

# IMPACTS OF CLIMATE CHANGE ON AQUACULTURE

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## Executive Summary

The dominant species currently produced by marine [aquaculture](#) ([mariculture](#)) in Scotland are Atlantic salmon, mussels and oysters. To date, there has been little published research or consensus opinion on the effects of climate change on Scottish mariculture. However, much can be inferred from the published literature on the effects of environmental variables on cultured species.

Given the current predictions (Reddin *et al.*, 2006), climate change is unlikely to have a significant effect on Scottish mariculture over the next decade. However, within the next 50 years or more, the forecast changes are likely to result in noticeable effects. Rising average water temperatures will result in faster growth rates for some species (e.g. Atlantic salmon, mussels and oysters) but prolonged periods of warmer summer temperatures may cause thermal stress, particularly for cold water species (e.g. cod and Atlantic halibut) and intertidal shellfish (oysters), possibly preventing their culture at some sites, causing welfare problems and necessitating temperature control for [broodstock](#) of some species (Cano and Nicieza 2006). However, warmer waters may provide opportunities to culture new species, or species that are currently economically marginal in Scotland (Tackle *et al.*, 2006).

Diseases of cultured fish and shellfish (Goniaea *et al.*, 2006), including bacterial (Galbreath *et al.*, 2006), viral (Larsson and Berglund 2006), parasitic (Levesque *et al.*, 2005) and fungal (Claireaux *et al.*, 1995) diseases, will be affected by a changing thermal regime, but in a largely unpredictable manner, due to the uncertainties in the temperature induced variations in the immune response of the cultured species. However, under conditions of thermal stress, cultured species are likely to be more susceptible to disease. Warmer conditions may also allow the establishment of exotic diseases, whereas diseases that occur under cool conditions, e.g. cold water [vibriosis](#), may become much rarer. Sea lice are likely to remain a problem in salmon culture and rising temperatures will extend their season and may increase infective pressure, requiring more clinical interventions (Levesque *et al.*, 2005). Increased storminess (higher frequency of strong wind speeds) (Hurst *et al.*, 2005) predicted for certain seasons in some regions will increase the risk of escapes through equipment failure and may require relocation of some sites or changes in equipment design.

The forecast warmer waters with calmer, drier summer months will have an effect on planktonic communities, although this will be difficult to predict in detail. There may be an increase in the frequency of harmful algal (Imsland *et al.*, 2000) and

jellyfish blooms, potentially causing more fish kills and closures of shellfish harvesting areas, but the forecast reduction in summer precipitation may benefit classification of shellfish growing areas (Aune *et al.*, 1997). Increased temperatures and more abundant plankton could also enhance early spawning success and spat fall of cultured shellfish species, to the benefit of the shellfish industry.

### **Level of Confidence**

See supporting evidence (explanatory notes for each subject have individually assigned confidence levels)

### **Key sources of Information**

See supporting evidence

## Supporting Evidence

### Explanatory notes for executive summary

#### <sup>1</sup> Ocean climate change in mariculture areas

Scottish aquaculture in the marine environment (mariculture) is concentrated in the West coast of mainland Scotland and the Western and Northern Isles. Predictions of climate variables in these areas taken from the UKCIP published forecasts on [www.ukcip.org/scenarios/ukcip02/scenarios/maps](http://www.ukcip.org/scenarios/ukcip02/scenarios/maps), were used to derive the subsequent predictions of effects on aquaculture. The following points relating to the predicted climate change in the key Scottish mariculture areas were used as the basis for predicting effects on mariculture:

All areas are predicted to experience rises in annual and seasonal mean water temperature up to 0.5 °C by 2020 and up to 2.5 °C by 2080. Over the same timescales, the summer precipitation is predicted to decrease (0-10% by 2020 and 10-30% by 2080) and winter temperature are predicted to increase (10-15% by 2080).

#### <sup>2</sup> Direct effects of temperature increase. Medium confidence

An increase of 2°C may well adversely affect some species currently being farmed in Scotland as the thermal optima for the animals physiology may be exceeded for long periods of time during the summer months. Aquaculture of species such as Atlantic cod and Atlantic halibut may not be possible in the south of the country or be limited to areas of deep-water up-welling where the water is cooler than normal. Salmonid species are more tolerant of higher temperatures (Reddin *et al.*, 2006, Cano and Nicieza 2006; Tackle *et al.*, 2006; Goniea *et al.*, 2006; Galbreath *et al.* 2006; and Larsson and Berglund 2006) than Atlantic cod (Levesque *et al.*, 2005; Claireaux *et al.*, 1995 and Neat and Righton 2006) and Atlantic halibut (Hurst *et al.*, 2005; Imsland *et al.*, 2000; Aune *et al.*, 1997 and Bjornsson and Tryggvadottir 1996) but higher peak temperature in the summer months, which may well be of longer duration than present could cause issues with thermal stress and potentially make some sheltered, warmer sites unsuitable for those species during the summer months.

