Annex 1

modus vivendi

for WWF Scotland

Scotland's Secret?

Aquaculture, nutrient pollution eutrophication and toxic blooms

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Summary

Nutrients are serious marine pollutants. Scottish Highland and Island salmon farming has grown dramatically over the last fifteen years, and is predicted to reach 125,000 metric tonnes this year. Until now, its overall contribution to nutrient pollution has been unquantified. On the 31st August 2000, OSPAR, the responsible international inter-governmental body, published guidelines for calculating nutrient losses for aquaculture. The application of these guidelines in this report indicates for the first time the full extent of nutrient pollution from Scottish aquaculture: this year some 7,500 tonnes of nitrogen, comparable to the annual sewage inputs of some 3.2 million people; and 1,240 tonnes of phosphorous, comparable to that from 9.4 million people. In 1997 Scotland's population was 5.1 million.

This obviously presents risks in what were relatively pristine waters. Nutrients stimulate plant growth. It is known from other parts of Europe that they may affect important Highland and Island habitats such as seaweed forests and eelgrass meadows, where the cloudiness of the water resulting from increased phytoplankton, and the proliferation of epiphytes on the surface of these larger plants, reduces the depth to which forests and meadows can grow.

The major economic threat comes from the proliferation of toxic blooms. Evidence has accumulated, especially in the last few years, that increases in nutrients, and the distortion of nutrient ratios, result in an increased risk from toxic blooms, both in their frequency of occurrence and their geographic extent. This includes Amnesic Shellfish Poisoning, ASP, responsible for the major closures affecting scallop fisheries. Assertions that these recent events are entirely natural ignores scientific evidence to the contrary. Concern also extends to other toxic and harmful blooms. It has direct implications for aquaculture with a prospect of major fish losses. It may also have implications for fin fisheries, as there is evidence that toxic blooms can kill fish larvae. Apart from the commercial considerations, an increase in toxic blooms has wider consequences for wildlife. It is established that toxic blooms can be lethal to birds and sea-mammals, for which Scotland has major international responsibilities in this area. Shellfish bans do not protect wildlife.

As long as major reductions in nutrient inputs remain unimplemented the aquaculture industry risks significant fish losses and legitimate compensation claims from other users. Means are available for an equitable mechanism for compensation that takes into account the uncertainties. However, this will not meet international obligations regarding environmental protection.

Overall, it reinforces existing concerns over the sustainability of aquaculture. Rather, we need to identify what prevents the recovery of wild stocks, and take the steps that maximise their prospects for recovery.

Introduction

Over the last decade and more, the direct and indirect problems caused by nutrient enrichment has emerged as a major issue affecting the marine environment.

At first sight this may seem puzzling. One might expect that more nutrients means more plants, and more plants means more food, directly or indirectly, for everything else. Unfortunately, it isn't as simple as this, and the reason why it isn't so simple is partly to do with the astonishing scale of human inputs, which have overwhelmed natural cycles. From northern Europe natural inputs of nitrogen are now calculated to make up between 12% (Denmark) and 39% (Norway – North Sea catchment) of nitrogen, while natural inputs of phosphorus make up only between 7% (Switzerland) and 34% (Norway)[1]. Last year a United Nations evaluation reported that nutrient pollution is creating problems with *"global implications comparable to those caused by disruption of the carbon cycle"* that lead to global warming[2]. Like global warming, part of the problem is that this pollution has no smell or colour; effectively it is 'out of sight out of mind'.

As nutrient levels change, and the proportions between the nutrients are distorted, this can result in the proliferation of usually rare species, or the 'abnormal' behaviour of usually inoffensive species. In Scotland, this is most apparent with the suffocating beds of green algal weeds at sites such as the Ythan and Eden estuaries and the Montrose Basin. But offshore it can have similar, but less obvious, distorting effects on microscopic single celled plant plankton ('phytoplankton') species. World-wide the evidence is mounting that nutrients are a contributory factor to the increasing global occurrence of toxic algal blooms.

