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Future of the Sea: Marine Biodiversity

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Evidence Review

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The future of marine biodiversity and marine ecosystem functioning in UK coastal and territorial waters (including UK Overseas Territories)

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Contents

Executive summary

Marine biodiversity and ecosystem functioning in the territorial waters of the UK and its Overseas Territories is facing unprecedented pressures.

Key stressors on biodiversity in UK waters (including overseas territories) are changes in ecosystem functioning due to biodiversity loss caused by ocean warming (e.g. species replacement and migration), sea level rise (e.g. loss of habitats including salt marshes), plastic pollution (e.g. entanglement and ingestion), alien species (e.g. outcompeting native UK species and parasite transmission), overexploitation (e.g. loss of energy supply further up the food web), habitat destruction (e.g. loss of nursery areas for commercially important species) and ocean acidification (e.g. skeletal weakening of ecosystem engineers including cold water corals). These stressors are currently affecting biodiversity, and there impact can be projected for the future. All stressors may act alone or in synergy, and importantly, contemporary stressors may also continue into the future.

UK marine biodiversity provides us with crucial goods and services. These include food provision, raw materials, leisure and recreation, resilience and resistance, nutrient cycling, gas and climate regulation, bioremediation, disturbance prevention and alleviation, cultural heritage cognitive values (e.g. information used in education) and habitats created by living organisms. While there is a paucity of quantitative data to assess exact biodiversity loss, metanalysis suggests that species turnovers of up to 60% may disrupt such ecosystem service provision. The exact impact of biodiversity loss in the future is hard to quantify due the interacting nature of multiple stressors, however, there has been some work to put a financial valuation on them. UK biodiversity is worth up to an estimated ~£2670 billion including the services it provides to the UK. Specific at-risk services at risk include: coastal protection (~£50bn), carbon dioxide sequestration (£1bn), aquaculture and fisheries (aquaculture worth £800k), recreation (£3.9 bn) and marine education (£310m).

Climate change and biodiversity loss pose new challenges for legislation; there is however scope to integrate this via existing references to environmental variability, review cycles and secondary legislation. In particular, there are implications of climate change for the designation and management of marine protected areas and natural carbon removal by marine systems to help control the global climate system. The UK currently has legal obligations to protect biodiversity under international and European law.

The global marine environment is currently undergoing unprecedented change at multiple levels due to multiple stressors including biodiversity loss, climate change, overfishing, eutrophication, colonization by alien species, habitat destruction (e.g. by coastal developments) and marine litter. Biodiversity loss rarely occurs on its own, but it is usually a consequence of drivers acting either alone or in synergy. The purpose of this review is to summarize the current state of scientific knowledge on biodiversity loss, warming and ocean acidification, especially for the coastal and territorial waters of the UK, and the relevance and impacts of these developments for the UK's society and economy – however, it should be highlighted that most of the issues discussed here are global.

Globally, the marine Living Planet Index (LPI) shows a 49% decline in populations of marine mammal, bird, reptile and fish species, highlighting dramatic biodiversity loss (WWF, 2015). Climate change and other forms of environmental change also pose new challenges to legislation. For example, the network of marine protected areas (MPAs) in UK waters was in many cases designed around some localized features which are potentially vulnerable to climate change, meaning that the on-going utility of MPAs as a conservation tool could be affected (MCCIP, 2015). A general challenge for assessing most types of such change affecting the distribution and abundance of living organisms in the marine environment is the shortage or complete lack of historic baseline data to assess environmental change, which has been termed the "shifting baselines concept" (Knowlton and Jackson, 2008, Jackson et al., 2001).

A systematic search of the ISI Web of Science was conducted with a combination of the search terms (1) ocean acidification, (2) sea level rise, (3) pollution, (4) plastic pollution, (5) biodiversity loss, (6) ocean warming on their own and in combination with (a) Atlantic, (b) UK, (c) Europe, (d) Falkland, (e) South Georgia, (f) Ascension, (g) Chagos, (h) Caribbean, (i) Pitcairn, (j) Bermuda), respectively, for covering both the UK's maritime areas in Europe as well as in the Overseas Territories (Table 1).

1. Current trends and effects on UK interests

Key stressors currently impacting marine life in UK waters are (1) biodiversity loss, (2) ocean warming due to climate change, (3) overexploitation (in particular, overfishing) of certain target species affecting the food web, (4) plastic pollution and (5) alien species.

1.1 Biodiversity loss and implications for ecosystem functioning

Little knowledge exists about overall biodiversity loss in UK waters but significant range shifts are ongoing mostly due to climate change, which are expected to be compounded in the next decades by ocean acidification (below). Globally, climate change alone is predicted to result in dramatic species turnovers of over 60% of the present biodiversity, implying ecological disturbances that potentially disrupt ecosystem services (Cheung et al., 2009). Studying sedimentary, soft-bottom systems in the UK's North Sea, a recent study (Frid and Caswell, 2015) into the links between changes in benthic biodiversity and ecosystem functioning found that the relationship is idiosyncratic, but a degree of temporal stability in functioning is maintained such that the ecosystem services they underpin would also be stable during decadal and longer-term changes. Further implications for marine carbon storage are discussed below.