Optimal temperatures for on-growing large cod are generally low (approximately 7°C) (Neat and Righton 2006) and although rising temperatures in Scottish waters may have some benefit to the growth rates of juveniles, growth rates of adults are likely to suffer.

Predicted increased growth rates of shellfish species (mussels and oysters) are dependent on the continued availability of the planktonic food supply. Intertidal

shellfish, notably Pacific oyster (*Crassostrea gigas*), are currently susceptible to occasional mortality events during prolonged periods of hot weather. These would be likely to increase in frequency under warmer conditions. This species of oyster is not endemic to the UK and our current thermal regime is not optimal for spawning and natural recruitment from cultured stocks to establish wild populations. Under conditions of increased temperature, this may change.

Broodstock of some species (e.g. Atlantic halibut, Arctic charr) require low winter temperatures (3 months <6°C) for egg maturation. Production of high quality ova could require increased energy costs and capital expenditure associated with temperature control of broodstock and the availability of suitable broodstock sites may be restricted in the future.

### <sup>3</sup> **Opportunities for new species. Low confidence.**

Warmer water conditions could, potentially, allow new species to be cultured in Scotland where the current temperature maximums and minimums are marginal for the species, such as sea bass, sea bream, turbot, hake, scrombiforms (e.g. blue fin tuna), nori, ormer and Manilla clams.

### <sup>4</sup> **Diseases of fish and shellfish. Low confidence.**

From a disease point of view an increase in temperature can have many effects. Bacterial, viral and fungal disease will, in general, have shorter generation times. It is possible that some diseases, which transmit above a minimum temperature, will increase in prevalence. Not all effects on disease will be detrimental. For example the seasonal window of infectivity of some serious infectious conditions such as viral haemorrhagic septicaemia virus (VHSV) or Infectious pancreatic necrosis virus (IPNV) could be shortened, whilst others that require a minimum temperature to cause clinical symptoms and transmission, such as Bacterial Kidney disease (BKD), could be lengthened. However, as most fish are [poikilothermic](#) their physiology is largely governed by the temperature of their surrounding environment and warmer water will mean the immune system of these animals will function more effectively in preventing the establishment of infections (up to the thermal optimum of the animal). It is therefore possible that clinical infections will not increase as fewer infections become established in the host. Once the thermal optimum is exceeded, then the function of the immune system will decline and physiological stress and oxygen depletion (warmer water holds less oxygen in solution than cold water) may well lead to disease and welfare issues.

Some viral infections can only occur between narrow temperature ranges, often 10-12°C usually during spring and autumn. Under warmer conditions this temperature window may decrease in the spring (and occur earlier in the year) as more rapid warming of water occurs in spring. Conversely if cooling of the environment is delayed during the autumn this temperature window may become extended and occur later in the year. Additionally warmer water conditions may

allow the establishment of exotic diseases, which are currently excluded as the climate is too cool to permit transmission. Beneficially, diseases that occur under cool environments, e.g. cold water vibriosis, may become much rarer if the ecosystem is not cold enough for their biology.

If shellfish experience super-optimal thermal conditions (as will be more likely, particularly for inter-tidally cultivated species, given the predicted changes in temperature for the regions where they are cultivated) they will also be more susceptible to bacterial, viral and parasitic infections.

By their nature it is difficult to understand the response of diseases of unknown [aetiology](#) to increase in temperature. Some may become established in the UK, new ones may develop as a result of the warmer conditions while others that occur under cooler water regimes may decline.

## <sup>5</sup> **Bacterial infections**

As a rule of thumb as temperature increases the generation time of bacteria decreases (Duguid *et al.*, 1978) so under higher temperature regimes most bacterial infections would be predicted to progress faster once the host was infected, however, as mentioned above, assuming the animal is not at its thermal limit the fishes immune system will be operating more effectively and may well overcome the infection (Le Morvan *et al.*, 1996; Lillehaug 1997; Van Muiswinkel and Wiegertjes 1997 and Eggset *et al.*, 1997).

