Climate change and European aquatic RESources

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Deliverable D4.2:

Report on minimising economic losses, opportunities and challenges for aquaculture in Europe.

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Milestone(s) achieved: MS24 Data collected for core model and typical farms; MS30 Interviews and focus groups on results from first model runs and data validation

CERES Project

CERES advances a cause-and-effect understanding of how climate change will influence Europe's most important fish and shellfish resources and the economic activities depending on them. The project will provide the knowledge and tools needed to successfully adapt European fisheries and aquaculture sectors in marine and inland waters to anticipated climate change. We will identify and communicate risks, opportunities and uncertainties thereby enhancing the resilience and supporting the development of adaptive management and governance systems in these blue growth sectors. CERES strongly supports important European policy goals including self-sufficiency of the domestic supply of fish and shellfish.

This four-year project is designed to:

1. Provide regionally relevant short-, medium- and long-term future, high resolution projections of key environmental variables for European marine and freshwater ecosystems;

2. Integrate the resulting knowledge on changes in productivity, biology and ecology of wild and cultured animals (including key indirect / food web interactions), and 'scale up' to consequences for shellfish and fish populations, assemblages as well as their ecosystems and economic sectors;

3. Utilize innovative risk-assessment methodologies that encompass drivers of change, threats to fishery and aquaculture resources, expert knowledge, barriers to adaptation and likely consequences if mitigation measures are not put in place;

4. Anticipate responses and assist in the adaptation of aquatic food production industries to underlying biophysical changes, including developing new operating procedures, early warning methods, infrastructures, location choice, and markets;

5. Create short-, medium- and long-term projections tools for the industry fisheries as well as policy makers to more effectively promote blue growth of aquaculture and fisheries in different regions;

6. Consider market-level responses to changes (both positive and negative) in commodity availability as a result of climate change;

7. Formulate viable autonomous adaptation strategies within the industries and for policy to circumvent/prevent perceived risks or to access future opportunities;

8. Effectively communicate these findings and tools to potential end-users and relevant stakeholders.

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02	26.09.19	Additional edits by Cornelia Kreiß
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List of Symbols and Abbreviations

BSS	European Seabass
CC	Climate change
DE	Germany
DK	Denmark
ES	Spain
FCP	Common carp
FCR	Feed Conversion Ration
GB	Great Britain
GS	Global Sustainability
IE	Ireland
LS	Local Stewardship
MUS	Blue mussel
NE	National Enterprise
NL	Netherlands
NO	Norway
NUTS	Nomenclature of Territorial Units for Statistics
PGI	Protected Geographic Indications
PL	Poland
P10	Percentile 10-extreme cold year (finfish)/worst production year (shellfish)
P90	percentile 90- extreme warm year (finfish)/best production year (shellfish)
RCP	Representative Concentration Pathway
SAL	Atlantic salmon
SBG	Gilthead seabream
T	Task
TI	Thünen Institute
TR	Turkey
TRR	Rainbow trout
WM	World Market
WP	Work Package

Executive summary

Globally aquaculture provides an important high-quality protein source and supplies over 50% of fish consumed. Though small in volume compared to Asian production, European aquaculture focusses largely on the production of high value finfish and shellfish, providing an economically (and socially) important commodity. Climate change has the potential to pose significant challenges and opportunities to European aquaculture, however, to date little research has been conducted to evaluate the economic consequences of these. For the growth of aquaculture, sectors must be profitable. Both local and global conditions determine the potential profits of a farm and both are likely to be influenced by climate change. Local conditions such as temperature determine growth rates of the cultured species, but also influence negative factors such as the occurrence of disease, whilst global markets influence feed, fuel and energy prices, which are major costs in many forms of aquaculture production.

This CERES deliverable examined the present-day costs and profits associated with key aquaculture species produced across Europe and attempted to determine how and why costs and profits may change under the four CERES socio-political scenarios. Six species (rainbow trout, carp, Atlantic salmon, European sea bass, sea bream and blue mussel) farmed across a total of ten European countries (Germany, Denmark, Ireland, Norway, United Kingdom, Netherlands, Spain, Poland and Turkey) were investigated to understand the production opportunities and risks associated with each of the four CERES scenarios. For four of these countries' (Germany, Turkey, Poland and Denmark) multiple species and/or farm types were investigated allowing within country comparisons to be made. The profits, costs opportunities and challenges to each of these sectors were assessed at both the farm and regional level to understand how climate change may affect the profitability of the different farm types in different countries, and, identify the potential winners and losers under the four CERES socio-political scenarios.

Across the species investigated, there was substantial variability between the profitability of the different farm types investigated. As a general rule, analysis of present-day profitability showed that in the absence of public payments and subsides, larger more vertically integrated farm types were more profitable than smaller independent enterprises. When looking at the projections for future profitability, this pattern also held true, and the analysis suggests that such businesses are more resilient to the effects of climate change and some may actually benefit from some or all of the future scenarios. For all farm types, the trade focussed WM and NE scenarios appeared to provide the greatest potential opportunities to increase profits, with more environmentally friendly GS scenario the lowest.

Throughout the analyses conducted within this task, several common key factors emerged for many of the sectors. These included how feed ingredients, fuel and energy are influenced by global market forces, whereas others such as disease or growth rates are influenced by local conditions. In this analysis, we found that, the main impacts of climate change on aquaculture profitability acted through the effects on global markets,

rather than direct local effects associated with temperature changes. The main challenges associated with global markets related to changes in fish meal and fish oil process which greatly influenced the profitability of all intensive fin fish aquaculture. To overcome this major challenge to future aquaculture profitability and growth it will be essential that global developments in feeds are made potentially through the replacement of fishmeal and fish oils with alternative ingredients such as insect meal, single cell protein, marine algal oil or gene modified plant oils.

Introduction

Globally there is high demand for aquatic animal protein, which constitutes a high quality and often high value healthy nutritional source of food. Historically this demand was met through harvesting of wild capture fisheries, however, demand has now outstripped the sustainable supply from this sector and supply through aquaculture production systems has, in recent years overtaken the supply from fisheries (FAO 2019). Though fisheries are always likely to constitute an important part of the aquatic food supply chain, aquaculture represents the main future basis to meet growing global food demands. Climate change (CC) has the potential to pose many challenges to aquaculture as temperature may affect water availability, disease occurrence and extreme weather events may impact infrastructures and equipment. Changing temperature may however pose both challenges and opportunities in terms of the physiological thresholds and optimal growth rates for cultured species. Increases in temperature may mean that species held in existing aquaculture sites may be impacted, but temperature shifts may open opportunities to farm new species or utilise new locations. Understanding economic consequences of climate change on existing aquaculture production will help stakeholders realise new opportunities and understand future risks so that contingency plans can be developed.

Defining the Challenge

Understanding the operating costs associated with aquaculture production and their drivers is key to projecting how profits may change in the future. For aquaculture sectors to expand they must attract investment and, to do this, they must adapt culture practices and business models to realise maximum profits. The challenge for this deliverable was to understand the key costs to production of different species and understand factors that influences profitability, in order to make predictions as to the impacts of climate change and make recommendation on how to overcome challenges and realise any future opportunities.

Approach

Working with WP, Storyline and Task leaders across CERES, and by engaging with key stakeholders representing each species, a typical farm approach was developed and applied to identify and capture operating costs and earnings for different farm types. By using projections of fishmeal and fish oil prices generated within CERES Tasks 4.3, as well as external projections for future energy and fish prices, we captured the key costs to

each farm type and determined future potential changes in profitability. Where possible, the outputs from the biological and pathogen risk models developed in WP3 were also used to analyse the impact of future harvest weight, feed conversion ratios (FCR) and disease risks at a national scale. This approach allowed areas that may potentially benefit from increased profits or be at risk of losses from climate change to be identified.

CERES WP4 Task 4.2 examines the potential economic effects of CC on marine and freshwater resources at spatial (local, regional, national) and temporal (short- to long-term) scales, appropriate for industry planning and adaptation. Analyses consider scenarios from WP1 and WP3 (e.g. potentials for the growth of existing and emerging cultured species). WP4 applies models to link the climate-driven impacts from WP2 to examine the economic costs and trade-offs of different strategies and decisions aquaculture farmers using an analytical framework. WP4 also contextualises the economic impacts from multiple spatial (local, national and regional) and temporal scales. This information is delivered for synthesis (vulnerability and solutions) of activities in an iterative loop involving stakeholder engagement (WP5).

Economic analyses in this deliverable are tailored to specific differences existing among regions in terms of climate sensitivity and production type/capacity for aquaculture producers. For example, for inland aquaculture, we distinguish between traditional production systems (e.g. trout and carp) in ponds, depending on space and water availability, compared to e.g. recirculation systems. CERES provides supporting information to member states and the EU Commission on projected growth and sectorial allocation of funds under e.g. the EMFF.

WP4 provides tools and a list of options for aquaculture production systems based on climate-driven bioeconomic drivers and will not only deliver information needed to assess adaptive capacity and vulnerability (WP5), but also support decision making by licensing authorities, producers, and investors with respect to target species, spatial management and site selection, and capacity of different production methods at local and regional levels. At the global level, the availability of fishmeal may limit the growth of carnivorous aquaculture in the future and we will examine the possible barriers/opportunities with respect to European fisheries and aquaculture on the supply of fishmeal as well as potential changes in European and global demand for fishmeal. Finally, WP4 applies national input-output models as well as a multi-regional input-output model to highlight the potentially wider economic impacts (i.e. outputs and employment) due to changes in the fisheries and aquaculture sectors.

This deliverable (T4.2) builds on analyses in WP3 projecting how climate change will impact on aquaculture production systems via ecological and biological mechanisms, by performing economic analyses across a range of scales (from individual farms to whole sector (country) level). Overall CERES covers the main species produced in Europe (esp. salmon, trout, carp, shellfish, sea bass/sea bream) and explores opportunities for adapting to changing conditions. Thereby, typical farm and model mussel farms were defined in various countries (e.g. Atlantic salmon in Ireland and Norway, Sea bass and

Sea bream in Turkey and on the Canary Islands, Blue mussel in Denmark and the Netherlands) within expert stakeholder focus groups in CERES as well as part of earlier EU H2020 and TI pilot projects, which were respectively updated for the analysis in CERES.

Thereby profitability and productivity of different productions systems (low input to intensive) are defined for a variety of species in specific regions, and the effects of CC on future economic (e.g. costs for feed, energy and fish (returns)) trajectories of change will be addressed. CERES applies a well-established method from agricultural economics (typical farm) to build theoretical farms, based on regional statistics, farm observations, focus groups and interviews with experts, consultants and scientists familiar with specific local/regional characteristics. These typical finfish farms and adapted mussel farms models will be defined for various production countries (e.g. Atlantic salmon in Ireland and Norway, Sea bass and Sea bream in Turkey and on the Canary Islands, blue mussel in Denmark and the Netherlands) and existing datasets representing typical farms from earlier EU H2020 and pilot projects will be updated and used within analyses presented here. This specific analysis explores the adaptation potentials for specific farm types under specific regional conditions.

Based on the individual model farms, the whole sector level is analysed. Specially the relative impact of disease and the influence of temperature stress will be applied to the model farm data to assess the relative impact of region-specific environmental change (Moran & Fofona 2007, Aunsmo et al. 2010). The economic models include a wide range of potential climate change impacts (e.g., impact of increased disease burden or temperature stress) and, in contrast to previous work, CERES will integrate farm-level economics with sector-level patterns.

Contribution to the Project

The results of this deliverable will contribute directly to the objectives of WP4 and provide critical information to each of the aquaculture Storylines relating to the future profitability of their sector. Outputs from the deliverable include 19 typical farm models covering 6 species and 10 European countries, and vulnerability and profitability maps for each country and farm type. The deliverable identifies the main costs and vulnerabilities to the profits of each farm type and makes recommendations on how the sectors may adapt to change focussing on producing estimates of the economic consequences of climate change for the main aquaculture sectors in Europe from the level of the individual businesses to the national scale. The results of this task (changes in aquaculture production in terms of costs, gross value added and profit) are then used in T4.3.

Dissemination and Exploitation

Results of the typical farm and regional models have already been presented to key stakeholder groups and future engagements are planned. Results will also be provided

to Storyline and WP leaders to facilitate CERES synthesis. Results will also be presented at relevant aquaculture science conferences (e.g. EIFAAC 2019, EAS 2019). Manuscripts on the future challenges and opportunities that climate change may bring to European aquaculture will be prepared for submission to relevant scientific journals. Methodological dissemination of the typical farm approach was achieved by training a number of partners to successfully apply this method. Moreover, the successful application of the method within the project contributed to the decision to include the typical farm approach as an additional method within the “Data Collection Framework” for freshwater aquaculture economic data collection.

Chapter 1 Economic Modelling Methods and Data

To assess the influence of climate change on European aquaculture in terms of risk and opportunity, a multidisciplinary approach was applied. A series of methodological steps was taken in a variety of farming systems for each species analysed to assess the response to a changing climate. The initial focus was on individual farms in specific regions, projecting economic consequences of biological changes and future price trends that could occur under different climate change scenarios. Then, farm specific impact was scaled across the selected countries to provide an insight as to how entire regions would be impacted, identifying where potential benefit could occur and regions that could experience negative changes.

Both, future individual farm economics and regional analyses were built on previous CERES work and thereby interconnect different tasks and work packages throughout the project (Figure 1.1). The framework is provided by the CERES scenarios defined in T1.2 and the future temperature projections deriving from the work in T1.1 that set the baseline for biological modelling (T3.3) and the fish meal/fish oil model (T4.3). The resulting feed conversion ratios, future harvest weight and fish meal/oil price trends shape together with price trends for fish, energy and crop feed ingredients from an external model and applied to the future typical finfish and model mussel farms. In addition, scenario-based assumptions on public payments and marketing are included in the analysis. Resulting overall individual farm profitability is further validated by a sensitivity analysis based on historical price variation.

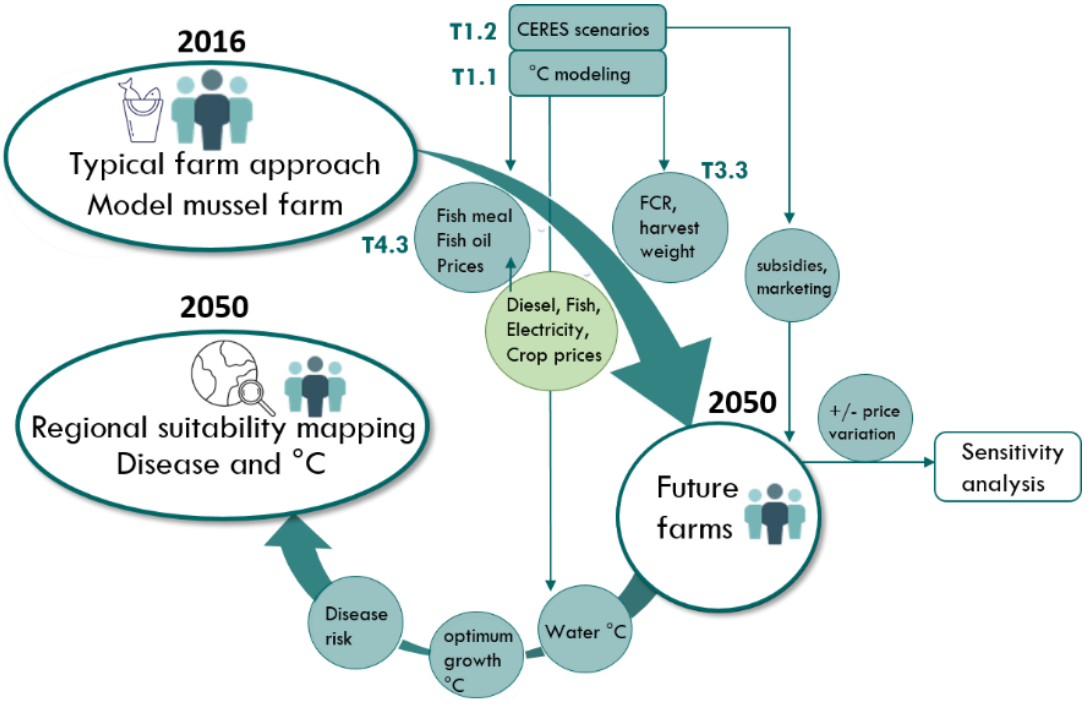

Figure 1.1. *Dataflow and analysis for Task 4.2. Work performed in other tasks within the CERES project is indicated by Task numbers, the modelling of diesel, fish, electricity and crop prices indicated in green derives from the external MAGNET model. Stakeholder engagement is indicated by "group" icon. FCR = feed conversion ratio.*

Future individual farm profitably projections were then combined with regional water temperature suitability for optimum growth (modelled using baseline data from ocean and air temperature data from T1.1) and disease occurrence (future pathogen risk change projections transferred from T3.1) to visualize profitability trends on a regional scale. All projections in this deliverable are for the mid-century time slice (2040-2060) under each of the four CERES scenarios (defined in WP1, deliverable D1.2), which are compared to farm operations and performance within the present-day (2016).

1.1 Aquaculture Production Data

Before climate change impact was projected, data were generated and collected on present-day farming activities. This included production levels and economic performance both of which could potentially be influenced by a changing climate. Initially, information was collected that highlighted the regions that are currently responsible for the greatest production through direct correspondence with storyline leaders and consultation of available data sets. Data were compiled relating to the total production of each target species in 2016 within storyline countries per region (regions included total production per federal state, per county, per Nomenclature of Territorial Units for Statistics (NUTS) region, or, per area defined by storyline leaders. The information provided was displayed using maps generated by a geographic information systems (GIS) approach. Within each mapped country, growing regions were numbered and the associated total production in 2016 was matched to its corresponding regional number in Microsoft Excel. The spreadsheet was then imported into ArcMap 10.5 and the numbered regions and associated production were joined to shapefiles that displayed the outline of the countries and the growing regions within them (shapefiles downloaded from www.diva-gis.org). A graduated quantities symbology option was then used to re-display the regional polygons within the shapefiles so that they were colour coded based on the 2016 production that occurred.

The selection of species for the economic analysis reflects the five most important finfish aquaculture species in Europe, based on volume and value: Atlantic salmon (*Salmo salar*), Rainbow trout (*Oncorhynchus mykiss*), European seabass (*Dicentrachus labrax*), Gilthead sea bream (*Sparus aurata*) and Common carp (*Cyprinus carpio*) (Eurostat 2016). For shellfish, blue mussel production in the North Sea region was included as a case study. Country selection was based on the importance of production and the capability of the consortium to approach the respective sector, as well as to contribute to the defined

storylines in CERES. Significant production regions within the countries of choice were identified according to literature and the regional production. Sector diversity in production technique and size was considered by defining multiple farm types per species and country, where relevant and feasible.

