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Executive Summary

In light of increasing demands for seafood around the world and reduced productivity in the fisheries sector, there will be an increasing requirement for aquaculture to address the short fall. Also, one objective of the draft National Marine Plan (MSS, 2012a) is to increase finfish production in Scotland by 50% on 2010 levels by 2020.

Understanding what the limiting factors are with regard to the environmental impacts of an expanding aquaculture industry will ensure that the industry is not unnecessarily restricted and that environmental impacts are managed effectively. Environmental guidelines currently place limits on allowable nutrient enrichment and benthic impact from fish farming and new European directives will set targets for the environmental status of the marine environment (Marine Strategy Framework Directive, MSFD 2012). Other limitations include the availability of raw feed materials, the capacity for used medicines and other chemicals to be assimilated and degraded in the environment and the challenges associated with an expansion into more open waters. This paper presents a GIS based aquaculture decision support tool (ADST) to assist with planning the sustainable development of the aquaculture industry in Scotland. This tool has been developed alongside and incorporates elements of a project to develop ecological sustainability indicators for Scottish aquaculture (Greathead *et al*., 2012, in press). It provides advice to better understand the distribution of and the potential limitations due to the deposition of organic matter onto the seabed from fin fish aquaculture.

As part of the indicators project, new thresholds for the degree of nutrient (µmol N l^{-1}) and benthic enrichment (% loch area degraded) were proposed. These thresholds corresponded to a theoretical maximum biomass of fish that could potentially be farmed in a specific sea loch ($B_{TMAX(i)}$; t yr^{-1}).

The area required to produce the B_{TMAX} (A_{REQ}) was calculated using a standard value for the amount of fish that could potentially produced per km^2 (P_d). The results showed that in the majority of the sea lochs (81%), due to the limited area with depths suitable for aquaculture (15-70 m), it would be extremely improbable that they could reach their maximum potential biomass, with regard to nutrient and benthic enrichment; although some increase in production would be possible.

When calculating the benthic impact of a fish farm the position of the fish farm in the sea loch is one of the key parameters. Present models predict the environmental impact from existing sites; whereas the ADST described in this paper allows the environmental impacts from any future potential sites to be predicted. This will help plan sustainable future aquaculture development within sea lochs.

The ADST visualised the number and position of potential new aquaculture sites within each sea loch and the maximum biomass suitable for each site based on benthic impact. At the heart of this tool was a modified version of the Marine Scotland Science benthic impact (MSS - BI) model. This calculated the maximum biomass that could be placed on each of these potential new sites before the peak organic deposition limit (7 kg m^2 yr^{-1}) was breached below the cages (B_{CMAX}).

To develop the ADST, a base layer of bathymetric data (15-70 m) was taken for the whole of Scotland and specific areas considered inappropriate for salmon aquaculture development were masked out. The resulting area remaining (31 977 km^2) was used to determine the total potential aquaculture production this area could support by combining it with a standard potential production value per km^2, calculated from annual production data resulting in a total of 158 x 10^6 t yr^{-1}. This does not include any environmental, social or economic restrictions that might apply.

This base layer was then clipped to just include the sea lochs that were currently in the Scottish Government' s Locational Guidelines for fish farms (Gillibrand *et al*., 2002). This resulted in a total area within sea lochs potentially available for salmon aquaculture development of 2 736 km^2. The number of new farms that could be placed in a sea loch would be restricted by the physical space available; this number and the potential biomass held at each site could be further restricted by the benthic impacts and nutrient enrichment of these potential new sites, local planning guidelines and economic and logistical limitations.

Tools were developed to determine the number of new farms that were possible to be placed within the Potential Aquaculture Development Area (PADA) of each sea loch, given certain criteria. The modified MSS – BI model was then applied to each of these potential new sites.

The application of the MSS-BI.m model to these theoretical fish farm site positions has produced a definitive figure for the maximum potential biomass that can be produced in a sea loch (sum of B_{CMAX} values), bearing in mind both organic deposition and spatial factors. When these results were compared to the B_{TMAX} results it was clear that benthic impacts were the key limiting factor for the further development of aquaculture in sea lochs, excluding any planning restrictions.

The MSS-BI model also calculated the degraded area beneath a fish farm so a further dimension to this tool was to calculate how many new sites could be placed in each sea loch at maximum biomass before the degraded area precautionary threshold (BI_{pa}) of 8% of the low water area (A_{LW}) (Greathead *et al.,* 2012) was breached. None of the individual sites had B_{CMAX} values that produced degraded areas that were more than the BI_{pa} (8% of the A_{LW}). However, the total degraded areas in three of the 114 (2.6%) sea lochs were more than 8% of the A_{LW}.

The analysis and results from the ADST as well as the ecological indicators project show that although the maximum potential theoretical fish biomasses within the majority of sea lochs is high, the benthic impact below individual fish farm sites could limit the biomass held at each site and in the sea loch as a whole. Also, the areas in sea lochs within the 15-70 m depth range and available to aquaculture development is finite, which means that the positioning of sites to obtain maximum biomass potential for the least environmental impact should be considered carefully. Therefore, the ADST will be a key tool to identify which sites would be most suitable for development (i.e. least environmental impact for maximum production).

Although there could still be limitations such as the requirements of other sea users and technical advancements, there is also potential for the expansion of aquaculture into the offshore areas of Scotland.

1. Introduction

In light of increasing demands for seafood around the world and reduced productivity in the fisheries sector, there will be an increasing requirement for aquaculture to address the short fall. Fisheries Commissioner, Dr Joe Borg, speaking at the *'European Aquaculture and its Opportunities for Development'* conference in Brussels on 16 November 2007, commented:

"There is growing demand for seafood worldwide not only due to population growth but also because per capita consumption of seafood is expected to grow between now and 2030 by 50%", and further said that "...aquaculture appears to be the only viable option to meet this growing demand". Aquaculture now accounts for nearly 50% of the world's food fish; whereas in 1980 only 9% of the fish consumed by people came from aquaculture (SSPO website, 2012). Also, one objective of the draft National Marine Plan (MSS, 2012a) is to increase finfish production in Scotland by 50% on 2010 levels by 2020.

Understanding the environmental impacts of an expanding aquaculture industry will ensure that the industry is not unnecessarily restricted and environmental impacts are managed effectively. This paper presents a GIS based aquaculture decision support tool (ADST) to assist Marine Scotland with planning the sustainable development of the aquaculture industry in Scotland. This tool has been developed alongside and incorporates elements of a project to develop ecological sustainability indicators for Scottish aquaculture (Greathead *et al*., 2012, in press). It will provide advice to better understand the distribution of and the potential limitations due to the deposition of organic matter onto the seabed from fin fish aquaculture, that could feed into the development of Marine Scotland's National Marine Plan. Present models predict the environmental impact from existing or intended sites;

whereas this method allows the environmental impacts from any future potential sites to be predicted.

This GIS tool visualises the number and position of potential new aquaculture sites within sea lochs and the maximum biomass suitable for each site based on benthic impact by using a modified version of the Marine Scotland Science benthic impact (MSS - BI) model. This has also been used to visualise the amount of suitable space available to aquaculture development and provide advice on the “spatial requirement” necessary to support the theoretical maximum biomass (B_{TMAX}) in a sea loch. Both these processes should assist in determining where there is scope for aquaculture development.

The final outcome, in conjunction with the indicators project, will be to obtain a definitive figure for the maximum potential biomass that can be produced at potential individual sites and in a sea loch as a whole, bearing in mind organic deposition and spatial factors.

Background

Aquaculture is a vital part of the Scottish economy and culture with its roots going back to the experimental beginnings in the 1960s, to the large commercial expansion from the 1980s to the present. Commercial salmon farming in Scotland has grown from about 5000 tonnes production per annum (t yr^{-1}) in the 1980s to about 130 000 t yr^{-1} in 2008 (Marine Scotland Science (MSS, 2008)). The average size of fish farm has also grown from about 85 t yr^{-1} in 1985 to over 490 t yr^{-1} in 2006. Operations are increasingly becoming concentrated on larger sites with over half the production coming from sites with a consented biomass of greater than 1000 tonnes during 2007 (MSS, 2007).

This increase in production has not just been due to the expansion of the number and size of sites; but also is due to improvements in feed and feeding technology (Black, *et al*., 2008), husbandry techniques, the use of vaccines and immuno-stimulants (Bricknell and Dalmo, 2005 and Galeotti, 2007) and cage technology (James and Slaski 2009).

At present, further expansion of aquaculture could be difficult both financially and environmentally as the aquaculture industry is frequently challenged on its interactions with the marine environment and the degree to which current practices may be considered sustainable. To ensure that future growth in the aquaculture industry is acceptable, this growth will need to be shown to be sustainable. In addition, the aquaculture industry relies on the goods and services provided by the marine environment, such as the provision of clean oxygenated water and the dispersion of wastes. A sustainable industry will need to ensure that these goods and services are not compromised.

“Sustainable Development is the management and conservation of the natural resource base and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such sustainable development (in the agriculture, forestry and fisheries sectors) conserves land, water, plant and animal resources, is environmentally non-degrading, technically appropriate, economically viable and socially acceptable" (Code of Conduct for Responsible Fisheries (Food and Agriculture Organisation of the United Nations, 1995)).

The aquaculture industry will always have a global footprint as it relies on globally sourced ingredients for feed, energy and chemicals and may, therefore, never be considered truly sustainable (Wurts, 2000). The task for Marine Scotland will be to ensure that the local and regional impacts of aquaculture are sustainable in the long term. This would require that irreversible damage to the ecosystem does not occur and that it does not impact on the capacity of the ecosystem to provide the goods and services needed not only for the aquaculture industry but also other users. Also, the long term health and functioning of all the biological components that make up the ecosystem should be protected. This project, as well as the indicators project (Greathead, *et al.*, 2012), will concentrate on the environmental aspects of aquaculture, where it is assumed that environmental sustainability equates with a level of aquaculture that maintains good ecological status. However, social and economic sustainability should also be considered when planning for a sustainable aquaculture industry (Figure 2.1) (Marine Conservation Society, 2007).

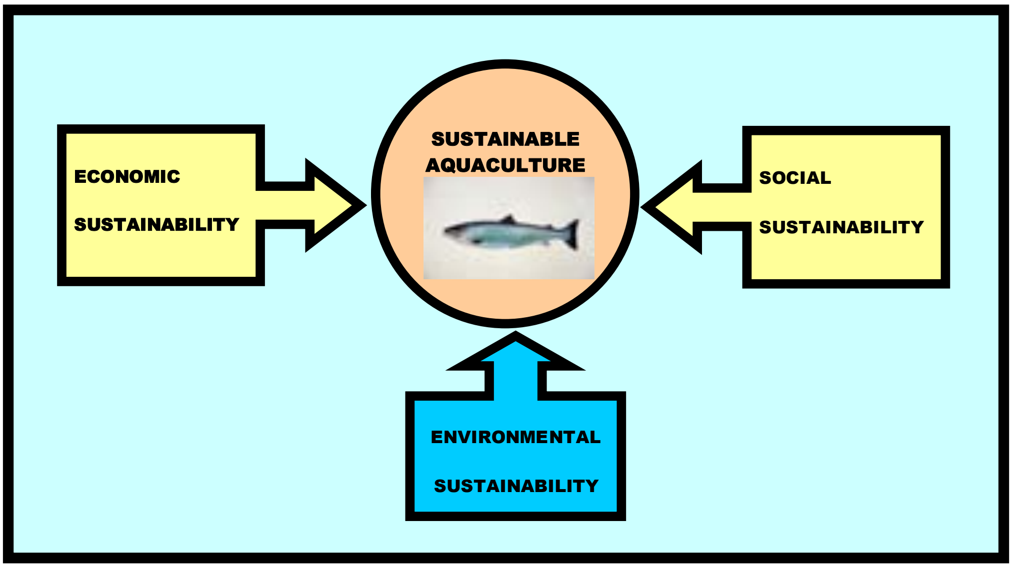


Figure 2.1: The three components necessary for sustainable aquaculture (Marine Conservation Society, 2007)

Recent developments in the aquaculture industry have not only allowed increased production, but have also reduced its environmental footprint. For example, improvements in feed and feeding technology have meant that less feed is required to produce the same amount of growth with less waste, which reduces the amount of waste food and faeces that reaches the sea-bed. The use of vaccinations has reduced the requirement for antibiotics to treat bacterial diseases such as furunculosis and "in-feed" immune system stimulants have helped reduce mortality due to viral diseases (Bricknell & Dalmo, 2005 and Galeotti, 2007).

In 1993, only 5 500 tonnes of salmon were produced for every tonne of antimicrobials sold, in 2000 this figure increased to 67 000 tonnes of salmon for every tonne of antimicrobials (Marine Conservation Society (MCS, 2007)).

Environmental guidelines currently place limits on allowable nutrient enrichment and benthic impact from fish farming. These impacts are regulated by the Scottish Environmental Protection Agency (SEPA) by discharge consent licences, issued under the Water Environment (Controlled Activities) (Scotland) Regulations 2005 (CAR). These environmental concerns ultimately limit the total production of farmed fish that can be accommodated in Scottish coastal waters. The Scottish Government Locational Guidelines (MSS, 2012b) are published quarterly and provide advice on the level of development in 115 sea lochs around Scotland, based on the cumulative impacts of nutrient enhancement and benthic impact of all the fish farms with a discharge licence from SEPA in each sea loch. Predictive models are used to assign each sea loch an index of 'nutrient enhancement' and 'benthic impact'. These index values are then combined and the resulting value determines the Category of that sea loch, one, two or three (Gillibrand *et al.,* 2002). A Category One sea loch is where new fish farming developments were unlikely to be acceptable due to an already high level of development. Category Two sea lochs are where the prospects for future developments were likely to be limited and Category Three sea lochs are where there appears to be greater potential for future development. These categories state a predicted level of impact given a certain level of development and do not reflect the actual environmental status of the sea lochs. The detailed methodology for the Scottish Government Locational Guidelines can be found in Gillibrand *et al.* (2002).

1.1 Benthic Impacts of Marine Aquaculture

Most of the studies into benthic impacts from aquaculture have concentrated on the local effects as fish farm wastes rarely travel more than a few kilometres from the site of origin. The cumulative effects of multiple areas of degraded seabed within a sea loch or regional sea area are poorly understood due to the complexity of seabed habitats and ecosystem processes. The accumulation of organic waste (fish faeces and uneaten fish feed) on the seabed results in localised deterioration of sea bed habitats and changes to benthic (seabed) communities, biodiversity and nutrient balances. The effects of this organic enrichment can be seen to be graduated away from the source of input (i.e. the salmon cages), following the pattern first described by Pearson and Rosenberg (1978), which was based on studies of organic enrichment from paper mill effluent before aquaculture became an established industry. Pearson *et al.* (1986) also related the long term changes in the sedimentary benthos to organic inputs and long-term temperature changes. Organic enrichment of sediments is the most widely studied of the impacts from fish farming with documents by Brown *et al.* (1987) and Gowen and Bradbury (1987) being some of the first to describe in detail the effects of effluent from salmon farms on the benthos and environment of Scottish sea lochs and coastal waters respectively. The effects documented included highly reducing sediments close to the cages, reductions in dissolved oxygen in water overlying the sediment, changes in benthic fauna abundance and diversity and increased carbon content.

These studies have concentrated on the impacts on benthic macro-fauna; other studies that have concentrated on the meio-fauna have indicated that the meio-fauna may be less stressed by organic enrichment than the macro-fauna (Austen *et al.*, 1989), although there is much variation in response, possibly due to other factors such as the degree of oxygenation of the sediments and the presence of toxic contaminants (Warwick, 1993). With regard to the geochemical and physio-chemical changes in sediments as a result of fish farm wastes, the most comprehensive study was made on behalf of the Technical Advisory Group of the British Columbia Ministry of Environment (Brooks, 2001).

Some habitats are more susceptible to benthic enrichment than others, for example Maerl beds (Hall-Spencer *et al.*, 2006) and eel grass beds (Diaz-Almela *et al.*, 2008). A large proportion of the species on rocky reefs are filter feeders and are, therefore, also susceptible to smothering from solid wastes.

Figure 2.1.2 describes the key impacts of marine fish farming and the link between these impacts and the amount of food that is put into the cage system and fish. Feed pellets were composed primarily of fish meal and fish oil, together with other minor components such as binders, added minerals and anti-oxidants. However, the fish products are now significantly substituted with vegetable derivatives. The fish obtain an insignificant proportion of their nutrition from natural food items present in the surrounding water, which means that the inputs and wastes from a fish farm can be accurately proportioned. Nitrogen supplied to the fish is held in the fish meal (protein) component of the feed. While a small proportion of the pellets may not be ingested and hence lost as waste feed, the bulk of the nitrogen is partitioned between increase in fish biomass, faeces and soluble excretion products. The amounts of nitrogen in these various compartments, per tonne of production of fish, can be calculated from simple mass balance models (Davies, 2000). The estimated value for waste input to the water column therefore takes account of both soluble and particulate organic nitrogen, and the nitrogen loss associated with waste feed.

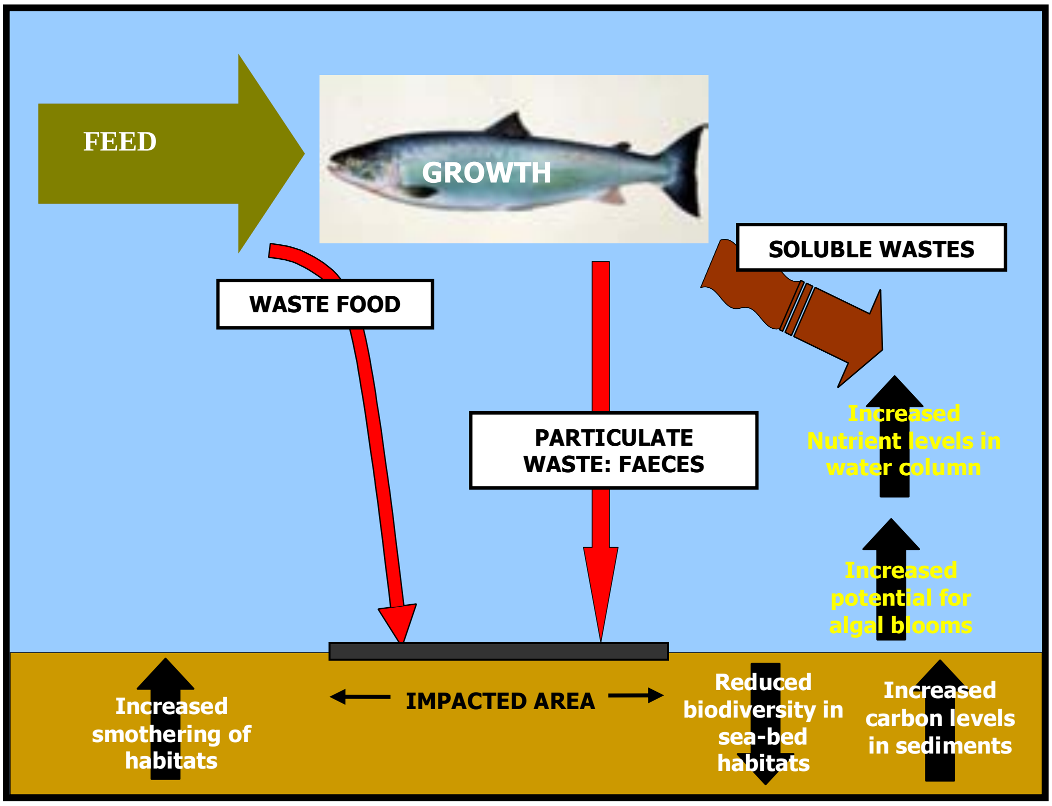


Figure 2.1.2: Key impacts of marine fish farming originating from the feed input to the system; solid wastes are closely linked to benthic impact and soluble wastes are closely linked to water column impacts

Spatial Requirement Advice

There is a limited amount of space available for the development of aquaculture in Scotland. Therefore this advice has been developed to provide advice on the "spatial requirement" necessary to support the theoretical maximum potential biomass (B_{TMAX}) in a sea loch, and limitations for aquaculture with regard to available space within sea lochs.