Under a rising temperature regime some bacterial disease of fish such as *Moritella viscosa* (Benediktsdottir *et al.*; 2000 and Coyne *et al.*, 2006) and cold water vibriosis (Nordmo and Ramstad 1999; Nordmo *et al.*, 1997 and Steine *et al.*, 2001) may decline in abundance as these diseases are characteristically seen in winter under cold water conditions and the new warmer environment may well adversely affect these bacteria. *Aeromonas salmonicida* and BKD, however, tend to occur under rising temperature regimes and during the summer months (Nordmo and Ramstad 1999; Lillehaug *et al.*, 2000; Eggset *et al.*, 1997; Rose *et al.*, 1989; Roberts 1976; Hirvela-Koski *et al.*, 2006; Bruno 2004; Jacobson *et al.*, 2003; Nagai and Lida 2002; Piganelli *et al.*, 1999 and Jonsdottir *et al.*, 1998). If the environment warms by 2°C then it is possible that diseases such as these will occur earlier in the year (as the spring will be warmer and earlier) and the period in which these diseases are common may well be extended, increasing the infectious pressure of these pathogens in the environment. Warmer conditions may also favour currently rare bacterial infections such as *Clostridia*, allowing this pathogen to extend its range further north.

## <sup>6</sup> **Viral diseases**

Viruses effectively hijack the host's cells to replicate and the rate of replication is governed by the animal's physiology (Duguid *et al.*, 1978). As most fish are poikilothermic (Bond, 1996) their physiology is largely governed by the temperature of their surrounding environment and warmer water will mean the animals will have a faster metabolism, which in turn will lead to increased viral replication within the host. It is worth pointing out again that, assuming the animal is not at its thermal limit, the fishes' immune system will be operating more effectively and may well overcome the infection as described above.

Some viruses can only infect their host during a very narrow temperature window (usually 10-12°C for most viruses currently of interest in Scotland (Bricknell *et al.*, 2006; Skall *et al.*, 2005a; Skall *et al.*, 2005b; Einer-jensen *et al.*, 2004; Bowden 2003; Park and Reno 2005; Bowden *et al.*, 2002; Kollner *et al.*, 2002; Jarp *et al.*, 1996 and Stangeland *et al.*, 1996)) so an increased temperature regime may shorten this window as spring warming of water may well be increased reducing the period when infection can take place. Conversely cooling of the aquatic environment in autumn may be slower and the autumn infectious window may well increase in duration. This may result in a change in the seasonal distribution of diseases and it may well allow the pathogens to encounter new hosts as their duration in the aquatic environment is different from today. For example an increased infectious window in the autumn may mean that autumn migrating fish such as the critically endangered smelt may encounter pathogens that it does not normally meet.

## <sup>7</sup> **Parasitic diseases**

As parasites of fish and shellfish often have very complex life cycles involving many intermediate hosts, understanding how climate change would affect parasite abundance and the incidence of infection is more difficult to predict. Some parasites will become rare or disappear from Scottish waters because their physiology is not suitable to the warmer environment or their intermediate and final hosts decline in numbers as the environment changes, (Drinkwater 2005; Rose 2005 and Clark *et al.*, 2003) migrate further north to cooler waters (Drinkwater 2005; Rose 2005 and Clark *et al.*, 2003) or the parasites thermal limits are exceeded (Boxaspen 1997 and Boxaspen and Naess, 2000). However other parasites will become more abundant as their definitive host and intermediate hosts colonise the new environment or, as Scottish waters warm up, the environment will be able to support new parasitic organisms, which are currently at or below their thermal minimum, and they would be able to survive and colonise new hosts in the warmer ecosystem. For example *Caligus curtis*, currently rare in Scottish waters, may effectively extend their range further north, especially if susceptible fish hosts can over-winter or establish viable populations.

The biology of parasites with direct life cycles, such as sea lice (*Lepeophtheirus salmonis*) is a little easier to predict potential changes in. It would be expected that a 2°C increase in water temperature will decrease the life cycle by approximately 2 days and permit more generations in a season (Boxaspen 1997; Boxaspen and Naess 2000 and Heuch *et al.*, 1995), potentially increasing the infective pressure of this parasite in Scotland. However, the time the [copepodid](#) stage remains infectious will also decrease from about 10 days under current climatic conditions to around 8 days under the warmer regime suggested here (Johnson and Albright 1991a, 1991b). During the over-wintering period more copepodid and mobile stages may survive allowing a more rapid establishment of infection each spring. Currently *L. salmonis* has a population boom in early May and declines in numbers in late October (Pike and Wadsworth 2000). Under a warmer regime with warmer springtime temperatures the spring lice bloom may occur earlier in the year and the autumn decline push into November or even December. Such an extended season would undoubtedly lead to more clinical interventions to control lice as well as increased lice infective pressure within the environment.