1.2 Typical Farm Modelling Approach

For the economic assessment of climate change impacts on Europe's most important aquaculture finfish species, the typical farm approach was applied as a baseline for farm level predictions. Essentially an engineering approach, typical farm models are empirically grounded, "virtual" datasets (Isermeyer 2012, Walther 2014). They combine the qualitative sampling methods through focus groups, expert interviews and farm observations to define representative farm datasets for selected production regions. Thereby focus groups, organised with expert participants from research and the business sector formed the central data source for the method. The resulting farm level economic dataset comprised of a maximum of 548 variables was validated discursively for its coherence and allowed a high detail of micro economic analysis (see Lasner et al. 2017 for more details).

Currently, the typical farm approach is implemented by several international agricultural institutions (ICFN 2019), including the *agri benchmark* network headed by the Thuenen-Federal Research Institute for Rural Areas, Forestry and Fisheries in Braunschweig (Germany) (for SOP see Deblitz and Zimmer 2005). Originating in the agricultural sector, the typical farm approach has, for the first time been applied to aquaculture production systems by the *agri benchmark* network in 2014, defining and comparing typical rainbow trout farms in Germany, Denmark and Turkey (Lasner et al. 2017). On this basis, the method was further developed and implemented for carp production in Germany and Poland (Lasner et al. in prep) within the EU Horizon 2020 Project SUCCESS. In CERES, these existing datasets were updated for the year 2016 and complemented by new 2016 datasets including additional species and production countries.

A full list of typical finfish farms included within the economic analysis of climate change impacts on individual farm level is depicted in table 1.1. Each model farm is coded with the first letters of the ISO 639 country code, the FAO 3-Alpha Species Code (ASFIS) and the annual production of the target species produced in tons live weight. As an example, an Irish Atlantic salmon farm producing 1540 tons is coded as IR-SAL-1540. The only exception is the Turkish seabream/seabass farm, where production of the two species is equal, but seabass (BSS) was chosen as species code.

Table 1.1. *Typical farm model information generated on country, NUTS region, production system, water source and data collection involved partners and projects. Farm codes are based*

on the first letters of the ISO 639 country code, the FAO 3-Alpha Species Code (ASFIS) and the annual production of the target species produced in tons live weight.

Species	**Country, Region (NUTS)**	**Production system, Water source**	**Farm Code**	**Data collection (Project, Partners)**
Rainbow trout	Germany, Bavaria	RAS raceway, pond; mainly surface	DE-TRR-100	Lasner et al. 2017, updated for CERES
	Germany, Baden-Württemberg	Raceway, pond; mainly surface	DE-TRR-500	Lasner et al. 2017, updated in CERES
	Germany, Baden-Württemberg	Pond, raceway, Spring water	DE-TRR-7.5	CERES, TI-SF
	Denmark, Southern DK	Pond; surface	DK-TRR-150	Lasner et al. 2017, updated in CERES
	Denmark, Mid Jutland	Raceway, pond; groundwater	DK-TRR-700	Lasner et al. 2017, updated in CERES
	Turkey, Muğla	Pond; spring water	TR-TRR-500	Lasner et al. 2017, updated in CERES
	Turkey, Elazığ	Net cages, dam lake	TR-TRR-450	CERES, MEU
	England, South / South West	Raceway, surface water	GB-TRR-360	CERES, CEFAS
Common carp	Germany, Bavaria	Pond, precipitation	DE-FCP-20	SUCCESS, updated in CERES
	Germany, Bavaria	Pond, precipitation	DE-FCP-5	SUCCESS, updated in CERES

	Poland, Dolina Baryczy	Pond, surface water	PL-FCP-90	SUCCESS, updated in CERES
	Poland, Dolina Baryczy	Pond, surface water	PL-FCP-190	SUCCESS, updated in CERES
Atlantic salmon	Ireland, Donegal	Net cage, marine	IR-SAL-1540	CERES, TI-SF, NUIG/UCC
	Norway, Nordland	Net cage, marine	NO-SAL-3680	CERES, GIFAS
Gilthead seabream/	Turkey, Muğla	Net cage, marine	TR-BSS-2000	CERES, MEU
European Seabass	Spain, Canary Islands	Net cage, marine	ES-BSS-1320	CERES, IEO

Through focus groups, interviews and farm visits, all relevant costs were estimated based on the expertise of the selected stakeholders involved. Pre-conditions for data collection varied between countries and the datasets obtained for Atlantic salmon in Norway, sea bass in Spain and rainbow trout production in England which were mainly based on bilateral interviews with relevant sector stakeholders, whereas all other farms were defined in focus groups. According to the *agri benchmark* approach, the collected data can be categorized into “cash costs”, “depreciation costs” and “opportunity costs” (see Deblitz 2013, Lasner et al. 2017 for more details). Hereby, cash costs include all relevant fixed and variable costs such as feed, energy, wages, fingerlings, licences, insurances or accountancy costs. Depreciation costs reflect the linear relationship between replacement value and economic lifetime of machinery, buildings and production systems. Opportunity costs consider the value of internal resources, such as unpaid labour, own land and capital. These costs are subtracted from the market returns (the weighted mean of returns of all relevant sale channels) to obtain the profitability of each typical farm. Within CERES, the analysis focused on operating earnings (market returns against cash costs without interests), but the results are also discussed in the context of additional depreciation and opportunity costs. All economic values are calculated without value added tax (VAT) and economic efficiency analyses on the collected raw data is performed within the *agri benchmark* simulation “abFishCALC” (Lasner et al. 2017).

The updating of existing typical farm datasets for the year 2016 (see table 1.1) was conducted in a combined approach of desk research on price indexes, interests and energy prices and interviews with farmers/consultants on fish prices, wages and feed prices. Data collection was conducted by respective partners and projects as listed within table 1.1. The discursive validation of all datasets was done in close cooperation with TI-

SF, the updating of already existing typical farms and economic efficiency analysis was done by TI-SF.

With shellfish comprising a very significant volume of the overall aquaculture production in Europe, it was decided to apply a similar individual farm approach to blue mussel (*Mytilus edulis*) production in the North Sea area as a case study. The costs categories applied for finfish farms were adapted to mussel production. Farms were defined by experts within the consortium and based on individual farm economic data of the whole national sector and most important production regions, but without direct stakeholder involvement (table 1.2). To distinguish this approach from the typical finfish farms we are referring to "model mussel farms" in the following:

Table 1.2. *Model mussel farm information on country, NUTS region, Production system and data collection involved partners and projects. Farm codes are based on the first letters of the ISO 639 country code, the FAO 3-Alpha Species Code (ASFIS) and the annual production of the target species produced in tons live weight.*

Species	**Country, Region (NUTS)**	**Production system**	**Farm Code**	**Data collection (Project, Partners)**
Blue mussel	Denmark, North Jutland	Longline	DK-MUS-900	CERES, DTU-aqua
	Netherlands, Zeeland	Bottom culture	NL-MUS-1120	CERES, WUR

1.3 Future Prices and Trends

Future fish and mussel farm profitability was analysed for the four socio-political CERES scenarios "World Market" (WM), "Global Sustainability" (GS), "National Enterprise" (NE) and "Local Stewardship" (LS) described in Deliverable D1.1 and D1.2. Thereby, different prices for energy resources, aquaculture products as well as other relevant commodities expected under the four scenarios and their underlying social and economic assumptions were developed. These were based on some of the shared socio-economic pathways (SSPs) developed by the Intergovernmental Panel on Climate Change (IPCC) (see D1.2). For a consistent application of future price trends across different CERES tasks, the selection and usage of future price trends for fuel and seafood commodities was developed together with T4.1 and T4.3. Besides selecting a model that represents the socio and economic narrative, it was decided to use trends from a global model, as both, fuel and seafood are also influenced by the global market. The selected general

equilibrium MAGNET model (Woltjer & Kuiper 2014) is also based on the SSPs and uses the same GDP and population development assumptions (Doelman et al. 2018) underlying the four CERES scenarios defined in D1.2. Further, it allows for the usage of region-specific results for the whole of Europe. See D4.1 for a more detailed description of the trends in future prices used within CERES and the comparison to other sources for future fish and crude oil prices.

The MAGNET model output was used for future electricity price trends within CERES. Power and electricity are traded on a pan-European market, as opposed to on a broader global scale. However, the electricity price development was found to be correlated with the oil price development for Europe (Madaleno et al. 2015), so an indirect impact by global market developments is expected. Moreover, no other suitable source was available that matched the scenarios and modelling time slice. Reports on the transformation of the European power supply, energy transition and greenhouse gas emissions for Europe (Capros et al. 2016), also with a time horizon until the year 2050, do exist, but do not include different scenarios, price trends or are not comparable to the ones applied in CERES. The overall percental change for nominal crude oil/fuel, electricity and fish prices between the year 2016 and 2050 deriving from the MAGNET model is displayed in table 1.3. For the future typical finfish and model mussel farms the overall nominal price development until the year 2050 was considered.

Table 1.3. *Overall future nominal price trends for fish, fuel, electricity and fish feed ingredients between the year 2016 and 2050 under the four different CERES scenarios. Price trends for fishmeal and fish oil are derived from the FM/FO model, price trends for all other commodities from the MAGNET model. Historic price variation is derived from a generalised additive model using historic price trends from WHO, FAO and EC databases and statistical reports.*

	World Markets [RCP8.5, SSP5]	**National Enterprise [RCP 8.5, SSP3]**	**Global Sustainability [RCP 4.5, SSP1]**	**Local Stewardship [RCP 4.5, SSP2]**	**Historic price variation**
Fish price	+70%	+76%	+57%	+74%	+/- 5%
Fuel price	+139%	+163%	+138%	140%	+/- 15%
Electricity price	+152%	+129%	+144%	138%	+/- 6.5 %
Plant ingredients other than vegetable oil	+97 %	+109%	+61%	+85%	+/- 12.6%
Vegetable oil	+121%	+116%	+89%	+101%	+/- 14%

Fish meal	+14%	+92%	+26%	+77%	+/- 15%
Fish oil	+41%	+85%	+51%	+64%	+/- 21%
Inflation	+96 %	+96 %	+96 %	+96 %	

A number of typical farms include public payments as additional returns within their farm economics. These derive from different sources and cover EU direct payments for agricultural land for carp in Poland, county specific direct payments for extensive carp production in Germany, and European subsidies for seabass production on the Canary Islands to compensate insularity. Within the future profitability analysis of the typical farms, subsidies were included for those scenarios, where such payments are coherent with the respective scenario narrative. The same is true for region marketing, which is seen as a future opportunity for the carp sector in Germany to achieve higher prices than the current non-labelled marketing under the local scenarios (Table 1.4).

Table 1.4*. Assumptions on public payments and region marketing that were applied for relevant typical farms in Germany, Poland and on the Canary Islands under the four CERES scenarios. Farm codes are based on the first letters of the ISO 639 country code, the FAO 3-Alpha Species Code (ASFIS) and the annual production of the target species produced in tons live weight.*

Public payments	**World Markets [RCP8.5, SSP5]**	**National Enterprise [RCP 8.5, SSP3]**	**Global Sustainability [RCP 4.5, SSP1]**	**Local Stewardship [RCP 4.5, SSP2]**
DE-FCP-20	N	Y	Y	Y
PL-FCP-90	N	Y	Y	Y
PL-FCP-190	N	Y	Y	Y
ES-BSS-1224	N	Y	N	Y
Regional Marketing				
DE-FCP-5	N	Y	N	Y
DE-FCP-20	N	Y	N	Y

Feed is often the major cost within aquaculture finfish production and therefore a crucial cost factor to consider for future profitability analysis of finfish farms. The current costs per kg fish feed were obtained during the typical farm focus groups per species and country. The estimation of future fish feed prices was conducted in three steps:

1. **Fish feed composition assumptions** were made for all target aquaculture species based on literature and verified by relevant stakeholders from the fish feed and

farming industry. Thereby, plant protein and plant sourced ingredients other than vegetable oil were combined within the category "plant ingredients other than veg. oil". All fish feed composition assumptions are displayed in table 1.5.

2. **Absolute cost allocation per fish feed ingredient** - The current raw material costs for plant commodities were obtained from FAO, WHO and EC databases (FAO 2019), those for fishmeal and fish oil from a web database (indexmundi.com) and commodity statistics report (GLOBEFISH 2019), and allocated to the respective amount of raw material in the different fish feeds defined within the first step. For the merged category of "plant ingredients other than veg. oil" the prices for wheat, grains and oilseeds were used as an average. No differentiation between prices for conventional fishmeal/fish oil and those deriving from trimmings was made due to a lack of available information. The remaining difference between the total raw material costs and the feed price per kg feed for each typical farm, was categorized as "other costs." These include costs of other specific ingredients, e.g. for vitamins, minerals or land animal protein and unknown costs such as ingredient handling, feed processing, administration, general equipment deterioration as well as the profit of the fish feed producers.

3. **Future fish feed price projections under the four CERES scenarios** – Future prices for plant-based future fish feed composition prices for the four CERES scenarios were obtained from the same source as energy and fish price trends, the MAGNET model. Thereby, the price trends for "wheat and meslin", "other grains" including maize (corn), barley, rye, oats, other cereals, "oilseeds" including soybeans and other oilseeds and "vegetable oil", were used. For the merged category "plant ingredients other than veg. oil" an average price trend of "wheat", "other grains" and "oilseeds" was applied. We are aware of other sources addressing climate change impacts on agriculture commodities and prices (e.g. Nelson et al. 2010, Fallon and Betts 2010, Brown et al. 2015), but again, the MAGNET model output was most suitable as it is a global model that provides output for Europe and considers the same SSPs as our CERES scenarios. Future fishmeal and fish oil price trends derive from a bio-economic fishmeal/fish oil trade model (FM/FO model) that was applied to the CERES scenarios in Task 4.3 (see Mullon et al. 2009 and T4.3 deliverable for more information). The model is described by economic production and consumption functions linked by trade flows and thereby also considers the availability of potential fishmeal and fish oil substitutes under the different scenarios. The future fish feed ingredient prices were applied to the absolute cost allocation per fish feed ingredient calculated in step 2. For the category "other costs" an inflation factor of 2% per year was applied. The overall percent change for nominal fish feed ingredient prices between the year 2016 and 2050 deriving from the MAGNET and the FM/FO model is displayed in Table 1.3.

Table 1.5. *Fish feed composition assumptions for all species part of the economic analysis in CERES based on literature and stakeholder feedback.*

Fish feed ingredient	**Rainbow trout composition (%)**	**Seabass/Seabream composition (%)**	**Salmon conventional composition NO (%)**	**Salmon organic composition (%)**	**Carp traditional composition (%)**
Fishmeal	10	20	10	33 (trimmings)	
Fish oil	8	8	8	23	
Vegetable oil	12	12	21	8	
Vegetable protein (Soy, wheat, rapeseed)	55	45	54	33	100 (wheat and grains)
Land animal protein (e.g. blood meal, feather meal)	12	12	-	-	
Vitamins, minerals	3	3	7	3	

Future feed conversion ratio (FCR) and harvest sizes were derived from the biological model developed and run in CERES Task 3.3, which provided projections for extreme cold (P10) and an extreme warm (P90) years for RCP 4.5 and RCP 8.5 within the defined time slices (see D3.2) for finfish species; and best (P10) and worst (P90) production for shellfish species. The results were applied for all matching species and region pairs between T3.3. and T4.2, resulting in FCR and harvest size changes for trout and seabass production in Turkey, Atlantic salmon production in Ireland and Norway, and, harvest size changes for blue mussel production in Denmark and the Netherlands. The model output used was the percentage change in FCR and harvest size, which was applied to the typical farm feed volume and the typical model mussel farm harvest volume with related impacts on costs and returns. In order to match the time horizon of the economic analysis, the time slices or the P10 and P90 years identified within the time slices, that were closest to the year 2050, were chosen from the biological model output. Consequently, for Atlantic salmon production in Norway, the results of the time slice 2030-2049 were used (P10 year: 2046, P90 year: 2040), for all other species-country pairs the results of the time slice 2040-2050 were applied to the typical and model mussel farm results. Thereby, RCP 4.5 FCR and harvest size results for P10 and P90 years were combined with future price trends of the "Global sustainability" and "Local stewardship" scenarios and RCP 8.5 outputs for the P10 and P90 years with price trends for the "World market" and "National enterprise"

scenarios, resulting in a total of 8 scenario outputs for those farms including results from the biological model compared to 4 for those without.

In order to consider potential price variation around the 2050 price trends used (table 1.3), a range was set around the price trends for energy, fish and fish feed ingredients derived from the MAGNET and FM/FO model. To define the width of the ranges, historical price variability was used. For fish, we used the European prices from FAO data (FAO 2019) and for fuel the European prices of crude oil import from the OECD (2018). For the different fish feed ingredients, the same FAO, WHO and EC databases and sources as for the current prices were used. The variability in the price of electricity for Europe was based on the Eurostat database. Historic data coverage varied between commodities. Mostly, yearly data were available from 1980 or 1990 onwards. For European electricity prices, however, data were only available from 2008 onwards. A generalised additive model (GAM) was used with a gamma distribution to fit the general trend of the non-normally distributed historic price data (Figures 1.2 & 1.3). The variability produced by the gamma distribution increases with higher values, which is in line with this approach. The smoothing factor of the GAM (k) was always set to 10. The predicted standard error of the model fit was used to calculate the upper and lower 95% confidence limits (Figures 1.2 & 1.3). The proportional deviation of the highest fit value was then used to build the upper and lower range of the projected future price output of the Magnet and FM/FO model. Within CERES scenarios the prices are expected to increase over time, hence the maximum of the fit was selected, which is relative to the maximum historic price observed (table 1.3, last column). The resulting range from the observed historic price development trend is applicable to all CERES scenarios.