1.2 Methods

To determine the spatial requirement for the maximum potential development of aquaculture in Scotland several components were required:

1. A standard value for production per km^2.
2. The precautionary limits of benthic impact (BI_{pa}) and nutrient enhancement (ECE_{pa}) calculated in the indicators project (Greathead *et al.*, 2012, in press).
3. The theoretical maximum biomass of farmed fish in each loch (i), such that the precautionary limits for nutrient enhancement (ECE_{pa}) and benthic impact (BI_{pa}) are not exceeded ($B_{TMAX(i)}$; t yr^{-1}).
4. The surface area suitable for aquaculture for each sea loch ($A_{(15\text{-}70\ m)}$; km^2).

The standard production value was calculated from annual fish farm production data and Crown Estate leased areas. Data from the Crown Estate on the current areas leased for fish farm development (Sept 2008) were collated for each sea loch and the total area of seabed within each sea loch that was leased to fish farms calculated (A_L; km^2). The total surface area that would be suitable for aquaculture (surface area where depth 15 - 70 m, $A_{(15\text{-}70m)}$; km^2) in each sea loch was also calculated from a previous MSS GIS project to re-digitise the sea lochs (Annex 1a and 1b). The shallower depth of 15 m was chosen as most pens at salmon aquaculture sites are 10 m deep, an extra 5 m was added to this to allow for adequate water circulation below the cages at all tide and wave heights. The deeper depth of 70 m was chosen as the maximum depth fish farms are currently moored at. There could be much debate about these values, however, it was felt that they represented best practice without being too restrictive.

Annual production data in each sea loch were collated to determine an average production value for each sea loch for each year from 2000-2008 ($P_{(i)}$; t yr^{-1}) (MSS, 2006-2008). Each sea loch has different production data for various reasons (water quality, husbandry/management techniques), therefore, the data for each sea loch were averaged using three different scenarios; 2004-2008 and 2005-2008 and 2006-2008. The values for 2004-2008 were used to determine a mean production value for all sea lochs ($\overline{P}$; t yr^{-1}), as these data had the smallest standard error (SE) and standard deviation (SD) (157.18 and 1388.15 respectively). The complete production data can be seen in Annex 2a. The Crown Estate leased areas were also very variable therefore the total leased area values for each sea loch were taken for 2008 and the mean area ($\overline{A_L}$; km^2) for all the sea lochs with available data was calculated. The standard errors and standard deviations were also calculated for the $\overline{A_L}$ values and recorded in Annex 2b. The $\overline{A_L}$ and $\overline{P}$ values were then used to calculate the standard value for production per km^2 (P_d; t km^{-2}) as in Equation 3.1.1. Zero returns were ignored in the averaging process in this case as the aim was to produce an average figure for production for active sites in a sea loch.

3.1.1 $$P_d = \overline{P} \div \overline{A_L} \qquad \text{NB:}(\text{SE } P_d = (\text{SE } \overline{P} \div \overline{A_L}) + \text{SE } \overline{A_L})$$

The P_d value could be taken as a proxy for production efficiency (production per km^2), which can either be calculated as an industry wide standard as here, or as a loch specific value using loch specific $\overline{A_L}$ and $\overline{P}$ values (Annex 4).

The maximum biomass of farmed fish in each loch (i), such that precautionary limits for nutrient enhancement and benthic impact were not exceeded ($B_{TMAX(i)}$; t yr^{-1}), was calculated using a modified version of the Equilibrium Concentration Enhancement model (ECE.bas) outlined in Gillibrand *et al.* (2002). This model calculated the degree of nutrient enrichment in terms of concentration of nutrient nitrogen (ECE, µmol N l^{-1}) and the percentage of the low water area of a sea loch that is 'degraded' (BI, % LW area), resulting from the total stocking biomass of fish in that sea loch.

To allow the ECE.bas code to perform iterative functions it was transcribed into Matlab and modified. This was verified to ensure that the two variations of the code gave identical results. The code was modified to allow iterative variation of the total farmed fish biomass in each loch until set limits were reached (ECE_MOD.m). Where a loch had multiple farm sites, the proportion of biomass in each farm was kept constant. The modified code calculated the maximum potential biomass in each sea loch, such that the precautionary levels of benthic impact and nutrient enhancement were not breached.

The maximum limit for nutrient loading (ECE_L) for Shetland and Mainland Scotland were 12.6 μmol l^{-1} and 8.7 μmol l^{-1} respectively, based on OSPAR guidelines. The precautionary limits for nutrient loading (ECE_{pa}) for Shetland and Mainland Scotland were 9.9 μmol l^{-1} and 6.4 μmol l^{-1} respectively, based on the standard deviations of the data (Greathead *et al.*, 2012, in press). The critical limit for area of the loch floor classified as "degraded" (BI_L) was 10% of the suitable area and the precautionary limit (BI_{pa}) was 8%, based on the Joint Nature Conservation Committee's Guidance for undertaking habitat assessments. A carbon loading on the loch floor of greater than 7 kg m^{-2} yr^{-1} was regarded as degraded (Gillibrand *et al.*, 2002; Greathead *et al.*, 2012, in press). The minimum value of the two biomass values for each loch gave an indication of whether benthic impact or nutrient enrichment was the limiting factor; i.e. the threshold that was breached first as levels of fish farming were increased. This value was taken as the $B_{TMAX(i)}$. Full details of this methodology and how the thresholds were set are available in Greathead *et al.* (2012, in press).

The value for $B_{TMAX(i)}$ (t yr^{-1}) was divided by the standard production per km^2 (P_d, t km^{-2} yr^{-1}) to provide the total area required ($A_{REQ(i)}$; km^2) to achieve the $B_{TMAX(i)}$ (Equation 3.1.2). This area was then converted to a percentage of the area suitable for aquaculture for each sea loch (% $A_{(15\text{-}70\,m)}$).

3.1.2 $$A_{REQ\,(i)} = B_{TMAX(i)} \div P_d$$

Conversely the percentage of the B_{TMAX} that could be achieved in each sea loch, given P_d and $A_{(15\text{-}70m)(i)}$, was also calculated (Equation 3.1.3).

3.1.3 $$\%\, B_{TMAX} = ((A_{(15\text{-}70\,m)(i)}\, x\, P_d)/B_{TMAX(i)})\; x\; 100$$

Data for 114 sea lochs were compiled. However, there were insufficient data to calculate sea loch specific production for 36 of these as either there were no production data returned from these sealochs in the MSS production surveys, or there were no leased area data recorded by the Crown Estate. Therefore, the standard average production value was calculated from 78 sea lochs. This calculated standard value was then used to calculate A_{REQ} for all sea lochs as values for B_{TMAX} and P_d were available for all sea lochs.

1.3 Results

The total average area of seabed within each sea loch that has been leased to fish farms in 2008.

$$\overline{A_L} = \mathbf{0.304\ km^2 \pm 0.037\ (0.355)(93)}\ \text{(Value} \pm \text{SE (SD)(N))}$$

The average production value for all sea lochs for 2004-2008

$$\overline{P} = \mathbf{1499.59\ t\ yr^{-1} \pm 157.18\ (1388.15)\ (78)}$$

The average value for production per km ^{2}

$$P_d = \mathbf{4929.323 \pm 517.076\ t\ km^{-2}\ yr^{-1}}$$

The total surface area that would be suitable for aquaculture in each sea loch as well as other sea loch attributes are shown in Annex 1.

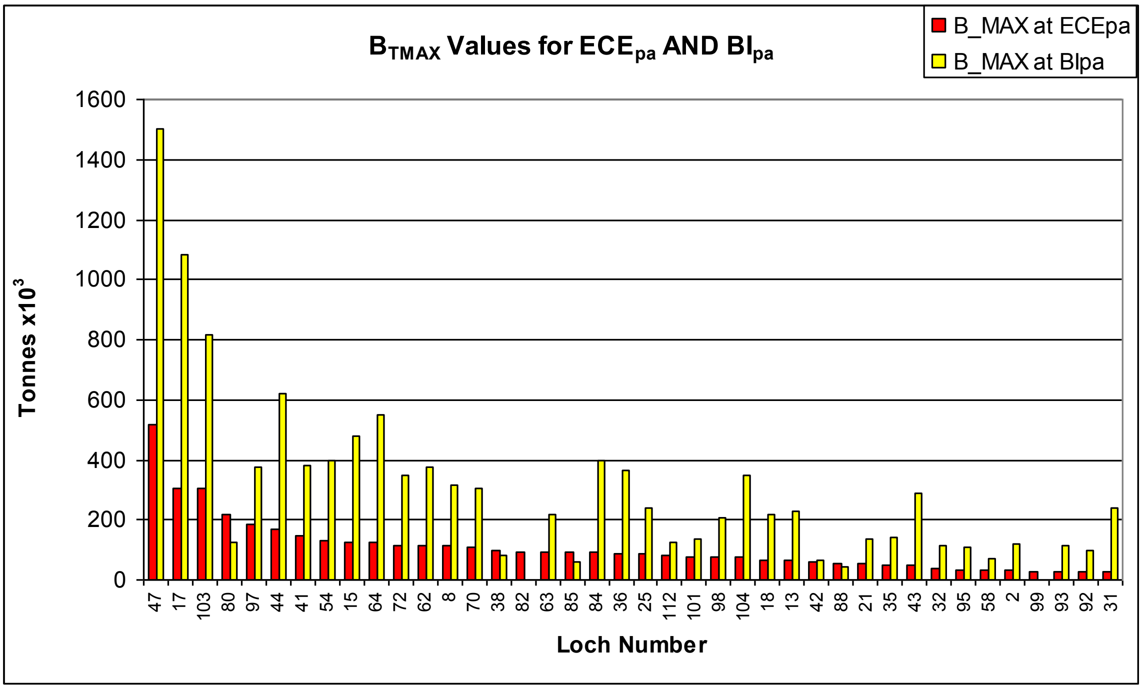


Figure 3.2.1: The relationships between the maximum biomass at the precautionary thresholds for nutrient enrichment (ECE_{pa}) and benthic impact (BI_{pa}) by sea loch. The smallest value in each loch is the limiting factor in each sea loch (i.e. lochs 80, 38, 85 and 88 were limited by benthic impact). Only top 40 sea lochs ordered by ECE_{pa} are shown (see Annex 3 for data for all 114 sea lochs).

Figure 3.2.1 shows the maximum theoretical biomasses, calculated with the ECE_MOD.m model, that corresponded to precautionary levels of nutrient loading and benthic impact for the top 40 sea lochs with respect to nutrient loading (ECE_{pa}).

The full results for the 114 sea lochs used in these calculations can be seen in Annexes 3 and 4. Only six sea lochs were limited by benthic impact. There were not enough data to run ECE_MOD.m for 11 sea lochs, which meant that the B_{TMAX} in these sea lochs was based only on nutrient enrichment.

When the values for B_{TMAX} were compared with the biomass that is currently licensed for each sea loch (B_C), the B_{TMAX} was less than the licensed biomass in three sea lochs (Annex 4). Therefore, if no other factors are taken into consideration, there is potential for the expansion of aquaculture in the majority of sealochs (97%). However, this does not take into consideration spatial issues or site specific benthic impacts.

Annex 4 also shows the total area required (A_{REQ}) to achieve the precautionary B_{TMAX}, for the 114 sea lochs used in these calculations and the percentage of the B_{TMAX} that could be achieved in each sea loch.

When described as percentages of the 'Low Water' area of each sea loch, these areas ranged from 107% of the loch area down to just 17%. Alternatively, when A_{REQ} was described as percentages of the surface area of each sea loch suitable for aquaculture ($A_{(15\text{-}70\ m)}$), these areas ranged from 120 857% of the loch area down to 48%, due to very small surface areas with depths between 15 and 70 m in some sea lochs. All of the sea lochs would require more than 45% of the $A_{(15\text{-}70m)(i)}$ to achieve their maximum potential biomass. Only 27 of the 114 sea lochs (24%) would require < 100% of the $A_{(15\text{-}70\ m)}$ to achieve their maximum potential biomass, which means that the majority of the sealochs would require more than the available $A_{(15\text{-}70\ m)}$ to support the B_{TMAX}. Ten sea lochs (8.7%) had no areas between 15 m and 70 m depth and, therefore, could not support any of the B_{TMAX}.

Looking at these calculations from an alternative point of view; the percentage of the B_{TMAX} that could be achieved in each sea loch, given P_d and $A_{(15\text{-}70m)(i)}$, ranged from 0% to 1313%. Only 26 of the 114 (23%) of the sea lochs were able to support 100% or more of the B_{TMAX}.

1.4 Discussion

There is a limited amount of space available for the development of aquaculture in Scottish sea lochs. Therefore, this advice has been developed to provide information on the limitations for aquaculture with regard to available space within sea lochs.

The spatial advice developed in this section will be a useful tool in planning for the future development of aquaculture in Scotland. The areas in sea lochs within the 15-70 m depth range and available to aquaculture development is finite, which means that the expansion of aquaculture should be concentrated where space is available. The calculations for the 'area required' advice showed that only 20% of the 114 sea lochs would require < 100% of the $A_{(15\text{-}70m)}$ to achieve their maximum potential biomass. Therefore, it would appear that in the majority of the sea lochs (80%), due to the limited area with depths suitable for aquaculture, it would be extremely improbable that the maximum potential biomass could be reached.

This is confirmed by the percentage of the maximum potential biomass that each sea loch could support, where only 22% of sea lochs had the potential to produce 100% of their B_{TMAX}, with 8.7% not able to support any aquaculture production within the $A_{(15\text{-}70\ m)}$.
So, although there is a high theoretical potential for increasing the biomass of fish produced in the majority (97%) of sea lochs, the potential level of aquaculture development in a sea loch is limited by a combination of suitable available area and production efficiency not necessarily by the environmental limits used in current environmental guidelines. For example if the P_d increased, the percentage of B_{TMAX} that could potentially be produced in a sea loch would also increase.

These results are theoretical, designed to be the first step in giving an overall picture of how feasible aquaculture development would be in certain areas, given a certain level of production and space available and do not consider the environmental impacts of the expansion of aquaculture. Environmental factors have been applied in Section 4. Spatial planning enforced by Local Authorities also will place restrictions and criteria on further aquaculture development in their area based on the requirements of the other users of the area.

Coastal areas are utilised for many other activities and so in some sea lochs there is extreme competition for space and the issue of visual amenity can be an important factor for the development of aquaculture sites. This highlights the need for spatial planning to assist with the prioritisation of activities. The responsibility for the planning and development of aquaculture has now been transferred to the Local Authorities. The Scottish Government have reviewed the various Aquaculture Framework Plans and similar planning documents prepared by local authorities within Scotland. For example the Loch Fyne ICZM plan (Argyle and Bute Council, 2009) indicated that there is limited scope for the expansion of aquaculture even though it could potentially produce 516 549 t of fish per year without breaching the nutrient enrichment and benthic impact thresholds; 99% of which would be able to be produced within the $A_{(15\text{-}70\ m)}$ (Annex 4).

The Crown Estate leased area data needed to be evaluated with caution when used to calculate the standard production value (P_d), as leased areas varied considerably in size in relation to the actual size of the farm. This was highlighted by the high SE and SD values. Another possible figure would possibly be the 25m AZE (Allowable Zone of effect) area recorded by SEPA or actual farm sizes; however, these data are not available for each farm. Another option would be to use an area value calculated from the average stocking density; however, this would entail an unacceptable level of variability as both the stocking densities used by each farm and the size and depth of cages vary considerably. Variation in the production data was mitigated by using average values (i.e. 2004-2008) with the smallest SE and SD values. Loch specific values for P_d could also be used for more accurate planning at the sea loch scale.

It is not just spatial competition issues that could affect the amount of production in a sea loch; logistics for the effective management of each site, such as distance for boats to travel from the shore base, road access, shore base availability and deep water access for supply boats will also affect how much of the potential biomass is feasible in each sea loch. These factors need to be assessed on a site by site and loch by loch basis and will also vary with the standard operating procedures, area management agreements and codes of conduct for each fish farm company.

GIS Based Aquaculture Decision Support Tool (ADST)

The benthic impact of a fish farm is determined by the position of the fish farm in the sea loch. This GIS tool visualised the number and position of potential new aquaculture sites within each sea loch and the maximum biomass suitable for each site based on benthic impact. At the heart of this tool was a modified version of the Marine Scotland Science benthic impact (MSS – BI.m) model. This will assist in the spatial visualisation of the positioning of potential new fish farm sites based on associated environmental impacts. As shown in Section 3, the spatial aspect of aquaculture is important considering the increasing pressure on space from many other sectors, such as offshore energy production, tourism and leisure, pipelines, navigation and fishing. The development of marine spatial planning tools is ongoing in organisations, such as Marine Scotland, Local Authorities (Aquaculture Framework Plans) and Universities (Hunter, *et al.*, 2006). Considering these issues, highlighting areas regionally and nationally, where aquaculture would be most suitable and areas where further development of aquaculture would be unsustainable would be a useful tool. This could in turn provide information on the total possible productivity of the aquaculture industry given certain criteria. This is envisaged to be a guidance tool not a tool for detailed placement of aquaculture sites. The GIS aspects of the ADST were undertaken by Seazone Solutions Ltd.

1.5 Methods

This project was divided into two phases: Phase 1, to determine areas that are potentially available for aquaculture within sea lochs; and Phase 2, to determine the benthic impact of any new aquaculture sites in each sea loch and the cumulative benthic impact from these. The final outcome, in conjunction with the indicators project, will be to obtain a definitive figure for the maximum potential biomass that can be produced at any potential new sites and in each sea loch as a whole bearing in mind environmental and spatial factors and which sites would be environmentally sustainable.

1.5.1 Phase 1

A bathymetric base layer was created in order to extract areas of bathymetric depth of between 15 m and 70 m for use in the project; bathymetric modelling using charted bathymetry data (best scale available UK Hydrographic Office S57 holdings, i.e. derived from charted sources at varying scales) was conducted using the modelling software package BathySIS.

Depth soundings, contours and areas of fixed water depth (i.e. dredged areas) from Electronic Navigation Charts (of best scale) in the project areas of interest, were used as inputs into the GIS project.

Model results were exported as half degree grid cells; each grid had 1800x1800 cells with an approximate cell size of 30 m^2 (depending on the latitude of the cell). The grid defined geographic space as an array of equally sized square grid points arranged in rows and columns. Each grid point stored a numeric value that represented a geographic attribute (such as elevation or surface slope) for that unit of space. Each grid cell is referenced by its x, y coordinate location.

Masking layers were then created (as ESRI Shapefiles) based on the following sets of features:

1. Protected Areas.
2. Port and Harbour exclusion zones with a 1000 m radial buffer around point features.
3. Existing fish and shellfish farms with a 1000 m buffer.
4. Existing Crown Estate aquaculture Leases.
5. Marine infrastructure e.g. wind farms and pipelines with a 1 km buffer for points and a 100 m buffer for linear features.
6. MOD exclusion zones (PEXA Areas)
7. Activity and licence areas e.g. oil and gas, wind farm licence areas.
8. Transportation routes e.g. ferry routes with a 1000 m buffer.
9. All wrecks in Seazone list with a 1000 m buffer.
10. East coast from Duncansby Head to the English Border (due to presumption against aquaculture development).

Each masking layer was removed from the bathymetric base layer using a clipping tool. The resulting areas were called Potential Aquaculture Development Areas (PADA).

The results of this exercise do not take into consideration other restrictions such as local amenity, wave and tidal restrictions, and environmental impact. The environmental restrictions regarding nutrient and benthic enrichment were assessed with new tools and existing models modified to accommodate iterative functions in Phase 2.