1.2 Ocean warming due to climate change

The North Atlantic Current (Gulf Stream) creates a climatic anomaly by providing a more temperate climate than what would be expectable at the UK's latitude. This, in turn, is a determining factor for the biodiversity found in the North Atlantic and therefore around the UK and Western Europe. The North Atlantic Current is part of the Atlantic Meridional Overturning Circulation (AMOC), abrupt changes of which have long been hypothesized to be a central driver for the onset and end of ice ages – evidence for which was provided only recently (Henry et al., 2016). Any change to the AMOC system and, consequently, rapid climate change, would have profound implications both for the terrestrial and maritime climatic conditions of the UK. Consequently, this has received considerable attention in the public.

While, at present, long-term changes impacting the UK are not detectable , (McCarthy et al., 2015), the North Atlantic Current demonstrates the importance of ocean temperature for determining marine biodiversity. Ocean temperature is projected to rise by between 1.2°C and 3.2°C by 2100, depending on greenhouse gas emission levels (Genner et al., 2017).

This is likely to have a number of effects, depending on future climate change scenarios, including on species distributions (Cheung et al., 2009). For example, in the North Sea and on the Scottish west coast, a survey of > 300 fish species has revealed that taxa with southern biogeographic affinities have increased in abundance since the mid-1990s (Beare et al., 2004), with trawl data suggesting that the North Sea is experiencing waves of immigration by exotic, southern species (e.g. red mullet, anchovy and pilchard).

This will interact with other stressors, such as ocean acidification and increased storminess, which are well documented in UK and European seas (Mackenzie and Schiedek, 2007). The exact extent of the impacts is difficult to predict as the exact combinations of stressors over the coming century are not yet know, but could be significant. For example, the combined impacts of these stressors may cause structurally diverse seaweed canopies, which are habitats to a wide range of flora, to be replaced by less diverse habitats dominated by noncalcified, turf-forming seaweeds (Brodie et al., 2014).

1.3 Overexploitation

Overexploitation (in particular, overfishing) is threatening many marine vertebrates – particularly large vertebrates and top predators such as tunas and sharks which have seen large declines (Baum et al., 2003) – with UK waters being no exception from this global trend. After the collapse of the populations of large whales, whaling is currently only conducted by very few countries in limited areas and no longer an issue in territorial waters of the UK and its Overseas Territories. Nevertheless, overfishing of certain target species at low trophic levels can also substantially affect the ecosystem, especially when they constitute a high proportion of the biomass or are highly connected in the food web (Smith et al., 2011). In UK waters, cod and sand eel stocks have particularly suffered overexploitation. The latter case having serious impacts on seabird populations (Frederiksen et al., 2013) – with the impact being compounded by the synergy of sand eel overfishing and the range shift of the copepod *C. finmarchicus*, a main food species of sand eel (below, *Seabirds*). In the case of cod, the combination of intense fishing pressure and climate change (discussed above) has led to a northward shift of distribution ranges (Engelhard et al., 2014). In the territorial waters around the Falklands and South Georgia, the management of the Patagonian toothfish stock is a good example of sustainable management of a species that has only recently received major commercial interest, resulting in a strongly expanded fishery (Collins et al., 2010).

1.4 Plastic pollution

Plastic pollution, both of large items such as fishing gear as well as the microscopic particles resulting from physical and chemical breakdown, has emerged as a major environmental issue affecting the world's oceans (Andrady, 2011) and the UK's coasts and territorial waters are no exception from this (e.g. Horton et al., 2017, Gallagher et al., 2016). Plastic particles may directly impact marine animals by ingestion, mistaken for food particles, and subsequent choking of the digestive system but also by entanglement leading to injury, drowning etc., and as absorbents of pollutants (Gregory, 2009) and as vectors of marine life, potentially greatly increases the odds of alien species transfers (Barnes, 2002, Gregory, 2009). Significantly, sewage treatment plants of current design are not capable of eliminating significant inputs of microplastic pollution into a freshwater and marine water bodies (Mason et al., 2016).

1.5 Invasive alien species

Invasive alien species are considered a major threat to biodiversity, especially in synergy with other drivers of change (Roy et al., 2014). The UK's waters are not exempt from the arrival of alien marine species. A recent review (Roy et al., 2014) lists and ranks 52 alien species, of which 8 are considered invasive, with the majority of them originating from Asia. Impacts on native species can be due to predation / herbivory, competition, transmission of parasites and pathogens to native species, and genetic effects. In this study, the quagga mussel, *Dreissenia rostriformis bugensis*, received maximum scores for risk of arrival, establishment and impact on native biodiversity, followed by two Asian-origin shore crabs (*Hemigrapsus sanguineus*, *H. takanoi*), American lobster (*Homarus americanus*) and American comb jelly (*Mnemiopsis leidyi*).