Nutrients come from various sources. Amongst those usually acknowledged are sewage and agriculture. The combustion of fossil fuels is also an important source of nitrogen. Marine aquaculture has grown so fast – arguably outpacing regulatory control – that its contribution to overall nutrient inputs has been largely overlooked until now.

Nutrients from Scottish Salmon farms

Aquaculture has grown dramatically in Scotland. Since the mid-1980s industrial salmon production has grown from virtually zero to reach 115,000 tonnes in 1998, and is predicted by industry to reach 125,000 tonnes in 2000[3, 4]. This activity takes place over a far shorter stretch of coastline compared to Norway, the largest European salmon producer (total production 343,000 tonnes in 1998, predicted to reach 450,000 in 2000[4]). Due diligence demands the self-protective step of calculating nutrient budgets; knowing how much nitrogen and phosphorus enters the seas, comparing the inputs with those of other sources, and exploring the possible consequences. Yet information on the total amount of nutrients released from fish farms is not readily available from government agencies, for example from either the Scottish Environmental Protection Agency (SEPA) or the Aberdeen Marine Labs Fisheries Research Services (FRS) web-sites[5, 6]. The absence of official information on nutrient inputs from aquaculture in Scotland is doubly surprising as the calculations are not difficult to make. When this is done it becomes apparent that Scottish aquaculture is responsible for one of the largest – perhaps the largest, per unit length of coastline – distortion of nutrient cycles of any European sea body in recent years.

Danish comparison

One possible means of assessing nutrient burdens is by comparison with other countries. However, the only European country with a significant aquaculture sector to have published an assessment is Denmark. In the mid 1990s it produced some 39,000 tonnes of trout, of which 7,352 tonnes (in 1998) was saltwater in cages or land-based, and the remainder freshwater[4, 7]). In 1995, this resulted in an additional 1,150 tonnes of nitrogen reaching the North Sea. This is not trivial compared to the 3,200 tonnes from sewage and 1,350 tonnes from industrial sources, although dwarfed by 51,000 tonnes from Danish agriculture[8]. For phosphorus 90 tonnes were released from aquaculture, compared to 130 tonnes from industry, 375 from sewage and domestic waste, and 1,005 tonnes from agriculture. This level of inputs follows concern about the general impact of nutrients in the Danish marine environment and a programme of aquaculture sludge removal and subsequent treatment: in 1989 even though aquaculture production levels were much smaller, nutrient inputs were larger, some 2,351 tonnes nitrogen and 275 tonnes phosphorus. However the dominance of freshwater production, enclosure of salt-water production systems, and treatment of sludge, means that these figures are of limited relevance to the predominately open-system marine aquaculture of Scotland.

OSPAR guidelines

Instead one can use the guidelines adopted within the Oslo and Paris Commission, OSPAR, (the international regulatory body set up and composed of North-East Atlantic Governments and the European Commission[9]) for calculating inputs of nitrogen and phosphorus from aquaculture (in turn based on the scientific literature available since the early 1990s[10]). These guidelines have been available in draft form for consultation for some time confidentially within OSPAR[11], and were finally published on the 31st August this year[12]. The calculations are relatively simple (see *OSPAR guideline calculation of nutrient load from salmon aquaculture*). The option used here, while of course dependent on the accuracy of the OSPAR formulation, should be adequate for broad comparative purposes. Applying the guidelines, by 1998, assuming that all of the feed was actually consumed (otherwise the result would be worse), 6,900 tonnes of nitrogen and 1,140 tonnes of phosphorus per year entered the marine environment from Scottish salmon aquaculture, the majority on the west Highland coast and Islands. If industry projections are borne out, by 2000 this will have increased to 7,500 tonnes nitrogen and 1,240 tonnes phosphorus. Remarkably, by way of comparison, based on OSPAR North Sea catchment statistics[1, 13] for seven countries*, this is equivalent to the sewage inputs, for nitrogen, of 3.2 million people and of the inputs of 9.4 million people for phosphorus. Scotland's population in 1997 was 5.1 million people[14]. The difference in both the nature and nutrient ratios between aquaculture pollution and sewage may have significant implications†.