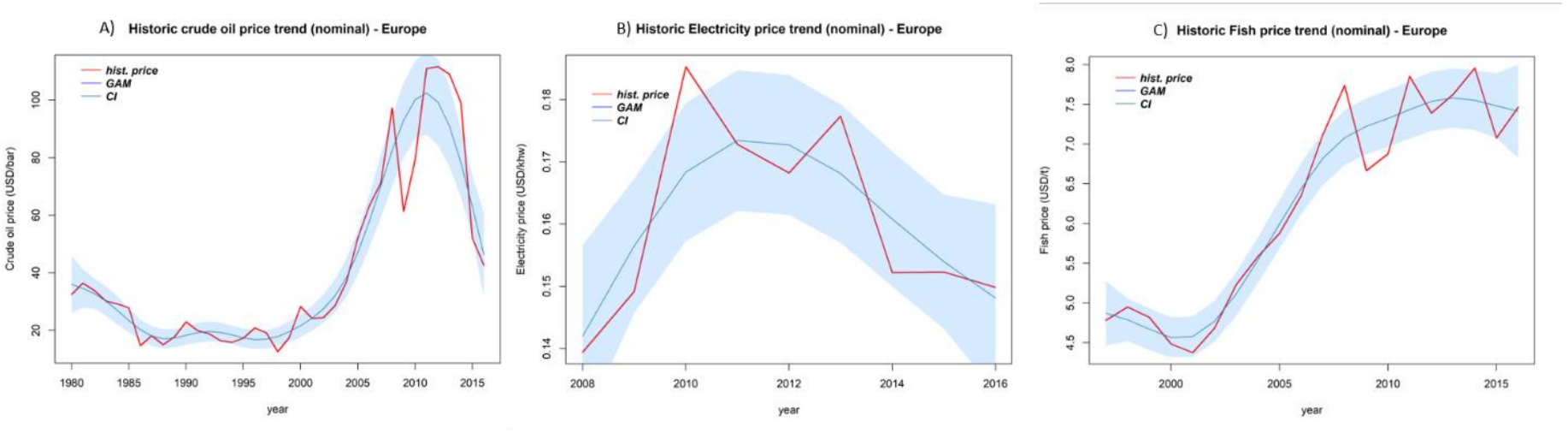

Figure 1.2. *Historical crude oil (A), electricity (B) and fish price (C) trends including the historical data coverage (red line) in USD/unit with the fit gam model (blue line) and the corresponding 95% confidence interval (blue shading).*

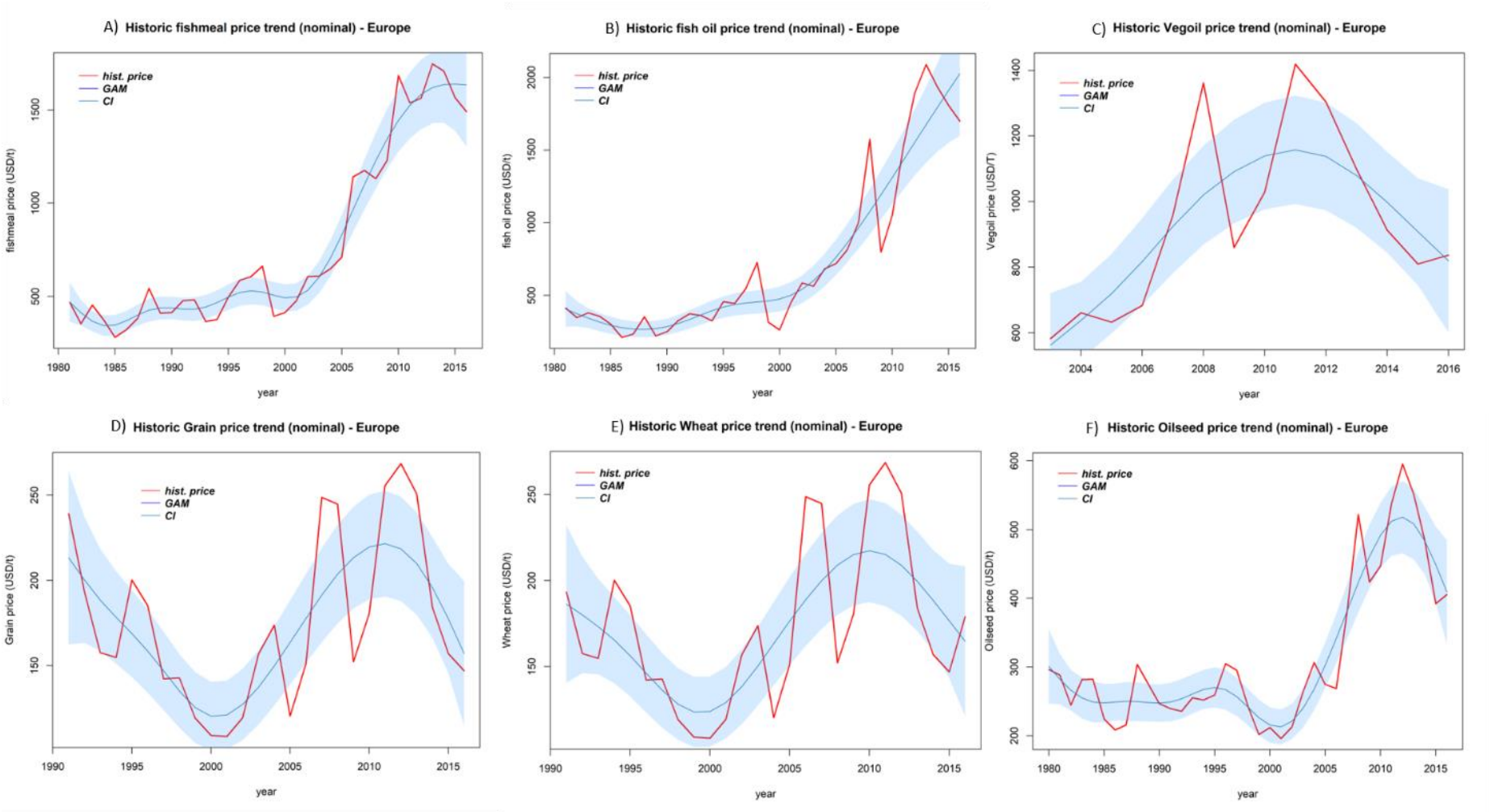

Figure 1.3. *Historical fish feed ingredient price trends for fishmeal (A), fish oil (B), vegetable oil (C), grains (D), wheat € and oilseed (F) for the respective available historical data coverage (red line) in USD/unit with the fit gam model (blue line) and the corresponding 95% confidence interval (blue shade).*

The resulting ranges from the observed historical price development trends were used to conduct Monte Carlo simulations for the operating earnings of every individual farm in Microsoft Excel. Random numbers for electricity, fuel and fish price were created between a minimum related to “price trend 2050 minus historical price range” and a maximum deriving from “price trend 2050 plus historical price trend” for 2050 price trends of each of the four CERES scenarios. For fish feed, the overall minimum and maximum price trends of all fish feed ingredients were calculated based on the specific feed composition per species and 2050 feed price per farm, creating the respective boundaries for the applied random numbers. For fuel price no simulation of random numbers between the defined price ranges was applied for finfish farms in order to prevent the combination of contradicting trends between fuel price and electricity or fish feed price, as the latter two are influenced by fuel price developments. However, for mussel farms it was decided to vary the fuel price instead of the electricity price to reflect the higher importance of fuel costs over electricity costs for mussel production. 1,000 iterations of typical and model mussel farm operating earnings were calculated with energy, feed and fish prices varying randomly between the pre-defined range in prices. From the resulting average of the 1000 operating earnings, twice the standard deviation was added and subtracted in order to cover >95% of the expected future operating earnings between the defined price ranges.

1.4 Scaling Impacts Across Regions

In addition to projecting future operating earnings of individual typical farms that were identified, potential economic impact across geographic regions in relation to climate change scenarios was assessed. Regional differences required consideration because although some costs will be consistent across a sector (e.g. changes in fuel price will be the same for all businesses in a region) temperature relate impacts effecting animal growth and disease occurrence will vary throughout each of the study regions of interest. To investigate these sub-regional effects, GIS methods were used to map the distribution of current and future projections of environmental conditions across regions to determine their likely relative impact or benefit on typical operating earnings.

During engagement meetings with inland stakeholders, future water levels were identified as a concern by trout and carp farmers, whose operations are reliant on surface water input. Specifically, a lack of water during extended summer dry spells was identified as a main concern. Future projections state that several locations across Europe may experience drier and longer summers in the future (smhi.se). Wetter winters are also projected for large areas of Europe, which could potentially lead to additional issues such as flooding of farming areas (smhi.se). The distribution of the potential water levels during the mid-century times slice period was therefore compared to the present-day

summer and winter precipitation for all relevant rainbow trout and carp producing countries that are part of the economic analyses.

Due to an absence of data layers that provide future projections of freshwater levels on a spatial scale, future precipitation projections were sourced as a proxy to suggest what future water levels could be. Data was sourced from WP1 (deliverable D1.3) that consisted of Network Common Data Form files (NetCDFs) containing a series of data layers in the form of grid cells that held information relating to the distribution of average precipitation during each month within the present-day, and projections of precipitation during the mid-century time slice under RCP 4.5 and RCP 8.5. The data layers were displayed in ArcMap 10.5 and initially covered the whole of Europe. Precipitation data relevant to the freshwater farms (rainbow trout farms in the UK, Germany and Turkey, and carp farms in Germany and Poland) were then extracted using the country specific shape files (Spatial Analyst Tools: Extraction: Extract by Mask).

The resultant regional NetCDF files for precipitation in each of the time slice periods were read in RStudio using the ncdf4 package. The time variables were converted from a "time since unit" to the required real monthly time units for all years. A data frame for each regional time slice combination was then created in R, stating the mean precipitation values for every month within the time slice periods per longitude and latitude values. The data frames were then used to calculate a regional precipitation average for every month in the time slice period, by taking the mean of all grid cells within a given region.

To determine seasonal changes in precipitation between the time slice periods, only precipitation estimates that fell within meteorological winter period (December, January, February) and summer period (June, July, August) were selected. The regional means for each of these 3-month sets, for every year, were combined to provide an annual estimate of seasonal precipitation for summer and winter. A per time slice estimate of each season's precipitation was then determined by taking the mean of all the annual estimates of winter and summer precipitation that fell within that time slice. A projected percentage change in winter and summer precipitation from the present-day value was then calculated for both RCPs in the mid-century time slice.

Temperature has been identified as a key driver in the biological performance and health of farmed finfish and shellfish in both the freshwater and the marine environment (FAO 2019). Most farmed species are seen to have a minimum and maximum temperature threshold where optimal growth and health occurs. Changes in water temperature as a result of climate change could potentially impact the suitability of the aquatic environment for target species or impact the costs that farmers incur to keep their sites within certain temperatures and related water quality ranges. Alternatively, changes in temperature could increase the duration of the most suitable conditions for farmed species over the course of a year. Output was therefore generated to assess the potential impact of changing temperatures on the projected operating earnings of the freshwater and saltwater farmed species across Europe, considering the influence of differences in localised temperature change projections under the different scenarios.

The mapping techniques, analysis and data sources were developed under WP3, allowing future temperature suitability for several fish and shellfish pathogens to be mapped in relation to optimal infection temperature thresholds was applied to the economic analyses (methods described in deliverable D3.1, section 5.1). In this work package thresholds were collected and mapped in relation to known optimal growing temperatures of each farmed species. Minimum and maximum thresholds of optimal growth were collected for each of the target species from the FAO Cultured Aquatic Species Information Programme (http://www.fao.org/fishery/collection/cultured-species/en). Within the FAO species information pages, specific optimal growing temperatures were stated within the overall thermal range of trout and carp, which were used as the mapping thresholds. For the remaining species (seabass, seabream, salmon and blue mussel), no additional information appeared in relation to optimal farming temperatures. Optimal ranges stated by the Maritime and Environmental Thresholds for Aquaculture (META) (https://longline.co.uk/meta/) within the overall FAO thermal ranges for farming each species were therefore used as the optimal growing thresholds. It was assumed that any increase or decrease in the period over which these temperatures occurred throughout a year would have a relative impact on future operating earnings between farms in different regions due subsequent changes in possible productivity. It is acknowledged, there is an array of physiological thresholds that could be attributed to each species, but the FAO and META optimal thermal ranges were prioritised due to them being widely recognised, consistent and directly comparable.

The final output consisted of maps that display the proportion of days per year that optimal growing temperatures occur for each species across key storyline regions for the present day and during the mid-century time slice under the RCP 4.5 and 8.5 scenarios. The maps split geographic areas within storylines into a matrix of cells, with each cell being given a proportion of days per year that the optimal temperatures occur in that location. The maps do not assume that farms reside within each grid square, but rather display the temperature suitability associated with each grid square. This temperature suitability is assumed to influence operating earnings between regions where farms are situated. Visual comparisons between the temperature suitability maps and the present-day (2016) regional production maps (discussed above) to understand the association between production and temperature.

The data within the maps was then exported into Microsoft Excel, producing sheets that contained the GPS coordinates representing each cell within the data layers with the present day and projected mid-century (under both RCP 4.5 and 8.5) proportion of days per year that optimal growing temperatures occurred. The percentage change in the proportion of days per year was then calculated by comparing the present-day with the mid-century projections under the two RCPs. This percentage difference was then applied to relative profitably distribution maps in the final assessment (discussed below).

Changes in the distribution of future pathogen risk was also identified as potentially having varying levels of influence on the relative operating earnings of farms depending

on their geographic location within storylines. The overall impact that such pathogens can have on infected sites can be significant due to high mortality rates of infected fish and the control measures that are imposed on infected farms (for more information, see deliverable D3.1). Often the impacts associated with infections persist for over a year which is greater than the time period that the operating earning calculations in the individual farm models were based on. An assumption was therefore made that any percentage increase or decrease in the pathogen risk at a GPS location over the course of a year in the mid-century compared to the present day would have an equivalent proportional impact on the relative operating earnings of a farm if it was situated in that location.

To generate an understanding of the relative impact that could occur, the pathogen that achieved the highest suitability score within WP3 (D1.3) for each target species was considered within the economic analysis. It was assumed that any change in risk of this pathogen would represent the highest level of influence on operating earnings and therefore incorporate any impact caused by other relevant pathogens (for more detail on the specific impacts of each individual pathogen species and their distribution, refer to D3.1). The data from the maps of these pathogens was transferred to the present economic analysis in the form of Microsoft Excel spreadsheets. Percentage changes in the proportion of days per year that optimum temperatures occurred for the highest risk pathogen in the mid-century under RCP 4.5 and 8.5, was compared to the present-day scores for each of the GPS points used in the temperature suitability maps. The resultant percentage changes were then incorporated into the final regional impact maps along with the target species temperature threshold suitability changes (discussed below).

The projected regional impact information was compiled to produce maps that combined the relative influence of future regional temperature suitability for each farmed species and the changes to pathogen risk in the mid-century on operating earnings. The percentage change spreadsheets were collated so that each GPS point had an RCP 4.5 and 8.5 temperature suitability and pathogen risk percentage change attributed to it. Four additional columns were then created that contained the mid-century operating earnings of the individual farms under each of the 4 CERES scenarios (without considering FCR and harvest size variation for P10 and P90 deriving from T3.3), so that the influence and distribution of specific environmental change at each GPS point could be applied.

Based on the aforementioned assumptions, the relative impact of environmental change was then applied. Initially, the influence of temperature suitability was assessed. Any percentage increase or decrease in the proportion of days over which optimal growing conditions occurred in the mid-century resulted in a directly proportional increase or decrease in the relative operating earning scores, as farm profitability and productivity was attributed to the duration of time that optimal growing conditions were theoretically possible. The RCP 4.5 percentage changes were applied to the “Global sustainability” and “local Stewardship” operating earnings results, whereas RCP 8.5 changes were applied to the “World Markets” and “National Enterprise” operating earnings. Then, the percentage

change in pathogen suitability was applied to the temperature influenced operating earnings using the same method. This assumed an increase in pathogen suitability would have a direct proportional decrease in operating earnings and a decrease in pathogen suitability would have a relative proportional increase on the operating earnings due to the long-term impact they are known to have on farms.

The resulting data columns were then reclassified to give descriptive comparisons of future relative operating earnings projected for the mid-century in relation to the possible present-day profitability that is currently possible at each GPS point. The reclassifications were done using the following command:

=IF(B2>A2,1, IF (B2=A2,2, IF (AND (B2<A2, B2>=0),3, IF(B2<0,4,0)))),

where "B2" is the relative scenario operating earnings score for a GPS point (repeated for each point) and "A$2" is the present-day operating earnings from the typical farm or mussel model. If a location had a higher operating earnings in the mid-century, it was given a score of 1; if there was no difference between present-day and projected future operating earnings, it was scored 2; if operating earnings decreased, it was scored 3 and if operating earnings became negative the location was classed as not viable and was scored as 4. The process resulted in four scenario specific profitability change rankings for each GPS point within the storylines.

The data columns were then imported into ArcMap 10.5 and displayed using the display XY tool based on their associated GPS points. The points were then converted back to a matrix of cells (raster data) using the impact reclassifications as the z-scores (Conversion Tools: To Raster: Point to Raster), resulting in data layers that showed the distribution of relative profitability changes in the mid-century under the four CERES scenarios compared to the present day. It is accepted that the relative profitability scores that the final reclassifications were based on are likely to not be exact, particularly as the influence of potential changes in critical extreme temperatures were absent, but they did generate an understanding of the spatial variation within the results of regional changes. It is anticipated that these projections may be used alongside the farm specific impact projections, calculated using the typical fish and model mussel farm approach, to highlight which locations may be subject to negative impacts from changing climate, and which locations may benefit.

1.5 Stakeholder Consultation

As indicated in section 1.1 and Figure 1.1, stakeholders were approached multiple times during T4.2 in order to validate sector assumptions and the scope of future analysis. The

most comprehensive stakeholder engagement was implemented for the definition of typical farm datasets in focus groups, bilateral interviews and farm visits including several relevant representatives of every sector (mostly farmers) and organized by the respective partners of the consortium (see table 1.1). Literature-based fish feed composition assumptions and future ingredients were validated with stakeholders and derived from a global fish feed company, the marine ingredients sector and aquaculture feed consultancy via email and telephone, but also during stakeholder feedback rounds with the aquaculture industry. The latter were conducted as bilateral interviews or group presentations on the results achieved in T4.2 and predominantly included representatives of the operating businesses and relevant authorities, again organized by the respective partners of the consortium.

Chapter 2 European Rainbow Trout Aquaculture

2.1 Introduction

Rainbow trout (*Oncorhynchus mykiss*) is the most produced aquaculture freshwater species within Europe and only Atlantic salmon has greater overall production across the continent (FEAP 2017, Eurostat). Production techniques range from earthen and concrete ponds to raceways, net cages and recirculation aquaculture systems. In Europe, the majority of the producers are smallholders and the production most often depends on local markets and tradition (Nielsen et al. 2016). Within CERES, we concentrated on Turkey, Germany, Denmark and England as freshwater production countries, and the predominant aquaculture product in these countries, which is portion-sized trout (FEAP 2017).