## <sup>8</sup> Fungal disease

Like bacteria, as temperature increases the generation time of fungal organisms decreases so that, under higher temperature regimes, most fungal infections would be predicted to progress faster once the host was infected. However, as mentioned above, assuming the animal is not at its thermal limit, the fishes' immune system will be operating more effectively and may well overcome the infection.

*Saprolegnia* is one disease that could cause concern in a warming environment. Currently this disease occurs each spring and causes major welfare issues with parr and smolts often necessitating clinical intervention and treatment with antifungal drugs. Under warmer conditions it is feasible that *Saprolegnia* would occur earlier in the year and progress faster in infected fish (Gieseke *et al.*, 2006; Udomkusonsri and Noga 2005; Lategan *et al.*, 2004; De Canales *et al.*, 2001; Howe and Stehly 1998, Howe *et al.*, 1998 and Quiniou *et al.*, 1998) and the autumn decline in the disease would occur later in the year.

Fungal diseases exotic to Scotland becoming established is a potential concern especially as the trade in tropical ornamental fish (including goldfish, which are often cultured under warm water regimes in the Middle and Far East, China and USA) may be a source of introduction of the exotic fish fungi into the country.

**<sup>9</sup> Storminess. Very low confidence.**

The UKCIP results for wind speeds are very uncertain, such that it is not possible to assign even a low confidence value to changes in wind speed. It is predicted that winter depressions will become more frequent, with deeper lows. However it is difficult to clearly predict regional effects. Based on the existing UKCIP forecasts, some areas are predicted to experience an increase (up to 10 percent) in the 20 year return period daily mean speeds in some seasons (e.g. West coast of Scotland in autumn/winter and Orkney/Shetland in summer). This represents an increase in the frequency of stormy conditions, which will have significance for the integrity of aquaculture structures and increase the risk of escapes. Mean daily wind speeds with 2 year return periods are predicted to decline over much of the West coast of Scotland during summer months. These calmer conditions are likely to have effects on planktonic communities (see below).

**<sup>10</sup> Harmful algal blooms. Low confidence.**

Climate change is having a complex effect on phytoplankton communities. Several studies have associated rising surface temperatures with an increase in the relative abundance of [flagellates](#) and [dinoflagellates](#) (compared to [diatoms](#)), e.g. in the NE Atlantic (Edwards *et al.*, 2006), North Sea (Edwards and Richardson 2004), Baltic Sea (Wasmund *et al.*, 1998) and Norwegian coast (Saetre *et al.*, 2003). Both of these groups contain potentially toxic or nuisance species which can be responsible for stress or kills of cultured finfish or result in harvesting closures for shellfish growing waters. There are many complicating factors and for the regions where Scottish aquaculture is concentrated there are no accurate predictions for the future trends in the occurrence of such [harmful algal blooms \(HABs\)](#). Changes in precipitation will affect the salinity of coastal waters as well as the stratification of water columns and the availability of nutrients for phytoplankton growth. In addition the zooplankton communities which graze on [phytoplankton](#) communities have also been observed to be changing.

It is possible that the future [hydrodynamic regime](#) will favour a different planktonic community to present. It is possible that species currently absent or rare in Scottish waters may become established and new toxic / nuisance species may pose problems for aquaculturists. The phenology (temporal patterns of occurrence) of planktonic species are also likely to be altered (Edwards and Richardson 2004), with effects on the timing and efficacy of shellfish spat fall.

**<sup>11</sup> Shellfish Classification. Low confidence.**

Precipitation, by influencing run-off from land, has an impact on shellfish classification (determined according to the presence of enteric bacteria in cultured shellfish). Increased run-off from land where livestock faecal material is present can increase the presence of enteric bacteria in shellfish. Shellfish farmers may be prevented from selling or be required to depurate shellfish harvested from areas with a poor Classification. Under a regime of reduced precipitation during summer months it is reasonable to expect that this situation will become less frequent.

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