A calculation of aquaculture inputs along these lines – which could have been done at any time during the expansion of aquaculture – was apparently never made. If it was, its significance was not appreciated or publicised. Surprisingly, there is just one 'National Monitoring Programme' site (in the Minch), between the Firth of Cyde and the Moray Firth, out of 20 in Scottish waters and 87 for the entire UK[15, 16]. Compared to other Scottish sites the nutrient concentrations for the Minch appear unproblematic[17, 18] – until it is appreciated that this offshore Minch site will inevitably have far lower concentrations than the peak sites located in estuaries, where the nutrient pollution from entire river catchments are briefly concentrated. Rather, the important comparison is the relative change in concentrations before and after the introduction of aquaculture, and from sites closer inshore. But, as even

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* Norway, Sweden, Denmark, Germany, Netherlands, Belgium and Switzerland.

† Of course it is true here, as for acknowledged continental European problem areas affected by eutrophication, that 'natural' nutrients are also brought into the area by offshore currents. But while this contribution may be significant in absolute terms, it is spread throughout the water-column, and unavailable to plants that need light to grow and whose growth is restricted to the top few metres. Because fresh and brackish water is less dense than salt water, it floats above it. Nutrient pollution, from land-based or inshore waters, is concentrated in this layer even at some distance from the source, where it can have a disproportionate influence on phytoplankton, particularly in circumstances that favour plant growth – calm conditions and its associated high light intensities.

OSPAR guideline calculation of nutrient load from salmon aquaculture

(after reference 11)

For farms without treatment (sludge removal):

$$L = 0.01(ICi - PCf)$$

Where:

L phosphorus (P) or nitrogen (N) discharge to water body (tonnes/year)
I feed used (tonnes/year)
Ci P or N content in feed (%)
P production (tonnes/year)
Cf P or N content in organisms (%)

And using industry (IFOMA) data on the conversion efficiency of fish feed to harvested fish[23], of 1.2 for salmon aquaculture in 2000, and where the typical content of nitrogen and phosphorus in dry feed and in produced fish (from the OSPAR guidelines) is:

	Total phosphorus content (%)	Total nitrogen content (%)
Dry feed	1.2	7.5
Fish	0.45	3.0

Then, with a production of 115,000 tonnes of aquaculture salmon in Scotland:

Loss N = 0.01(138,000 x 7.5%) - (115,000 x 3%)
= 6,900 tonnes N per annum

Loss P = 0.01(138,000 x 1.2%) - (115,000 x 0.45%)
= 1,138 tonnes P per annum.

The equivalent figures for a production level of 125,000 tonnes salmon is 7,500 tonnes nitrogen and 1,240 tonnes phosphorus.

current nutrient monitoring leaves much to be desired – a point accepted by the regulators[17] – there is little prospect for comprehensive data for the west and north coast prior to aquaculture. The little information available, for the Minch, has been used by the Aberdeen Marine Laboratory (FRS) to provide one average value for each month covering the period between the 1960s to the present[19]. This indicates that historically both nitrogen and phosphorus have been depleted by phytoplankton growth in the summer months, at least confirming the potential for a response to additional nutrients. Information on algal bloom trends is virtually non-existent, although SEPA's recent aquaculture manual does note that *"There is some anecdotal evidence of increasing frequency of algal blooms in west coast waters such as the incidence of the dinoflagellate* Gyrodinium aureolum [a toxin producing species potentially harmful to both fish[20] and shellfish[21]] *reported in August 1996"*[22].

Eutrophication

Over the last decade the amount of research into marine eutrophication – the increase in plant growth that results from nutrient pollution – has increased enormously. A literature search of specialist scientific journals such as *Estuaries*, *Limnology & Oceanography*, *Marine Ecology Progress Series* and the *Journal of Plankton Science*, rapidly confirms that there is now little scientific debate over the point that marine eutrophication exists; is extensive and increasing; and is damaging. Rather, there are now thousands of papers documenting, in increasing detail, the complex and sometimes subtle nature of its effects. Although information for Scotland is in short supply, a considerable amount is known for other parts of northern Europe and wider afield, and there is now a reasonable requirement for those who argue against action on nutrient pollution to produce compelling evidence to back up this position.