1.6 Ocean acidification

Ocean acidification, by its physicochemical nature impacting the carbonate-bicarbonate equilibrium, primarily affects calcifying organisms. In UK waters, these include in particular marine molluscs occurring in large beds such as blue mussels (West et al., 2016) and horse mussels (below), as well as coralline red algae (below) and cold-water corals (Roberts et al., 2006). Physiological studies of the cold-water coral *Lophelia pertusa* have revealed a complex response pattern to increased acidity and CO_2 (Hennige et al., 2015).

1.7 Sea level rise

Sea level rise projections by 2100 range between 0.2 (Alley and Joughin, 2012) and 2 metres (Alley and Joughin, 2012), with regional differences (Willis and Church, 2012). This is attributed to a combination of ice sheet / glacier melt, thermal expansion of sea water, and the balance between melting, snowfall, and the regular outflow of glaciers from the ice sheets (Willis and Church, 2012). This has major implications for the UK as an island nation and its Overseas Territories. Low-lying estuarine areas are at particular risk, including the London agglomeration. Some areas of the UK have suffered particularly damaging surge events, and the Firth of Clyde is a region with high risk due to its location and morphology, even more so with the prospect of global sea level rise (Sabatino et al., 2016). Salt marshes are important coastal habitats with major roles in blue carbon storage (below), as nurseries for marine species and as bird habitats. Interestingly, the elevation of salt marshes can also increase with rising sea levels and, thus, at least partially mitigate rising levels which gives them particular importance in the context of climate change adaptation of the UK (Reef et al., 2017). In the coastal zone, sea level alterations are measured by a combination of satellite altimetry and tide gauges (Cipollini et al., 2017).

2. Case studies

We have identified the following taxonomic groups as exemplary, however it is important to note that the consequences of these stressors will vary depending on which taxonomic group is considered.

2.1 Fish stocks and fisheries resources

Fish stocks and, consequently, fisheries resources in the territorial waters of the UK and its Overseas Territories are being profoundly impacted by climate change. It is well documented that climate change is leading to distribution shifts in marine fishes in UK waters (Perry et al., 2005) – in particular, species with southern affinities have been strongly expanding in the North Sea since the 1990s (Beare et al., 2004). Overall, species richness of the fish fauna seems to increase because of climate change (Hiddink and ter Hofstede, 2008), while key species such as cod are declining in UK waters and shifting their range northwards towards Arctic waters (Clark et al., 2003, Blanchard et al., 2005). Globally, a survey of 132 national economies revealed that many of the world's poorest countries are particularly vulnerable to climate change-induced impacts of climate change on fisheries (Allison et al., 2009).

2.2 Cold-water coral reefs

Cold-water coral reefs are fragile, rich and long-lived exosystems, which are particularly significant in the area of the continental margin and offshore sea mounts of the UK and neighbouring international waters (Roberts et al., 2006). They face double human impacts from bottom trawling, which can damage these fragile structures, and increasing ocean acidity, which together may have devaating consequences (Roberts and Cairns, 2014).

2.3 Filter feeders

Filter feeders have a major role in the functioning of the UK's seabed ecosystems. In this context, an important community, horse mussel beds (*Modiolus modiolus*), currently appear as a designated feature in ten marine protected areas. They form beds and reefs which stabilise the seabed, creating a home for many other creatures and good feeding grounds for young fish. Bottom trawls and dredges, particularly those used for scallops, are known to have caused widespread and long-lasting damage to some horse mussel beds. Based on modelling projections, it is feared that this feature will no longer be present in the UK network of MPAs by 2100 due to rising sea temperatures (Gormley et al., 2013).

2.4 Seabird populations

The UK's coasts are home to large and iconic seabird populations, which occupy high levels in coastal food webs. Major changes are expected for the UK's seabird fauna. The puffin (*Fratercula arctica*), tourist magnets e.g. of the Shetland Islands for example, has been declining in the UK and beyond (Frederiksen et al., 2013). This is strongly correlated with the climate-related decline of a major copepod species, *Calanus finnmarchicus* constituting the basis of the food web that puffins and other seabird species rely on (Frederiksen et al., 2013). Conversely, the little egret (*Egretta garzetta*), not recorded as a breeding bird until 1997 and considered a species with warm-temperate affinities, has recently strongly expanded its range into the UK (MCCIP, 2015, Wood and Stillman, 2014).