Turkey is the main producer of freshwater portion-sized trout in Europe providing 100300 tons and thereby 30% of total production in 2016 (FEAP 2017). In Turkey the predominant production systems are raceways in land-based farms using cold spring water or floating cages in natural/artificial lakes. The majority of the rainbow trout farms (72%) are family-run small-scale enterprises with a production capacity of less than 50 tons/year. Farms with a production capacity of 50 to 500 tons/year account for about 21%, while the remainder (7%) are mostly cage farms with a capacity of 500-1000 tons/year (BSGM 2019). Although rainbow trout farms are distributed across Turkey, there are a few key production areas located in the south-west and middle of the country: Elazığ, Muğla, Kayseri and Burdur (Figure 2.1). Turkish land-based rainbow trout farms are generally vertically integrated enterprises producing their own eggs and fry for on-growing operations. Cage farms either produce their own eggs and fry in land-based sister farms or purchase the fry from other enterprises. Portion-size trout supplies the domestic market; however, the main volume is exported as smoked or frozen fillets. In 2018 the value of Turkish rainbow trout exports reached €60.5m, with the EU (specifically Germany) and the Russian Federation being the main importing countries (Aegean Union of Exporters (EİB). Typical Turkish trout farms within CERES were selected for the provinces of Muğla and Elazığ, which are among the most important rainbow trout producing regions of the country (Figure 2.1). Thereby, a land-based farm with 500 tons production volume in concrete ponds was defined for Muğla (TR-TRR-500) and a 450 tons net cage farm located in a dam lake in the region of Elazığ (TR-TRR-450).

Denmark, although facing a decline in aquaculture production over the last decade (Ankamah-Yeboah et al. 2014, Robustfish), is still a major trout producer and remains the main exporter within the EU. In 2016, the total freshwater portion-sized trout production volume accounted for 20,970 tons, corresponding to a total value of €63.2m (Statistics Denmark, Eurostat). The sector consists of 190 inland trout farms, mostly in the region of mid Jutland as well as southern Denmark (Figure 2.1), with the majority of them being

traditional operations characterized by earthen pond production (Statistics Denmark, 2016). Around 17% of the inland farms are large and technologically advanced recirculation farms, which have developed since a structural change in 2005 (Nielsen et al. 2016). The main export market for Danish trout, is the EU with Germany being the biggest customer (Lasner et al. 2016). To represent the Danish trout sector within CERES, a traditional pond farm located in the area of Southern Denmark with a production volume of 150 tons (DK-TRR-150) as well as a 700 tons mainly raceway farm in Mid Jutland (DK-TRR-700), were selected (Figure 2.1).

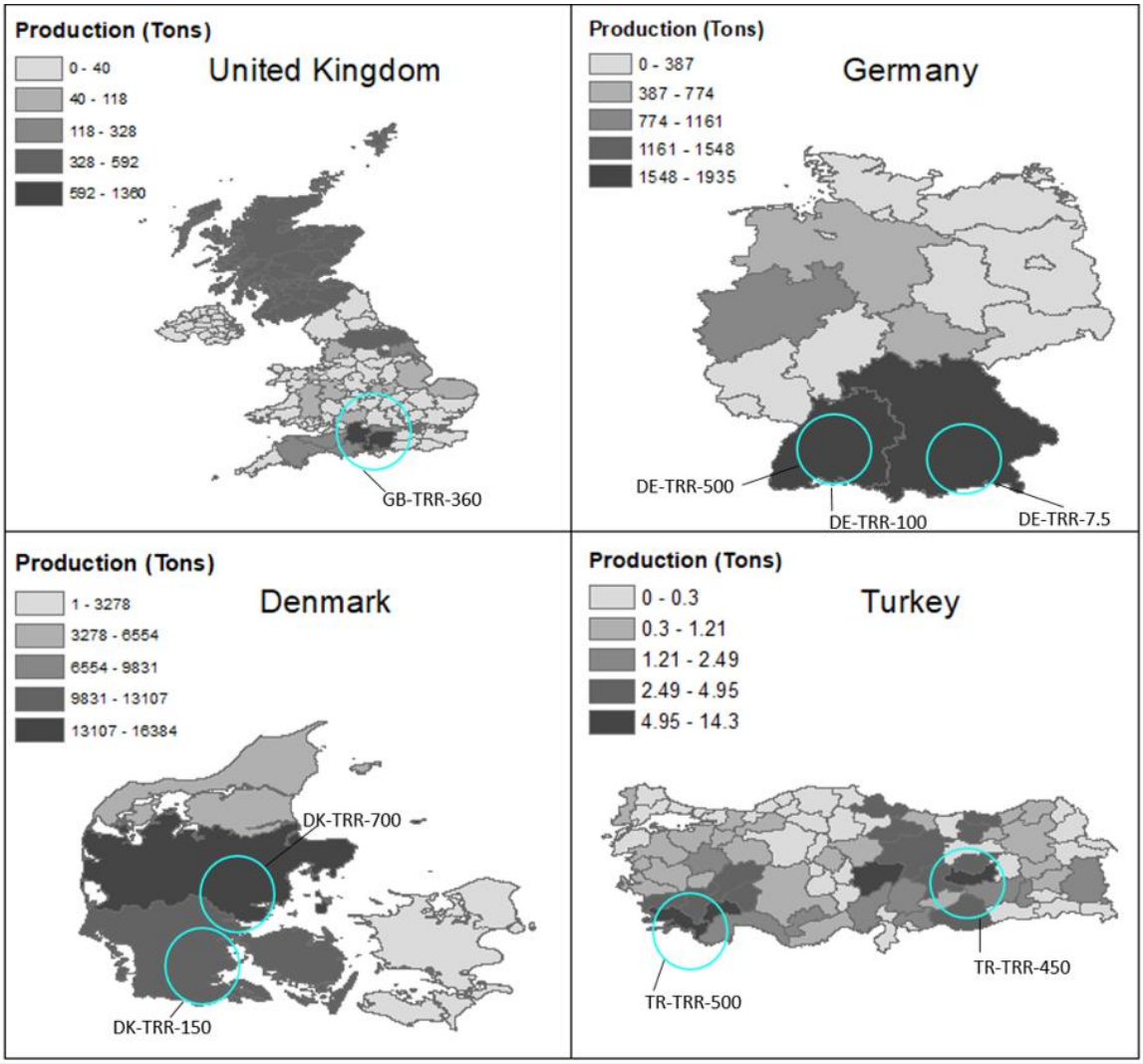

Figure 2.1. *Rainbow trout (Oncoryhnchus mykiss) regional production in tons for the year 2016 and selected production countries in CERES: England with Wales, Germany, Denmark and Turkey. Locations of the typical rainbow trout farms are indicated by circles and labelled with a country-species-yearly production code. Data sources: UK Cefas Starfish database, German Federal Statistics Office, Danish Agrifish Agency, Turkish Ministry of Agriculture/Forest.*

Germany, which is a modest producer and the main trout importing EU member state, had an annual production of 7039 tons in 2016, with the main producing regions being located to the south in the counties of Bavaria and Baden-Wurttemberg (German Federal

Statistics Office 2017) (Figure 2.1). Traditional pond production is the most common production technique for smaller operations, while raceways and (partly) recirculation systems are predominant for the few larger scale farms (Lasner et al. 2015). Economic value of the total production was €39m in 2016 (Eurostat). Typical German trout farms selected for CERES include two best practice farms located in the region of Baden-Wurttemberg with a yearly production of 100 (DE-TRR-100), and 500 tons (DE-TRR-500), with production mainly occurring in raceway systems (Figure 2.1). In addition, one smaller scale farm representing the traditional production in pond and raceway was defined for the county of Bavaria with a yearly production volume of 7.5 tons of portion-sized rainbow trout in spring water (DE-TRR-7.5) (Figure 2.1).

Within the UK, portion-sized rainbow trout production has remained relatively consistent (McKenzie and Wyness 2013), producing between 12000 and 17000 tons per year during the last 20 years (including re-stocking and on-growing). In England alone, 4852 tons were produced in 2016, which is equivalent to an economic value of €19.5m (Eurostat). The trout industry consists entirely of privately-owned business with most being classed as SMEs (small and medium-sized enterprises) (McKenzie and Wyness 2013) with most being based in the southwest and northeast of the country (Figure 2.1). Most of the trout produced in the UK goes to the UK market (two thirds of production), so the need for imports are comparatively low. Several methodologies for farming trout are employed for grow-out, which includes the use of tanks, ponds, and raceways (BTA 2018). The typical English trout farm defined in CERES is located in the region of Hampshire and produces 360 tons in raceway systems supplied by surface water (GB-TRR-360) (Figure 2.1).

2.2 Climate Change Effects on Habitat Suitability for Rainbow Trout

Temperature is of critical importance in aquaculture systems as it determines not only the growth rate and performance of the fish but also the likelihood of disease occurrence. According to the FAO the optimal growing temperatures for trout are between 12 and 21°C. When compared to the national average water temperature presented in table 2.1 of the 4 countries studied only Turkey appears to have temperatures within the optimal range with all other countries having temperatures below 12 °C. In terms of temperature, therefore, climate changes projected under both RCPs would appear to be beneficial (with RCP 8.5 being most beneficial) as average temperature are predicted to increase further into the optimal range for trout. These values, however, are averaged both in time and spatially across the countries studied and may therefore not provide a reliable estimate of current or climate change impacts on fish growth.

Table 2.1. *Average predicted water temperatures in case study countries and predicted change under RCP 4.5 and 8.5.*

Country	Average national present-day water temp	Average national 2050 water temp – RCP4.5	Average national 2050 water temp – RCP8.5	Percentage change in national average water temperature in 2050	
				RCP 4.5	RCP 8.5
UK	10.88˚C (SD= 0.86˚C)	11.10˚C (SD= 0.84˚C)	11.39˚C (SD= 0.86˚C)	2.04%	4.76%
Denmark	10.95˚C (SD= 0.26˚C)	11.12˚C (SD= 0.26˚C)	11.52˚C (SD= 0.24˚C)	1.55%	5.23%
Germany	11.13˚C (SD= 0.58˚C)	11.39˚C (SD= 0.55˚C)	11.87˚C (SD= 0.54˚C)	2.34%	6.66%
Turkey	12.05˚C (SD= 3.15˚C)	12.81˚C (SD= 3.04˚C)	13.21˚C (SD= 3.00˚C)	6.24%	9.59%

Rather than look solely at the average water temperatures across each country, the predicted number of days that waters within each of the study countries remain within the optimal growth window for trout reveals a different and more reliable picture to help understand potential economic effects of temperature on production. The greater the proportion of days within the optimal temperature range for trout growth the greater the potential profitability, as this will reduce the length of a production cycle allowing fish to be harvested for market sooner. The analysis presented in Table 2.2 suggests that, on average across each county, the number of days when water temperatures are within the optimal growing range is greatest in the UK, followed by Denmark then Germany with the fewest in Turkey. This analysis also suggests that the conditions predicted under RCP 4.5 are likely to lead to more days within the optimal temperature range in all countries except Denmark (which is likely to see a small reduction. The UK is predicted to receive the greatest benefits under this scenario. Conversely, only Turkey is likely to benefit under RCP 8.5, with a reduction in the number of days within the optimal temperature window in all other countries, with Germany being most negatively affected.

Table 2.2. *Predicted annual proportion of days in which water temperatures are predicted to be in the optimal growing temperature range for Rainbow Trout (12-21°C) under current climate and predicted percentage change under RCP 4.5 and 8.5 projections.*

Region	Present day proportion of optimal days per	2050 RCP 4.5 proportion of optimal days per	2050 RCP 8.5 proportion of optimal days per	Annual national average change in temperature suitability for Rainbow Trout in 2050	
				RCP 4.5	RCP 8.5

UK	0.41	0.43	0.41	4.07%	-0.12%
Denmark	0.30	0.30	0.30	-0.17%	-0.17%
Germany	0.27	0.27	0.25	2.11%	-7.04%
Turkey	0.21	0.21	0.21	0.54%	1.47%

Presenting maps of the average annual proportion of days within the optimal growing temperature for trout helps further understand the current situation and the potential impacts of climate change. Figure 2.2 shows that the distribution of days with suitable temperatures is fairly evenly distributed across Turkey and Denmark but is not evenly distributed across the UK and Germany (Figure 2.2). Overall temperature suitability currently looks greatest in the UK with areas highly suited to trout production being located in the North and West. Under RCP 4.5 there is little change to this pattern in the UK, but under RCP 8.5 there is an increase in suitability in the North, but the area of least suitable temperatures in the Southeast grows.

Based only on temperature, Germany seems less suited to trout production than the UK, however, most of the North and North western areas of Germany have moderate suitability with the East and South East only having a very low proportion of growing days in the optimal temperature range. The importance of other factors become apparent because trout production mostly takes place in the South of Germany due to the availability of oxygen-rich streaming water in mountainous regions. The temperature suitability pattern changes little under RCP 4.5, but the low suitability areas grow substantially under RCP 8.5.

No predicted change in temperature suitability was predicted for either Denmark or Turkey. Both countries showed poor temperature suitability with regard to Rainbow trout growth, with optimal suitability being particularly low in Turkey. The low suitability in Denmark was due to the fact that temperatures were predominantly < 12°C, whereas in Turkey water temperatures were predicted to spend little time below the 21°C maximum. It should be noted, however, that these are predictions for Stillwater temperatures, and it is likely that those farms receiving river or spring water could be substantially cooler.

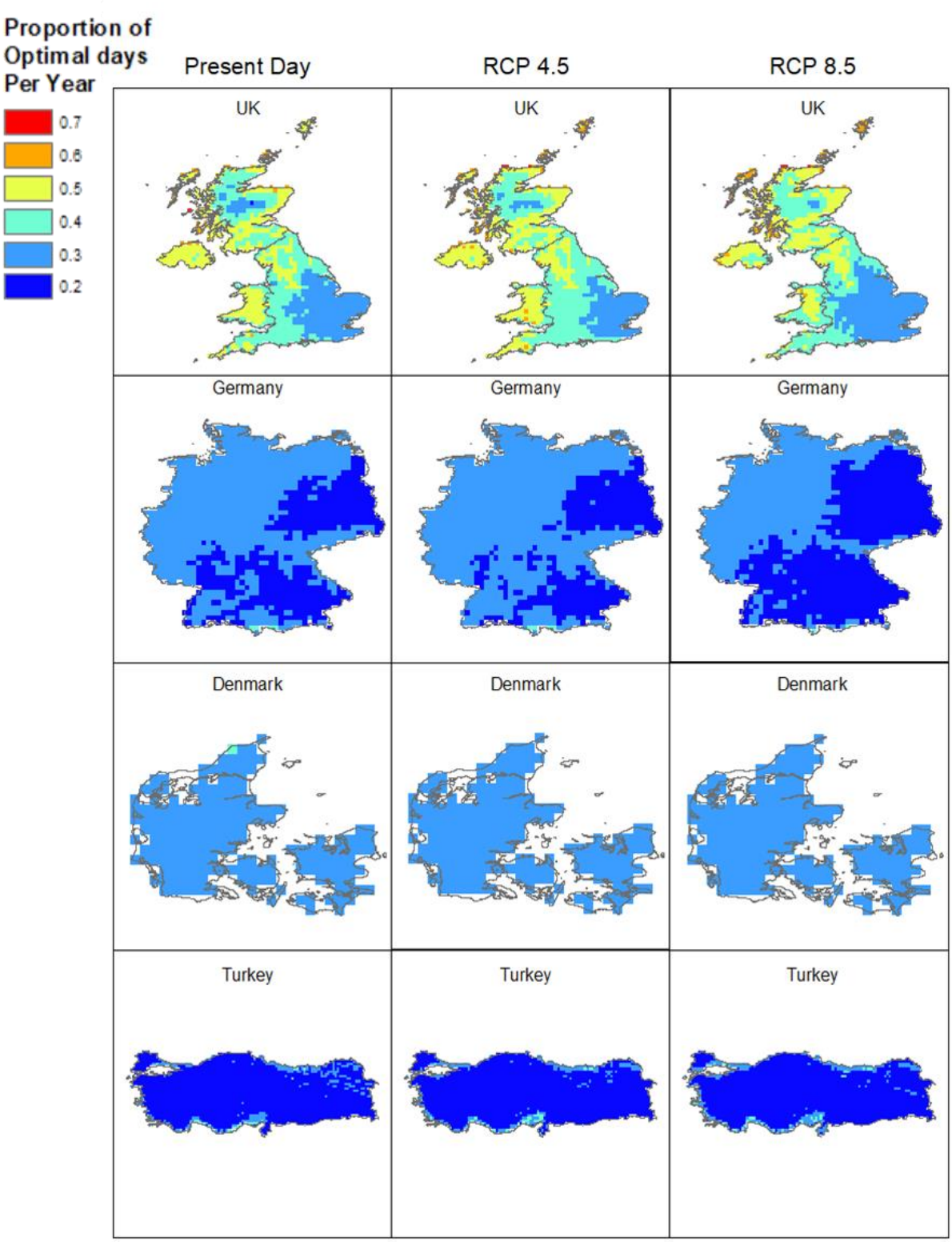

Figure 2.2. *Predicted annual proportion of days in which water temperatures are predicted to be in the optimal growing temperature range for Rainbow Trout (12-21°C) under current climate and RCP 4.5 and 8.5 projections.*

Although some trout aquaculture in Turkey uses floating cages in lakes, most freshwater trout are grown in online flow through systems that rely on their water supply from springs, boreholes or rivers. As a consequence, production is often limited by the amount of available water, especially in summer when temperatures can be high and oxygen levels declining. These factors and high amounts of metabolic waste products require reduced fish densities and/or increased flow rates/oxygen levels. As summer water supply can be limited, especially during drought periods, farms generally must reduce stocking densities. This reduced stocking density has a subsequent knock on effect to economic returns. In winter, water supply is less of a concern, but extreme weather event can lead to flooding which may damage farm infrastructure and equipment and lead to loss of stock through escapes. High water flows in winter can also lead to a build-up of debris around farm inlets which require regular clearing and maintenance to ensure ample water enters the farm, which may result in increased labour costs. Under RCP 4.5 Denmark the UK, and Germany are predicted to have increase summer rainfall in 2050, which is likely to be beneficial to operations in these countries (Figure 2.3). Denmark is also likely to see increases in summer precipitation under RCP 8.5 in 2050, but there is likely to be a small reduction in summer rainfall in the UK and Germany under this scenario. Summer rainfall is projected to decline under both RCP 4.5 and 8.5 in Turkey in 2050, although this is unlikely to impact its cage farming sites. Winter rainfall is due to increase in all countries under both RCP's except for under RCP 4.5 in Denmark and the UK which are predicted to experience little or no change (respectively) under both scenarios. Winter rainfall is predicted to increase substantially in Germany under both RCPs in 2050.