Phytoplankton

It is well established that even quite small changes in nutrients have major effects on the species composition of phytoplankton communities. We know this because some phytoplankton – such as some diatoms – have hard ‘shells’ that are preserved in the accumulating sediments when they die, along with ambient nutrient concentrations. Among the many studies one of the most impressive is a 2,500 year record of changes in Chesapeake Bay, on the US East coast[24]. This shows detectable increases in nutrient concentrations, and tightly correlated changes in species composition, dating back to the arrival of European colonists and their clearance of the land. These changes sharply accelerated during the twentieth century. One can anticipate that, were similar work done on the west coast of Scotland, not only will the effects of aquaculture be clearly visible, but also historic effects, such as those arising from land-use changes arising from the Highland Clearances, and the even earlier loss of the forests.

Because phytoplankton are not obvious it may come as a surprise to learn that they make up the bulk of plant production in the seas, and that changes in species composition can have important knock-on consequences; for example different species vary in their food value. One of the most important aspects, for us and other species, is the link between eutrophication and toxic algal blooms, discussed below.

Seaweed Forests and Eelgrass Meadows

However, it is the larger plants in shallow waters that we are most familiar; seaweeds and eelgrasses. On the north-west coast estuaries and mud flats are not as prominent as in the east, so some effects of nutrient pollution, such as the algal weed mats of the Ythan, are also less prominent. Rather, eutrophication reduces the depth to which seaweed and eelgrass can grow, as a result of the increase in phytoplankton – which intercept the light – and the proliferation of small 'epiphytes' on the surface of the plants themselves. Again, while there may be little long term work in Scotland it is well established, for example in Scandinavia, that the depth to which seaweed grows has been reduced during the twentieth century[25]. Of course any effect on the important seaweed habitats of the west coast is extremely undesirable, but for eelgrass Scotland has a very special responsibility. The sub-tidal eelgrass *Zostera marina* – the so-called 'common eelgrass' – once clothed the sub-tidal of many parts of northern Europe, supporting a very rich invertebrate, fish and bird fauna[26]. But in the 1920s and 1930s this species was largely wiped out by disease in the UK and adjacent North Sea coasts (and where stress caused by eutrophication reportedly can make them more vulnerable, and less able to recover). The west coast of Scotland survived as one *Zostera's* few remaining strongholds in the UK[27], and requires special protection under the EU Habitats Directive. It is important to take prudent measures to ensure that these sites are not threatened by an increase in nutrient inputs.

Toxic Blooms

Following the prominent recent Scottish scallop fishery closures, the most pressing issue is obviously that of the relationship between nutrients and toxic algal blooms. The toxin responsible for the closures, amnesic shellfish poisoning, ASP, is only one of a number of forms of which in Scotland paralytic shellfish poisoning, PSP and diarrhetic shellfish poisoning, DSP are also of concern.

Shellfish poisoning undoubtedly evolved and existed before the modern era[32, 33] and without human influence (see below: *What's the evolutionary advantage of toxic blooms?*), and some have argued that shellfish poisoning could be entirely natural, simply underreported in the past[34] (or perhaps resulting from increased shellfish consumption). But it is no longer possible to assert without doubt that toxic and other harmful blooms are a *purely* natural event. Both toxic and non-toxic blooms are reported to have increased world-wide[35] and, during the 1990s, a succession of field studies associated elevated nutrient concentrations with toxic blooms[36], including Argentina (PSP)[37], Australia (DSP, PSP and other toxins)[38], Canada (ASP, DSP, and others)[39, 40] Europe (DSP and others)[41, 42] the US west coast[43], the Gulf of Mexico (ASP)[44], Hong Kong (PSP)[45] and Japan (PSP)[46]. There is also some evidence that at least the species responsible for DSP can also exploit increased organic matter pollution[47] characteristic of sewage and fish-farming, while others can at least benefit indirectly via the ingestion of bacteria (e.g. *Chrysochromulina*, responsible for a 1988 Norwegian 1,000 km bloom, toxic to fish and other marine life, that caused major losses for the salmon industry[48, 49]). Moreover the phytoplankton responsible can reach densities which demand high nutrient levels[45, 46]. The 1988 *Chrysochromulina* bloom reached tens of millions of cells per litre and had a nitrogen demand of 10–13 μM (micromoles) per litre[42] – in practical terms, it was capable of absorbing the nitrogen content of heavily polluted European coastal waters. *Pseudo-nitzschia* (associated with ASP) have also been recorded at densities of hundreds of millions of cells per litre[44]. Overall, phytoplankton population trends are affected by many factors and are typically non-linear or even chaotic[50]. Broad correlations between increasing nutrient inputs and bloom frequency are to be expected, but not one-to-one relationships between the highest blooms and the highest nutrient