2.5 Seaweed

Seaweeds are exemplary for the UK's marine biodiversity and the changes and threats that it faces. Seaweeds provide significant habitats to marine organisms in UK waters. Large brown seaweeds, kelps (Laminariales) and wracks (Fucoids), are major structuring elements on rocky shores of the UK, forming large intertidal or subtidal, forest-like communities. Such seaweed forests are important as nurseries for a plethora of marine animals including commercial fish and shellfish species, for coastal protection (Bartsch et al., 2008), and for coastal atmospheric / climatic processes (e.g. cloud formation as a consequence of iodine emissions) (Küpper et al., 2011). In addition, the UK has significant quantities of calcifying seaweeds (called maerl) found primarily on the south, west and north coast (van der Heijden and Kamenos, 2015). These contrast to the fleshy seaweeds as maerl have a calcium carbonate skeleton, meaning they are more sensitive to ocean acidification (Yesson et al., 2015).

Seaweed distribution in UK waters has undergone significant changes in recent decades; this is associated with changing sea surface temperatures, which have led to significant declines in the south for kelp species and increases in northern and central areas for some kelps and wracks (Yesson et al., 2015). A recent review (Brodie et al., 2014) has covered potential changes in different vegetation communities of the North Atlantic, predicting that warming will kill off kelp forests in the south and that ocean acidification will remove maerl-formed habitats in the north. More specifically, the southern kelp species *Laminaria ochroleuca* is expected to proliferate on the Channel Coast, increasingly replacing *L. digitata* and *L. hyperborea*. Seagrasses are expected to proliferate (summarized in Fig. 1). While there is evidence that maerl forming algae may initially persist in the future under ocean acidification, however, the carbon rich deposits they create (composed of dead algae) may dissolve (van der Heijden and Kamenos, 2015, Brodie et al., 2014) and they may be outcompeted by faster growing fleshy seaweed (Kroeker et al., 2013).