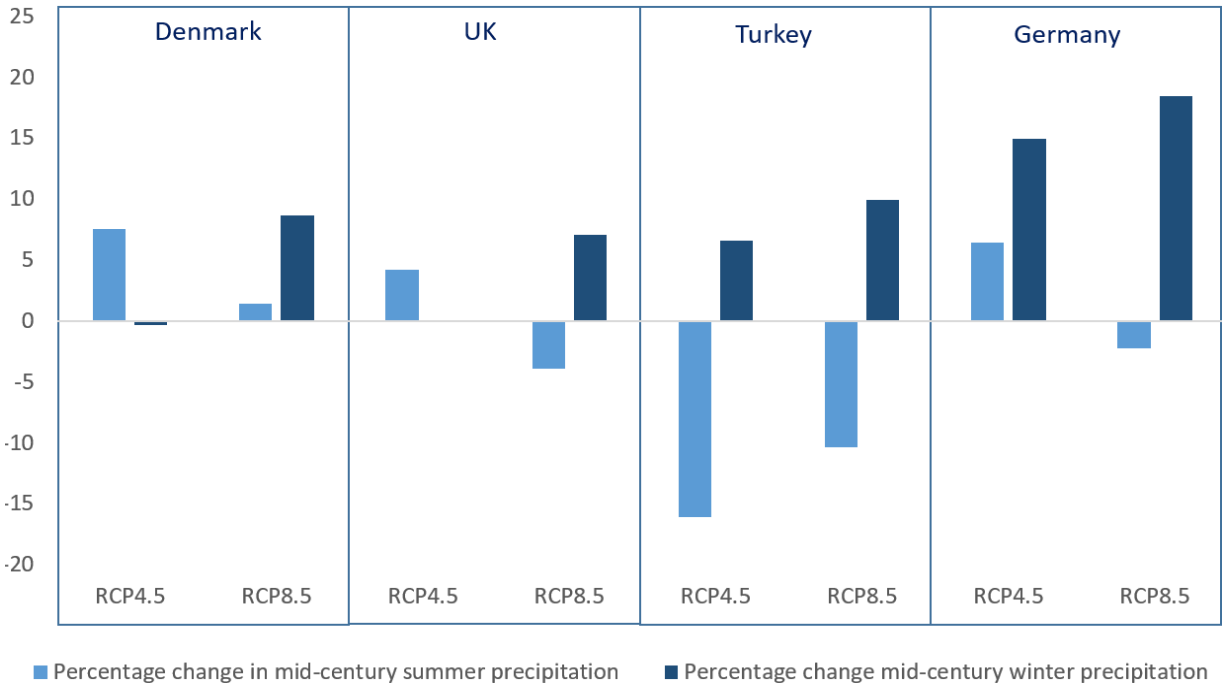

Figure 2.3. *Relative change in summer and winter precipitation predicted under RCP 4.5 and 8.5 in 2050 for selected CERES Rainbow Trout countries.*

Disease constitutes the most significant indirect economic impact to aquaculture production (Jennings et al. 2016). The impacts of key diseases have been addressed in CERES T3.1 and are included in subsequent regional analyses relating to the economic impacts of climate change on aquaculture productions. As discussed above, temperature is a key driver of disease and there is often a trade-off between optimal fish growth and the impacts of pathogens. In the trout sector the parasitic infection, Proliferative Kidney Disease (PKD) was found to be the disease of greatest concern through the stakeholder engagement sessions with the British trout industry and consistently archived the highest temperature suitability scores. This parasite causes disease at temperatures in excess of 15C and it is therefore well suited to the warmer Turkish water temperatures compared to the UK, Denmark and Germany (table 2.3). No change in habitat suitability for PKD was predicted for Denmark under either RCP but a substantial increase was predicted under both RCP's for the UK and Turkey and for Germany under RCP 8.5. Costs associated with this disease include preventative measures, mortality and reduced stocking densities.

Table 2.3. *Predicted annual proportion of days in which water temperatures are predicted to be in the optimal range for Proliferative Kidney Disease (PKD) in Rainbow Trout (>15°C) under current climate and predicted percentage change under RCP 4.5 and 8.5 projections.*

Region	Present day proportion of optimal pathogen infection days	2050 RCP 4.5 proportion of optimal pathogen infection days	2050 RCP 8.5 proportion of optimal pathogen infection days	National percentage change in optimal pathogen infection days in 2050	
				RCP 4.5	RCP 8.5
UK	0.37	0.37	0.39	2.38%	5.42%
Denmark	0.40	0.40	0.40	0.59%	8.74%
Germany	0.40	0.40	0.44	0.59%	8.74%
Turkey	0.47	0.49	0.50	5.43%	7.72%

2.3 Farm level Economic Consequences of Climate change

Results from the typical farm models displayed in Figure 2.4 show that Turkish farms had the lowest returns compared to trout farms from other countries and farm types (with the exception of DE-TRR-500), which despite their relatively low operating costs meant that profitability is low in both Turkish farm types studied. Both types of Turkish farms had equal returns/kg fish and feed costs were the most important cost followed by other variable costs (Figure 2.5). In contrast to farms from other countries where electricity was the most significant energy cost, diesel costs were more prominent for TR-TRR-500, where they were the third highest cost (Figure 2.5) and thereby also around 3x higher than for the other Turkish farm TR-TRR-450. This is likely to be particularly important in the future as diesel price is projected to increase significantly in the future and the overall cost increase under all CERES scenarios was subsequently >3 % higher for TR-TRR-500 than predicted for TR-TRR-450. In contrast to diesel costs, stocking costs were 1.5 times higher per kg fish produced for TR-TRR-450 than TR-TRR-500.

There are, however, fundamental differences between the two different Turkish farm types with TR-TRR-500 representing a land-based farm that is vertically integrated and includes all production stages from broodstock to marketable sized fish. The productivity in hatchery stage of trout production is low in Turkey (i.e. high losses of eggs and fry) thus higher financial losses are present here. Climate change is likely to increase losses at this stage due to envisaged reductions in water quality. Conversely, the TR-TRR-450 farm represents on-growing cage production that purchase 3-20 g fingerlings and grow them to marketable size. Buying fish at this size reduces the impact from some of the key disease concerns associated with the land based full production farms, although bought-in fry is likely to increase in price with increasing risk of production as well.

The typical English farm GB-TRR-360 and the small Danish farm DK-TRR-150 showed similarly low profit margins to Turkey. Although returns on these farm types were higher than in Turkey, their operating costs were higher, of which feed and other variable costs

were the most important. Larger Danish farms are more profitable, as although their returns were similar to the small Danish farms the operating costs were lower. The difference in profit margin between the two Danish farms mainly traces back to the high stocking costs for the 150-ton farms, which are twice as high as for DK-TRR-700 than the DK-TRR-150 which generally produce their own fingerlings (Lasner et al. 2017). GB-TRR-360 has higher feed costs/kg fish produced, which are explained by the combination of high feed conversion ratios (FCRs) and comparably higher costs per kg feed than for other typical farms analysed.

German trout farms are the most profitable. Profit in the German farms increases with size as the operating costs reduce. Returns for the small (DE-TRR-7.5) and smaller of the two large farms (DE-TRR-100) were similar but were lower in the farm with highest production volume (DE-TRR-500). Despite this DE-TRR-100 was the most profitable as its operating costs is comparatively low. Though feed costs are the most significant costs for all farms, other cash costs such as stocking, labour and farmstead costs are more prominent for the small German farm than the two large farms. The small farm is much more labour intensive in terms of production than the two professional larges farm types (DE-TRR-100 and DE-TRR-500). In addition, FCRs and thereby feed costs per kg fish produced are highest for the small German farm compared to all other typical trout farms analysed in CERES. Furthermore, fixed costs are higher for the typical small farm than for the other two German farms. This leads to the comparably lower profit margin, although returns are quite similar for all three German farms. Difference in returns across all farms are due to variations in sale channels, target market (export/domestic market) and farm size.

In addition to the variations in cash costs between the different sites described above, there are also some key differences in additional costs (opportunity costs, depreciation interests). The typical small German farm had the highest additional costs on long-term scale equivalent to more than 50% of the cash costs relevant to the short-term. The UK farm (GB-TRR-360) and the Turkish net cage farm TR-TRR-500 show the lowest additional costs (around 7%), whereas the other farms have mostly 10-20% additional costs relative to their operative costs within one year. Thereby, Turkish farms have high opportunity costs, but low depreciation, whereas Danish, English and large German farms show the opposite.

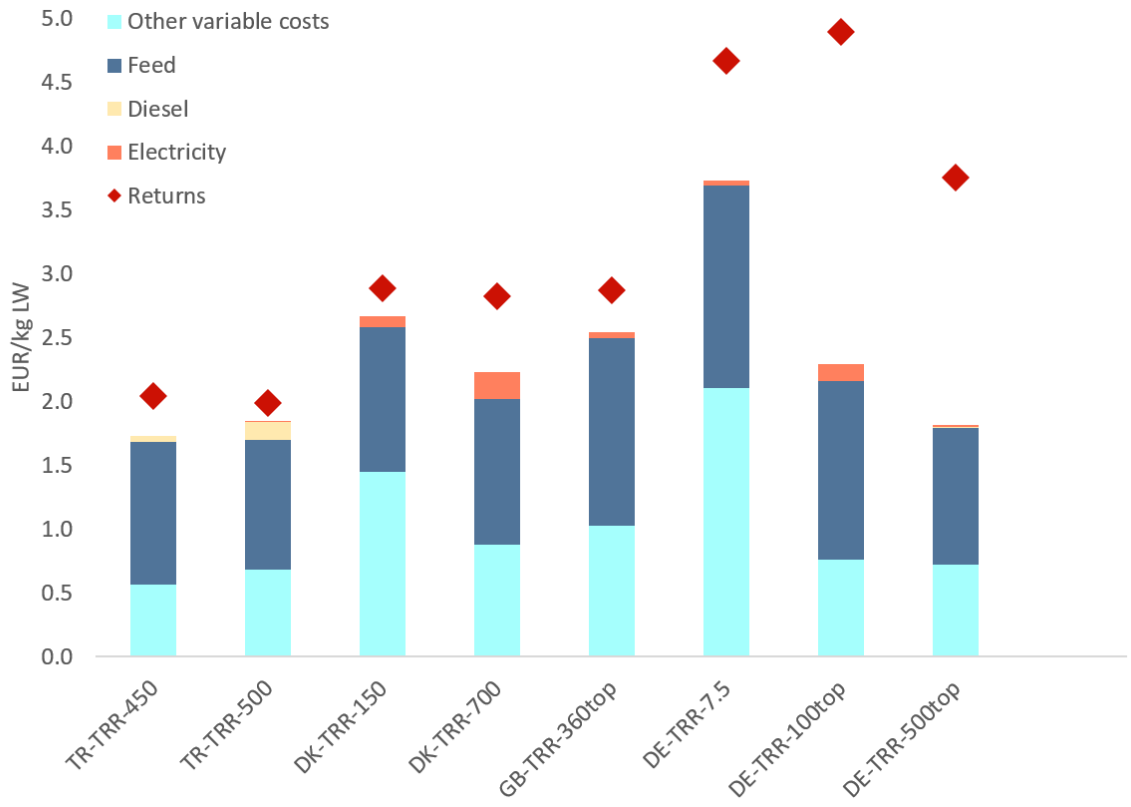

Figure 2.4. *Costs and returns (farmgate) from typical trout farm models. The distance between the red returns point and the top of the stacked costs represents the short-term profit/loss made by a farm. TR=Turkey, DK= Denmark, DE=Germany, GB = Great Britain. TRR=Rainbow Trout. Numbers refer to annual production in Tons.*

TR-TRR-500	**2016**	**DK-TRR-150**	**2016**	**GB-TRR-360**	**2016**	**DE-TRR-500**	**2016**
Operating earnings (€/kg)	0.14	Operating earnings (€/kg)	0.21	Operating earnings (€/kg)	0.33	Operating earnings (€/kg)	1.93
Most prominent costs in % from operational costs		Most prominent costs in % from operational costs		Most prominent costs in % from operational costs		Most prominent costs in % from operational costs	
Feed	55.53	Feed	42.62	Feed	57.89	Feed	58.77
Stocking	21.17	Stocking	33.05	Stocking	14.74	Stocking	14.77
Diesel	7.60	Labour	5.08	Labour	8.33	Machinery	9.63
Labour	6.82	Electricity	3.24	Advisory service	4.49	Labour	6.55
Other variable costs	3.46	Maintenance Machinery	2.95	Oxygen	3.08	Oxygen	3.95
TR-TRR-450	**2016**	**DK-TRR-700**	**2016**	**DE-TRR-7.5**	**2016**	**DE-TRR-100**	**2016**
Operating earnings (€/kg)	0.31	Operating earnings (€/kg)	0.59	Operating earnings (€/kg)	0.94	Operating earnings (€/kg)	2.60
Most prominent costs in % from operational costs		Most prominent costs in % from operational costs		Most prominent costs in % from operational costs		Most prominent costs in % from operational costs	
Feed	64.43	Feed	50.99	Feed	42.37	Feed	61.05
Stocking	14.39	Stocking	19.80	Stocking	21.64	Stocking	16.72
Maintenance Machinery	5.64	Electricity	9.60	Labour	10.88	Oxygen	6.90
Labour	5.98	Labour	5.59	Farmstead running costs	8.48	Electricity	5.77
Other variable costs	3.89	Maintenance Machinery	3.49	Accounting	3.33	Machinery	2.89

Figure 2.5. *Present operating earnings and most prominent costs in percent from overall operational costs for all typical trout farms analysed in CERES. TR=Turkey, DK= Denmark, DE=Germany, GB = Great Britain. TRR=Rainbow Trout. Numbers refer to annual production in Tons.*

Future profitability is dependent on the profit margin and model predictions suggest that the GS scenario will result in the least profitability of the four modelled scenarios, with the three other scenarios having similar consequences to profitability (Figure 2.6). Model predictions suggest that Turkish land-based farms (TR-TRR-500) and small Danish farms (DK-TRR-150), which both had a 2016 profit margin of around 7% will not be profitable under any of the four future scenarios. Conversely, the medium and large German best practice farms (DE-TRR-100, DE-TRR-500) with a 2016 profit margin of over 50% will become even more profitable under all future scenarios. Farms with a profit margin of 15-21% are still profitable under all scenarios, although operating earnings under GS are already quite small. The English trout farm (GB-TRR-360) with a 2016 profit margin of 11.55% will not be profitable under the GS scenario and would only just be profitable under the three other scenarios. With the exception of the medium and large German farm sites, all four CERES scenarios will have a negative effect on the profitability of trout farming if no adaptation is made to practices or supply chains and markets.

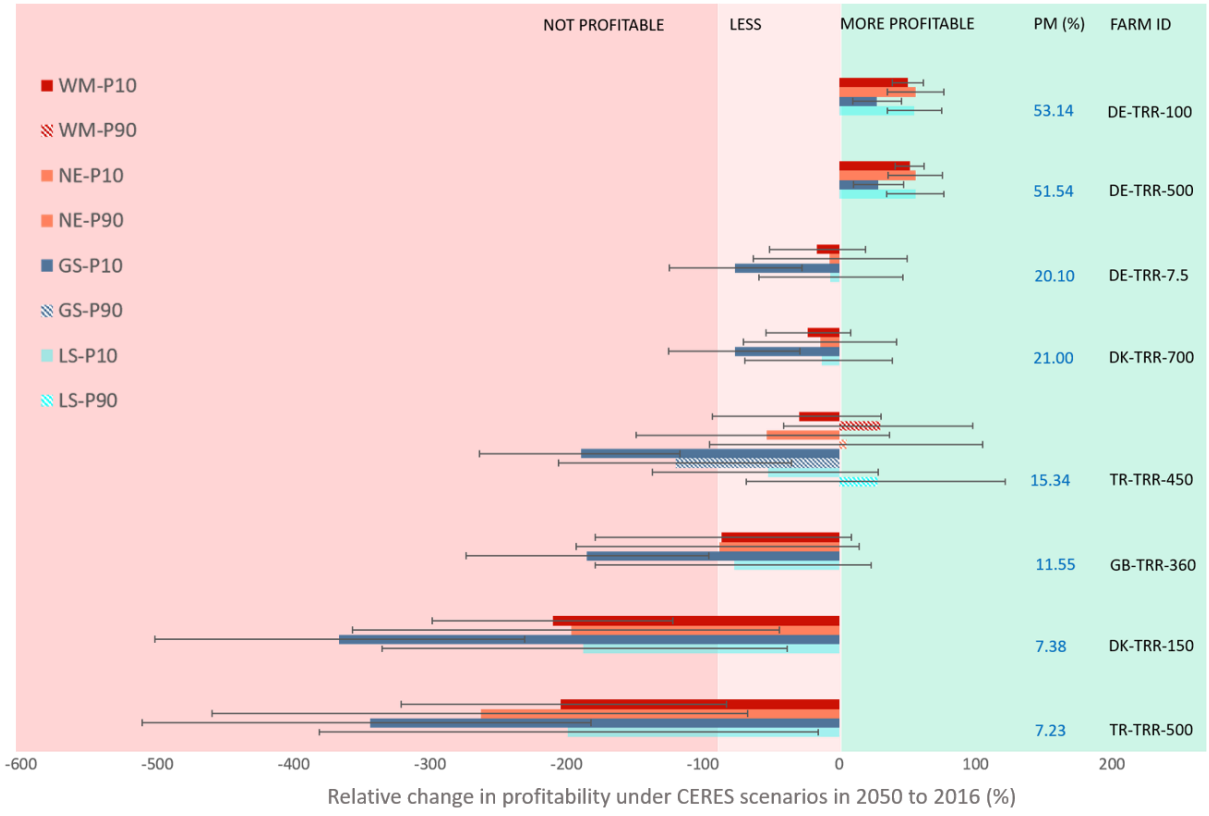

Figure 2.6. *Relative profitability change under the 4 CERES scenarios in 2050 compared to 2016 for the typical trout farms. World Market = WM, National Enterprise= NE, Global Sustainability= GS, Local Stewardship = LS. P10 = extreme cold year, P90= extreme warm year is only valid for TR-TRR-450. Error bars indicate 95% upper and lower probability ranges from Monte Carlo simulation. PM = Profit Margin in percent.*

Predictions averaged across the trout sector as a whole show that overall cash costs will increase more than returns under all four CERES scenarios (Figure 2.7) leading to reduced profitability in the future. Cash costs and return increase is least favourable for the GS

scenario, followed by NE, WM and LS with very little cash cost variation between the different farms (Figure 2.7). This leads to the observed results distribution with farms being least profitable under the GS scenario, but most profitable under LS (Figure 2.6). The reason for this is the comparably low fish prices under GS, which are derived from SSP-specific changes in population, income, international trade, agricultural expansion and technological change being major drivers for long-term changes in world food prices (see related publication on SSP modelling (Popp et al. 2017). Thereby GS shows lowest demand for agricultural commodities, resulting in more rapid growth in agricultural productivity and globalized trade (Popp et al. 2017).