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What's the evolutionary advantage of toxic blooms?

One possible explanation[28] is that this is closely tied to the natural shortage of nutrients in the summer months following the burst of plant growth and death that occurs in spring with the arrival of higher light levels. At least some toxins are toxic to other phytoplankton[29], reducing or eliminating these nutrient competitors. Then, in turn, a variety of animals from molluscs[30] to fish[81] are both immune to these toxins, and able to accumulate them as a form of defence against predation. In this they are relatively successful – it is known that a variety of predators including gulls[31], sea otters[30] and, of course, people learn which species are toxic and avoid them. However when there is no prior history of these toxins species including birds[70, 84] mammals[71], and people, are extremely vulnerable.

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concentrations in space or time.

Field studies have been complemented by laboratory work demonstrating the ability of many species to maximise their growth rates at high nutrient levels, although some can grow well – displacing other species – even when nutrient concentrations in the water are low[34, 51, 52, 53]. At least some (DSP) toxins appear to inhibit the growth of other phytoplankton[54]. High nutrient levels *per se* do not necessarily result in more toxin *per cell*. However a *distorted* nutrient ratio (i.e. by one or other nutrient being in short supply or excess) can have this effect[45, 55, 56, 57] although less marked in other species and / or strains[58, 59]. We are also beginning to better understand how nitrogen and phosphorus have a functional role in the synthesis or composition of shellfish poisons.

In summary two points can be made:

- on the balance of probabilities it seems that increased nutrient concentrations benefit many toxic species, although not necessarily result in more toxin per cell. But as there are more cells, the net effect can be an increase in toxicity overall;
- the evidence suggests that increased nutrient pollution and altered nutrient ratios are a necessary but not sufficient condition for increased blooms in a chain of events that also includes suitable weather conditions (raising issues about interactions with climate change[60, 61]), other physical factors and biological interactions. One might reasonably anticipate broad trends of increasing frequency, higher levels of toxicity and greater geographic spread, rather than a tight correlation in space or time.

Amnesic Shellfish Poisoning

ASP, responsible for the scallop closures, is a newly described phenomena. The first reports of toxicity date from Canada in 1987[62], with the first European event reported in 1994[63]. Prior to its occurrence in Scotland nutrient enrichment and distorted nutrient ratios had been identified as risk factors for ASP. The species responsible (from the genus *Pseudo-nitzschia*) are, of course, not new – they are widespread and known to have been present in European waters[64] the Gulf of Mexico[44] and US west coast[65] prior to the identification of any toxic ASP blooms[64]. A European study predating the first European ASP events reported that the by then known potentially toxic *P. multiseries* had apparently declined during the 1990s while *P. pseudodelicatissima* apparently increased. Subsequently, in 1999, researchers in the Gulf of Mexico reported that varieties of *P. pseudodelicatissim* were far more toxic that previously reported[66]. The Gulf of Mexico study also noted an increase in abundance of *Pseudo-nitzschia* species prior to the first toxic blooms, and associated this with the doubling of riverine nutrient inputs to the Gulf between 1950s and 1990s. In the laboratory when nitrogen, phosphorus and silicon* are supplied in excess, they multiply rapidly but levels of ASP toxins are low. However when nitrogen and phosphorus only are supplied in excess, high levels of toxins are generated[67]. Human activities increase nitrogen and phosphorus inputs, but are generally thought to have less effect on silicon. If only nitrogen is supplied in excess this too appears to increase the production of ASP toxins[68].