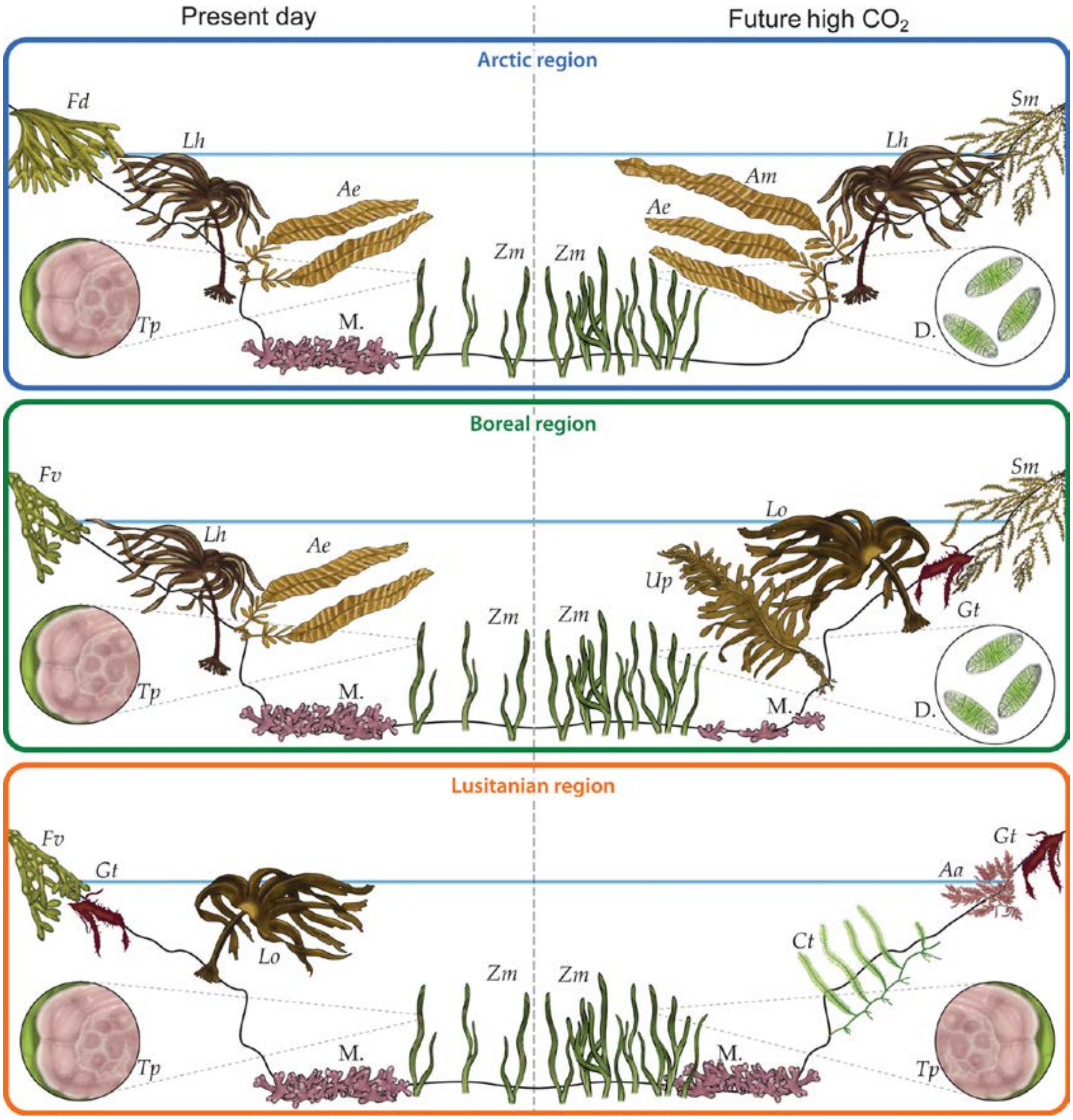

Figure 1: Predicted change in northeast Atlantic benthic marine flora if CO_2 emissions continue. In the Arctic acidification may corrode calcifying species and warming will be detrimental to cold adapted species. In Boreal areas invasive species will continue to spread and kelp forests will dominate over fucoids. Calcareous species may be corroded by acidification In Lusitanian regions kelps will dominate replacing smaller species and invasive species will proliferate. The effect of acidification on calcareous species will be less marked. Reproduced from the review by Brodie et al. (2014)

3. UK Overseas Territories

Overall, the 14 UK Overseas Territories are subject to all of the drivers of change discussed above, in varying degrees depending on their location. Key issues in the context of this review include climate change, biodiversity loss, and alien / invasive species. The coastal and maritime areas of UK Overseas Territories are large.. While the European UK has an Economic Exclusion Zone of 773,676 km^2, that of all UK Overseas Territories is 6,031,910 km^2 (NationalArchives, 2013).

While the UK is entirely located in the cold-temperate North Atlantic, UK Overseas Territories represent diverse climate zones and biomes from polar to tropical – from the Antarctic to the Equator. Many of these areas have had moderate or virtually no local human impact so far and constitute prime wilderness areas. To some extent, the high conservation value of these areas has been recognized by the creation of very large **Marine Protected Areas** (MPAs) e.g. around the British Indian Ocean Territory (BIOT; Sheppard et al., 2012) or, most recently, the proposal for the creation of a large MPA around Ascension Island. Similar to our recent work in the southwestern Antarctic Peninsula (Mystikou et al., 2014) or the Canadian Arctic (Küpper et al., 2016), scientists monitoring environmental change in most if not all UK Overseas Territories are likely confronting the shifting baselines problem (Jackson, 2008, Jackson et al., 2001, Knowlton and Jackson, 2008), i.e. due to the lack of reliable datasets of community composition prior to the onset of major **environmental change** it may be difficult to assess the impacts of the change on the community in question. Recent studies (Asensi and Küpper, 2012, Tsiamis et al., 2013) have highlighted the value of historic datasets in assessing the changes in seaweed-dominated coastal ecosystems.

Compared to other UK Overseas Territories, the marine biodiversity and inshore ecology of Ascension Island has been relatively well-studied. A synopsis is provided by the papers stemming from the 2012 *Painted Shrimp Expedition* led by the South Atlantic Environmental Research Institute (SAERI; upcoming special issue in *Journal of the Marine Biological Association of the UK*). In comparison to the above, much less – if any – knowledge exists for other UK Overseas Territories such as Pitcairn, Anguilla or the BIOT. However, as UK trends appear to be reflected globally (van der Heijden and Kamenos, 2015), indications are the that UKOTs will face similar threats to their biodiversity.

3.1 Climate change

Climate change is the major issue confronting biodiversity in UK Overseas Territories at higher latitudes. Antarctic marine species have been found to have extreme sensitivity of biological function to temperature (Peck et al., 2004). South Georgia is unique in many respects and particularly worth mentioning. Located at the Antarctic Convergence, biota include many taxa which are at their northern range limit (Antarctic species) but also numerous endemics as well as cold-temperate species which are at the southernmost range limit. Antarctic species and endemic species in South Georgia will likely come under increased pressure in South Georgia with progressing climate change (Hogg et al., 2011). In the same context, the Falkland Islands are significant for large breeding populations of penguins and seals, including the largest breeding population of gentoo penguins (*Pygoscelis papua*) in the world. Population variability of the latter has been found to be driven by climate (Baylis et al., 2012). Increasing heat episodes are having a toll on recruitment of non-burrowing penguin species (especially gentoos). The Falklands are also home to a very rich marine flora, with very large stands of giant kelp (*Macrocystis*). Overall, the flora still has to be considered underexplored in light of the many new records of algal taxa from recent work and numerous more expected to come (Mystikou et al., 2016).