1.5.2 Phase 2

The number and size of farms that can be placed in a sea loch will be restricted by the physical space available, local amenity use and planning, the maximum potential biomass for each sea loch and the potential benthic impact at each site.

The PADA for individual sea lochs were calculated by filtering the final results polygons from Phase 1 to include only the polygons that intersected with the polygons of the sea lochs defined by the "Locational Guidelines" (Gillibrand *et al.*, 2002), used throughout this project.

A combination of automated and manual processing was then applied to identify the potential maximum number of farms within the PADA of each sea loch using the following criteria:

1. The new site shapefiles were 1 km in diameter, so that there would be 1 km distance between centre points.
2. The centre points of all the new site shapefiles must be within the boundaries of the PADA in each sea loch.
3. The new site shapefiles do not overlap with the other aquaculture masking shapefiles (e.g. existing aquaculture sites and CE lease areas).
4. The centre point of new sites may not overlap the other masking shapefiles.
5. The new tool will only apply to PADA polygons of >1 km^2 within the defined sea lochs.

The values for PADA and number of sites (existing plus new) were entered into the attribute table for the ‘sea loch’ layer in the ADST GIS project.

Two processes were then applied to determine the maximum potential biomass that can be produced in a sea with regard to environmental factors and which sites would be environmentally sustainable. It was assumed that the biomass of fish held at a site would be sustainable if this did not result in the nutrient enrichment or benthic impact thresholds being breached.

1. Maximum potential biomass in each sea loch limited by SEPA modelling restrictions ($B_{SMAX(i)}$).
2. Maximum potential biomass in each sea loch limited by $B_{TMAX(i)}$ and then modified by the benthic impact below the individual sites ($BI_{(s)}$) to determine a new maximum potential biomass based on C-flux below the individual sites ($B_{CMAX(i)}$).

Currently the Scottish Environmental Protection Agency (SEPA) grants consents to fish farms to discharge wastes. SEPA use the “AutoDepomod” model to determine the potential amounts and distribution of wastes produced by a certain biomass of fish held on an individual fish farm. This model is currently validated up to 2500 t, which means that presently fish farm sites can only be licensed to hold up to 2500 t of fish at any one time. Therefore, the number of predicted new sites in a sea loch ($n_{P(i)}$) plus the number of existing sites ($n_{E(i)}$) were multiplied by 2500 t to determine the maximum biomass in each sea loch, taking these modelling restrictions into consideration ($B_{SMAX(i)}$) (Equation 4.1.1).

4.1.1 $$B_{SMAX\ (i)} = (n_{P(i)} + n_{E(i)}) \times 2500$$

The number and size of new sites that would be environmentally sustainable in each sea loch is dependant on the B_{TMAX} for the sea loch as a whole but also could be restricted by the benthic impact below the individual sites ($BI_{(s)}$). Benthic impact, measured by Carbon flux (C-flux, g m^{-2} yr^{-1}) on the seabed, should not be so great as to produce conditions that would not support a community of bioturbating organisms. Carbon accumulations of 548 g m^{-2} yr^{-1} (Cromey *et al*., 1998) and 1498 g m^{-2} yr^{-1} (Eleftheriou, *et al*., 1982) have been shown to cause degraded benthic conditions. Black *et al*. (2008) states that carbon accumulation greater than 10 kg m^{-2} yr^{-1} would produce highly significant effects on the seabed. Therefore, in this study a C-flux level of 7 kg m^{-2} yr^{-1} has been taken to be the point at which a benthic community becomes degraded, but still able to support a viable bioturbating community of opportunistic deposit-feeding invertebrates (Gillibrand *et al.*, 2002; Cromey *et al.*, 2002; Hargrave *et al.*, 2008).

The number and position of fish farm sites that would be environmentally sustainable in each sea loch with respect to C-flux under individual sites was then calculated. The MSS_BI.m model was modified to allow an iterative function to calculate the maximum biomass that could be placed on each of these new sites before the peak C-flux limit was breached below the cages. Set values for other parameters such as stocking density (20 kg m^{-3}), cage net depth (10 m) and Food conversion ratio (1.17) were used. This model also calculated the area that was degraded beneath each fish farm. Therefore, a further dimension to this tool was to calculate the percentage degraded area (% A_{LW}) associated with the B_{CMAX} at each site and the total in each sea loch. The percentage of LW area was used in this case as the benthic impacts should be assessed for the whole sea loch not just the $A_{(15\text{-}70\text{ m})}$.

The new sites generated by this process were added to the existing sites in each sea loch to generate a new input file for the MSS_BI.m model. The new sites were assigned 'x' values (distance from sea loch mouth (x, km)), a parameter within the model that allowed more biomass on sites nearer the mouth of the sea loch (Figure 4.1.1). This is because tidal currents are stronger near the sea loch mouth and therefore there would be greater potential for the dispersion of particulates within and out of the loch. A larger dispersion area means that although the impacted area would be larger the peak deposition would be less (Gillibrand *et al.*, 2002).

The model was run to determine the maximum biomass that could be held at each site before the C-flux threshold of 7 kg m^{-2} yr^{-1} was breached. These values were summed for each sea loch to produce a new maximum potential biomass for each sea loch (B_{CMAX}).

All the new sites within each sea loch, their associated 'x' values, B_{CMAX} values and '% Degraded Areas' were entered into the attribute table for the 'New Farm Area' layer in the ADST GIS project. Colour grading was applied to the B_{CMAX} values in the 'New Farm Area' layer to reflect the level of benthic impact at each potential new site (Figure 4.1.1).

The attribute table for the 'sea loch' layer was updated with the total B_{CMAX} for all sites in each sea loch and the final B_{MAX}, which was the most limiting value for the maximum potential biomass in each sea loch from all the calculations.

Colour grading was applied to the B_{MAX} values in the 'sea loch' layer to reflect the level of benthic impact in each sea loch.

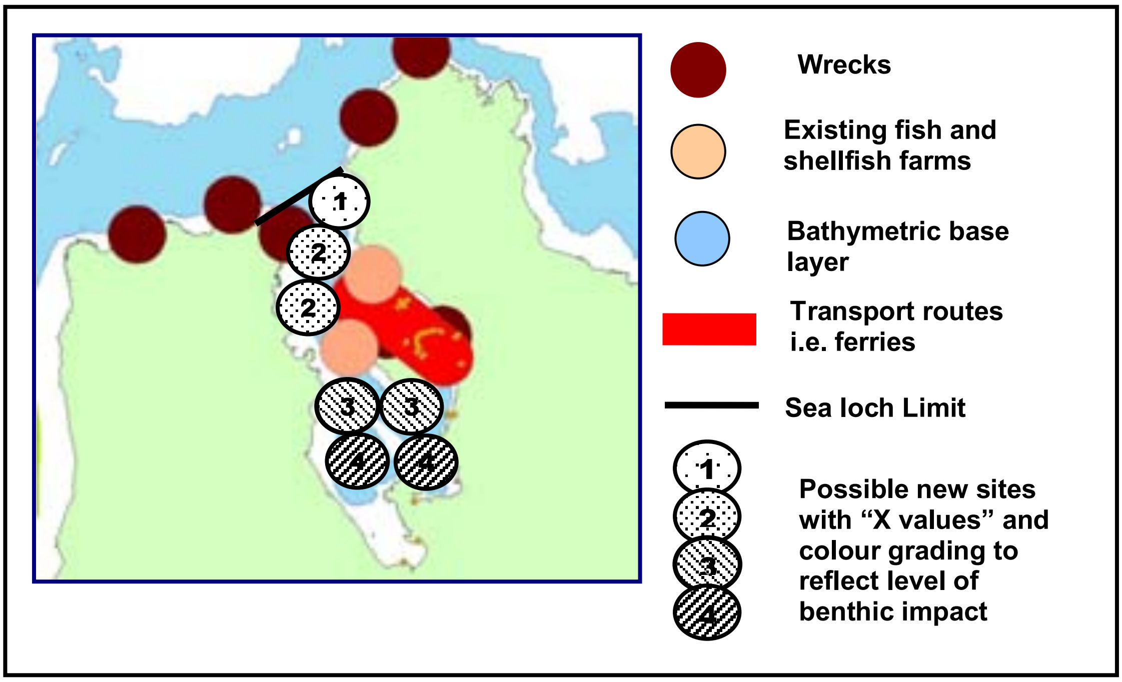


Figure 4.1.1: Example of how the new tools in the ADST were used to identify the number of potential new sites within the bathymetric base layer of each sea loch; potential new sites are assigned ‘x’ values according to how close they are to the sea loch mouth (e.g. 1-4 km), which would result in greater benthic impacts further from loch mouth

1.6 Results

1.6.1 Phase 1

Figure 4.2.1 below is an extract from the ADST from around the Isle of Mull on the west coast of Scotland. This shows the bathymetric base layer and some of the masking layers that represent potential restrictions to possible aquaculture development.

The outputs from Phase 1 of the ADST included: the area of the bathymetric base layer, the area of each of the masking layers and two values for the total area available to aquaculture (PADA) (Table 4.2.1). The initial area for the PADA (PADA 1) included a masking area identified as MOD exclusion zones; these areas were extensive and were not necessarily exclusive to aquaculture, therefore, a second and final PADA (PADA 2) area was calculated omitting these areas from the masking layers (Annex 5). Figure 4.2.2 is an extract from the ADST that shows the distribution of the bathymetric base layer. Figures 4.2.3 (a) and Figure 4.2.3 (b) show the considerable difference in extent between PADA 1 and PADA 2.

1.6.2 Phase 2

Table 4.2.2 summarises the results from the first part of Phase 2 of the ADST and shows that nearly 3 000 km^2 is potentially available to aquaculture within the sea lochs. However, of the 114 sea lochs included in this project only 33 had space available for new farms, the majority of which were on the Scottish mainland and Western Isles. Only two Voes in Shetland had space available for new farms (Ronas Voe and Selivoe). In total it would be spatially possible to place 389 new farm sites in these 33 sea lochs. The range in number of new sites within these sea lochs was between one and 51. The full list of sea lochs and allocation of new farm sites as well as existing sites can be found in Annex 5.

Annex 6 shows the results after applying the two processes to all the sites in each sea loch (existing and new) to determine the definitive figure for the maximum potential biomass that can be produced in a sea loch bearing in mind environmental and spatial factors and which sites would be environmentally sustainable. Six sea lochs were limited by the fact that at present, due to model validation issues, the maximum biomass on a site is 2500 t. However, this is a false restriction as the 'AutoDepoMod' model validation could be improved or a different model used.

Therefore, this resulted in a list of sea lochs where the total biomass was limited by three factors: the total theoretical biomass (B_{TMAX}); the C-flux modelling (B_{CMAX}) and the potential degraded area as a percentage of A_{LW}.

B_{TMAX}: 3 (2.6%) sea lochs were limited by the total theoretical biomass; the sum of the B_{CMAX} values of all the sites in Lochs Meanavagh, Seaforth and Sheilavaig was more that the B_{TMAX} in these sea lochs. These lochs were also limited by % A_{LW} degraded (see below).

B_{CMAX}: 111 (97%) of the sea lochs were limited by the deposition of carbon below the farm site. However, 11 of these were zero returns because there were no sites, new or existing to apply the MSS_BI.m model to.

% Degraded Area: None of the individual sites had B_{CMAX} values that produced degraded areas that were more than the BI_{pa} (8% of the A_{LW}). However, the total degraded areas in three of the 114 (2.6%) sea lochs were more than 8% of the A_{LW}. These three sea lochs were also actually limited by B_{TMAX}.

The limiting factors were highlighted in bold in Annex 6.

The application of these factors has resulted in a final definitive figure for the maximum potential biomass that can be produced in a sea loch bearing in mind both environmental and spatial factors (B_{MAX}). The total B_{TMAX} for all the lochs was 4,753,690 t yr^{-1} and the final total B_{MAX} was 1,146,892 t yr^{-1}, which is approximately 24% of the B_{TMAX}.

The application of benthic models has, therefore, generally resulted in a reduction in the maximum potential biomass in the sea lochs compared to those calculated in Section 3 (B_{TMAX}), even where this was previously restricted by nutrient enhancement. This B_{MAX} value was recorded in the 'Sea Loch' layer of the ADST GIS project as well as in Annex 6.

Figure 4.2.4 shows an extract from Phase 2 of the ADST showing the bathymetric base layer and the distribution of the potential new aquaculture sites with colour grading applied to the B_{MAX} values in two lochs on the West coast of Scotland.

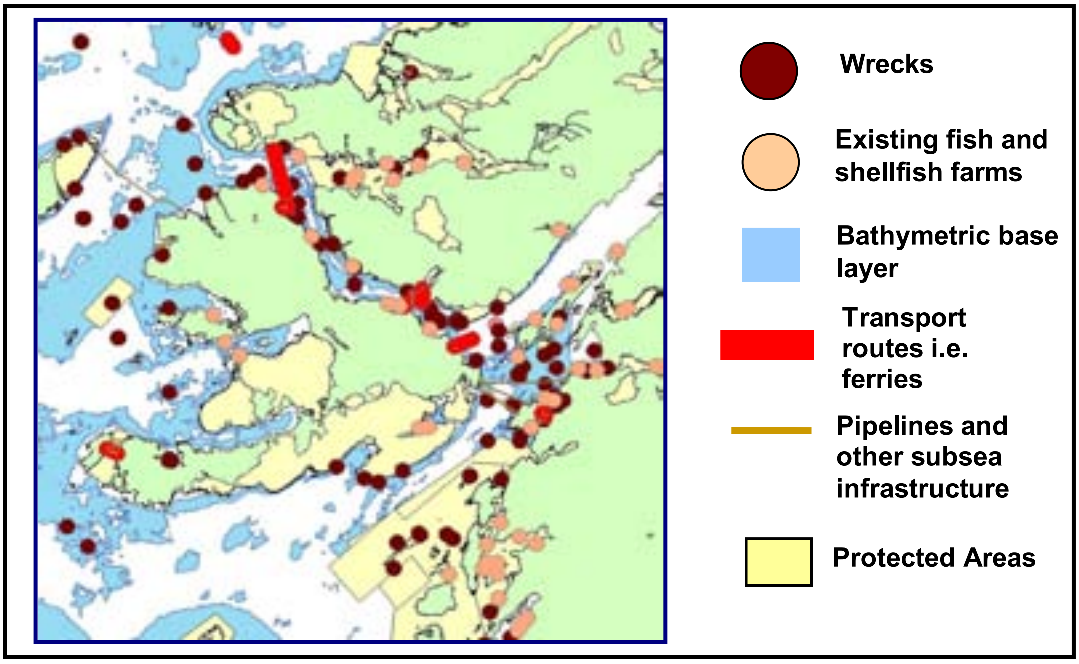


Figure 4.2.1: Extract from the ADST from the area around the Isle of Mull (West coast Scotland), showing the bathymetric base layer and some of the masking layers used; potential space for aquaculture development are indicated by the blue areas not covered by the masking layers

Table 4.2.1

Results from Phase 1 of the ADST.

Layer number	Layer Name	Area (km^2)
0	Bathymetric Base Layer	43 140.62
1	Protected Areas	11 249.37
2	Port and Harbour zones	1 964.72
3	Existing fish and shellfish sites	1 126.44
4	Existing Crown Estate fish farm lease areas	49.10
5	Marine Infrastructure	1 542.72
6	MOD exclusion areas	81 754.65
7	Licensed activity areas	10 575.30
8	Transport routes	4 257.93
9	Wrecks	5 010.17
PADA 1	Results layer including MOD exclusion areas	10 084.80
PADA 2	**Results layer excluding MOD exclusion areas**	**31 977.04**

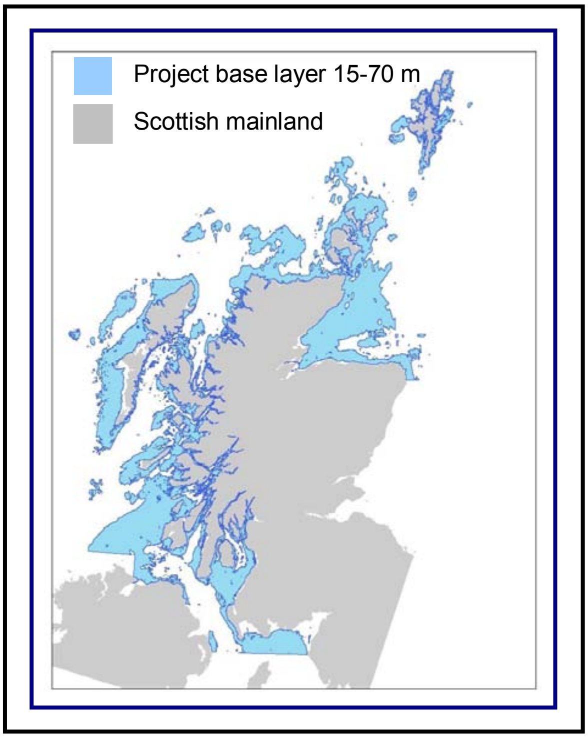


Figure 4.2.2*:* Results from Phase 1 of the ADST; the bathymetric base layer of the ADST, surface area with depths 15-70 m.