ASP has had a devastating effect on the scallop fisheries, and attention has understandably been focused on the human consequences. What is less appreciated, however, is that ASP can also have major toxic effects on, and consequences for, other marine species[69], including birds (Californian pelicans and cormorants[70]) and sea mammals (Californian sea-lion[71]). In these cases the ASP toxin was transmitted via anchovies. This suggests that we need to direct attention to possible food web consequences arising via plankton-feeding fish and their predators; fish such as herring, sprat and mackerel.

Other toxic and noxious blooms

Obviously, attention in Scotland is currently focused on ASP. However it would be a mistake to disregard other toxic and noxious species that present a risk as a result of increasing nutrient loads. The dinoflagellates of the genus *Alexandrium*, responsible for PSP, are known to respond to eutrophic conditions[46], and an Orkney *Alexandrium* bloom, reported in 1998, was equal in PSP toxicity to the most toxic forms known from the US, in contrast to other European blooms of lower or non-toxic forms[72]. Similarly, DSP species also respond to increased nutrient levels and distorted nutrient ratios. DSP also emphasises the need to ensure that we are looking in the right places – for example DSP toxins can arise from species living on the seabed[73], or as epiphytes on larger plants[74] as well as from suspended phytoplankton.

Moreover the aquaculture industry is not immune to the effects of eutrophication, as the highly irregular but damaging *Chrysochromulina* blooms have made clear. The 1988 *Chrysochromulina* bloom has already been mentioned, but in 1991 a bloom in northern Norway also resulted in major disruption and the loss of hundreds of tonnes of farmed salmon. It is notable that the initiating factor was speculated to be fish: albeit in this case the nutrients released the previous winter by an (estimated) 1.5 million tonnes of over-wintering herring[75]. This begs the question as to why historically larger shoals of herring apparently did not cause the very obvious effects on fish and other marine life[76] resulting from such blooms. Moreover the contribution of nutrients from aquaculture appears not to have been assessed. Similarly, a *Prymnesium* toxic bloom which also caused the death of Norwegian

* *Pseudo-nitzschia* belongs to a group of phytoplankton, diatoms, that require silicon for their shell, although not in the amounts required by other diatoms.

aquacultural salmon and sea trout, was attributed to elevated nutrient concentrations and a distortion of the N:P ratio[77]. SEPA have reported the presence of another potential fish-killing species, *Gyrodinium*, in west coast waters[22].

The only thing we know for certain is to expect the unexpected; for example it has only recently been established that *Phaoecystis* – increases of which are one of the most widespread eutrophication indicators in Europe, responsible for the masses of foam washed up on some beaches – previously thought to be non-toxic, actually has toxic effects on cod larvae[78, 79] and potentially on other fish. This parallels earlier work demonstrating that PSP toxins were toxic to mackerel larvae and postlarvae, and where it was argued that a proliferation of toxic algal blooms represented a threat to fish populations[80]. Adult mackerel are resistant to PSP but, for the eastern Atlantic at least[81], are known to bioaccumulate PSP toxins to concentrations that are fatal to predators. So toxic blooms may present a variety of risks to commercial fisheries. Transportation by natural ocean currents or in ship's ballast water means that distance is no protection from problems elsewhere in the world, such as the devastation of the US eastern Long Island scallop fishery by *Aureococcus* brown tides that exploit the vastly increased nutrient inputs[82]. As elsewhere in Europe[83], we should anticipate that new forms of toxic blooms will occur in Scottish waters.

Finally, as with ASP, we should not overlook the fact that harmful blooms have consequences for species other than us – the increasing number of deaths of kittiwakes on the north east coast of England, climaxing in a mass mortality in 1998–99 was attributed to shellfish toxins[84]. The 1988 *Chrosochromulina* bloom had a major impact on seabed fauna[76]. Birds, marine mammals and other wildlife living in these important west coast and island sites are not protected by market bans!