Although operating earnings are lowest under the RCP 4.5 GS scenario, it has to be kept in mind, that compared to the RCP 8.5 WM and NE scenarios less climate change related impacts are assumed, e.g. less extreme weather variation that might need to be balanced with additional investments e.g. for potential additional aeration or shadowing of raceways. Conversely, changes in harvest weight and FCR (induced by variations in environmental parameters) might have a significant impact as well. For example the Turkish cage trout farms in the region of Elazığ was found to be positively influenced by extreme warm temperature years (P90) under RCP 8.5 with FCR and harvest size changes (see D. 3.3) causing even higher profits than today for WM and NE scenarios in the year 2050 (Figure 2.6). Extreme cold years within RCP 4.5 (GS P10 and LS P10 scenarios) had a negative impact on operating earnings due to lower harvest weight, but stable FCR, whereas an extreme warm year in the time slice of 2040-2060 leads to more favourable conditions with even higher operating earnings than today due to better growth and stable FCR.

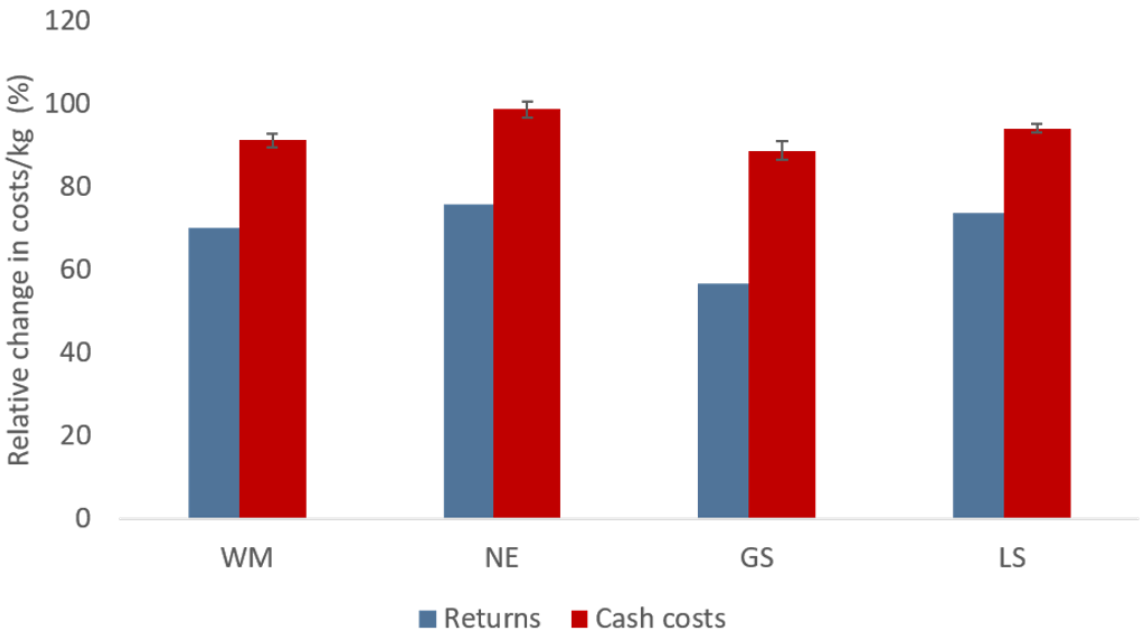

Figure 2.7. *Average percentage change in returns and overall cash costs (including feed, diesel, electricity and other costs) for all trout farms under the four CERES scenarios: WM = World*

Market, NE = National Enterprise, GS = Global sustainability, LS = Local. Error bars indicate standard deviation.

Prices may vary due to different reasons and especially those of globally traded commodities such as feed ingredients, crude oil or the product itself, might be dependent on a variety of market dynamics. A Monte Carlo simulation of future farm profitability considering variation based on historical changes in the price for feed ingredients, diesel and electricity and fish (returns) was conducted. Farms with "medium profit margin" (11.5-21%) could get even more profitable under optimal price development of costs and returns for WM, NE and LS scenario and in the worst case be no longer profitable under the GS scenario and less profitable under the other three scenarios (DE-TRR-7.5 & DK-TRR-700) or not profitable under all four scenarios (GB-TRR-360) (see error bars in Figure 2.7). The two farms with poor future prospects, DK-TRR-500 and DK-TRR-150, could reach the range of positive, but lower operational earnings compared today for the two local scenarios in the case of the Danish farm and for all scenarios except GS for the Turkish farm.

2.4 Regional Economic Consequences of Climate Change

The typical farm model shows the cash costs and returns for individual farms of the prevailing production system in important trout producing regions. Although changes in many of the costs incurred by farms under the four CERES scenarios will scale equally across the regional sector (e.g. changes in fuel and feed costs), directly induced climate change impacts (such as the effect of temperature on growth and disease and disease occurrence) will operate at the local level and cannot therefore be scaled equally across a region. Regional analysis must therefore make assumptions regarding the distribution of production across a region in relation to these localized impacts. Figures 2.8 to 2.15 provide maps showing the predicted change in relative profitability for a typical farm type located within a grid square within each of the countries of interest. These maps present the results of the typical farm model under the four CERES scenarios adjusted for the local effects of temperature on growth and disease occurrence and costs.

The potential changes in the profitability of trout farming across Turkey are presented in Figures 2.8. and 3.9. Under all four scenarios, land-based trout farming (TR-TRR-500) will not be profitable across the vast majority of the country (Figure 2.8), with only farms in a small number of grid cells retaining the potential to make profit, albeit lower than currently observed, particularly if the land in these areas is not suitable for trout farming (e.g. urban area).

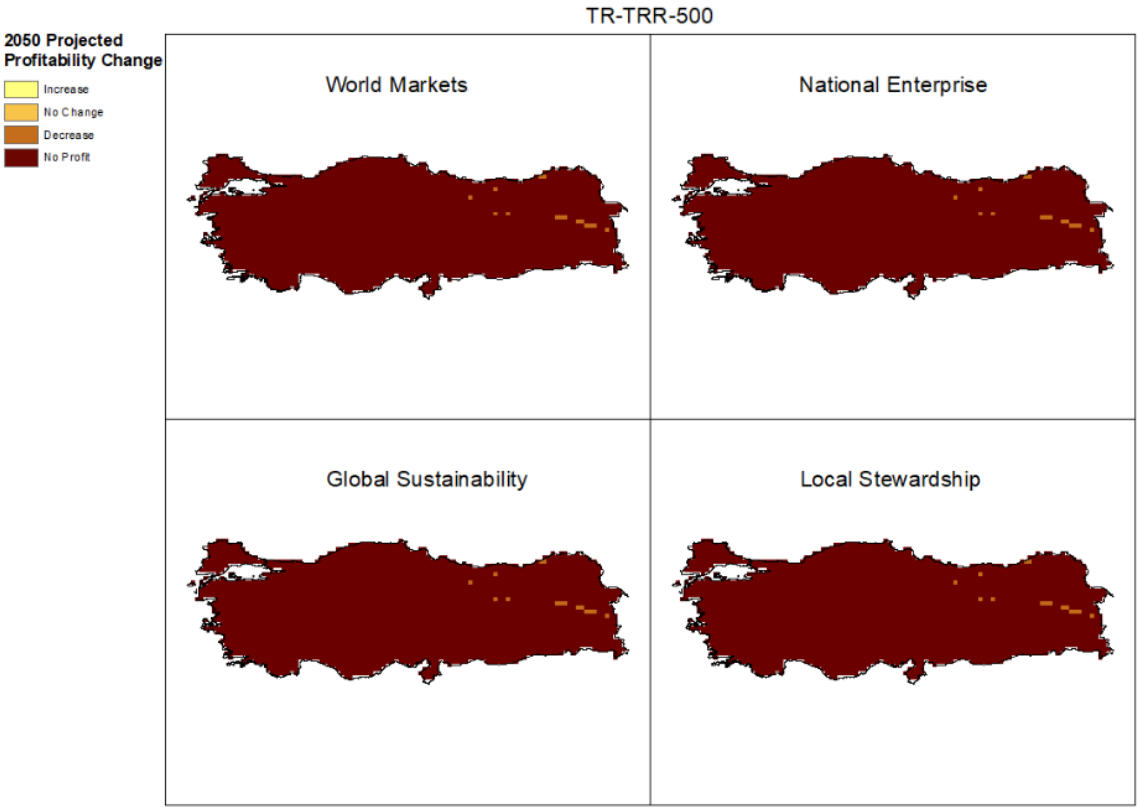

Figure 2.8. *Predicted consequences of the four CERES climate change scenarios on the profitability of land based Turkish Rainbow trout farms (TR-TRR-500).*

Figure 2.9 shows that cage-based trout farming (TR-TRR-450) is likely to experience reduced profitability whilst remaining viable across the vast majority of Turkey under all four scenarios. Under the WM and LS scenarios, however, there are a small number of grid squares where increased profitability could occur if it is possible to locate cage sites due to the relative suitability of temperature and lower disease risk.

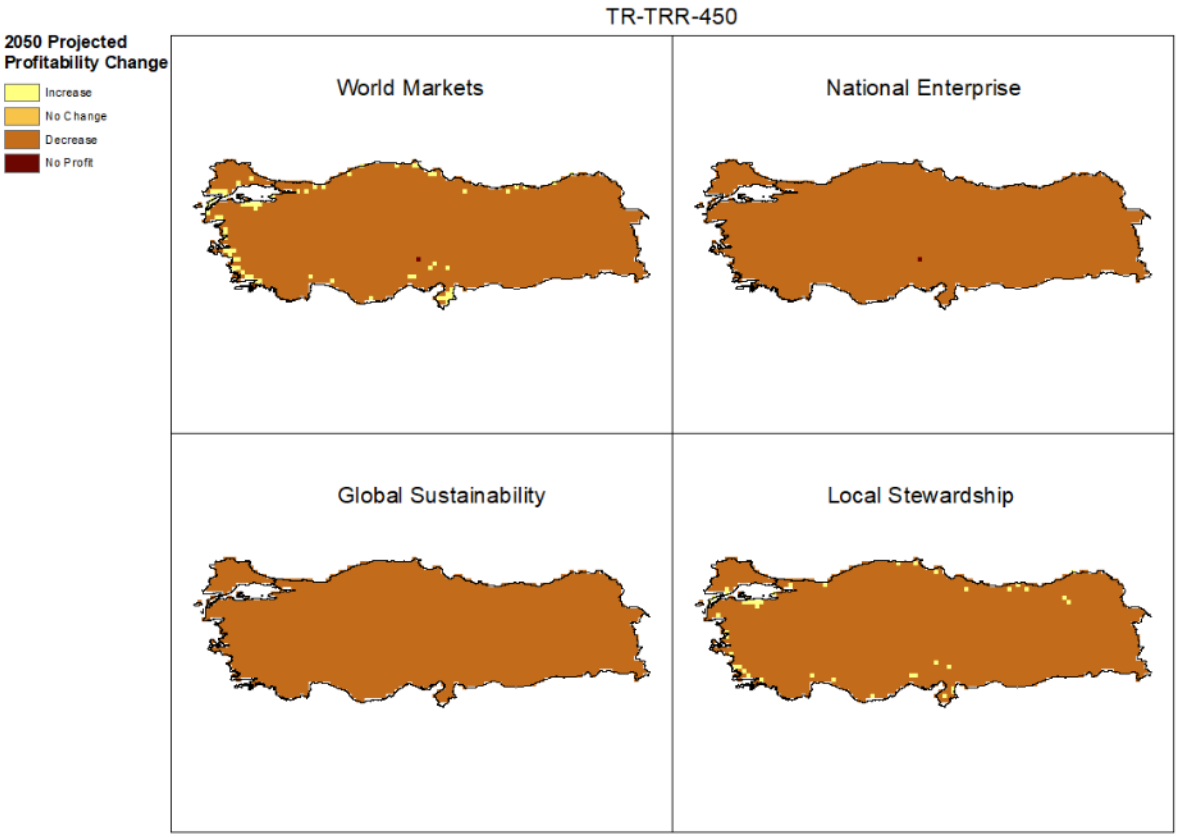

Figure 2.9. *Predicted consequences of the four CERES climate change scenarios on the profitability of cage based Turkish Rainbow trout farms (TR-TRR-450).*

The potential changes in the profitability of trout farming across Denmark are presented in Figures 2.10. and 2.11. Figure 2.10 shows large Danish trout farming (DK-TRR-700) is likely to experience reduced profitable whilst remaining viable across all of Denmark under all four scenarios. However, Figure 2.11 shows that under all four scenarios, small Danish trout farms (DK-TRR-150) will not be profitable across the country.

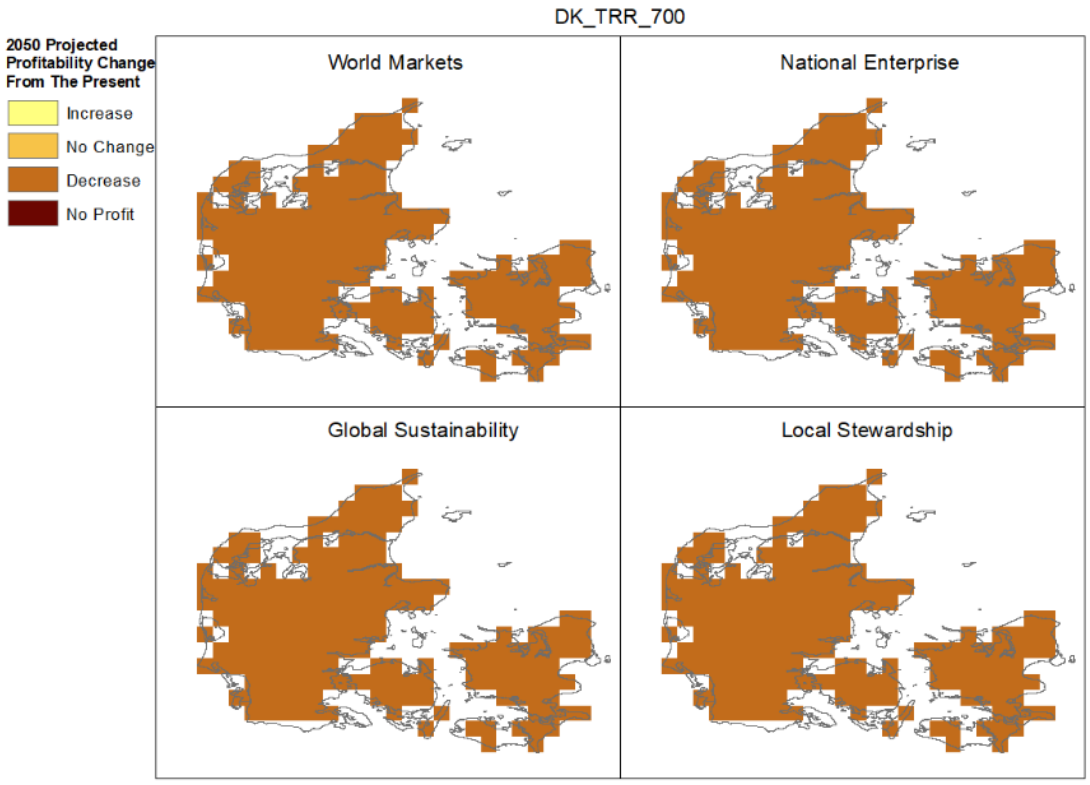

Figure 2.10. *Predicted consequences of the four CERES climate change scenarios on the profitability of large Danish Rainbow trout farms (DK-TRR-700).*

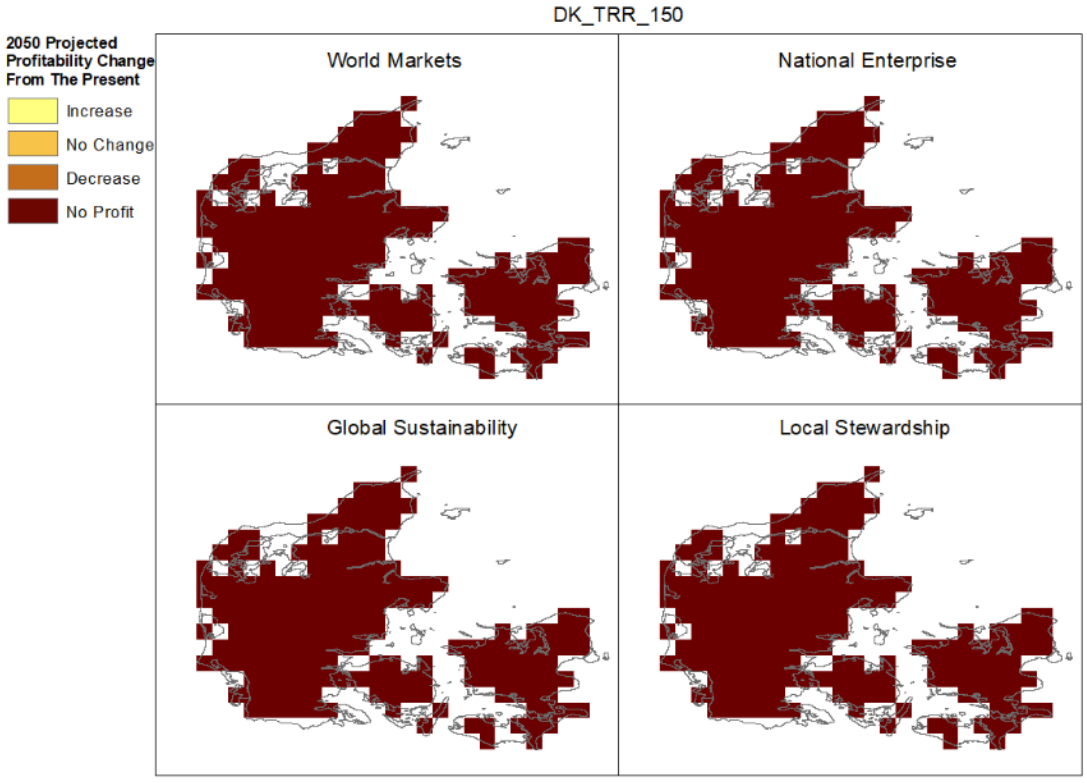

Figure 2.11. *Predicted consequences of the four CERES climate change scenarios on the profitability of small Danish Rainbow trout farms (DK-TRR-150).*

The potential changes in the profitability of trout farming across Germany are presented in Figures 2.12, 2.13 and 2.14. Figure 2.12 and 2.13 shows large (DE-TRR-500) and medium German (DE-TRR-100) trout farms are likely to generally experience increased profitability across Germany under all four scenarios. For both large and medium farms, the LS scenario is the most favourable, as under the three other scenarios small pockets of Germany are projected to experience reduced profitability, though this represents a small proportion of the total land mass, where there is a negative relative impact of the regional environmental factors. In contrast, small German trout farms (DE-TRR-7.5) are projected to experience reduced profit across the majority of Germany under all four scenarios. Again, LS is the most favourable scenario, with a small number of grid cells towards the Southwest of Germany predicted to experience increased profitability, indicating potential opportunity in regions where the majority of present-day trout farms are situated.