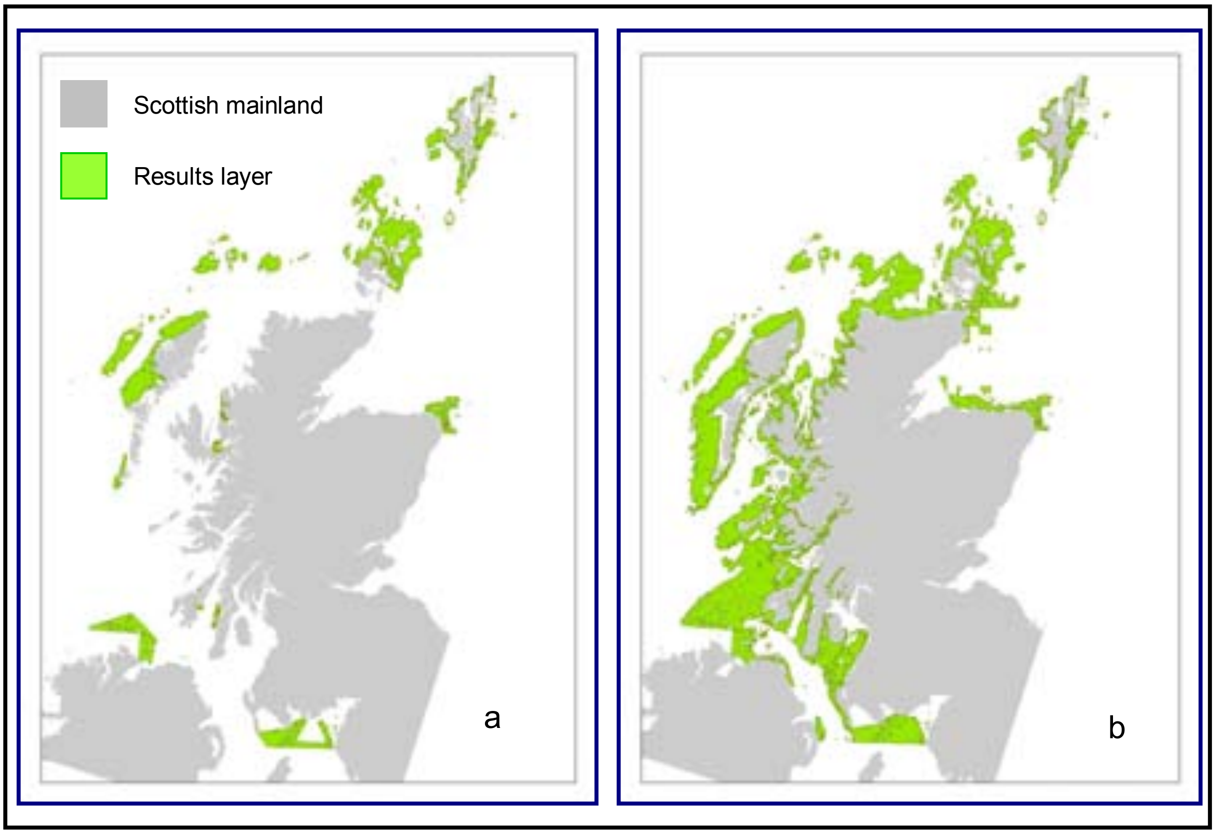
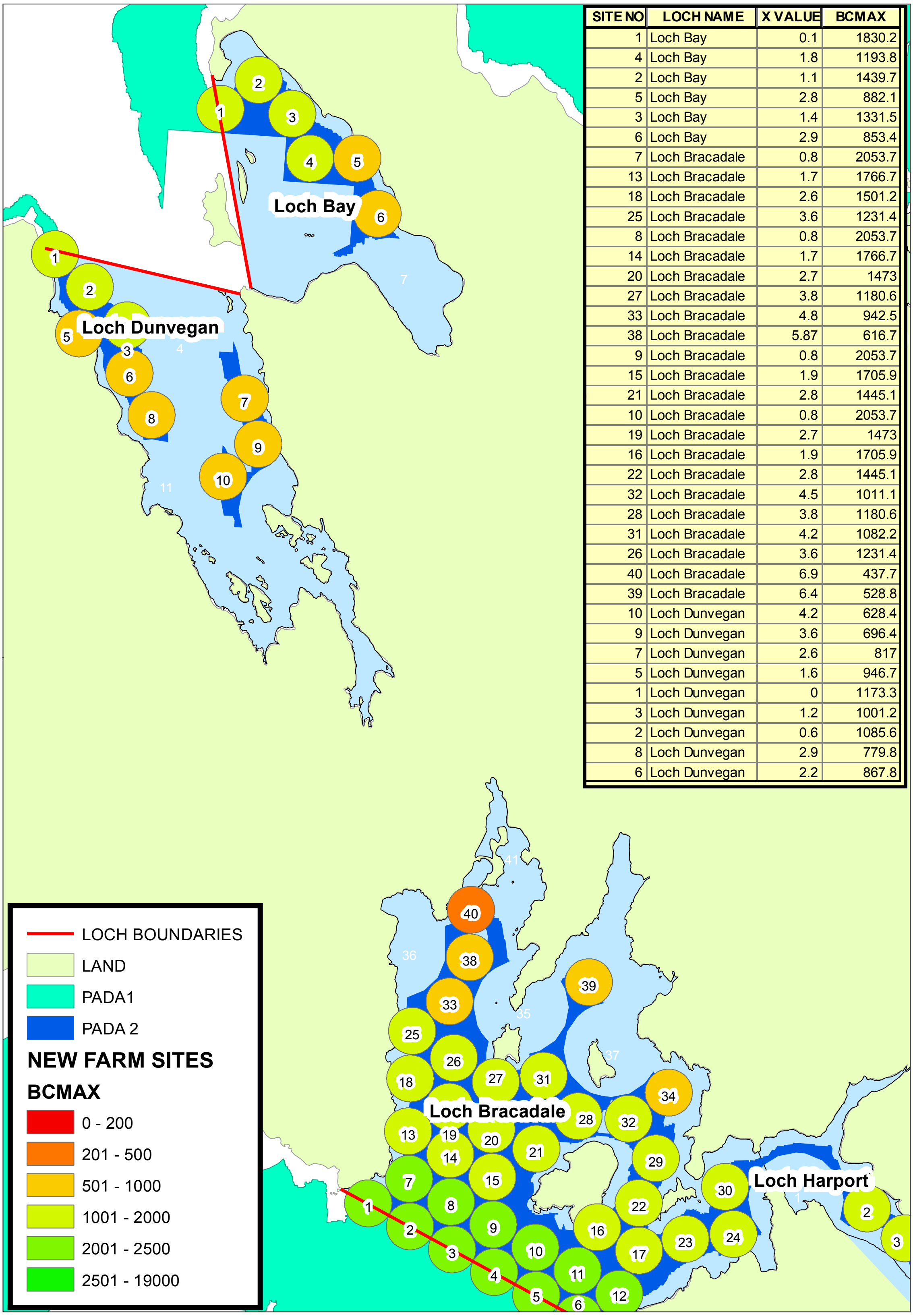


Figure 4.2.3: Results from Phase 1 of the ADST: Comparison of the two PADA, (a) PADA 1: final results including the military practice zones in the masking layers and (b) PADA 2 excluding the military practice zones from the masking process.

Table 4.2.2

Results from Phase 2 of the ADST (NW Mainland = Loch Duich to Loch Eriboll; SW Mainland = Loch Ryan to Loch Hourn; (% All Lochs, % Regional Lochs)).

Parameter	**Result**
Total PADA in sea lochs	2 735.95 km^2
Total number of new sites	389
Total number of sea lochs containing potential new sites	33 (29 %)
Number of sea lochs containing potential new sites in Shetland and Orkney (33)	2 (1.7 %, 6 %)
Number of sea lochs containing potential new sites in Western Isles (24)	7 (6 %, 29 %)
Number of sea lochs containing potential new sites in NW mainland and Skye (31)	12 (10 %, 39 %)
Number of sea lochs containing potential new sites in SW mainland and Mull (26)	12 (10 %, 46 %)
Range of number of new sites	0-51



SITE NO	LOCH NAME	X VALUE	BCMAX
1	Loch Bay	0.1	1830.2
4	Loch Bay	1.8	1193.8
2	Loch Bay	1.1	1439.7
5	Loch Bay	2.8	882.1
3	Loch Bay	1.4	1331.5
6	Loch Bay	2.9	853.4
7	Loch Bracadale	0.8	2053.7
13	Loch Bracadale	1.7	1766.7
18	Loch Bracadale	2.6	1501.2
25	Loch Bracadale	3.6	1231.4
8	Loch Bracadale	0.8	2053.7
14	Loch Bracadale	1.7	1766.7
20	Loch Bracadale	2.7	1473
27	Loch Bracadale	3.8	1180.6
33	Loch Bracadale	4.8	942.5
38	Loch Bracadale	5.87	616.7
9	Loch Bracadale	0.8	2053.7
15	Loch Bracadale	1.9	1705.9
21	Loch Bracadale	2.8	1445.1
10	Loch Bracadale	0.8	2053.7
19	Loch Bracadale	2.7	1473
16	Loch Bracadale	1.9	1705.9
22	Loch Bracadale	2.8	1445.1
32	Loch Bracadale	4.5	1011.1
28	Loch Bracadale	3.8	1180.6
31	Loch Bracadale	4.2	1082.2
26	Loch Bracadale	3.6	1231.4
40	Loch Bracadale	6.9	437.7
39	Loch Bracadale	6.4	528.8
10	Loch Dunvegan	4.2	628.4
9	Loch Dunvegan	3.6	696.4
7	Loch Dunvegan	2.6	817
5	Loch Dunvegan	1.6	946.7
1	Loch Dunvegan	0	1173.3
3	Loch Dunvegan	1.2	1001.2
2	Loch Dunvegan	0.6	1085.6
8	Loch Dunvegan	2.9	779.8
6	Loch Dunvegan	2.2	867.8

Figure 4.2.4: Results from Phase 2 of the ADST: Extract from the ADST, showing an extract from the attribute table, the bathymetric base layer and potential new aquaculture sites in Lochs Dunvegan, Bracadale and Bay on the West coast of Scotland. The sites have been colour graded according to B_{MAX} values

1.7 Discussion

Section 3 provided information on the general capability of a sea loch to produce the theoretically maximum potential biomass with regard to nutrient enrichment and benthic impact. The majority of the B_{TMAX} values used in these calculations were limited by the nutrient enhancement in the water column, as only six sea lochs had B_{TMAX} values set by the benthic impact threshold (BI_{pa}). In this section a GIS tool was used to further define the limiting factors in sea lochs, with regard to benthic impacts.

At present models can only predict the environmental impacts of existing or planned new sites as the position of the site is a required parameter for the predictive models. The ADST provides the positions of possible new sites and, therefore, can clearly ascertain a definitive figure for the maximum potential biomass that can be produced at potential new sites and in a sea loch, bearing in mind environmental and spatial factors. This will assist with the future planning, regulation and licensing of a sustainable aquaculture industry in Scotland by prioritising farms for development by benthic impact (i.e. highest biomass without breaching C-flux threshold).

In Phase 1, the PADA could vary in size and position depending on the depth parameters set for the bathymetric base layer and the masking layers parameters. For example, the masking layer for ports and harbours could be completely removed as not all ports and harbours exclude aquaculture. Also the masking layers for existing fish farm sites and leases could be modified as not all these farms are actually being used.

At present, the masking layers do not include meteorological and hydrological phenomena such as wind strength, wave height and currents. The tolerances of cage equipment to environmental stresses will limit where a fish farm could be placed without the risk of the cages collapsing; however, the technology is improving all the time with offshore submersible cages becoming a real possibility in the future (James and Slaski, 2009). These offshore areas also will require suitable impact models to be developed to regulate the amount of fish that can be held on these sites to ensure that there is limited risk of harm to the environment (Holmer, 2010).

There is the perception that in some areas, particularly Shetland, all the available suitable sites for aquaculture have already been developed has been shown to be accurate; only two of the 33 Voes in Shetland and Orkney had any potential space for aquaculture development. Other regions such as the South West of mainland Scotland were shown to have more scope with regard to the expansion of aquaculture in sea lochs. However, as highlighted in the discussion for Section 3, regional ‘Aquaculture Framework Plans’ may place the needs of other sea users over the expansion of aquaculture even within environmental boundaries.

Although Section 3 showed that spatial competition issues affect the potential amount of production that is theoretically possible in a sea loch, environmental limitations also apply.

Environmental factors need to be assessed on a site by site and loch by loch basis and will also vary with the standard operating procedures and codes of conduct for each fish farm company.

The environmental restrictions regarding benthic enrichment were assessed in Phase 2 of the ADST and concentrated only on the PADA within sea lochs to rule out any uncertainty surrounding the PADA in offshore areas and to provide distinct quantifiable study areas.

Although some criteria were applied, the allocation of sites within the PADA was purely arbitrary and was not intended to show definitive positions of potential new sites. The site positioning was used only as a framework for the BI model, as the level of impact is dependant on the positioning of the sites. In future, more sophisticated 3D models will make this positioning even more important. The exact parameters used to determine the new site positions could also change, as will possibly the size and shape of the PADA, which will both influence the number and position of potential new farms.

The application of the benthic impact model to the potential new sites in the sea lochs shows that benthic impacts could be the key limiting factor for the further development of aquaculture in sea lochs, excluding any planning restrictions.

The impact of organic deposition on the sea bed varies considerably, due to the highly variable hydrographic conditions at the sea bed, the complicated processes of benthic-pelagic coupling, the variability in composition of the sea bed and the debate around the role of species richness and or biomass in ecosystem processes (Bolam *et al*., 2002). There are, however, some primary driving factors that need to be considered when assigning a threshold for organic deposition on the sea bed which include: maintaining the redox values and oxygen concentrations above levels that could cause anoxic conditions, maintaining some bioturbating organisms to ensure recovery of the seabed, and maintaining biodiversity to ensure that ecosystem processes are not inhibited (Nickell, *et al*., 2003; Widdicombe, *et al*., 2000).

Within sea lochs there are varying proportions of Priority Marine Features (PMFs), such as Maerl beds that are particularly sensitive to sedimentation and organic enrichment (Hall-Spencer *et al*., 2006). In future the ADST could incorporate known areas of such sensitive habitats and remove them from the PADA. This will consequently reduce again the areas that are potentially available to aquaculture development and therefore the potential maximum biomass each sea loch could produce.

The results from Phase 1 showed that the area available to aquaculture within the sea lochs is limited; however, there are considerable areas that could be available to aquaculture out with the sea lochs. Presently the positioning of fish farm cages is limited by the technical and management challenges faced in more exposed areas. There is also a maximum current speed that the fish can tolerate (James and Slaski 2009). Figure 4.2.3 showed that the majority of the PADA are offshore and therefore more susceptible to the effects of wave height, tidal streams and currents. To exclude areas where the conditions are too extreme for cage farming will require modelling or more detailed investigation; e.g. the "Exposure algorithm" available from the Scottish Association for Marine Science (SAMS). The threshold levels for cage integrity also vary depending on technical developments. These areas also do not take into consideration other restrictions such as local amenity and environmental impact. Local amenity issues should be covered within the Local Authorities "Aquaculture Framework Plans" or Marine Spatial Plans.

Specialised offshore cages are in development and include fully submersible cages; however, this technology poses different management and husbandry challenges and may not be suited to conditions in the majority of UK offshore waters (James and Slaski 2009).

To expand the ADST into coastal waters, distinct areas will need to be defined that are hydrographically or geographically distinct. This may require the use of a tidal excursion model to delineate areas, as used for the ISA management areas, or more complex hydrographic models. Although this report has presented certain factors to ascertain ecological sustainability other factors that are not covered here such as the effective treatment of sea-lice and the sustainability of the fish meal and oil that comprises the fish feed may eventually be more limiting than any of the factors presented.

The ADST could be further improved by incorporating exposure algorithms (including known cage/net tolerances), PMF mapping and developing a model that can run within the GIS, possibly by the use of a pseudo layer.

The ADST could be then be used within other Marine Spatial plans to highlight areas that could be suitable for aquaculture development and avoid compounding pressures across sectors, similar to the tool used by the Crown Estate (Marine Resource System, MaRS) to highlight areas that could be suitable for offshore wind energy production.

Acknowledgements

To Seazone Ltd, for their work on the initial structure of the GIS project and the development of new tools to enable some of the GIS modelling.

To the aquaculture Industry and colleagues from other organisations for their input at a Seminar in December 2008 that helped to steer the direction of this project and the indicator project.

Also, to colleagues at SEPA, for their considerable support in obtaining data from the fish farm benthic monitoring surveys.

Glossary of Acronyms and Symbols

Acronym	Meaning
$A_{(15\text{-}70m)}$	Area in a sea loch that is between the 15 m and 70 m depth contours, as calculated by the ADST (km^2)
ADST	High Level GIS Decision Support Tool
A_L	Total area of seabed within each sea loch that was leased to fish farms (km^2)
$\overline{A_L}$	Average total leased area in all sea lochs (km^2)
A_{LW}	Surface area of sea loch calculated at mean low water
A_{REQ}	Area required in each sea loch to produce B_{TMAX} (km^2)
AZE	Allowable Zone of Effect
B	Total biomass consented to be held in a sea loch by the CAR licences issued by SEPA (t)
B_C	Current total consented biomass
B_{CMAX}	Maximum potential biomass considering the maximum peak C-flux beneath the sites in a sea loch (t)
BI	Benthic Impact
BI_L	Benthic impact Limit threshold for ECE_MOD.m model (10 % Sea loch area)
BI_{pa}	Benthic impact Precautionary threshold for ECE_MOD.m model (8 % Sea loch area)
B_{MAX}	The most limiting value for the maximum potential biomass in each sea loch from all the calculations (t)
B_{SMAX}	Maximum potential biomass in each sea loch, taking SEPA modelling restrictions into consideration (i.e. 2500 t per site) (t)
B_{TMAX}	Theoretical maximum biomass of farmed fish in a sea loch, such that the precautionary limits for nutrient enhancement and benthic impact were not exceeded (t)
CAR	Water Environment (Controlled Activities) (Scotland) Regulations 2005
ECE	Equilibrium Concentration Enhancement (ECE) of nutrients. The ECE is the extra concentration that would occur if a steady input of nutrients were to be balanced by steady removal by seawater exchange. Use by algae is ignored ($\mu mol\ N\ l^{-1}$)

ECE.bas	Model used in the 'Locational Guidelines' to predict the ECE and % degraded areas
ECE_MOD.m	ECE.bas model modified in 'MatLab' to calculate the maximum fish biomass that can be produced in a sea loch before the precautionary levels of nutrient enhancement and benthic impact are breached
ECE_L	Nutrient Enrichment Indicator: Limit Threshold for ECE_MOD.m model (µmol N l^{-1})
ECE_{pa}	Nutrient Enrichment Indicator: Precautionary threshold for ECE_MOD.m model (µmol N l^{-1})
GIS	Geographic Information System
ICES	International Council for the Exploration of the Sea
LW Area	Surface area of sea loch calculated at mean low water
MaRS	Crown Estate's GIS based Marine Resource System
MSS	Marine Scotland Science
MSS_BI.m	ECE.bas model modified in 'MatLab' to calculate the maximum fish biomass that can be produced at a fish farm site before the c-flux threshold is breached (in this case 7 kgC m^{-2} yr^{-1})
n_E	Number of existing sites in a sea loch before the ADST
n_P	Number sites predicted in each sea loch by the ADST
P	Annual total tonnage of fish produced (t yr^{-1})
PADA	Potential Aquaculture Development Areas
P_d	average value for production per km^2 (t km^{-2})
$\bar{P}$	Average annual production (t yr^{-1})
SAMS	Scottish Association for Marine Science
SEPA	Scottish Environmental Protection Agency
SSPO	Scottish Salmon Producers Organisation

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Annex 1a

List of Sea lochs

Loch No	Loch ID	Loch Name	Length (km)	Area (km^2)	Volume (km^3)	Tidal Range (m)	Tf (days)	Q (Mm^3yr^{-1})	Area 15-70 m (km^2)
1	SW01	A'CHOIRE	2.3	1.3	17.1	3.4	3.0	2077	0.58
2	SW02	AILORT	8.1	8.7	91.3	4.3	1.9	17542	2.37
3	SK01	AINORT	3.9	3.5	52.5	4.6	2.5	7665	1.70
4	NW01	AIRDBHAIR	2.2	0.4	2.1	4.2	0.9	839	0.00
5	SH01	AITH VOE	4.0	4.8	117.7	1.7	10.7	4015	3.19
6	WI01	A'LAIP	2.5	1.1	5.7	3.9	1.0	2072	0.00
7	SW03	ALINE	3.5	2.3	17.5	3.4	1.7	3757	0.35
8	NW02	ALSH	13.1	27.2	933.9	4.6	5.6	60873	13.01
9	NW03	ARNISH	2.0	2.0	61.1	3.2	7.2	3097	1.61
10	NW04	BADCALL BAY	1.9	1.3	13.9	3.6	2.3	2208	0.34
11	SH02	BALTASOUND	2.9	3.7	30.5	1.9	3.3	3375	0.42
12	SH03	BASTA VOE	5.2	5.7	75.5	1.9	5.2	5298	2.62
13	SK02	BAY	6.9	15.4	343.0	4.5	3.7	33837	11.02
14	WI02	BOISDALE	5.7	4.7	55.1	3.8	2.3	8749	1.82
15	SK03	BRACADALE	10.5	45.8	1053.9	3.1	5.6	68693	32.06
16	SH04	BRINDISTER	5.5	5.0	46.2	1.7	4.1	4112	1.17
17	WI03	BROAD BAY	14.0	82.5	1357.7	4.1	3.0	165188	45.78
18	NW05	BROOM	14.7	16.0	391.6	4.5	4.1	34864	9.62
19	SH05	BURWICK	0.9	0.4	4.4	0.9	8.5	189	0.11
20	SH06	BUSTA	3.0	3.0	50.7	1.7	7.3	2537	1.71
21	NW06	CAIRNBHAIN	14.9	14.0	330.6	4.2	4.2	28727	7.78
22	NW07	CALBHA BAY	1.4	0.7	8.2	3.6	2.6	1153	0.24
23	SW04	CAOLISPORT	8.3	14.9	163.4	0.9	9.1	6552	5.14
24	WI04	CARNAN	1.8	0.7	2.1	3.9	0.6	1294	0.00
25	NW08	CARRON	26.7	20.6	602.5	4.7	4.7	46791	7.32
26	SH07	CAT FIRTH	3.0	2.8	26.9	1.8	4.1	2395	0.60
27	WI05	CLAIDH	6.7	4.5	97.6	4.2	3.9	9134	3.44