3.2 Alien / invasive species

In marine systems, alien / invasive species seem to be much less of an issue in UK Overseas Territories than in their terrestrial systems. For the Falkland Islands and Ascension, very few alien marine species have been recorded, with no obvious, major impact. In contrast, in the Overseas Territories in the Caribbean (Anguilla, Montserrat, the British Virgin Islands and the British Cayman Islands), the invasive, omnivorous lionfish is having major, detrimental impacts (Rocha et al., 2015, Hixon et al., 2016). As a predator, it overconsumes native, ecologically important species, in particular in coral reef systems. In numerous cases, on land, invasive mammalian predators continue to severely impact native seabird populations (Hilton and Cuthbert, 2010). Priority islands for conservation action against mammalian predators include Gough (which according to one published prioritization scheme is the highest-ranked island in the world for mammal eradication), St. Helena and Montserrat, but also on Tristan da Cunha, Pitcairn and the Falkland Islands (Hilton and Cuthbert, 2010). One of the few studies covering alien seaweeds in UK Overseas Territories mentions the brown alga *Cystoseira compressa* and the filamentous red alga *Womersleyella setacea*, which is considered one of the worst marine invasive species worldwide (Schneider and Lane, 2007)

3.3 Ocean acidification

Ocean acidification can be expected to have a major impact in seabed ecosystems of UK Overseas Territories in the future, given the high importance of calcifying organisms (especially coralline algae and corals). Analogous to the UK’s territorial waters in Europe, this process will likely be more pronounced at higher latitudes (in particular, in the British Antarctic Territory, South Georgia and the Falkland Islands) than towards the Equator.

3.4 Mass coral mortality

In recent years, the Caribbean has been marked by mass coral mortality due to bleaching (loss of algal symbionts; e.g. Eakin et al., 2010, Alemu I and Clement, 2014), and the UK Overseas Territories in this region are no exception to this. Loss of coral reefs and their replacement by turf algal-dominated communities constitutes a significant phase shift and major loss of biodiversity in the areas affected. This is widely accompanied by a decline in reef fish abundance (Paddack et al., 2009).

4. Consequences of Biodiversity loss for UK interests

UK marine biodiversity may be worth up to ~ £2670 billion[1] to the UK (Beaumont et al., 2006) including the services it provides. This figure was calculated by based on 2002-2004 valuation of goods and services provided to the UK; those valuations were determined using the total economic valuation framework using data derived from peer reviewed literature, Defra Sea Fisheries Statistics 2004, European Parliament Report 2004 and Hebridean Whale and Dolphin Trust (Beaumont et al., 2008). These services include; food provision, raw materials, leisure and recreation, resilience and resistance, nutrient cycling, gas and climate regulation, bioremediation, disturbance prevention and alleviation, cultural heritage, cognitive values (e.g. information used in education and medicine), and biologically mediated habitats (habitat created by living organisms with other organisms use e.g. seagrass and coralline algae) (Beaumont et al., 2008).

At present, there is a paucity of consistent quantitative data available to assess the exact projected loss in biodiversity loss due to particular aspects of climate change (Ramírez et al., 2017); this is especially true for the impacts of services we discuss below. However, as a guide, meta-analysis approaches suggest species turnovers of up to 60% implying ecological disturbances that may disrupt ecosystem services (Cheung et al., 2009). Significantly, biodiversity hotspots often occur in the areas most affected by projected climate change; in particular, biodiversity changes in the North Sea will likely respond most to increasing sea surface temperatures (Ramírez et al., 2017). As a guide, in terrestrial systems climate change induces biodiversity loses are expected to fall between 15-35% (Thomas et al., 2004) with worst case scenarios leading to possible large scale species extinctions (Bellard et al., 2012)

Here we focus on some of the consequences of stress-driven changes biodiversity with particular focus on the loss of the carbon storage capacity by marine systems driven by their high biodiversity.

[1] While a financial valuation is a helpful tool for communicating the value of biodiversity, the complexity of ecosystems means it is difficult to accurately do this. There are also wider challenges around ownership of this valuation, as the costs and benefits are not necessarily directly held by a signal group of people or sector, and can be shared across society.

4.1 Carbon storage

Carbon storage falls within nutrient cycling in many assessments of carbon's role in ecosystem service provision. For example, marine nutrient cycling provides £2320 bn of ecosystems services in the form of nutrients available for life but also those that increase marine productivity (i.e. making nutrients available to all levels of the food chain where they are required for the survival of marine organisms) (Beaumont et al., 2006). It is only recently the value of blue carbon has been recognized with marine vegetated systems including sea grass, salt marshes and coralline algae being important in organic carbon burial due the their own biomass or that of other organisms associated with them (van der Heijden and Kamenos, 2015). Thus, at present, little research exists on its valuation in the UK. However, its scope is highly significant, for example, around half the carbon that enters the oceans (~80% of global carbon) is stored in marine blue carbon repositories (Duarte et al., 2013).