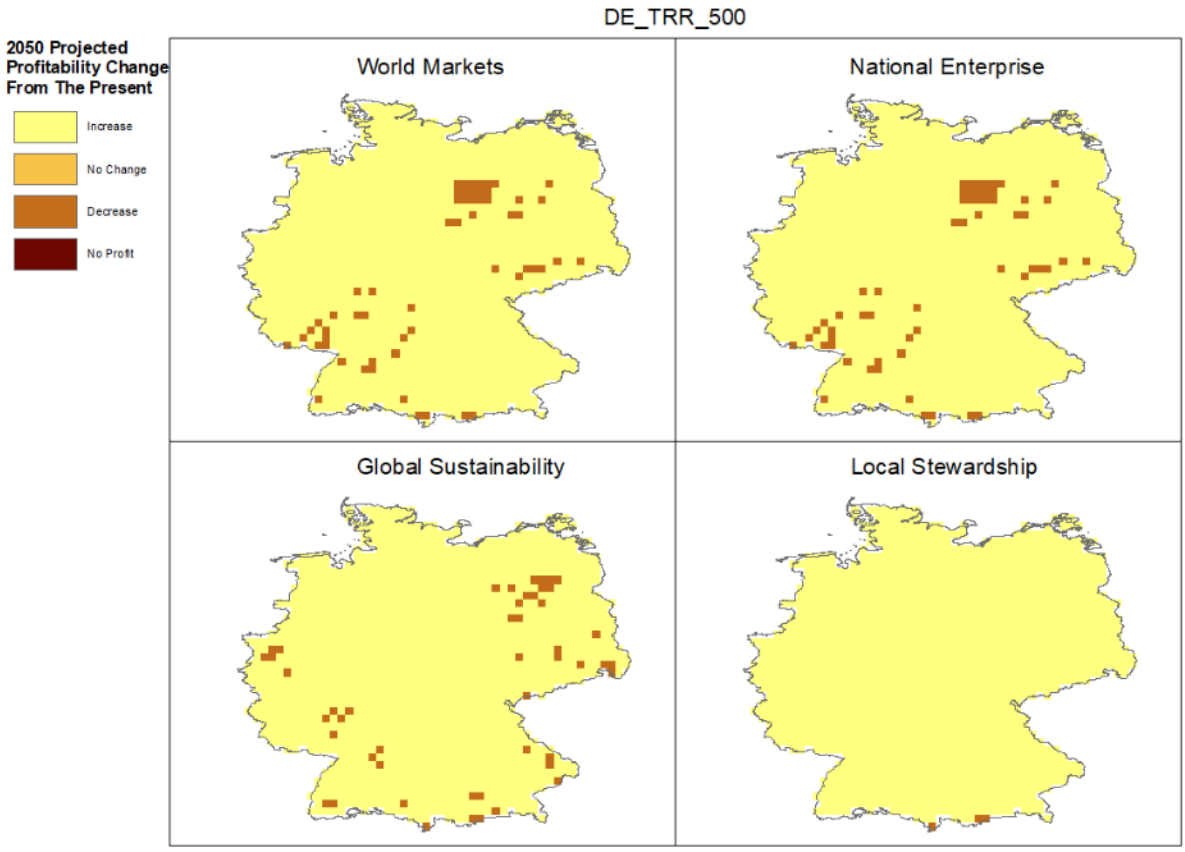

Figure 2.12. *Predicted consequences of the four CERES climate change scenarios on the profitability of large German Rainbow trout farms (DE-TRR-500).*

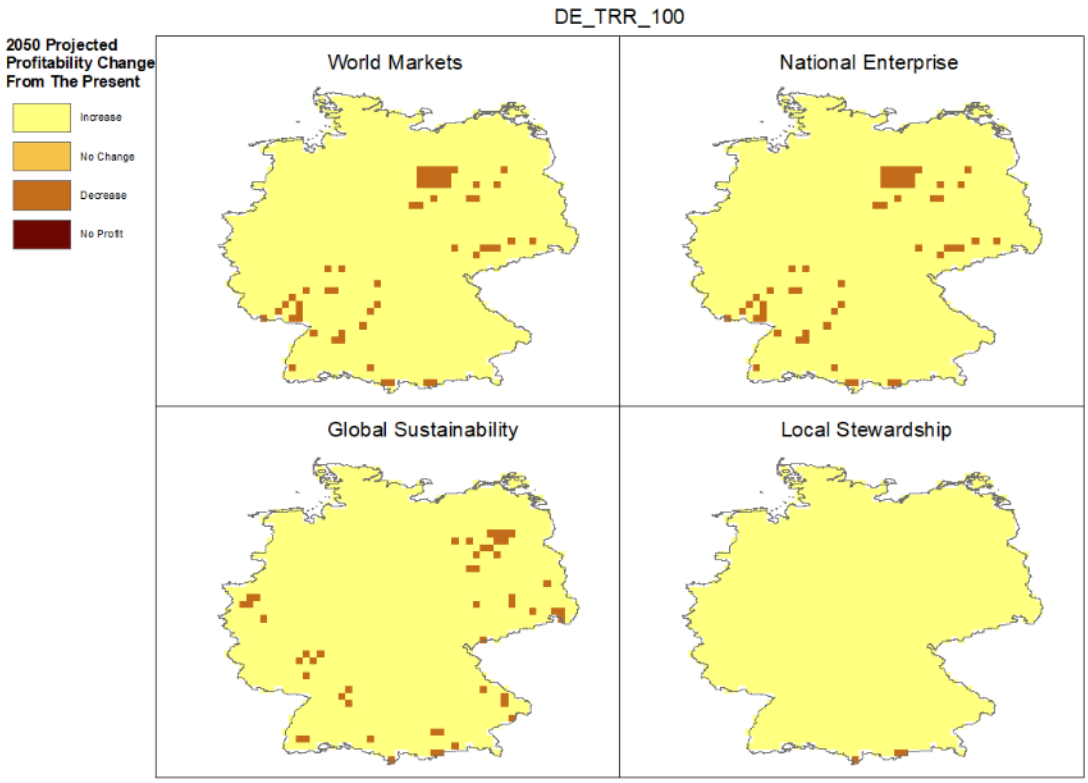

Figure 2.13. *Predicted consequences of the four CERES climate change scenarios on the profitability of medium German Rainbow trout farms (DE-TRR-100).*

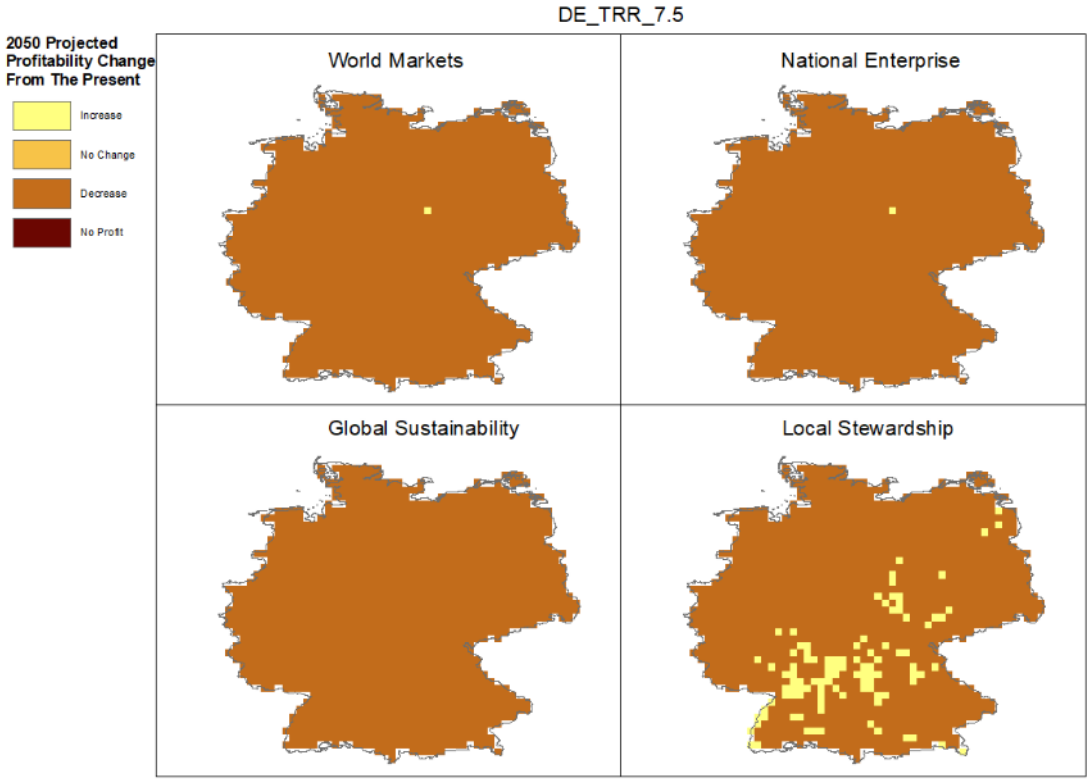

Figure 2.14. *Predicted consequences of the four CERES climate change scenarios on the profitability of small German Rainbow trout farms (DE-TRR-7.5).*

The potential changes in the profitability of trout farming across the UK are presented in Figures 2.15. This shows that all four scenarios will have a negative impact on profit across the whole of the country. Under the Global Sustainability scenario, farms across the whole country are projected to make no profit, whilst under the other three scenarios business could continue to operate but at reduced profit margins.

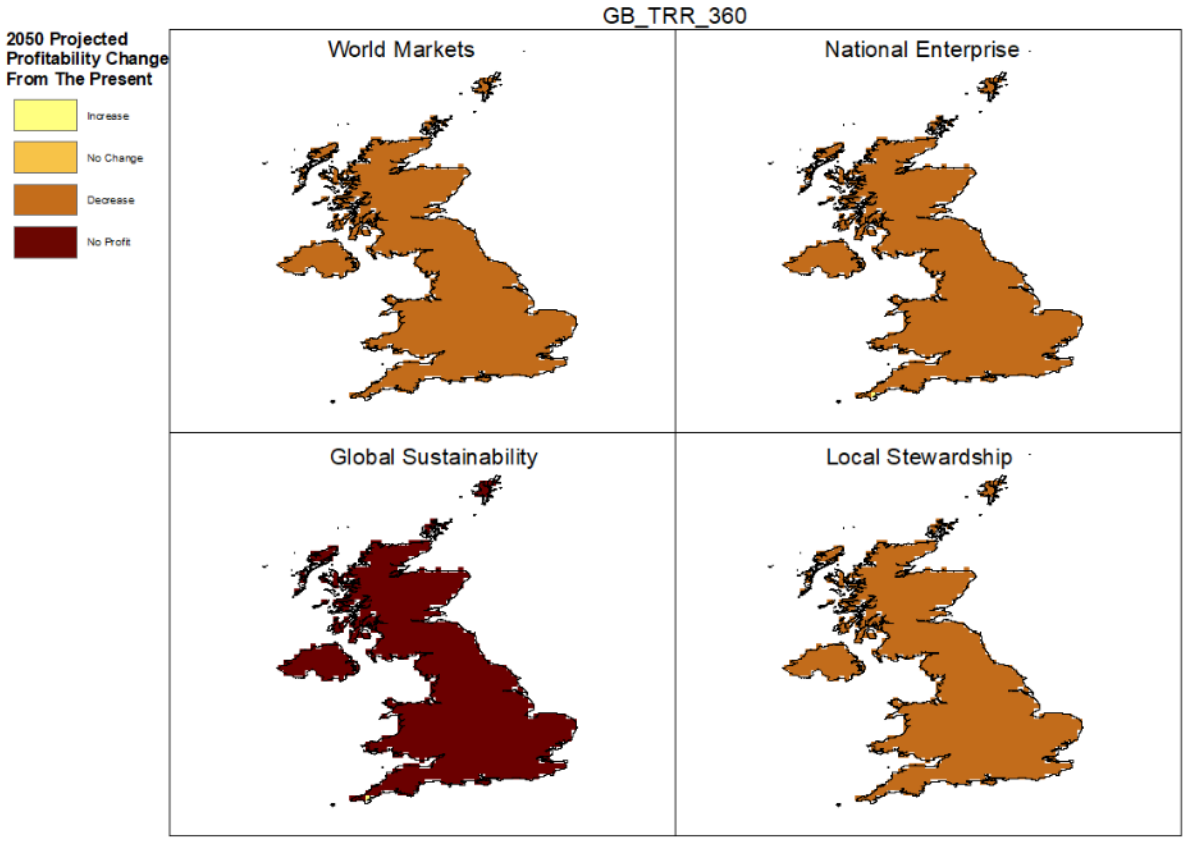

Figure 2.15. *Predicted consequences of the four CERES climate change scenarios on the profitability of UK Rainbow trout farms (GB-TRR-360).*

Overall, with the exception of and the two large German trout farms which are predicted to benefit in terms of profitability from climate change under all four scenarios, all other European trout farm types studied in this project will experience negative consequences. The lack of variation in predictions across each of the countries studied suggest that the localized effects of climate change on fish growth and pathogen impact have relatively little impact on the profitability of farms compared to changes in the cash costs and returns that are consistent across each farm type (e.g. feed and labour).

3.5 Conclusions, Opportunities and Challenges for Rainbow Trout Production

Within Europe, rainbow trout are the most commonly produced freshwater aquaculture species. Most of the industry across Europe is comprised of small- to medium-sized enterprises and, although there are some cage farming in lakes, the majority of sites are flow-through systems that rely on rivers, boreholes or springs to provide water of sufficient quality and quantity on a continuous basis to maintain their stocks. Analysis within this deliverable shows that in many cases farms of this nature operate on relatively small profit margins, largely due to high costs associated with feed and other cash costs. Some larger more intensive farm systems are however emerging across Europe that rely of greater use of technology to reduce their reliance on high levels of water supply and maintain good water quality. These include use of liquid oxygen to permit higher stocking densities and recirculation/partial recirculation systems which reduce the need for external water sources. Although such farms have a greater cost of initial investment and ongoing running costs, they are able to produce large volumes of fish and operate more efficiently at higher stocking densities, resulting in much greater returns and profit margins than the smaller farms.

At the physiological level, temperature is a key factor determining the growth of rainbow trout, and the FAO states temperatures between 12 and 21°C enable optimal growth to occur. Analysis under this CERES deliverable shows that of the countries investigated within the project, the UK currently has the greatest number of days per year in this threshold, with Turkey the least due to predicted temperatures exceeding the upper limit for much of the year. Periods below the optimal temperature threshold will slow growth, meaning longer time to market is required. Above the temperature threshold will also slow growth but can also result in increased oxygen demand, mortality and disease (plus associated treatment and veterinary costs). Under the future scenario's modest changes in the number of optimal growing days are predicted across the countries with the most extreme differences being -7% in Germany under RCP8.5 and +4% in the UK under RCP 4.5. These temperature changes are also predicted to lead to modest changes in the occurrence of key diseases such as PKD, which are predicted to increase as the temperatures increase. However, mapping both the direct changes in temperature and disease and their economic consequences show that there will be relatively little change across regions due to these factors, although extreme warm years under RCP 8.5 could lead to profit increase for TR-TRR-450 under the WM scenario when considering future FCR and individual weight. However, cage farming of rainbow trout in dam lakes in Turkey is also more vulnerable to increasing water temperatures. To date, warm temperatures have caused early harvests in May or June due to low oxygen concentrations and hypoxia. Early harvest leads to high quantities of rainbow trout entering the market and lower prices. This has a negative impact on the profitability of all rainbow trout farming

operations in Turkey, regardless of farming system (i.e. cage or land-based raceways) and is a challenge for economic sustainability of Turkish rainbow trout farming sector.

Of more concern than changes in temperature are changes in water availability, especially in the summer when water temperatures are high and increased flows are required to keep oxygen levels high and to remove waste products from flow-through farms. Projections suggest that under RCP4.5, all study countries with the exception of Turkey are likely to experience increased summer rainfall which is likely to be beneficial to the sector, however, under RCP 8.5 scenarios, all countries are likely to experience reduced summer rainfall which could limit carrying capacities and therefore production on sites. Under both RCPs, Turkey is likely to experience substantially less summer rainfall, and this is of great concern to the land-based farms. Winter rainfall is projected to increase for all the study countries under RCP8.5, and for Germany and Turkey, under RCP4.5. Increases in winter rainfall are predicted to be especially apparent in Germany. Although feedback from industry via stakeholder consultation meetings suggested this is less of a concern to the industry than reduced summer rainfall, there may still need to be some adaptation to cope with flood risk and prevent the build-up of debris in farm inlet channels.