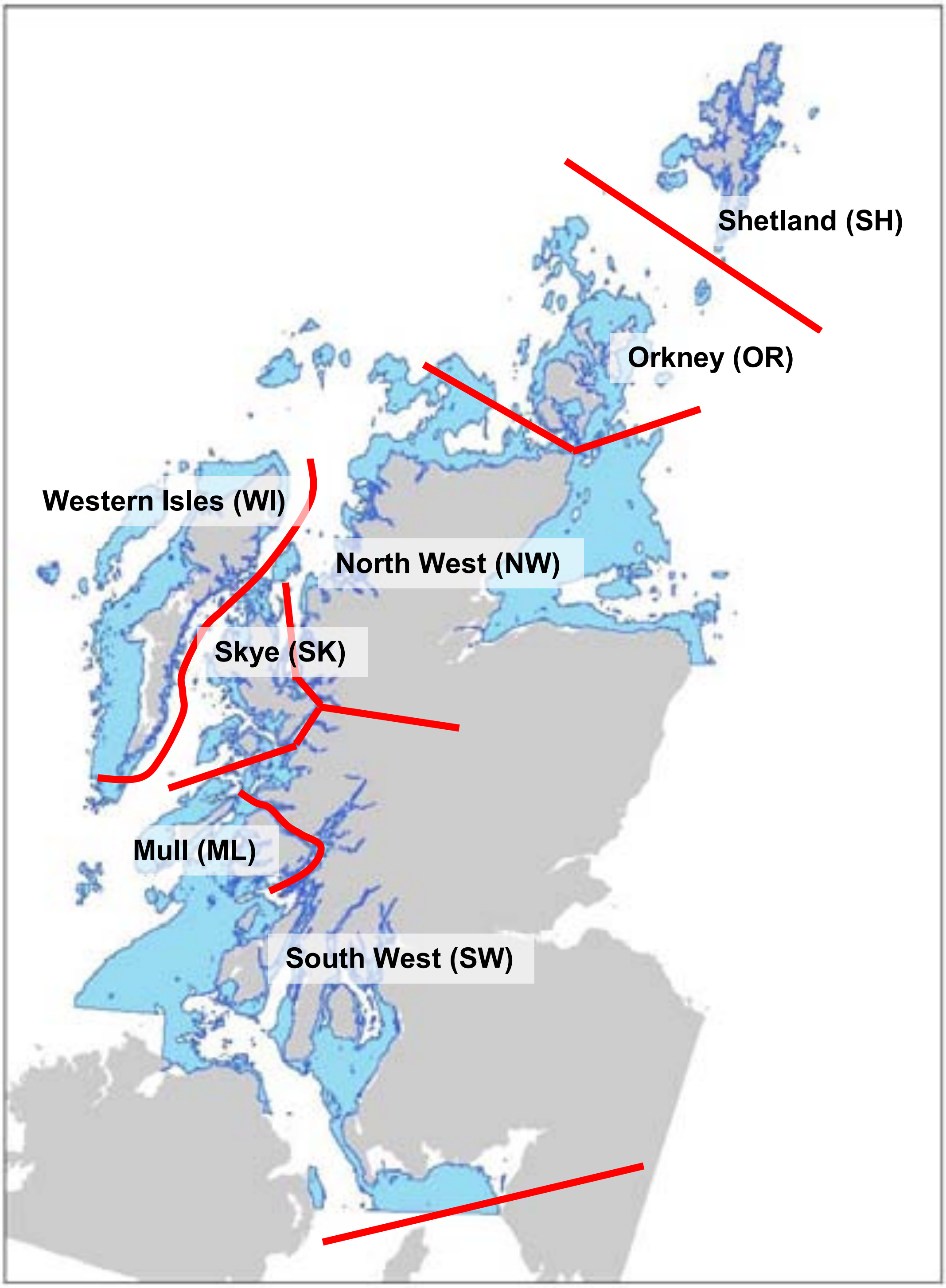
Loch No	Loch ID	Loch Name	Length (km)	Area (km^2)	Volume (km^3)	Tidal Range (m)	Tf (days)	Q (Mm^3yr^{-1})	Area 15-70 m (km^2)
28	NW09	CLASH	1.6	1.0	17.2	4.2	3.0	2096	0.51
29	SH08	CLIFT SOUND	10.0	8.5	123.6	1.4	7.8	5782	4.27
30	SH09	COLLAFIRTH	2.4	0.9	11.5	1.8	5.1	820	0.32
31	SW05	CRAIGNISH	8.8	14.6	202.0	2.1	5.0	14750	4.08
32	SW06	CRERAN	12.8	12.4	161.1	3.3	3.0	19600	3.91
33	SH10	DALES VOE	4.9	3.2	47.3	1.2	9.2	1877	1.46
34	SH11	DALES VOE NORTH	5.1	3.1	48.2	1.8	6.4	2751	1.50
35	NW10	DUICH	8.3	11.2	510.7	4.6	7.4	25191	6.01
36	SK04	DUNVEGAN	10.4	21.7	1255.5	4.5	9.6	47736	6.07
37	SH12	DURY VOE	6.5	13.0	308.5	1.4	13.1	8597	8.63
38	WI06	EAST LOCH TARBERT	8.5	26.2	518.5	4.2	3.6	52575	17.10
39	SK05	EISHORT	5.2	2.5	19.4	4.3	1.4	5045	0.25
40	WI07	EPORT	7.0	3.9	27.4	4.1	1.3	7695	0.36
41	NW11	ERIBOLL	15.5	37.5	954.1	4.3	4.4	79150	24.71
42	WI08	ERISORT/LEURBOST	14.6	15.8	227.0	4.1	2.6	31873	6.62
43	SW07	ETIVE	29.5	28.3	948.7	1.8	13.9	24913	18.73
44	NW12	EWE	11.9	43.0	846.3	4.4	3.4	90853	23.98
45	WI09	EYNORT	4.3	2.2	17.3	4.1	1.4	4502	0.40
46	SW08	FEOCHAN	6.7	3.9	17.9	3.3	1.1	5940	0.25
47	SW09	FYNE	60.5	183.3	9440.2	3.1	12.4	277876	104.54
48	WI10	GEOCRAB	2.5	0.6	5.4	4.2	1.6	1227	0.15
49	SK06	GRESHORNISH	5.9	4.7	74.1	4.6	2.6	10403	2.27
50	WI11	GRIMSHADER	3.5	0.9	8.4	4.1	1.7	1806	0.20
51	WI12	GROSEBAY	2.6	2.9	47.9	4.2	2.9	6025	1.56
52	SH13	GRUTING	7.6	6.7	95.7	1.1	9.7	3600	3.06
53	SK07	HARPORT	12.5	7.2	108.8	4.3	2.7	14710	3.95
54	SW10	HOURN	21.3	34.5	1905.0	4.2	9.8	70953	16.70
55	NW13	INCHARD	6.6	3.7	77.1	4.2	3.7	7608	2.25
56	WI13	KILERIVAGH	4.2	1.0	2.2	3.9	0.5	1606	0.00

Loch No	Loch ID	Loch Name	Length (km)	Area (km^2)	Volume (km^3)	Tidal Range (m)	Tf (days)	Q (Mm^3yr^{-1})	Area 15-70 m (km^2)
57	OR02	KIRK HOPE	1.8	0.6	4.4	2.3	2.4	669	0.00
58	NW14	KISHORN	4.1	7.8	191.3	4.7	3.9	17901	4.89
59	SH14	LAXFIRTH	3.8	2.3	21.1	1.8	3.9	1977	0.51
60	NW15	LAXFORD	7.0	7.2	107.5	4.2	2.7	14528	2.53
61	SW11	LEVEN	13.4	8.1	149.2	3.7	3.8	14335	4.60
62	SW12	LINNHE	29.1	33.7	1303.7	3.7	7.8	61006	17.60
63	NW16	LITTLE L BROOM	12.7	23.0	914.7	4.5	6.6	50587	14.82
64	SW21	LONG	26.9	44.0	1758.0	3.1	9.6	66840	34.54
65	WI14	MEANERVAGH	1.4	0.2	0.8	3.9	0.9	315	0.00
66	SW13	MELFORT	6.0	10.2	256.5	2.3	8.2	11418	8.27
67	WI15	MHARABHIG	1.3	0.5	1.7	4.1	0.7	864	0.00
68	SH15	MID YELL	3.3	1.7	11.7	1.9	2.7	1576	0.08
69	SW14	MOIDART	2.8	0.9	8.6	4.3	1.7	1846	0.05
70	ML01	NA KEAL	10.7	32.2	694.7	3.8	4.3	58966	17.62
71	NW17	NEDD	2.4	0.5	3.3	4.2	1.1	1110	0.01
72	SW15	NEVIS	17.2	29.9	1505.0	4.3	8.8	62424	15.55
73	SH16	NORTHRA VOE	1.0	0.3	2.2	1.5	4.2	187	0.03
74	WI16	ODHAIRN	3.6	1.8	29.8	4.1	3.1	3511	0.85
75	SH17	OLNA VOE	4.6	4.0	79.6	1.7	8.7	3341	2.51
76	OR03	PIEROWALL HARBOUR	1.6	1.1	3.5	2.3	1.0	1286	0.00
77	SK08	POOL TIEL	3.9	3.9	111.4	3.1	7.0	5808	2.43
78	SK09	PORTREE	4.9	4.1	88.3	4.6	3.5	9212	2.77
79	SW16	RIDDON	5.3	2.8	49.8	2.6	5.1	3561	1.69
80	WI17	ROAG	14.0	68.3	1135.5	3.6	3.5	118419	35.18
81	SH18	RONAS VOE	9.4	9.4	176.0	1.7	8.2	7834	5.90
82	SW17	RYAN	13.4	40.3	166.4	2.8	1.2	50613	0.09
83	SH19	SANDSOUND	8.6	6.0	69.7	1.1	7.9	3219	1.86
84	ML02	SCRIDAIN	12.0	27.0	734.2	3.7	5.5	48721	18.74
85	WI18	SEAFORTH	22.6	24.6	604.1	4.2	4.4	50111	15.89

Loch No	Loch ID	Loch Name	Length (km)	Area (km^2)	Volume (km^3)	Tidal Range (m)	Tf (days)	Q (Mm^3yr^{-1})	Area 15-70 m (km^2)
86	SH20	SELIVOE	4.0	4.8	88.9	1.1	12.5	2597	2.66
87	WI19	SHEILAVAIG	3.0	0.6	1.5	4.1	0.5	1105	0.00
88	WI20	SHELL	7.5	15.0	391.5	4.1	4.8	29769	9.98
89	WI21	SKIPORT	4.6	3.0	38.9	4.1	2.4	5919	1.13
90	SK10	SLAPIN	3.4	2.1	11.6	4.3	1.0	4219	0.00
91	SK11	SLIGACHAN	4.4	1.7	15.7	4.6	1.5	3809	0.34
92	SK12	SNIZORT BEG	4.7	6.9	101.9	4.6	2.5	14884	2.89
93	ML03	SPELVE	7.7	8.9	144.9	3.5	3.5	15111	4.38
94	WI22	STOCKINISH	3.5	1.5	17.8	4.2	2.1	3093	0.48
95	SW18	STRIVEN	12.9	14.3	546.7	2.6	11.0	18142	11.96
96	SH21	STROMNESS VOE	4.6	2.3	13.6	1.1	4.1	1209	0.30
97	SW19	SUNART	30.7	50.6	1754.0	4.0	6.5	98493	31.86
98	SH22	SWARBACKS MINN	13.0	30.9	995.1	1.7	14.1	25759	11.34
99	SW20	SWEEN	14.8	20.0	216.9	1.6	5.1	15523	7.27
100	SH23	SWINING VOE	4.0	3.5	63.1	1.8	7.6	3031	1.82
101	SH24	SWINISTER VOE	6.3	14.9	367.5	1.8	4.9	27377	5.90
102	ML04	TOBERMORY BAY	1.6	1.9	36.6	3.7	4.0	3340	1.13
103	NW18	TORRIDON	22.2	68.5	3300.2	4.9	7.4	162779	41.97
104	ML05	TUATH	9.5	23.4	412.4	3.5	3.8	39616	14.55
105	SK13	UIG BAY	8.8	3.1	64.8	3.1	5.1	4639	1.67
106	WI23	UISKEVAGH	3.3	1.9	10.0	4.1	1.0	3652	0.00
107	SH25	VAILA SOUND	3.5	3.6	35.6	1.2	6.1	2128	0.79
108	SH26	VIDLIN VOE	3.0	2.7	37.3	1.8	5.7	2392	1.06
109	SH30	WADBISTER VOE	2.1	1.6	18.2	1.8	4.7	1416	0.56
110	SH27	WEISDALE	6.7	6.0	104.0	1.1	11.7	3244	3.29
111	SH28	WEST BURRA FIRTH	1.6	0.8	10.4	1.3	7.5	506	0.25
112	WI24	WEST LOCH TARBERT	6.5	23.2	396.9	3.8	3.4	42614	16.12
113	SH31	WHALEFIRTH	6.3	3.1	28.0	1.9	3.6	2839	0.00
114	SH29	WHITENESS VOE	4.5	3.0	36.0	1.1	8.3	1583	0.90

Annex 1b

Map of Sea areas.



Annex 2a

Average production data by sea loch with standard error and standard deviation information (P, t yr^{-1}).

Loch ID	Loch No	Loch Name	Average 2004-2008	SEM	Average 2005-2008	SEM	Average 2006-2008	SEM
SH01	5	AITH VOE	828.67	148.42	940.00	170.00	940.00	170.00
SH02	11	BALTASOUND	158.60	18.80	148.75	20.67	153.33	28.50
SH03	12	BASTA VOE	1498.40	472.76	1359.25	583.30	1735.67	630.15
SH04	16	BRINDISTER	1124.40	446.90	997.75	553.30	1224.67	713.65
SH05	19	BURWICK	282.67	73.71	209.50	15.50	225.00	0.00
SH06	20	BUSTA	105.50	17.50	123.00	0.00	123.00	0.00
SH07	26	CAT FIRTH	2157.50	121.50	2157.50	121.50	2036.00	0.00
SH08	29	CLIFT SOUND	1414.60	564.33	1667.00	651.61	1424.00	855.04
SH12	37	DURY VOE	1528.50	89.93	1488.67	114.03	1564.50	147.50
SH13	52	GRUTING	1386.00	868.99	1475.00	1222.47	1999.00	1913.00
SH14	59	LAXFIRTH	1203.25	152.26	1321.33	135.93	1456.00	32.00
SH15	68	MID YELL	322.00	96.69	264.00	134.00	130.00	0.00
SH17	75	OLNA VOE	1618.67	52.47	1669.50	22.50	1669.50	22.50
SH18	81	RONAS VOE	1372.00	669.15	1802.00	725.07	1321.50	940.50
SH19	83	SANDSOUND	1482.40	193.78	1461.00	248.64	1429.67	348.82
SH20	86	SELIVOE	877.00	0.00	877.00	0.00	877.00	0.00
SH21	96	STROMNESS VOE	1206.50	250.59	965.33	96.26	1056.50	53.50
SH22	98	SWARBACKS MINN	2953.00	711.44	2265.50	236.23	2419.33	253.54
SH23	100	SWINING VOE	1772.50	767.50	1005.00	0.00	1005.00	0.00
SH24	101	SWINISTER VOE	4813.20	786.89	4874.50	1012.78	4654.33	1398.04
SH25	107	VAILA SOUND	2394.25	498.91	2774.33	457.06	3223.00	151.00
SH26	108	VIDLIN VOE	425.50	420.50	425.50	420.50	425.50	420.50
SH27	110	WEISDALE	2277.50	824.62	1619.33	702.58	1619.33	702.58
SH30	109	WADBISTER VOE	633.50	8.50	633.50	8.50	625.00	0.00
OR03	76	PIEROWALL HARBOUR	172.00	59.73	201.33	73.58	171.50	116.50
NW01	4	AIRDBHAIR	464.50	107.15	561.67	63.85	518.50	81.50
NW02	8	ALSH	1745.60	434.87	1574.00	515.86	1861.67	605.57
NW04	10	BADCALL BAY	889.50	430.50	889.50	430.50	459.00	0.00
NW05	18	BROOM	450.80	215.66	534.25	256.73	317.00	193.46
NW06	21	CAIRNBHAIN	673.00	94.47	685.33	132.46	817.00	25.00
NW07	22	CALBHA BAY	912.25	361.49	786.33	479.21	942.00	785.00
NW08	25	CARRON	1264.67	614.16	1264.67	614.16	1878.50	34.50
NW10	35	DUICH	1086.60	215.96	896.00	131.10	1005.33	102.30
NW11	41	ERIBOLL	1081.50	519.27	774.00	591.75	774.00	591.75
NW12	44	EWE	1444.00	546.96	1444.00	546.96	1347.50	932.50
NW14	58	KISHORN	3228.75	1012.54	2935.67	1370.65	2935.67	1370.65
NW15	60	LAXFORD	1205.50	475.50	1681.00	0.00	1681.00	0.00
NW16	63	LITTLE L BROOM	981.67	616.03	1384.00	808.00	576.00	0.00
NW18	103	TORRIDON	2594.80	869.46	3014.50	983.03	2468.33	1155.90
WI02	14	BOISDALE	1693.60	316.95	1585.75	384.76	1672.33	530.18
WI06	38	EAST LOCH TARBERT	1198.50	194.35	1198.50	194.35	1080.67	218.57
WI07	40	EPORT	202.75	41.95	184.33	53.30	199.50	88.50
Loch ID	**Loch No**	**Loch Name**	**Average 2004-2008**	**SEM**	**Average 2005-2008**	**SEM**	**Average 2006-2008**	**SEM**
WI08	42	ERISORT/LEURBOST	2772.00	241.19	2311.00	128.50	2311.00	128.50
WI12	51	GROSEBAY	275.00	82.40	275.00	82.40	210.00	71.62
WI14	65	MEANERVAGH	190.20	61.18	201.75	77.57	148.67	79.98
WI16	74	ODHAIRN	1426.40	518.82	1207.50	607.25	1548.67	710.44