Implications

Drawing back from the detail, we need to consider the implications for policy. When eutrophication problems – for example in the German Bight – emerged in the late 1980s, other countries carried out detailed scientific research with the intention of better forecasting and managing the occurrence of harmful blooms. However the researchers advised that the uncertain number of variables, the high cost of monitoring, and the lack of precision, meant that the exercise was futile[85] other than in the broadest terms. The governments instead adopted a strategy of prudent avoidance based on major reductions in nutrient inputs. One can question just how successful those policies has been: nevertheless it is evident that Scotland now faces a similar challenge with aquaculture, which demands an urgent policy response.

With regard to the agencies – SEPA, the FRS at Aberdeen, and Scottish Natural Heritage, SNH – it is surprising that while they recently took a high profile over estuarine eutrophication at sites such as the Ythan, and on phasing out untreated discharges of sewage on the east coast, they appear not to have highlighted the overall scale of nutrient inputs from aquaculture. It may have been a case of 'out of sight, out of mind'; or that the expansion of aquaculture was an unchallengeable paradigm; or because the scale and speed of expansion of the aquaculture industry was not initially apparent. Decisions taken at the outset of a policy can cast a long shadow over subsequent events.

Whatever the reasons, had the rapid increase been anticipated, or subsequently calculated, this might have prompted a greater response. As it is, the approach to monitoring and assessing the cumulative impact of aquaculture on the marine environment remains limited and piecemeal. The national monitoring network has been shown to be inflexible, unable to adjust to, and adequately assess, the impact of a significant redistribution of industrial pollution towards the Highlands and Islands. If an issue of resources, it raises questions of their ability to fulfil their role.

The general and specific implications for the **Scottish Executive** are significant. Turning to general implications first, it once again raises issues concerning the *appropriate level of proof*, on *'sound science'*, and in assessing the *costs* and *benefits* of actions[86].

Thus, in the past, faced with the eutrophication of sites such as the Ythan estuary, 'without possible doubt' was demanded[87] – a higher level of proof than once demanded for the death penalty – whereas a more rational and defensible response, given both the circumstances and the inevitable lack of historical and site-specific information, is civil law's judgement 'on the balance of probability'. Indeed there is now a treaty obligation, within Europe, to apply a precautionary approach in such circumstances.

Similarly, nobody, in their own mind, bases their arguments on 'unsound science'. Sound science has become something of a slogan, a not very convincing claim to value-free judgements for implacably value-laden assessments of the costs and benefits of alternative choices. For the Ythan, coupled with the requirement for absolute proof, this resulted in an infinite recursion to ever more detailed points of argument, and came to be seen as a tactical ploy. So much for the past: the important point is that such disputes should be avoided in future, as they both bring science into disrepute, and get in the way of a legitimate discussion about the costs and benefits of alternative choices.

However, some aspects of the assessment costs and benefits are constrained, these deliberations having taken place in the negotiations leading up to the relevant EU Directives, and is reflected in their requirements. Thus an attempt to reduce treatment of sewage discharges to the major English estuaries was overturned in the courts in the mid-1990s, it being ruled that the appeal to economic cost were inadmissible under the Urban Wastewater Treatment Directive (the point being that the economic costs had already been considered in the discussions leading up to the Directive, and deemed worthwhile). When it came to the Ythan, there were similar Directive requirements concerning nutrient levels, the protection of wildlife and the balance of evidence. For aquaculture it can be anticipated there are, or may be, similar 'absolutes' concerning the general protection of wildlife and shellfish waters and possibly other areas.

Turning to the specifics, no one could disagree with the driving force behind the Scottish Executive's support of aquaculture; the need to generate and sustain employment and prosperity in the Highlands and Islands. But one must be clear-headed, and re-evaluate in the light of experience. On the one hand are the ca. 6000 jobs supported, and millions of pounds injected into the Highland economy, by aquaculture – points that cannot lightly be disregarded. But we now know more about the downside of than we did a decade ago. Aquaculture is an intensive industrial process and, just like other industrial sectors, requires appropriate pollution controls. Not only the nutrients and other pollutants, but also other consequences, for example the increase of disease and parasitism in wild population of salmonids, could be reasonably predicted. Awareness of the high level of nutrient inputs from aquaculture, and the associated risks, carries with it a number of implications.