The mechanisms of damage include warming changing species distributions (so carbon is no longer stored efficiently) or dissolution of habitats that store carbon by ocean acidification (Brodie et al., 2014, van der Heijden and Kamenos, 2015). The consequences of damage to blue carbon ecosystems is a significant reduction in removal of atmospheric CO_2 further exacerbating global warming and ocean acidification (Duarte et al., 2013). In addition, the removal of these ecosystems leads to a significant loss in coastal protection and thus a loss in land and further carbon (e.g. via loss of coastal salt marshes) (Fitton et al., 2016). Globally, the loss of blue carbon ecosystems due to climate change represents a storage capacity loss of 7-29 teragrams CO_2 per year (Duarte et al., 2013) resulting in an estimated £5-34 per year billion loss of CO_2 sequestration alone (Pendleton et al., 2012). In the UK, coastal habitats alone (e.g. saltmarshes) are estimated to contribute £1bn in CO_2 sequestration, however, that may fall to £0.25bn by 2060 if habitat loss continues (Beaumont et al., 2014).

4.2 Climate regulation

In addition to the role of carbon storage in climate regulation, marine biodiversity is in part, controlled through biogeochemical cycling by marine biota. For example, emission of sulphur-based gases in the coastal zone (Burdett et al., 2015) may contribute to climate regulation (for example stablising climate) (Charlson et al., 1987). As with carbon storage, loss of such services will impact the rate of climate change.

4.3 Coastal protection

Within the UK, coastal habitats account for ~£50 bn of services including coastal protection from marine ingress, for example, by protecting coastal communities during storm surges (Fitton et al., 2016). Saltmarshes alone are predicted to reduce in extent by 25% by 2100 exposing coastal communities to flooding losing up to 25% of the £1bn services they provide (Beaumont et al., 2014) (including carbon storage) .

4.4 Aquaculture and fisheries

UK aquaculture is worth ~£800 million across all species (SEAFISH, 2014), while fisheries landings into the UK by the home fleet in 2015 were valued at £775 million (Organisation), 2015). Biodiversity provides the species targeted by fisheries or bred by in situ aquaculture. The stressors described above are likely to change the species targeted by both in UK waters, potentially causing a loss of employment (Beaumont et al., 2006) and possibly affecting food supply chains. Projected levels of ocean warming would lead to relocation of cod (Drinkwater, 2005) while projected ocean acidification would cause increased fragility in mussel shells (Fitzer et al., 2014), making them unsuitable for aquaculture. Not all species are likely to be impacted by warming and ocean acidification.

4.5 Raw materials

Biodiversity is responsible for the provision of materials including seaweeds which are commonly used as soil conditioners (Brodie et al., 2014) as well as fish meal which is used as an aquaculture food source (Beaumont et al., 2008) and marine genetic resources which come from the raw materials collected (Leary et al., 2009). Changes to the type of seaweed available (see above) could affect not only direct unemployment of the harvesters, but indirectly the aquaculture industry (De Silva and Soto, 2009).

As marine genetic resources often come from raw materials, the stressors affecting biodiversity, for example, are also likely to affect marine genetic resources such as those used for medicinal applications (Beaumont et al., 2006).

4.6 Bioremediation

Marine biota can modify anthropogenic waste via burial, dilution and detoxification effectively removing these wastes from the environment (e.g. significant breakdown of oil spills by marine bacteria (Gutierrez et al., 2013)). The impact of climate change on this process is uncertain as valuations for the UK do not exist.

4.7 Recreation

Biodiversity supports human use of the marine environment (e.g. fishing and SCUBA diving). Marine Protected Areas (MPA) alone are estimate to provide £3.9 billion in services (Kenter et al., 2013). Monetary values in the loss of these services extended to the whole UK coastlines is expected significantly higher as MPAs only cover 4% of the UKs seas and valuations have not been made of OSTs where extensive MPAs exist (e.g. St Helena).

Should marine biodiversity decline this would result in reduced technological and medicinal applications with subsequent economic implications (Beaumont et al., 2006).

4.8 Ability of marine environments to recover (resilience)

As biodiversity declines due to ocean warming, marine systems lose their ability to recover from other disturbances (e.g. pollution).This is particularly hard to value, as it interacts with many of the above impacts with complex outcomes. For example, in Australia, warming reduced the ability of habitat forming seaweeds to recover from the stressor as juveniles could not compete ecologically (Wernberg et al., 2010). Overall, reduced resilience due to reduced climate change will exacerbate the other impacts of reduced biodiversity as systems will be very slow to recover.

5. Legislation

Climate change and biodiversity loss pose new challenges for legislation, in particular for legislation intended to promote sustainable marine resource management (Frost et al., 2016). The implications of climate change for the designation and management of MPAs are major (above). This is a significant field for policymakers, but they go beyond the scope of the present review. For further, detailed reading, the reader is referred to a recent review paper (Frost et al., 2016).