WI17	80	ROAG	5070.80	634.53	5224.75	794.70	5047.00	1095.40
WI18	85	SEAFORTH	2029.00	753.61	1500.25	693.23	1732.00	923.98
WI20	88	SHELL	3160.67	650.23	2671.00	741.00	2671.00	741.00
WI21	89	SKIPORT	1160.80	343.59	1352.00	368.55	1160.67	445.47
WI22	94	STOCKINISH	210.00	21.00	210.00	21.00	210.00	21.00
WI23	106	UISKEVAGH	300.33	173.28	376.00	270.00	376.00	270.00
WI24	112	WEST LOCH TARBERT	3904.50	512.50	3904.50	512.50	3392.00	0.00
SK01	3	AINORT	1813.33	175.04	1639.50	35.50	1639.50	35.50
SK02	13	BAY	193.67	44.86	190.50	77.50	113.00	0.00
SK04	36	DUNVEGAN	603.00	146.50	603.00	146.50	494.50	170.50
SK05	39	EISHORT	1256.25	433.37	1415.67	569.90	1497.00	977.00
SK06	49	GRESHORNISH	2095.00	246.39	1914.50	290.50	1914.50	290.50
SK07	53	HARPORT	1214.50	440.87	1336.67	599.07	1860.00	505.00
SK09	78	PORTREE	2567.00	199.72	2381.00	126.00	2381.00	126.00
SK10	90	SLAPIN	331.00	55.24	299.00	78.00	299.00	78.00
ML01	70	NA KEAL	3218.33	175.37	3366.50	162.50	3366.50	162.50
ML03	93	SPELVE	448.75	314.31	563.33	413.92	751.00	639.00
ML05	104	TUATH	1051.00	119.00	1170.00	0.00	1170.00	0.00
SW01	1	A'CHOIRE	1014.50	403.29	1159.33	532.29	858.00	760.00
SW02	2	AILORT	209.75	26.27	200.33	34.68	200.33	34.68
SW05	31	CRAIGNISH	729.20	323.69	909.50	347.05	627.67	286.41
SW06	32	CRERAN	871.80	488.92	1086.00	567.40	601.00	416.45
SW07	43	ETIVE	784.50	120.50	784.50	120.50	784.50	120.50
SW09	47	FYNE	7176.50	3695.95	9171.33	4400.15	8490.50	7529.50
SW10	54	HOURN	1285.40	361.93	1529.50	344.98	1444.33	472.78
SW11	61	LEVEN	785.50	399.59	1007.67	469.71	867.50	776.50
SW12	62	LINNHE	3074.00	1686.56	4008.33	1985.71	3369.50	3256.50
SW13	66	MELFORT	111.50	52.88	164.00	11.00	164.00	11.00
SW15	72	NEVIS	2740.20	275.43	2778.50	352.12	2912.00	460.79
SW16	79	RIDDON	434.50	5.50	434.50	5.50	440.00	0.00
SW18	95	STRIVEN	556.00	475.00	556.00	475.00	556.00	475.00
SW19	97	SUNART	6777.00	465.30	6489.00	633.00	6489.00	633.00
		Mean	**1499.59**		**1519.37**		**1488.97**	
		Standard Error	**157.18**		**169.55**		**163.05**	
		Standard Deviation	**1388.15**		**1497.40**		**1440.00**	
		N	**78.00**		**78.00**		**78.00**	
		MEAN ± SEM (N)	**1499.59 ± 157.18 (78)**		**1519.37 ± 169.55 (78)**		**1488.97 ± 163.05 (78)**	

Annex 2b

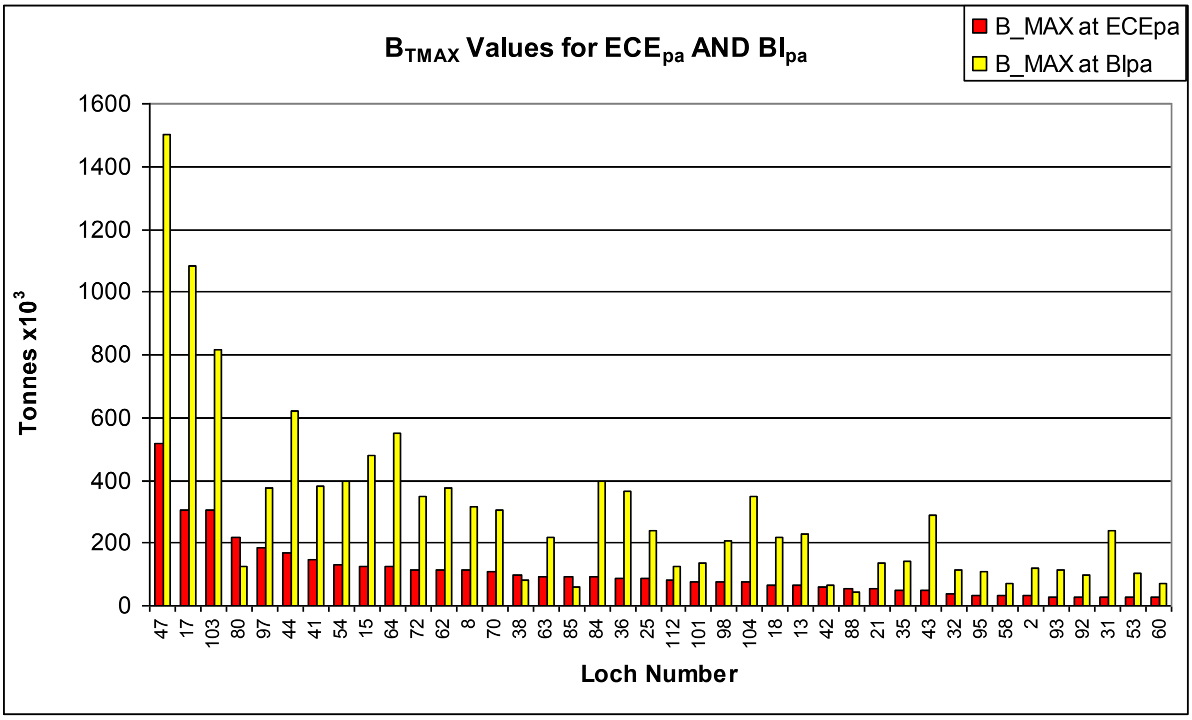
Average Crown Estate leased area data by sea loch with standard error and standard deviation information.

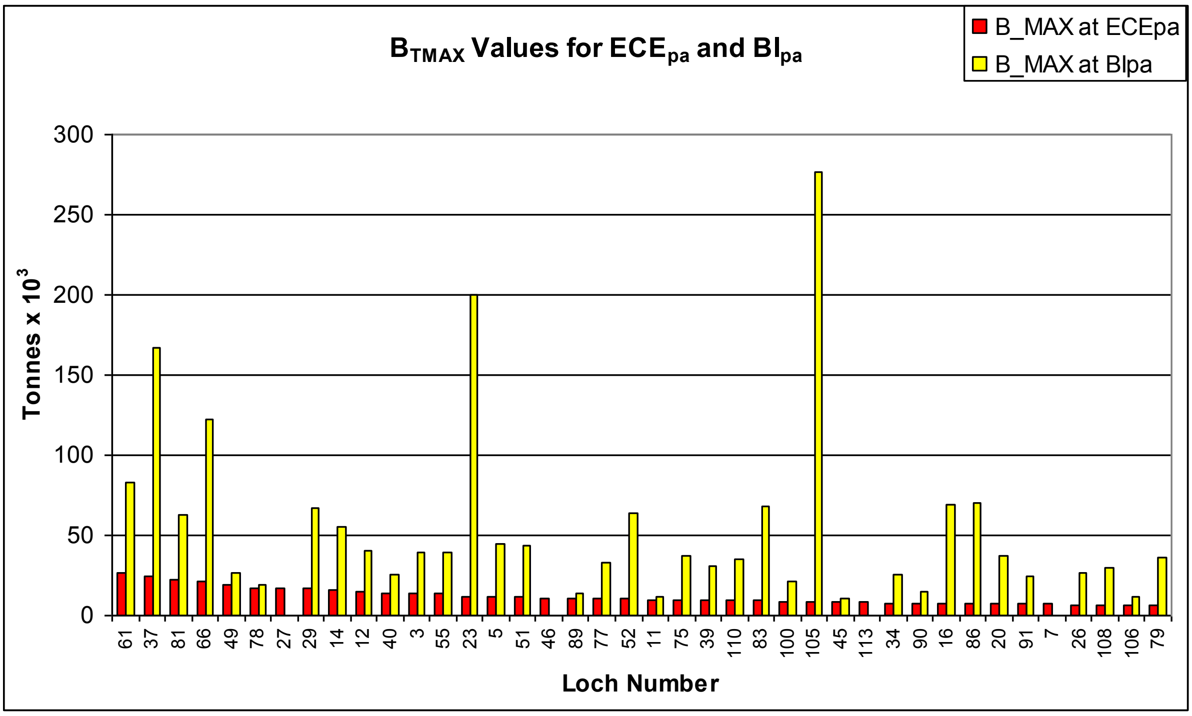
Loch ID	Loch No	Loch Name	Total Leased Area (km^2)
SH01	5	AITH VOE	0.280
SH02	11	BALTASOUND	0.225
SH03	12	BASTA VOE	0.245
SH04	16	BRINDISTER	0.170
SH05	19	BURWICK	0.077
SH06	20	BUSTA	0.046
SH07	26	CAT FIRTH	0.281
SH08	29	CLIFT SOUND	0.525
SH09	30	COLLAFIRTH	0.085
SH10	33	DALES VOE	0.224
SH11	34	DALES VOE NORTH	0.104
SH12	37	DURY VOE	0.330
SH13	52	GRUTING	0.142
SH14	59	LAXFIRTH	0.128
SH15	68	MID YELL	0.074
SH16	73	NORTHRA VOE	0.033
SH17	75	OLNA VOE	0.039
SH18	81	RONAS VOE	0.337
SH19	83	SANDSOUND	0.348
SH20	86	SELIVOE	0.028
SH21	96	STROMNESS VOE	0.062
SH22	98	SWARBACKS MINN	1.790
SH23	100	SWINING VOE	0.295
SH24	101	SWINISTER VOE	0.498
SH25	107	VAILA SOUND	0.184
SH26	108	VIDLIN VOE	
SH27	110	WEISDALE	1.090
SH29	114	WHITENESS VOE	
SH30	109	WADBISTER VOE	0.169
SH31	113	WHALEFIRTH	
OR03	76	PIEROWALL HARBOUR	0.212
NW01	4	AIRDBHAIR	0.062
NW02	8	ALSH	0.474
NW03	9	ARNISH	0.048
NW04	10	BADCALL BAY	0.178
NW05	18	BROOM	0.645
NW06	21	CAIRNBHAIN	1.031
NW07	22	CALBHA BAY	0.205
NW08	25	CARRON	0.483
NW09	28	CLASH	0.022
NW10	35	DUICH	0.413
Loch ID	Loch No	Loch Name	Total Leased Area (km^2)
NW11	41	ERIBOLL	0.168
NW12	44	EWE	0.314
NW14	58	KISHORN	0.500
NW15	60	LAXFORD	0.393
NW16	63	LITTLE L BROOM	0.278
NW17	71	NEDD	0.026
NW18	103	TORRIDON	0.713
WI01	6	A'LAIP	0.120
WI02	14	BOISDALE	0.315
WI03	17	BROAD BAY	0.423
WI04	24	CARNAN	0.014
WI06	38	EAST LOCH TARBERT	0.258
WI07	40	EPORT	0.040
WI08	42	ERISORT/LEURBOST	0.250
WI09	45	EYNORT	
WI10	48	GEOCRAB	0.038
WI11	50	GRIMSHADER	0.005
WI12	51	GROSEBAY	0.058
WI14	65	MEANERVAGH	0.023
WI15	67	MHARABHIG	
WI16	74	ODHAIRN	0.105
WI17	80	ROAG	0.639
WI18	85	SEAFORTH	0.827
WI19	87	SHEILAVAIG	0.028
WI20	88	SHELL	0.165
WI21	89	SKIPORT	0.060
WI22	94	STOCKINISH	
WI23	106	UISKEVAGH	0.043
WI24	112	WEST LOCH TARBERT	0.338
SK01	3	AINORT	0.365
SK02	13	BAY	0.243
SK03	15	BRACADALE	0.225
SK04	36	DUNVEGAN	0.049
SK05	39	EISHORT	0.280
SK06	49	GRESHORNISH	0.359
SK07	53	HARPORT	0.031
SK08	77	POOL TIEL	
SK09	78	PORTREE	0.095
SK10	90	SLAPIN	0.097
SK11	91	SLIGACHAN	0.085
SK12	92	SNIZORT BEG	0.266
Loch ID	Loch No	Loch Name	Total Leased Area (km^2)
SK13	105	UIG BAY	0.090
ML01	70	NA KEAL	0.101
ML02	84	SCRIDAIN	0.064
ML03	93	SPELVE	0.537
ML05	104	TUATH	0.072
SW01	1	A'CHOIRE	0.224
SW02	2	AILORT	1.083
SW04	23	CAOLISPORT	0.203
SW05	31	CRAIGNISH	0.366
SW06	32	CRERAN	0.261

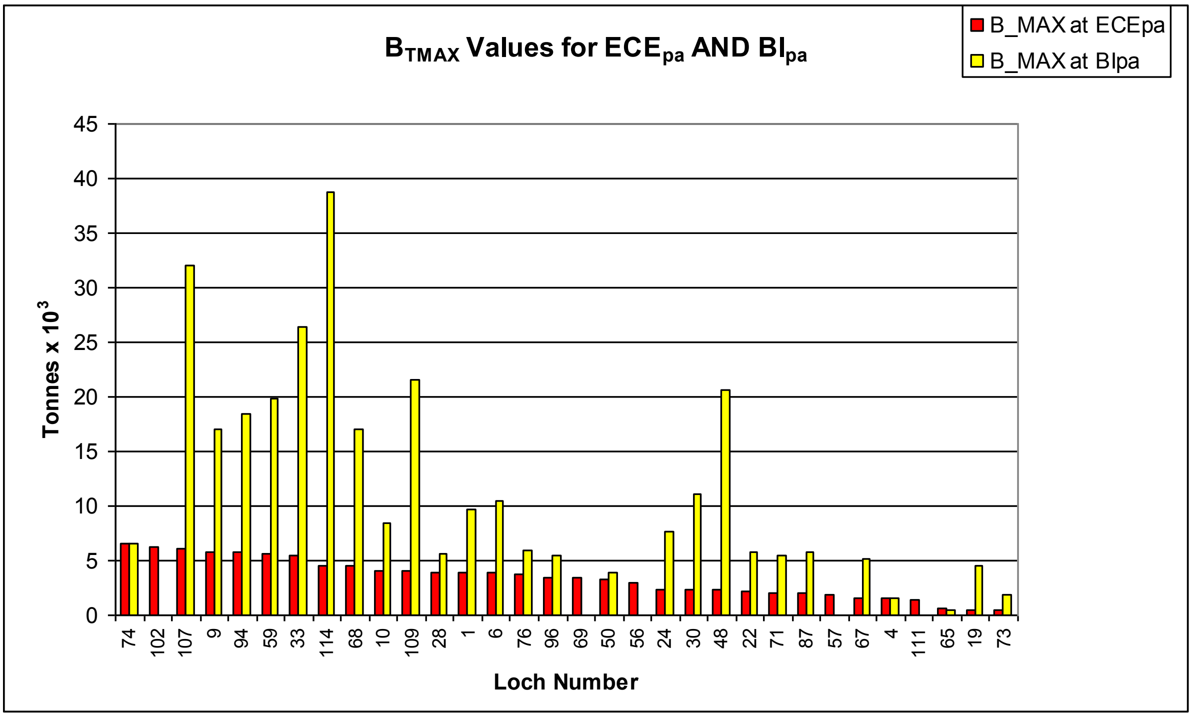
SW07	43	ETIVE	
SW09	47	FYNE	1.854
SW10	54	HOURN	0.282
SW11	61	LEVEN	0.212
SW12	62	LINNHE	1.500
SW13	66	MELFORT	0.003
SW15	72	NEVIS	0.418
SW16	79	RIDDON	
SW18	95	STRIVEN	0.196
SW19	97	SUNART	1.003
SW21	64	LONG	
		Mean	**0.304**
		Standard Error	**0.037**
		Standard Deviation	**0.355**
		N	**93**
		MEAN ± SEM (N)	**0.304 ± 0.037 (93)**

Annex 3

The relationships between the maximum biomass at the precautionary thresholds for nutrient enrichment (ECE_{pa}) and benthic impact (BI_{pa}) by sea loch. The smallest value in each loch is the limiting factor in each sea loch (i.e. lochs 80, 38, 85, 88, 74 and 65 were limited by benthic impact). There were zero values for BI_{pa} in sea lochs 7, 27, 46, 56, 57, 69, 82, 99, 102, 111 and 113.






B_{TMAX} Values for ECE_{pa} AND BI_{pa}
B_MAX at ECEpa
B_MAX at BIpa
Tonnes x 10^3
45
40
35
30
25
20
15
10
5
0
74
102
107
9
94
59
33
114
68
10
109
28
1
6
76
96
69
50
56
24
30
48
22
71
87
57
67
4
111
65
19
73
Loch Number

Annex 4

Theoretical potential maximum biomass (B_{TMAX}) values for Scottish sea lochs with the corresponding areas required to produce this biomass (A_{REQ}) (Lochs ordered by region).

(BOLD values = limiting factors)
(Italic values = Values where B_{TMAX} were based only on nutrient enrichment as there were not enough data to run ECE_MOD (11 sea lochs))
(*naa = no $A_{(15\text{-}70\ m)}$ available (10 sea lochs).

Loch ID	Loch No	Loch Name	Max Pot Biomass BI_{pa} ($t\ yr^{-1}$)	Max Pot Biomass ECE_{pa} ($t\ yr^{-1}$)	Max Pot Biomass B_{TMAX} ($t\ yr^{-1}$)	Current Consented biomass (B_C) (Feb 2012) ($t\ yr^{-1}$)	Biomass Gap between B_{TMAX} and B_C ($t\ yr^{-1}$)	Sea Loch Area 15-70 m (km^2)	Production per leased area km^{-2} (no 0s) (*P_d*, $t\ yr^{-1}\ km^{-2}$)	A_{REQ} for B_{TMAX} (km^2)	A_{REQ} for B_{TMAX} % $A_{(15\text{-}70\ m)}$	% B_{TMAX} possible within $A_{(15\text{-}70\ m)}$	B_{TMAX} possible within $A_{(15\text{-}70\ m)}$ ($t\ yr^{-1}$)
SH01	5	AITH VOE	44900	**11544**	11544	3484	8060	3.2	2958	2.3	73.5	136.1	15713
SH02	11	BALTASOUND	11200	**9705**	9705	1220	8485	0.4	705	2.0	**465.1**	21.5	2087
SH03	12	BASTA VOE	40900	**15234**	15234	2550	12684	2.6	6125	3.1	**117.9**	84.8	12926
SH04	16	BRINDISTER	68900	**7644**	7644	2666	4978	1.2	6598	1.6	**132.7**	75.3	5759
SH05	19	BURWICK	4500	**544**	544	600	**-56**	0.1	3682	0.1	**104.8**	95.5	519
SH06	20	BUSTA	37700	**7296**	7296	1050	6246	1.7	2309	1.5	86.7	115.3	8414
SH07	26	CAT FIRTH	26900	**6887**	6887	2300	4587	0.6	7674	1.4	**233.8**	42.8	2946
SH08	29	CLIFT SOUND	67000	**16627**	16627	4773	11853	4.3	2695	3.4	79.0	126.6	21045
SH09	30	COLLAFIRTH	11100	**2357**	2357	1225	1132	0.3	2835	0.5	**151.0**	66.2	1561
SH10	33	DALES VOE	26400	**5396**	5396	1600	3796	1.5	2895	1.1	75.2	132.9	7173
SH11	34	DALES VOE NORTH	25100	**7912**	7912	850	7062	1.5		1.6	**107.0**	93.5	7398
SH12	37	DURY VOE	167200	**24720**	24720	5460	19260	8.6	4638	5.0	58.1	172.1	42533
SH13	52	GRUTING	64100	**10351**	10351	4395	5956	3.1	9733	2.1	68.5	145.9	15102
SH14	59	LAXFIRTH	19800	**5685**	5685	2950	2735	0.5	9412	1.2	**224.9**	44.5	2527
SH15	68	MID YELL	17100	**4532**	4532	1210	3322	0.1	4330	0.9	**1218.4**	8.2	372
SH16	73	NORTHRA VOE	1900	**537**	537	500	37	0.0		0.1	**381.0**	26.2	141
SH17	75	OLNA VOE	36800	**9608**	9608	3100	6508	2.5	41404	1.9	77.7	128.7	12366
SH18	81	RONAS VOE	63000	**22528**	22528	2633	19895	5.9	4070	4.6	77.4	129.1	29088