- **Implications for the aquaculture industry.** At current levels of nutrient inputs – let alone if they continue to increase at the current rate – from what is known about algal physiology, and from experiences elsewhere in the world, it must be assumed that there is a significant probability that major toxic blooms will occur that will kill significant numbers of farmed stocks. This clearly has major implications for the industry, its insurers and investors.

- **Implications for other users.** It can be anticipated that significant increases in nutrient levels will lead to an increased frequency of toxic blooms of wider geographic extent. This will adversely affect the shellfish industry, and may affect the fin-fish fisheries (through impacts on fish recruitment and possible toxicity of fish), and recreational fishing (whose economic significance, and retention of funds within the local economy, is often overlooked). This in turn raises issues of due diligence, liability and compensation for both the aquaculture industry and government. Given the scientific literature, it is no longer possible to assert without doubt that the ASP episode, for example, is an entirely natural phenomena – any more that it is entirely the responsibility of aquaculture. There are established mechanisms for dealing equitably with this uncertainty. For example the *British Nuclear Fuels Compensation Scheme for Radiation Cancer in its Employees* allows some compensation to be paid, on a sliding scale, once there is judged to be more than a 15% probability that the cancer was radiation induced[95].
- **Implications for the natural environment.** Increased levels of nutrients can be anticipated to result in eutrophication, which may range from subtle changes in phytoplankton species composition to the reduction

The Wider Context

Taking a broader perspective, questions continue to mount over the sustainability of this industry. Leaving aside issues such as pollution, and its effect on other users and the environment, for which there may be technical fixes (at a cost), aquaculture amply illustrates some more fundamental problems. At one time salmon gathered their own food, required no polluting disease control, needed no maintenance, and transported themselves into estuaries where they could be captured with minimum effort. Much the same can be said of other stocks, such as the nineteenth century coastal Scottish long-line cod fisheries. Now instead we have to catch the fish that they require, transport these to Denmark or sites further afield to convert them to fish-feed, transport this feed in turn to Scotland (all of which costs money, demands labour and fossil fuels, and is certainly not an option with minimum environmental impact), all in order to produce an arguably inferior product. Moreover by removing the ca. 3 tonnes of fish for every one tonne of farmed fish[49] (industry figures of near 1:1 conversion of fish pellets to salmon are of dehydrated food to wet fish), we are removing fish that are required for the recovery of wild stocks, as well as by other marine species.

Given wild salmon's importance in Scottish culture, heritage, the rural economy and ecology, it is remarkable how little concern or ambition there is about restoring stocks to levels seen in previous centuries, or even in living memory. Not only did they support large scale estuarine and river fisheries that were sustained over a considerable period, but the migrations may well have played a significant role importing material from distant seas into Highland food webs, an aspect whose significance is only now being appreciated[88, 89, 90, 91, 92, 93, 94]. One might believe this restoration to be an impossible goal, but this is an assumption, not a fact. We should investigate the prospects and conditions for a reversion to such stock levels. If feasible we should rapidly move to a political commitment to work towards a restoration of stocks. There is no reason why the companies (and the employment) supported by aquaculture should not benefit from such a transition, and they should be encouraged to play a full and positive role in this evaluation.

of the depth to which seaweeds and eelgrasses grow. Toxic blooms may be anticipated that will harm bird and sea mammal populations, and may even effect other plants. Current policies, such as shellfish bans, do not provide wildlife with the protection required under national legislation and EU Directives. Moreover, there is a requirement for protection of certain habitats which include eelgrass meadows and seaweed forests, and for species, such as sea birds and sea mammals in this area, where Scotland has a international responsibility.

Conclusion

Currently the aquaculture industry is expanding dramatically. For the reasons set out here the problem of nutrient pollution and cumulative inputs must be dealt with urgently. In the immediate sense there are only two ways to deal with this; to either scale down production, or to isolate production sites from the sea, and remove nutrients (and chemical pollutants and pathogens) from discharges. However, as described in *The Wider Context*, this is only one aspect of a greater problem. It is highly questionable whether aquaculture is the best practical environmental option for the production of Scottish salmon. Rather, we need to identify what prevents the recovery of wild stocks and, if practical, take the steps that maximise their prospects for recovery.

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