The significance of natural carbon removal from the global system to help control climate change is such that international legislation now exists to respond to this. At present legal mechanisms exist for encouraging the mitigation of climate change through natural vegetated systems. While these mechanisms are focused on terrestrial vegetation, they also consider blue carbon, for example the United Nations Framework Convention on Climate Change (UNFCCC); Reducing Emissions through Decreased Deforestation (REDD+) and National Appropriate Mitigation Actions (NAMAs). Indeed, the UNFCCC has the Clean Development Mechanism which allows emission-reduction projects in developing countries to generate certified emission reduction credits. For the UK, coastal eco-engineering approaches that provide impetus for increased growth of UK blue carbon repositories may be an approach to ensure continued carbon sequestration (e.g. the provision of marine protection to enhance growth of carbon sequestering ecosystems). One of the challenges for effective conservation legislation in the UK is the occurrence of large-scale cold-water coral reefs in international waters close to, but outside the UK's national jurisdiction (Roberts and Cairns, 2014). This reflects the importance of international agreements relating to biodiversity protection.

The UK is subject to international and European law and there are agreements relating to marine biodiversity. At the international level, this includes the Convention on Biological Diversity (CBD, https://www.cbd.int/) and the UN Sustainable Development Goal 14 (Life Below the Sea) to ensure the conservation and sustainable use of the oceans and marine resources by reducing pollution, strengthen their resilience against a background of climate change by management, enhanced scientific collaboration and sustainable resource use.

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Table 1. Systematic search of the ISI Web of Science on May 4, 2017, using the drivers of changed as laid out in the specifications of this review in combination with search terms relevant to the geography of the UK and its Overseas Territories.

Search term(s)	No. of references
ocean acidification	4,811
ocean acidification AND Atlantic	587
ocean acidification AND UK	42
ocean acidification AND Europe*	124
ocean acidification AND Falkland	1
ocean acidification AND South Georgia	3
ocean acidification AND Ascension	0

Search term(s)	No. of references
ocean acidification AND Chagos	3
ocean acidification AND Caribbean	125
ocean acidification AND Pitcairn	0
ocean acidification AND Bermuda	21
sea level rise	19,471
sea level rise AND Atlantic	2,413
sea level rise AND UK	438
sea level rise AND Europe*	1,057
sea level rise AND Falkland	12
sea level rise AND South Georgia	33
sea level rise AND Ascension	10
sea level rise AND Chagos	8
sea level rise AND Caribbean	271
sea level rise AND Pitcairn	4

Search term(s)	No. of references
sea level rise AND Bermuda	70
pollution	199,048
pollution AND Atlantic	2,499
pollution AND UK	2,460
pollution AND Europe*	11,976
pollution AND Falkland	11
pollution AND South Georgia	45
pollution AND Ascension	23
pollution AND Chagos	3
pollution AND Caribbean	314
pollution AND Pitcairn	2
pollution AND Bermuda	71
plastic pollution	1,717
plastic pollution AND Atlantic	122
plastic pollution AND UK	16

Search term(s)	No. of references
plastic pollution AND Europe*	21
plastic pollution AND Falkland	2
plastic pollution AND South Georgia	5
plastic pollution AND Ascension	0
plastic pollution AND Chagos	0
plastic pollution AND Caribbean	12
plastic pollution AND Pitcairn	1
plastic pollution AND Bermuda	1
biodiversity loss	11,563
biodiversity loss AND Atlantic	480
biodiversity loss AND UK	222
biodiversity loss AND Europe*	1,283
biodiversity loss AND	1

Search term(s)	No. of references
Falkland	
biodiversity loss AND South Georgia	3
biodiversity loss AND Ascension	1
biodiversity loss AND Chagos	2
biodiversity loss AND Caribbean	75
biodiversity loss AND Pitcairn	0
biodiversity loss AND Bermuda	0
ocean warming	20,360
ocean warming AND Atlantic	6,559
ocean warming AND UK	76
ocean warming AND Europe*	1,009
ocean warming AND Falkland	35
ocean warming AND South Georgia	52

Search term(s)	No. of references
ocean warming AND Ascension	4
ocean warming AND Chagos	13
ocean warming AND Caribbean	331
ocean warming AND Pitcairn	1
ocean warming AND Bermuda	79
alien species	8,628
alien species AND Atlantic	317
alien species AND UK	130
alien species AND Europe*	1,744
alien species AND Falkland	7
alien species AND South Georgia	14
alien species AND Ascension	5
alien species AND Chagos	1
alien species AND	51

Search term(s)	No. of references
Caribbean	
alien species AND Pitcairn	2
alien species AND Bermuda	4
overexploitation	2,394
overexploitation AND Atlantic	186
overexploitation AND Europe*	118
overexploitation AND Falkland	3
overexploitation AND South Georgia	5
overexploitation AND Ascension	3
overexploitation AND Chagos	0
overexploitation AND Caribbean	46
overexploitation AND Pitcairn	0
overexploitation AND Bermuda	2

Search term(s)	No. of references
habitat destruction	3,111
habitat destruction AND Atlantic	98
habitat destruction AND Europe*	251
habitat destruction AND Falkland	3
habitat destruction AND South Georgia	8
habitat destruction AND Ascension	1
habitat destruction AND Chagos	0
habitat destruction AND Caribbean	37
habitat destruction AND Pitcairn	1
habitat destruction AND Bermuda	2

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