Loch ID	Loch No	Loch Name	Max Pot Biomass BI_{pa} (t yr^{-1})	Max Pot Biomass ECE_{pa} (t yr^{-1})	Max Pot Biomass B_{TMAX} (t yr^{-1})	Current Consented biomass (B_C) (Feb 2012) (t yr^{-1})	Biomass Gap between B_{TMAX} and B_C (t yr^{-1})	Sea Loch Area 15-70 m (km^2)	Production per leased area km^{-2} (no 0s) (P_d, t yr^{-1} km^{-2})	A_{REQ} for B_{TMAX} (km^2)	A_{REQ} for B_{TMAX} % $A_{(15-70\ m)}$	% B_{TMAX} possible within $A_{(15-70\ m)}$	B_{TMAX} possible within $A_{(15-70\ m)}$ (t yr^{-1})
SH19	83	SANDSOUND	67900	**9257**	9257	5136	4121	1.9	4265	1.9	**101.1**	98.9	9152
SH20	86	SELIVOE	69900	**7467**	7467	963	6504	2.7		1.5	57.0	175.5	13107
SH21	96	STROMNESS VOE	5400	**3477**	3477	1650	1827	0.3	19552	0.7	**237.0**	42.2	1467
SH22	98	SWARBACKS MINN	208500	**74071**	74071	17747	56324	11.3	1650	15.0	**132.5**	75.5	55916
SH23	100	SWINING VOE	21300	**8715**	8715	5760	2955	1.8	5999	1.8	97.0	103.1	8982
SH24	101	SWINISTER VOE	134200	**78724**	78724	18903	59821	5.9	9660	16.0	**270.7**	36.9	29082
SH25	107	VAILA SOUND	32000	**6118**	6118	5515	603	0.8	13006	1.2	**157.0**	63.7	3896
SH26	108	VIDLIN VOE	29500	**6877**	6877	4336	2541	1.1		1.4	**131.2**	76.2	5242
SH27	110	WEISDALE	35500	**9328**	9328	3952	5376	3.3	2090	1.9	57.6	173.7	16199
SH28	111	WEST BURRA FIRTH		**1455**	*1455*	0	1455	0.3		0.3	**117.1**	85.4	1243
SH29	114	WHITENESS VOE	38800	**4551**	4551	500	4051	0.9		0.9	**102.1**	98.0	4458
SH30	109	WADBISTER VOE	21600	**4073**	4073	800	3273	0.6	3744	0.8	**147.4**	67.9	2763
SH31	113	WHALEFIRTH		**8163**	*8163*	813	7350	0.0		1.7	**naa**	**0.0**	**0**
OR02	57	KIRK HOPE		**1924**	*1924*	0	1924	0.0		0.4	**naa**	**0.0**	**0**
OR03	76	PIEROWALL HARBOUR	5900	**3697**	3697	165	3532	0.0	811	0.7	**naa**	**0.0**	**0**
NW01	4	AIRDBHAIR	1600	**1559**	1559	750	809	0.0	7443	0.3	**naa**	**0.0**	**0**
NW02	8	ALSH	313000	**113159**	113159	5500	107659	13.0	3681	23.0	**176.5**	56.7	64107
NW03	9	ARNISH	17100	**5757**	5757	0	5757	1.6		1.2	72.4	138.1	7949
NW04	10	BADCALL BAY	8400	**4105**	4105	1560	2545	0.3	4996	0.8	**244.8**	40.8	1677
NW05	18	BROOM	217700	**64810**	64810	1050	63760	9.6	699	13.1	**136.7**	73.2	47419
NW06	21	CAIRNBHAIN	134900	**53402**	53402	2550	50852	7.8	653	10.8	**139.2**	71.8	38351
NW07	22	CALBHA BAY	5800	**2144**	2144	1080	1064	0.2		0.4	**182.2**	54.9	1177
NW08	25	CARRON	241700	**86980**	86980	1375	85605	7.3	2616	17.6	**241.0**	41.5	36091
NW09	28	CLASH	5700	**3897**	3897	1030	2867	0.5		0.8	**155.3**	64.4	2509
NW10	35	DUICH	143900	**46829**	46829	2125	44704	6.0	2630	9.5	**158.2**	63.2	29605

Loch ID	Loch No	Loch Name	Max Pot Biomass BI_{pa} ($t\ yr^{-1}$)	Max Pot Biomass ECE_{pa} ($t\ yr^{-1}$)	Max Pot Biomass B_{TMAX} ($t\ yr^{-1}$)	Current Consented biomass (B_C) (Feb 2012) ($t\ yr^{-1}$)	Biomass Gap between B_{TMAX} and B_C ($t\ yr^{-1}$)	Sea Loch Area 15-70 m (km^2)	Production per leased area km^{-2} (no 0s) (*P_d*, $t\ yr^{-1}\ km^{-2}$)	A_{REQ} for B_{TMAX} (km^2)	A_{REQ} for B_{TMAX} % $A_{(15\text{-}70\ m)}$	% B_{TMAX} possible within $A_{(15\text{-}70\ m)}$	B_{TMAX} possible within $A_{(15\text{-}70\ m)}$ ($t\ yr^{-1}$)
NW11	41	ERIBOLL	378300	**147134**	147134	1338	145796	24.7	6426	29.8	**120.8**	82.8	121810
NW12	44	EWE	620200	**168888**	168888	1370	167518	24.0	4598	34.3	**142.9**	70.0	118185
NW13	55	INCHARD	39000	**14143**	14143	0	14143	2.3		2.9	**127.5**	78.4	11094
NW14	58	KISHORN	68800	**33277**	33277	4548	28729	4.9	6459	6.8	**138.1**	72.4	24104
NW15	60	LAXFORD	72200	**27007**	27007	1840	25167	2.5	3068	5.5	**216.9**	46.1	12449
NW16	63	LITTLE L BROOM	216800	**94038**	94038	2062	91976	14.8	3530	19.1	**128.7**	77.7	73045
NW17	71	NEDD	5400	**2064**	2064	250	1814	0.0		0.4	**2838.2**	3.5	73
NW18	103	TORRIDON	818400	**302594**	302594	4535	298059	42.0	3641	61.4	**146.2**	68.4	206904
WI01	6	A'LAIP	10400	**3853**	3853	750	3103	0.0		0.8	**120857**	0.1	3
WI02	14	BOISDALE	55600	**16263**	16263	2600	13663	1.8	5375	3.3	**181.1**	55.2	8978
WI03	17	BROAD BAY	1082800	**307071**	307071	2240	304831	45.8		62.3	**136.1**	73.5	225675
WI04	24	CARNAN	7600	**2406**	2406	410	1996	0.0		0.5	**naa**	**0.0**	**0**
WI05	27	CLAIDH		**16980**	*16980*	0	16980	3.4		3.4	**100.1**	99.9	16962
WI06	38	EAST LOCH TARBERT	**79100**	97732	79100	7932	71168	17.1	4648	16.0	93.8	106.6	84301
WI07	40	EPORT	25300	**14304**	14304	1800	12504	0.4	5031	2.9	**804.9**	12.4	1777
WI08	42	ERISORT/LEURBOST	67400	**59250**	59250	4977	54273	6.6	11088	12.0	**181.7**	55.0	32615
WI09	45	EYNORT	10600	**8369**	8369	20	8349	0.4		1.7	**426.1**	23.5	1964
WI10	48	GEOCRAB	20600	**2282**	2282	200	2082	0.2		0.5	**305.0**	32.8	748
WI11	50	GRIMSHADER	3900	**3358**	3358	622	2736	0.2	29806	0.7	**342.4**	29.2	981
WI12	51	GROSEBAY	44100	**11200**	11200	450	10750	1.6	4741	2.3	**145.6**	68.7	7693
WI13	56	KILERIVAGH		**2985**	*2985*	0	2985	0.0		0.6	**naa**	**0.0**	**0**
WI14	65	MEANERVAGH	**400**	586	400	420	**-20**	0.0	8441	0.1	**naa**	**0.0**	**0**
WI15	67	MHARABHIG	5100	**1606**	1606	0	1606	0.0		0.3	**naa**	**0.0**	**0**
WI16	74	ODHAIRN	**6500**	6526	6500	2075	4426	0.9	13578	1.3	**154.6**	64.7	4205
WI17	80	ROAG	**125400**	220132	125400	14597	110803	35.2	7934	25.4	72.3	138.3	173406

Loch ID	Loch No	Loch Name	Max Pot Biomass BI_{pa} (t yr^{-1})	Max Pot Biomass ECE_{pa} (t yr^{-1})	Max Pot Biomass B_{TMAX} (t yr^{-1})	Current Consented biomass (B_C) (Feb 2012) (t yr^{-1})	Biomass Gap between B_{TMAX} and B_C (t yr^{-1})	Sea Loch Area 15-70 m (km^2)	Production per leased area km $^{-2}$ (no 0s) (*P_d*, t yr^{-1} km^{-2})	A_{REQ} for B_{TMAX} (km^2)	A_{REQ} for B_{TMAX} % $A_{(15\text{-}70\ m)}$	% B_{TMAX} possible within $A_{(15\text{-}70\ m)}$	B_{TMAX} possible within $A_{(15\text{-}70\ m)}$ (t yr^{-1})
WI18	85	SEAFORTH	**61300**	93153	61300	5961	55339	15.9	2455	12.4	78.2	127.8	78346
WI19	87	SHEILAVAIG	5800	**2054**	2054	2111	**-57**	0.0	7718	0.4	**naa**	**0.0**	**0**
WI20	88	SHELL	**43900**	55338	43900	3401	40499	10.0	19136	8.9	89.3	112.0	49182
WI21	89	SKIPORT	13700	**11003**	11003	2460	8543	1.1	19366	2.2	**196.7**	50.8	5594
WI22	94	STOCKINISH	18400	**5749**	5749	495	5254	0.5		1.2	**243.8**	41.0	2358
WI23	106	UISKEVAGH	11200	**6788**	6788	1455	5333	0.0	6975	1.4	**naa**	**0.0**	**0**
WI24	112	WEST LOCH TARBERT	122600	**79215**	79215	4658	74557	16.1	11562	16.1	99.7	100.3	79466
SK01	3	AINORT	39300	**14248**	14248	1800	12448	1.7	4968	2.9	**170.5**	58.7	8357
SK02	13	BAY	226800	**62899**	62899	500	62399	11.0	796	12.8	**115.8**	86.3	54307
SK03	15	BRACADALE	479100	**127695**	127695	2075	125620	32.1	6990	25.9	80.8	123.7	158014
SK04	36	DUNVEGAN	362600	**88737**	88737	2771	85966	6.1	12060	18.0	**296.6**	33.7	29922
SK05	39	EISHORT	30800	**9379**	9379	1200	8179	0.2	4487	1.9	**773.9**	12.9	1212
SK06	49	GRESHORNISH	26600	**19339**	19339	1875	17464	2.3	5832	3.9	**173.2**	57.8	11168
SK07	53	HARPORT	101400	**27344**	27344	2000	25344	4.0	39240	5.5	**140.4**	71.2	19481
SK08	77	POOL TIEL	33100	**10796**	10796	200	10596	2.4		2.2	90.2	110.8	11966
SK09	78	PORTREE	18700	**17124**	17124	1794	15330	2.8	26933	3.5	**125.6**	79.6	13630
SK10	90	SLAPIN	15200	**7843**	7843	350	7493	0.0	3402	1.6	**54827.1**	0.2	14
SK11	91	SLIGACHAN	24600	**7081**	7081	800	6281	0.3		1.4	**416.4**	24.0	1700
SK12	92	SNIZORT BEG	95300	**27668**	27668	500	27168	2.9		5.6	**194.3**	51.5	14243
SK13	105	UIG BAY	276100	**8623**	8623	1000	7623	1.7		1.7	**105.0**	95.3	8216
ML01	70	NA KEAL	303700	**109613**	109613	2000	107613	17.6	31784	22.2	**126.2**	79.2	86864
ML02	84	SCRIDAIN	396500	**90569**	90569	0	90569	18.7		18.4	98.0	102.0	92392
ML03	93	SPELVE	114900	**28090**	28090	1050	27040	4.4	836	5.7	**130.1**	76.9	21588
ML04	102	TOBERMORY BAY		**6208**	*6208*	0	6208	1.1		1.3	**111.0**	90.1	5591
ML05	104	TUATH	350200	**73643**	73643	850	72793	14.6	14506	14.9	**102.7**	97.4	71727

Loch ID	Loch No	Loch Name	Max Pot Biomass BI_{pa} (t yr^{-1})	Max Pot Biomass ECE_{pa} (t yr^{-1})	Max Pot Biomass B_{TMAX} (t yr^{-1})	Current Consented biomass (B_C) (Feb 2012) (t yr^{-1})	Biomass Gap between B_{TMAX} and B_C (t yr^{-1})	Sea Loch Area 15-70 m (km^2)	Production per leased area km^{-2} (no 0s) (*P_d*, t yr^{-1} km^{-2})	A_{REQ} for B_{TMAX} (km^2)	A_{REQ} for B_{TMAX} % $A_{(15\text{-}70\ m)}$	% B_{TMAX} possible within $A_{(15\text{-}70\ m)}$	B_{TMAX} possible within $A_{(15\text{-}70\ m)}$ (t yr^{-1})
SW01	1	A'CHOIRE	9700	**3861**	3861	1445	2416	0.6	4539	0.8	**135.2**	73.9	2855
SW02	2	AILORT	119400	**32610**	32610	300	32310	2.4	194	6.6	**279.6**	35.8	11662
SW03	7	ALINE		**6985**	*6985*	0	6985	0.3		1.4	**407.8**	24.5	1713
SW04	23	CAOLISPORT	199600	**12180**	12180	192	11988	5.1		2.5	48.0	208.2	25359
SW05	31	CRAIGNISH	239600	**27418**	27418	3498	23920	4.1	1990	5.6	**136.2**	73.4	20125
SW06	32	CRERAN	112900	**36435**	36435	3000	33435	3.9	3339	7.4	**189.1**	52.9	19268
SW07	43	ETIVE	288900	**46311**	46311	3208	43103	18.7		9.4	50.2	199.4	92333
SW08	46	FEOCHAN		**11041**	*11041*	0	11041	0.3		2.2	**889.6**	11.2	1241
SW09	47	FYNE	1502000	**516549**	516549	11684	504865	104.5	3872	104.8	**100.2**	99.8	515289
SW10	54	HOURN	395000	**131895**	131895	3225	128670	16.7	4560	26.8	**160.2**	62.4	82339
SW11	61	LEVEN	83200	**26647**	26647	1450	25197	4.6	3709	5.4	**117.6**	85.0	22653
SW12	62	LINNHE	374200	**113404**	113404	4490	108914	17.6	2049	23.0	**130.7**	76.5	86775
SW13	66	MELFORT	122000	**21225**	21225	615	20610	8.3	33691	4.3	52.0	192.1	40781
SW14	69	MOIDART		**3432**	*3432*	0	3432	0.1		0.7	**1382.0**	7.2	248
SW15	72	NEVIS	349100	**116042**	116042	4000	112042	15.5	6548	23.5	**151.4**	66.1	76647
SW16	79	RIDDON	36700	**6620**	6620	500	6120	1.7		1.3	79.4	126.0	8340
SW17	82	RYAN		**94086**	*94086*	0	94086	0.1		19.1	**22236.8**	0.4	423
SW18	95	STRIVEN	110300	**33724**	33724	1237	32487	12.0	2844	6.8	57.2	174.8	58940
SW19	97	SUNART	376100	**183091**	183091	7990	175101	31.9	6756	37.1	**116.6**	85.8	157073
SW20	99	SWEEN		**28856**	*28856*	0	28856	7.3		5.9	80.5	124.2	35836
SW21	64	LONG	549000	**124250**	124250	500	123750	34.5		25.2	73.0	137.0	170263

Annex 5

ADST Phase 1 results: Potential Aquaculture Development Areas (PADA) by sea loch with numbers of existing farms (Numbers of new farms are from ADST Phase 2).

Loch ID	Loch Name	PADA (m^2)	Number of existing farms	Number of new farms	Total Number farms
SH01	Aith Voe	0	4	0	4
SH02	Baltasound	0	4	0	4
SH03	Basta Voe	0	3	0	3
SH04	Brindister Voe/Vementry Sound	0	3	0	3
SH05	Burwick Bay	0	1	0	1
SH06	Busta Voe	0	2	0	2
SH07	Cat Firth	0	2	0	2
SH08	Clift Sound	0	7	0	7
SH09	Collafirth	0	2	0	2
SH10	Dales Voe	0	2	0	2
SH11	Dales Voe North	0	3	0	3
SH12	Dury Voe	0	5	0	5
SH13	Gruting Voe	0	6	0	6
SH14	Laxfirth Voe	0	2	0	2
SH15	Mid Yell Voe	0	2	0	2
SH16	Northra Voe	0	1	0	1
SH17	Olna Voe	0	4	0	4
SH18	Ronas Voe	3268300	3	4	7
SH19	Sandsound Voe	0	6	0	6
SH20	Selivoe	1326089	1	1	2
SH21	Stromness Voe	0	2	0	2
SH22	Swarbacks Minn	0	23	0	23
SH23	Swining Voe	0	3	0	3
SH24	Swinister Voe	0	15	0	15
SH25	Vaila Sound	0	6	0	6
SH26	Vidlin Voe	0	4	0	4
SH27	Weisdale Voe	0	5	0	5
SH28	West Burra Firth	0	0	0	0
SH29	Whiteness Voe	0	1	0	1
SH30	Wadbister Voe	0	1	0	1
SH31	Whalefirth Voe	0	1	0	1
OR02	Kirk Hope	0	0	0	0
OR03	Pierowall Bay	0	1	0	1
NW01	Loch Airdbhair (inc. Loch Droigniche)	0	1	0	1
NW02	Loch Alsh	2844871	4	2	6
NW03	Loch Arnish	1455512	0	2	2
NW04	Badcall Bay	0	4	0	4
NW05	Loch Broom	0	1	0	1
Loch ID	Loch Name	PADA (m^2)	Number of existing farms	Number of new farms	Total Number farms
NW06	Loch Cairnbhain	1568690	4	3	7

NW07	Calbha Bay	0	3	0	3
NW08	Loch Carron	0	1	0	1
NW09	Loch Clash	0	3	0	3
NW10	Loch Duich	0	2	0	2
NW11	Loch Eriboll	0	2	0	2
NW12	Loch Ewe	18641608	2	24	26
NW13	Loch Inchard	0	0	0	0
NW14	Loch Kishorn	0	4	0	4
NW15	Loch Laxford	0	6	0	6
NW16	Little Loch Broom	10415575	3	18	21
NW17	Loch Nedd	0	1	0	1
NW18	Loch Torridon	21433204	4	36	40
WI01	Loch a Laip	0	2	0	2
WI02	Loch Boisdale	0	2	0	2
WI03	Broad Bay	17172806	1	21	22
WI04	Loch Carnan	0	1	0	1
WI05	Loch Claidh	3284619	0	8	8
WI06	East Loch Tarbert	1178376	5	1	6
WI07	Loch Eport	0	3	0	3
WI08	Loch Erisort/Leurbost	1337728	4	2	6
WI09	Loch Eynort	0	1	0	1
WI10	Loch Geocrab	0	1	0	1
WI11	Loch Grimshader	0	1	0	1
WI12	Loch Grosebay	0	1	0	1
WI13	Loch Kilerivagh	0	0	0	0
WI14	Loch Meanervagh	0	2	0	2
WI15	Loch Mharabhig	0	0	0	0
WI16	Loch Odhairn	0	2	0	2
WI17	Loch Roag	0	18	0	18
WI18	Loch Seaforth	7742549	7	12	19
WI19	Loch Sheilavaig	0	3	0	3
WI20	Loch Shell	4536690	3	7	10
WI21	Loch Skiport	0	2	0	2
WI22	Loch Stockinish	0	1	0	1
WI23	Loch Uiskevagh	0	2	0	2
WI24	West Loch Tarbert	6244922	4	11	15
SK01	Loch Ainort	0	1	0	1
SK02	Loch Bay	4611428	1	6	7
SK03	Loch Bracadale	30969222	4	37	41
SK04	Loch Dunvegan	4437903	2	9	11
SK05	Loch Eishort	0	1	0	1
SK06	Loch Greshornish	0	1	0	1
SK07	Loch Harport	3939222	1	5	6
Loch ID	**Loch Name**	**PADA (m^2)**	**Number of existing farms**	**Number of new farms**	**Total Number farms**
SK08	Loch Pooltiel	2027766	1	5	6
SK09	Loch Portree	0	2	0	2
SK10	Loch Slapin	0	1	0	1
SK11	Loch Sligachan	0	1	0	1
SK12	Loch Snizort Beag	1018713	1	2	3

SK13	Uig Bay	0	1	0	1
ML01	Loch na Keal	14996698	2	19	21
ML02	Loch Scridain	16531897	0	23	23
ML03	Loch Spelve	2079351	2	1	3
ML04	Tobermory Bay	0	0	0	0
ML05	Loch Tuath	11420214	1	13	14
SW01	Loch a' Choire	0	1	0	1
SW02	Loch Ailort	0	1	0	1
SW03	Loch Aline	0	0	0	0
SW04	Loch Caolisport	1936300	2	3	5
SW05	Loch Craignish	1481782	4	1	5
SW06	Loch Creran	0	2	0	2
SW07	Loch Etive	0	5	0	5
SW08	Loch Feochan	0	0	0	0
SW09	Loch Fyne	47547565	11	51	62
SW10	Loch Hourn	12460336	3	26	29
SW11	Loch Leven	1709211	1	4	5
SW12	Loch Linnhe	11618322	2	22	24
SW13	Loch Melfort	0	2	0	2
SW14	Loch Moidart	0	0	0	0
SW15	Loch Nevis	4285305	3	7	10
SW16	Loch Riddon	0	1	0	1
SW17	Loch Ryan	0	0	0	0
SW18	Loch Striven	2011881	2	3	5
SW19	Loch Sunart	0	6	0	6
SW20	Loch Sween	0	0	0	0
SW21	Loch Long (inc. Loch Goil)	0	1	0	1

Annex 6

ADST Phase 2 results showing number of fish farm sites and potential biomass values given certain criteria for benthic impacts and the final potential biomass (B_{MAX}) (Lochs ordered by region).

