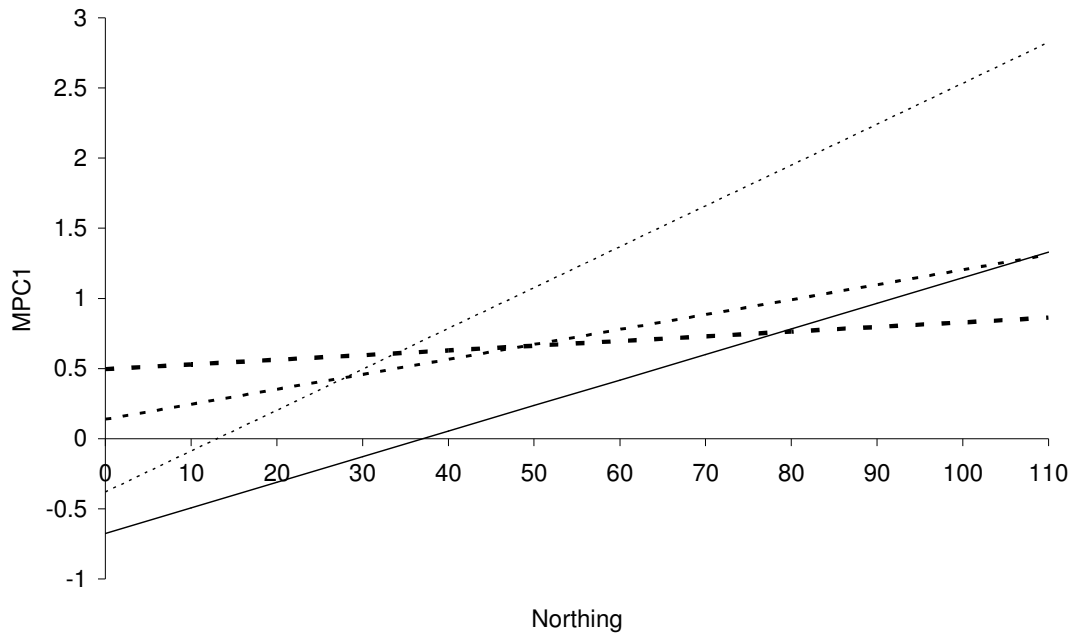


Figure 4. Projected geographical shifts in the composition of the marine community under a medium emissions scenario by 2020 (thin dash), 2050 (medium dash) and 2080 (thick dash), compared to the present (thin solid). For descriptions of MPC1 and MPC2 see Table 1c. There were no significant changes in MPC3 in relation to easting or northing.