(BOLD values = limiting facors)
(BOLD values = Final limiting factor)
(Italic values = Values where B_{TMAX} were based only on nutrient enrichment as there were not enough data to run ECE_MOD.m (11 sea lochs)).

Loch ID	Loch No	Loch Name	LW Area (km^2)	Area 15-70 m (km^2)	Number of existing farms	Number of new farms	Total Number farms	B_{TMAX} ($t\ yr^{-1}$)	B_{SMAX} ($t\ yr^{-1}$)	B_{CMAX} ($t\ yr^{-1}$)	Degraded Area (km^2)	% Degraded LW Area	Final Potential Biomass B_{MAX} ($t\ yr^{-1}$)
SH01	5	AITH VOE	4.80	3.19	4	**0**	4	11544	10000	**616**	0.016	0.34	**616**
SH02	11	BALTASOUND	3.72	0.42	4	**0**	4	9705	10000	**1181**	0.034	0.92	**1181**
SH03	12	BASTA VOE	5.73	2.62	3	**0**	3	15234	7500	**847**	0.024	0.42	**847**
SH04	16	BRINDISTER	5.01	1.17	3	**0**	3	7644	7500	**1170**	0.033	0.66	**1170**
SH05	19	BURWICK	0.43	0.11	1	**0**	1	544	2500	**73**	0.002	0.43	**73**
SH06	20	BUSTA	3.04	1.71	2	**0**	2	7296	5000	**273**	0.007	0.24	**273**
SH07	26	CAT FIRTH	2.76	0.60	2	**0**	2	6887	5000	**358**	0.010	0.36	**358**
SH08	29	CLIFT SOUND	8.48	4.27	7	**0**	7	16627	17500	**3344**	0.095	1.12	**3344**
SH09	30	COLLAFIRTH	0.94	0.32	2	**0**	2	2357	5000	**173**	0.005	0.48	**173**
SH10	33	DALES VOE	3.22	1.46	2	**0**	2	5396	5000	**497**	0.014	0.42	**497**
SH11	34	DALES VOE NORTH	3.10	1.50	3	**0**	3	7912	7500	**894**	0.025	0.80	**894**
SH12	37	DURY VOE	13.01	8.63	5	**0**	5	24720	12500	**1046**	0.029	0.22	**1046**
SH13	52	GRUTING	6.68	3.06	6	**0**	6	10351	15000	**1543**	0.042	0.64	**1543**
SH14	59	LAXFIRTH	2.28	0.51	2	**0**	2	5685	5000	**327**	0.009	0.39	**327**
SH15	68	MID YELL	1.73	0.08	2	**0**	2	4532	5000	**403**	0.011	0.65	**403**
SH16	73	NORTHRA VOE	0.30	0.03	1	**0**	1	537	2500	**71**	0.002	0.61	**71**
SH17	75	OLNA VOE	4.04	2.51	4	**0**	4	9608	10000	**997**	0.027	0.68	**997**
SH18	81	RONAS VOE	9.43	5.90	3	4	7	22528	17500	**2667**	0.075	0.80	**2667**
SH19	83	SANDSOUND	5.97	1.86	6	**0**	6	9257	15000	**1434**	0.040	0.67	**1434**
SH20	86	SELIVOE	4.80	2.66	1	1	2	7467	5000	**284**	0.008	0.16	**284**
SH21	96	STROMNESS VOE	2.27	0.30	2	**0**	2	3477	5000	**1131**	0.032	1.42	**1131**

Loch ID	Loch No	Loch Name	LW Area (km^2)	Area 15-70 m (km^2)	Number of existing farms	Number of new farms	Total Number farms	B_{TMAX} ($t\ yr^{-1}$)	B_{SMAX} ($t\ yr^{-1}$)	B_{CMAX} ($t\ yr^{-1}$)	Degraded Area (km^2)	% Degraded LW Area	Final Potential Biomass B_{MAX} ($t\ yr^{-1}$)
SH22	98	SWARBACKS MINN	30.87	11.34	23	**0**	23	74071	57500	**9659**	0.271	0.88	**9659**
SH23	100	SWINING VOE	3.46	1.82	3	**0**	3	8715	7500	**837**	0.023	0.67	**837**
SH24	101	SWINISTER VOE	14.90	5.90	15	**0**	15	78724	37500	**6333**	0.179	1.20	**6333**
SH25	107	VAILA SOUND	3.64	0.79	6	**0**	6	6118	15000	**767**	0.021	0.57	**767**
SH26	108	VIDLIN VOE	2.70	1.06	4	**0**	4	6877	10000	**949**	0.026	0.97	**949**
SH27	110	WEISDALE	6.02	3.29	5	**0**	5	9328	12500	**2144**	0.060	1.00	**2144**
SH28	111	WEST BURRA FIRTH	0.80	0.25	0	**0**	**0**	*1455*	0	**0**	0.000	0.00	**0**
SH29	114	WHITENESS VOE	3.00	0.90	1	**0**	1	4551	2500	**157**	0.004	0.14	**157**
SH30	109	WADBISTER VOE	1.61	0.56	1	**0**	1	4073	2500	**99**	0.003	0.16	**99**
SH31	113	WHALEFIRTH	3.10	0.00	1	**0**	1	*8163*	2500	**324**	0.009	0.30	**324**
OR02	57	KIRK HOPE	0.60	0.00	0	**0**	**0**	*1924*	0	**0**	0.000	0.00	**0**
OR03	76	PIEROWALL HARBOUR	1.14	0.00	1	**0**	1	3697	2500	**552**	0.016	1.43	**552**
NW01	4	AIRDBHAIR	0.44	0.00	1	**0**	1	1559	2500	**463**	0.013	2.99	**463**
NW02	8	ALSH	27.18	13.01	4	2	6	113159	15000	**8449**	0.247	0.91	**8449**
NW03	9	ARNISH	2.00	1.61	0	2	2	5757	5000	**586**	0.016	0.80	**586**
NW04	10	BADCALL BAY	1.29	0.34	4	**0**	4	4105	10000	**1414**	0.041	3.16	**1414**
NW05	18	BROOM	15.99	9.62	1	**0**	1	64810	2500	**806**	0.023	0.14	**806**
NW06	21	CAIRNBHAIN	14.05	7.78	4	3	7	53402	17500	**14270**	0.414	2.95	**14270**
NW07	22	CALBHA BAY	0.70	0.24	3	**0**	3	2144	7500	**458**	0.012	1.78	**458**
NW08	25	CARRON	20.59	7.32	1	**0**	1	86980	2500	**4655**	0.134	0.65	**4655**
NW09	28	CLASH	1.00	0.51	3	**0**	3	3897	7500	**500**	0.014	1.38	**500**
NW10	35	DUICH	11.21	6.01	2	**0**	2	46829	5000	**1836**	0.053	0.47	**1836**
NW11	41	ERIBOLL	37.48	24.71	2	**0**	2	147134	5000	**2230**	0.065	0.17	**2230**
NW12	44	EWE	43.05	23.98	2	24	26	168888	65000	**39374**	1.186	2.76	**39374**
NW13	55	INCHARD	3.70	2.25	0	**0**	**0**	14143	0	**0**	0.000	0.00	**0**
NW14	58	KISHORN	7.85	4.89	4	**0**	4	33277	10000	**1872**	0.054	0.69	**1872**
NW15	60	LAXFORD	7.20	2.53	6	**0**	6	27007	15000	**2826**	0.082	1.13	**2826**
NW16	63	LITTLE L BROOM	22.99	14.82	3	18	21	94038	52500	**17848**	0.514	2.24	**17848**

Loch ID	Loch No	Loch Name	LW Area (km^2)	Area 15-70 m (km^2)	Number of existing farms	Number of new farms	Total Number farms	B_{TMAX} ($t\ yr^{-1}$)	B_{SMAX} ($t\ yr^{-1}$)	B_{CMAX} ($t\ yr^{-1}$)	Degraded Area (km^2)	% Degraded LW Area	Final Potential Biomass B_{MAX} ($t\ yr^{-1}$)
NW17	71	NEDD	0.50	0.01	1	**0**	1	2064	2500	**417**	0.012	2.37	**417**
NW18	103	TORRIDON	68.51	41.97	4	36	40	302594	100000	**142199**	4.223	6.16	**142199**
WI01	6	A'LAIP	1.10	0.001	2	**0**	2	3853	5000	**976**	0.028	2.58	**976**
WI02	14	BOISDALE	4.73	1.82	2	**0**	2	16263	5000	**1494**	0.044	0.92	**1494**
WI03	17	BROAD BAY	82.50	45.78	1	21	22	307071	55000	**97351**	3.014	3.65	**97351**
WI04	24	CARNAN	0.70	0.00	1	**0**	1	2406	2500	**369**	0.011	1.53	**369**
WI05	27	CLAIDH	4.50	3.44	0	8	8	*16980*	20000	**5183**	0.148	3.30	**5183**
WI06	38	EAST LOCH TARBERT	26.18	17.10	5	1	6	79100	15000	**6895**	0.206	0.79	**6895**
WI07	40	EPORT	3.91	0.36	3	**0**	3	14304	7500	**3344**	0.097	2.49	**3344**
WI08	42	ERISORT/LEURBOST	15.84	6.62	4	2	6	59250	15000	**22132**	0.651	4.11	**22132**
WI09	45	EYNORT	2.20	0.40	1	**0**	1	8369	2500	**541**	0.016	0.71	**541**
WI10	48	GEOCRAB	0.60	0.15	1	**0**	1	2282	2500	**161**	0.004	0.73	**161**
WI11	50	GRIMSHADER	0.91	0.20	1	**0**	1	3358	2500	**179**	0.005	0.54	**179**
WI12	51	GROSEBAY	2.94	1.56	1	**0**	1	11200	2500	**418**	0.012	0.40	**418**
WI13	56	KILERIVAGH	1.00	0.00	0	**0**	**0**	*2985*	0	**0**	0.000	0.00	**0**
WI14	65	MEANERVAGH	0.17	0.00	2	**0**	2	**400**	5000	657	0.019	**11.10**	**400**
WI15	67	MHARABHIG	0.50	0.00	0	**0**	**0**	1606	0	**0**	0.000	0.00	**0**
WI16	74	ODHAIRN	1.79	0.85	2	**0**	2	6500	5000	**986**	0.028	1.55	**986**
WI17	80	ROAG	68.31	35.18	18	**0**	18	125400	45000	**24410**	0.738	1.08	**24410**
WI18	85	SEAFORTH	24.61	15.89	7	12	19	**61300**	47500	133632	3.892	**15.81**	**61300**
WI19	87	SHEILAVAIG	0.60	0.00	3	**0**	3	**2054**	7500	2248	0.065	**10.91**	**2054**
WI20	88	SHELL	14.95	9.98	3	7	10	43900	25000	**13282**	0.392	2.62	**13282**
WI21	89	SKIPORT	3.03	1.13	2	**0**	2	11003	5000	**1894**	0.055	1.82	**1894**
WI22	94	STOCKINISH	1.50	0.48	1	**0**	1	5749	2500	**362**	0.010	0.67	**362**
WI23	106	UISKEVAGH	1.87	0.00	2	**0**	2	6788	5000	**1542**	0.045	2.42	**1542**
WI24	112	WEST LOCH TARBERT	23.17	16.12	4	11	15	79215	37500	**15705**	0.474	2.05	**15705**
SK01	3	AINORT	3.45	1.70	1	**0**	1	14248	2500	**1269**	0.037	1.08	**1269**
SK02	13	BAY	15.44	11.02	1	6	7	62899	17500	**7741**	0.230	1.49	**7741**

Loch ID	Loch No	Loch Name	LW Area (km^2)	Area 15-70 m (km^2)	Number of existing farms	Number of new farms	Total Number farms	B_{TMAX} (t yr^{-1})	B_{SMAX} (t yr^{-1})	B_{CMAX} (t yr^{-1})	Degraded Area (km^2)	% Degraded LW Area	Final Potential Biomass B_{MAX} (t yr^{-1})
SK03	15	BRACADALE	45.82	32.06	4	37	41	127695	102500	**59727**	1.796	3.92	**59727**
SK04	36	DUNVEGAN	21.73	6.07	2	9	11	88737	27500	**9218**	0.266	1.22	**9218**
SK05	39	EISHORT	2.48	0.25	1	**0**	1	9379	2500	**495**	0.014	0.57	**495**
SK06	49	GRESHORNISH	4.66	2.27	1	**0**	1	19339	2500	**1692**	0.050	1.07	**1692**
SK07	53	HARPORT	7.22	3.95	1	5	6	27344	15000	**12362**	0.358	4.96	**12362**
SK08	77	POOL TIEL	3.86	2.43	1	5	6	10796	15000	**2549**	0.072	1.86	**2549**
SK09	78	PORTREE	4.14	2.77	2	**0**	2	17124	5000	**1106**	0.032	0.77	**1106**
SK10	90	SLAPIN	2.14	0.003	1	**0**	1	7843	2500	**790**	0.023	1.07	**790**
SK11	91	SLIGACHAN	1.70	0.34	1	**0**	1	7081	2500	**297**	0.008	0.49	**297**
SK12	92	SNIZORT BEG	6.90	2.89	1	2	3	27668	7500	**3296**	0.098	1.42	**3296**
SK13	105	UIG BAY	3.10	1.67	1	**0**	1	8623	2500	**1677**	0.048	1.54	**1677**
ML01	70	NA KEAL	32.18	17.62	2	19	21	109613	52500	**29794**	0.890	2.77	**29794**
ML02	84	SCRIDAIN	27.00	18.74	0	23	23	90569	57500	**31465**	0.926	3.43	**31465**
ML03	93	SPELVE	8.93	4.38	2	1	3	28090	7500	**1375**	0.039	0.44	**1375**
ML04	102	TOBERMORY BAY	1.90	1.13	0	**0**	**0**	*6208*	0	**0**	0.000	0.00	**0**
ML05	104	TUATH	23.37	14.55	1	13	14	73643	35000	**14649**	0.436	1.86	**14649**
SW01	1	A'CHOIRE	1.26	0.58	1	**0**	1	3861	2500	**233**	0.006	0.51	**233**
SW02	2	AILORT	8.66	2.37	1	**0**	1	32610	2500	**74**	0.002	0.02	**74**
SW03	7	ALINE	2.30	0.35	0	**0**	**0**	*6985*	0	**0**	0.000	0.00	**0**
SW04	23	CAOLISPORT	14.90	5.14	2	3	5	12180	12500	**1137**	0.032	0.21	**1137**
SW05	31	CRAIGNISH	14.58	4.08	4	1	5	27418	12500	**2058**	0.059	0.41	**2058**
SW06	32	CRERAN	12.45	3.91	2	**0**	2	36435	5000	**4491**	0.131	1.05	**4491**
SW07	43	ETIVE	28.30	18.73	5	**0**	5	46311	12500	**6805**	0.194	0.68	**6805**
SW08	46	FEOCHAN	3.90	0.25	0	**0**	**0**	*11041*	0	**0**	0.000	0.00	**0**
SW09	47	FYNE	183.32	104.54	11	51	62	516549	155000	**259871**	7.548	4.12	**259871**
SW10	54	HOURN	34.46	16.70	3	26	29	131895	72500	**46854**	1.354	3.93	**46854**
SW11	61	LEVEN	8.06	4.60	1	4	5	26647	12500	**7165**	0.206	2.56	**7165**
SW12	62	LINNHE	33.65	17.60	2	22	24	113404	60000	**57005**	1.642	4.88	**57005**

Loch ID	Loch No	Loch Name	LW Area (km^2)	Area 15-70 m (km^2)	Number of existing farms	Number of new farms	Total Number farms	B_{TMAX} ($t\ yr^{-1}$)	B_{SMAX} ($t\ yr^{-1}$)	B_{CMAX} ($t\ yr^{-1}$)	Degraded Area (km^2)	% Degraded LW Area	Final Potential Biomass B_{MAX} ($t\ yr^{-1}$)
SW13	66	MELFORT	10.17	8.27	2	**0**	2	21225	5000	**354**	0.010	0.10	**354**
SW14	69	MOIDART	0.90	0.05	0	**0**	**0**	*3432*	0	**0**	0.000	0.00	**0**
SW15	72	NEVIS	29.88	15.55	3	7	10	116042	25000	**7882**	0.224	0.75	**7882**
SW16	79	RIDDON	2.80	1.69	1	**0**	1	6620	2500	**221**	0.006	0.22	**221**
SW17	82	RYAN	40.30	0.09	0	**0**	**0**	*94086*	0	**0**	0.000	0.00	**0**
SW18	95	STRIVEN	14.26	11.96	2	3	5	33724	12500	**4663**	0.133	0.93	**4663**
SW19	97	SUNART	50.62	31.86	6	**0**	6	183091	15000	**25607**	0.744	1.47	**25607**
SW20	99	SWEEN	20.00	7.27	0	**0**	**0**	*28856*	0	**0**	0.000	0.00	**0**
SW21	64	LONG	44.00	34.54	1	**0**	1	124250	2500	**644**	0.018	0.04	**644**

Number of sea lochs limited by factor	Number of existing farms	Number of new farms	Total Number farms	B_{TMAX} ($t\ yr^{-1}$)	B_{SMAX} ($t\ yr^{-1}$)	B_{CMAX} ($t\ yr^{-1}$)	Degraded Area (km^2)	% Degraded LW Area
	0	**81**	**11**	**3**	6	**100**	0	**3**

	LW Area (km^2)	Area 15-70 m (km^2)	Number of existing farms	Number of new farms	Total Number farms	B_{TMAX} ($t\ yr^{-1}$)	B_{SMAX} ($t\ yr^{-1}$)	B_{CMAX} ($t\ yr^{-1}$)	Degraded Area (km^2)	% Degraded LW Area	Final Potential Biomass B_{MAX} ($t\ yr^{-1}$)
TOTALS	1511.75	801.44	306	389	695	4753690	1737500	1219676	36	174	1146893
AVERAGES	13.26	7.03	3	3	6	41699	15241	10699	0	2	10060

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