Mitigating the direct, negative effects associated with climate change is either through the implementation of new technologies or the transition to new species. One of the key challenges of higher temperatures is the increase in oxygen demand and reduced availability of oxygen in the water. Standard forms of aeration have limited effect at very high temperatures or stocking densities, but some larger farms overcome these issues (at least in part) by using liquid oxygen to supersaturate water in holding units. However, increased oxygenation does not overcome the other issues associated with high temperatures, such as increased physiological stress and increased disease burden. Improved treatment regimes, biosecurity and husbandry practices may reduce disease concerns. Reducing physiological stress, however, will only be possible by reducing water temperature. To do this, some sites may be able to use cooler ground water supplies to reduce temperatures in farms, but for most sites, technological solutions are required. Recirculation and partial recirculation systems may be able to partially regulate water temperatures; however, this is likely to be energy intensive and, thus, will increase investment and running costs in the investment in infrastructure required by these sites will be prohibitive to most small producers. Recirculation technologies may also provide resilience in the face of reduced summer flows as they minimise the need for external water sources and use integrated filtration systems to remove solid and nitrogenous waste products arising from food waste and excreted from fish. However, these systems bring with them their own unique challenges. In addition to the high set up and running costs, disease poses a significant concern, as well as recirculating water, they will also recirculate pathogens, allowing rapid transmission and amplification. Control of pathogens in these systems is also challenging, as many treatments will impact biological

filtration systems, which may render them ineffective and cause nitrogenous waste products to build up to toxic levels.

In some instances, farming different species or strains of trout may provide an opportunity to overcome environmental changes. Specific regional trout strains exist that appear to show better survival and growth under environmentally stressful local conditions than generic trout strains, for example the so-called "BORN"-strain of Rainbow trout produced in the northeast of Germany. This suggest that further research into selective breeding programs may be of benefit to the European trout sector. In terms of alternative species, Arctic char (*Salvelinus alpinus x fontinalis*) has been investigated by a number of farms as this species has proven to be more resilient to disease, but it is more sensitive to higher temperatures. Carp provide an obvious substitute where temperatures are warm and water supply is limited. Carps are tolerant to high temperatures and low oxygen and decreased water quality, but their sale value is not as high as trout. Another warm-water species that may be an option in some areas of Turkey, especially if combined with recirculating technology, that can be temperature controlled are species of tilapia. There is a wide global market for tilapia, and the recent emergence of disease within several key producing countries may mean there are opportunities to realise new markets. Tilapia are generally robust fish that grow quickly and do not require high water quality conditions, their limiting factor is that they are cold sensitive and will stop feeding if temperatures drop below 17°C.

Though environmental conditions are important in terms of the viability of a rainbow trout farm, the regional level analyses suggest they have little impact on the profitability of the sector when considering the average annual proportion of days within the optimal growing temperature compared to today. The analysis of minimum and maximum future FCR and harvest weight however shows that temperature variation will have an impact on profitability, which might give a strong effect in combination with future price trends as seen for TR-TRR-450 under extreme cold and warm year scenarios for the time slice 2040-2060. Operating costs are key to the profitability of a farm and fish feed is the single biggest expense. Model predictions under the four CERES scenarios investigated, show feed prices to rise significantly and increase costs of operating a farm. The models assume the same future feed composition as today but consider also the market influence of fishmeal and fish oil alternatives according to the different scenarios, assuming highest availability of substitutes under the two global and innovative scenarios WM and GS. Potential substitutes could be insect meal, single cell protein, animal protein or marine algal oil as well as gene modified plant oil. Besides reducing the amount of marine ingredients, the (partly) replacement of other ingredients with respective impacts on future feed prices is conceivable as well. In addition to alternative feed ingredients, there may also be opportunities to employ technology to improve feeding. At present many trout farms are hand fed (especially in the case of smaller farms), which may firstly not optimise growth but secondly may lead to fed waste. Integrating technology from larger sectors (such as the marine salmon industry) that automatically dispense food,

monitor feed up take and adjust feeding rates accordingly, may help reduce feed costs and reduce staff costs if the initial investment and ongoing maintenance costs of such systems are sufficiently low.

Projections undertaken here suggest that small farms, especially those in Denmark and land-based farms in Turkey, will find it challenging to remain profitable under any of the four global scenarios investigated. To survive, it is likely that small, independent farms will need to change their business model, potential by forming cooperatives which may increase their buying power and allow the sharing staff and costs relating to equipment and machinery, although sharing staff and equipment brings with it biosecurity risks that need to be mitigated. Alternatively, where possible farms may need to grow and intensify in a similar way to the larger German model farms that are predicted to benefit in each of the four, future climate scenarios. A key consideration under any of these scenarios will be the supply of fry, and potentially moving towards more vertically integrated business types that produce their own fry which given improvements in production technologies may reduce costs and reliance on otherwise potentially vulnerable suppliers, but increased risk of such operations will have to be managed.

The Turkish industry is predominately centred on exports. To offset some of the increasing costs to the Turkish sector it may be possible to target new markets that will pay premium prices to achieve higher market returns. This has been occurring and has been beneficial in recent years with expanding exports from Turkey to Japan and Russia. Under the WM scenario, there is greater potential for these opportunities due to the large predicted increase in the European population. However, under the other scenarios achieving a good price via exports could be challenging and may require a change in practices. For example, under the GS scenario where demand and fish prices are predicted to be lowest and environmental concerns important, moving to a high-quality low impact product will likely be required to effectively market trout for export. Although the NE scenario has the highest population increase and greatest expected fish prices, increased tariffs are also expected and a good profit margin would be important to take advantage of the higher demand, which based on projections made here, is likely to be challenging.

Declines in the Turkish trout industry would lead to opportunities for others. For example, at present production in the UK is only sufficient to meet domestic need, but projections made here suggest that trout farming conditions in the UK are likely to improve. If greater production can be realised by applying the business models suggested above, there may be a growing demand and potential for exported product. Increased export markets and demand may also provide incentives for increased marine rainbow trout production, which could result in massive increases in production and can produce product with a high market value. Marine trout are more thermotolerant than Atlantic salmon which may allow farming to move to new areas of coastline.

In summary, the future profitability for rainbow trout farming across Europe in its current form is likely to be challenging, however there are mitigations measures that could be implemented and opportunities for change. Although changes in environmental conditions are likely to increase the vulnerability of the sector, it is predominantly the changes in feed costs that affect profitability under the four future scenarios. Large German farms demonstrate profitability that may increase under all the future scenarios under the pre-condition of sufficient water availability and quality. At present such farms represent only a very small proportion of the total European trout production, so large changes will be required for profitability to be retained. Key to this will be greater use of technology to help intensification (increase carrying capacity) and reduce staff and feed costs. Additionally, moving away from the current situation of small independent producers to the formation of cooperatives or larger vertically integrated business is also likely to be critical. However, with a growing world population, there is likely to be increased demand and, under some of the scenarios, there will be greater potential to exploit the global export market.

Chapter 3 European Carp Aquaculture

3.1 Introduction

In Europe, production of common carp (*Cyprinus carpio*) ranks second after rainbow trout for the freshwater species, with aquaculture largely focussed in central and Eastern Europe (FEAP 2017, Eurostat). The predominant production technique is semi-intensive earthen pond aquaculture. Besides producing fish, these ponds fulfil multiple additional functions such as playing an important role in water and landscape management and contributing to the preservation of cultural heritage (Popp et al. 2018). Feed costs play a less prominent role than for other cultured finfish species as natural food sources available in ponds (e.g. insects, molluscs and annelids) are supplemented by grains or cereals, often the by-product of associated terrestrial agriculture activities (Kestemont 1995, EUMOFA 2016). A second unique attribute of this species is that it is pre-dominantly marketed as live fish, especially during the Christmas period, which also limits the transport and exportation radius (EUMOFA 2016). Within CERES, we concentrated on Poland and Germany as production country case studies of common carp.

Poland is one of the two main carp producers in the EU, next to Czech Republic. Both countries produced around 18,000 tons of carp in 2016 (FEAP 2017), but the area allocated to carp farming is significantly greater in Poland (Lirski and Śliwiński 2019), currently being around 54000 ha. Most of the carp farms are located in the south of Poland within the voivodeships Subcarpathia, Lesser Poland, Lublin, Silesia, Greater Poland and Opole (Figure 3.1). The overall economic value in 2016 was about €41 million (The EU fish market 2018, Turkowski 2018). EU direct payments for agricultural land play an important role for Polish carp farmers. At the EU level, Poland is a main importer of live carp, whereas the export volume is not significant (EUMOFA). Two typical Polish carp farms, originally defined within the SUCCESS project, were analysed within CERES. Both are located in the region of Barycz Valley and represent a medium-sized farm with a total production of 90 tons (PL-FCP-90) and a large-scale farm producing 190 tons (PL-FCP-190) (Figure 3.1).

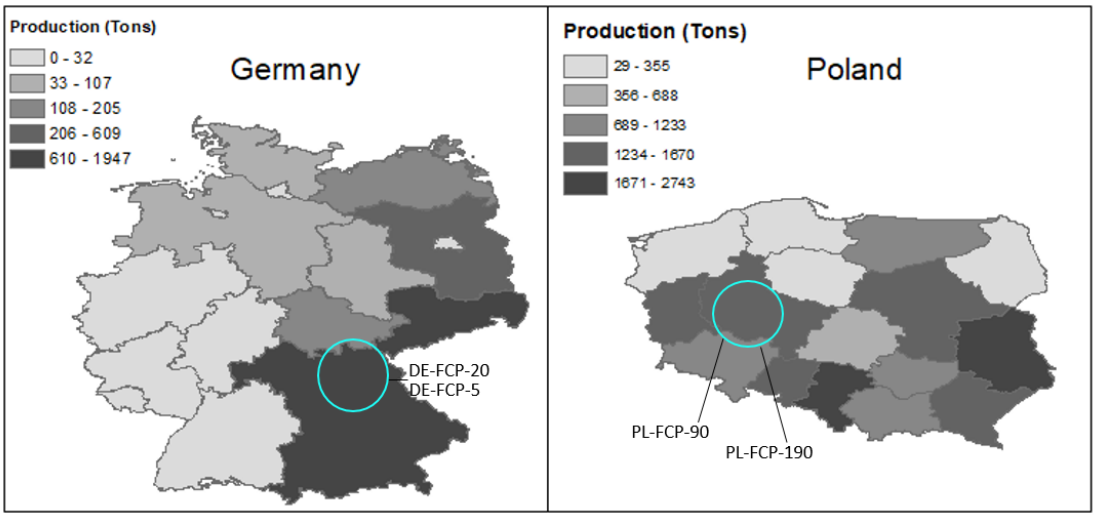

Figure 3.1. *2016 regional production (tons) of Common carp (Cyprinus carpio) for CERES case study countries: Germany and Poland. Locations of the typical carp farms are indicated by circles and labelled with a country-species-yearly production (t) code. Data sources: German Federal Statistics Office, Poland: Lirski 2016.*

Germany is a moderate producer of carp with around 5000 tons of annual production (5238 tons in 2016, German Federal Statistics Office 2017) with a total value of about €13 million (OECD Statistics). Main production regions are located in the east and south of Germany within the counties of Bavaria, Saxony and Brandenburg (German Federal Statistics Office, 2017). While the majority of the carp farms in Germany are small family businesses producing less than 1 ton (> 4000 farms). In 2016 only 160 farms were responsible for >75% of the total production (German Federal Statistics Office 2017). In Bavaria, direct payments for carp production is available for SMEs following specific feeding and stocking regimes (Bayerisches KUlturLAndschaftsProgramm "KULAP", Bavarian culture landscape programme). Like Poland, Germany is a main importer for live carp (ca. 4000 t in 2016), mainly from Czech Republic and Hungary (Destatis database). Five Protected Geographic Indications (PGI) for German carp are registered and three of these originate from specific areas in Bavaria (http://ec.europa.eu/agriculture/quality/door/list, The EU fish market 2018). Carp produced according to the respective EC regulations and certified by an accredited organisation may be branded under the protected name with the potential of higher market returns, which was also included as marketing option within the present economic analysis of the German carp farms in the year 2050. Typical farms analysed within CERES, where defined in the course of the SUCCESS project and are located within the "Aischgrund" region in Bavaria (PGI: carp from the Aischgrund region, EC 510/2006). A small-scale family-owned carp farm with a yearly production of 5 tons (DE-FCP-5) and a good practice farm with a production of 20 tons and an additional crop enterprise (DE-FCP-20) were selected (Figure 3.1). Both German farms produce in sky ponds (static ponds fed by rain and ground water), which is the prevailing production system in Bavaria (71%, Füllner et al. 2016).

3.2 Climate Change Effects on Habitat Suitability for Carp

Carp are a very temperature tolerant species being able to persist at temperatures between 3 and 35°C and survive at low dissolved oxygen levels associated with high temperatures and stagnant water bodies. It is due to this wide temperature tolerance that carp are globally distributed and are so frequently used in aquaculture. Optimal growth of the species is achieved at temperatures between 15 and 25°C. Assessment of the annual predicted average water temperatures within Germany and Poland suggests that at present the average temperatures for both countries are very similar, and they are well below this optimal range and will remain so under RCP 4.5 and 8.5 (Table 3.1).

Table 3.1. *Average predicted water temperatures in Carp case study countries, and the predicted change under RCP4.5 and 8.5.*

Country	Average national present-day water temp	Average national 2050 water temp – RCP4.5	Average national 2050 water temp – RCP8.5	Percentage change in national average water temperature in 2050	
				RCP 4.5	RCP 8.5
Germany	11.13^{0}C (SD= 0.58^{0}C)	11.39^{0}C (SD= 0.55^{0}C)	11.87^{0}C (SD= 0.54^{0}C)	2.34%	6.66%
Poland	10.94^{0}C (SD= 0.41^{0}C)	11.21^{0}C (SD=0.42^{0}C)	11.73^{0}C (SD = 0.39^{0}C)	2.54%	7.25%

Analysis to predict the number of days in the optimal growing temperature for each country also suggests both countries are similar, with 28% (Germany) to 30% (Poland) of days in the year on average across each country being in the optimal growth range for carp (Table 3.2). Under both RCP's, this proportion is set to increase for both countries. Under RCP 4.5 the increase in Poland is predicted to be over double that of Germany. Under RCP 8.5 the proportion of days in the optimal temperature range is predicted to increase by circa 22% for both countries, which is double the predicted increase for Poland under RCP 4.5. This analysis suggests increased opportunities for Carp production in both countries under either of the RCP's.

Table 3.2. *Predicted annual proportion of days in which water temperatures are predicted to be in the optimal growing temperature range for Carp (15-25°C) under current climate and predicted percentage change under RCP 4.5 and 8.5 projections.*

Region	Present day proportion of optimal days per	2050 RCP 4.5 proportion of optimal days per	2050 RCP 8.5 proportion of optimal days per	Annual national average change in temperature suitability for Carp in 2050	
				RCP 4.5	RCP 8.5
Germany	0.28	0.30	0.34	4.90%	21.71%
Poland	0.30	0.38	0.37	11.25%	22.01%

Assessing the temperature distribution in terms of optimal growing days at the regional level and the consequences of predicted changes suggests a significant change in growth potential across large areas of both countries (Figure 3.2). In Germany, present day projections suggest optimal growing days are around 30% and evenly distributed except for small areas in the far north, far south and central belt having slightly lower proportions of optimal growing days than the rest of the country. A small area in the southeast has slightly better growing conditions than the rest of the country. Under RCP 4.5 this area, and the far east of the country, are likely to increase slightly in range with an increased number of optimal growing days. Under RCP 8.5, these areas of improved growth expand substantially and around 50% of the country is projected to have improved growing conditions.

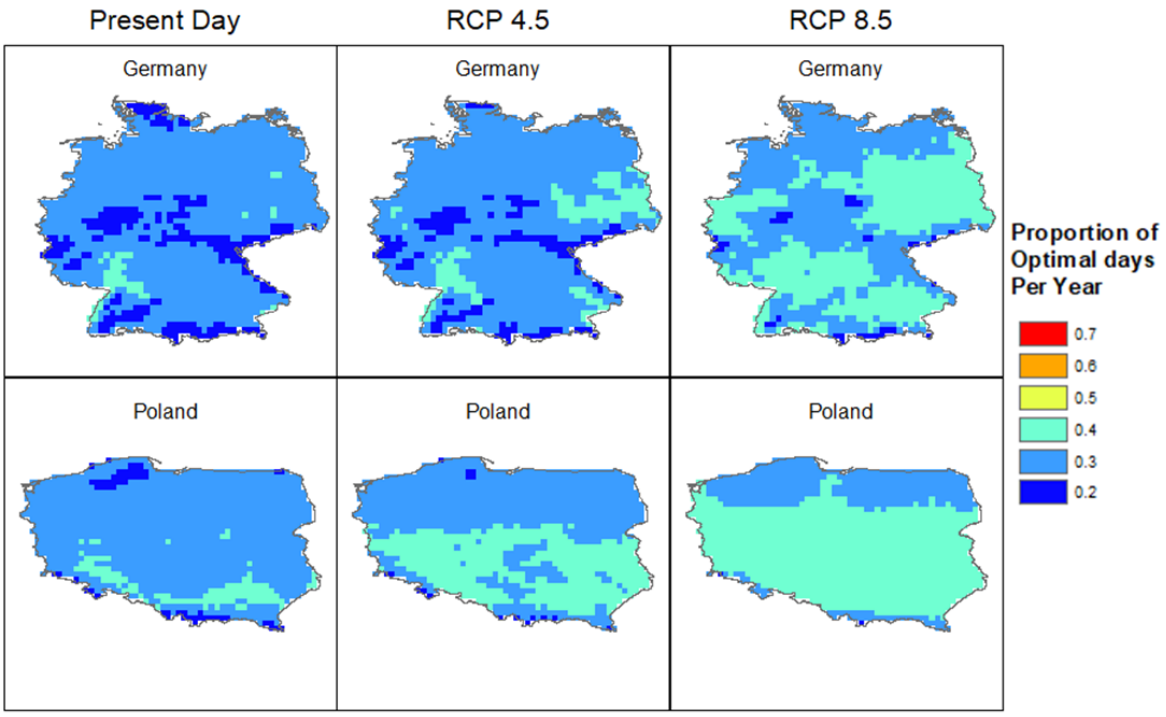

Figure 3.2. *Predicted annual proportion of days in which water temperatures are predicted to be in the optimal growing temperature range for Carp (15-25°C) under current climate and RCP 4.5 and 8.5 projections.*

In Poland, estimates of water temperature under current climate conditions suggests a fairly uniform pattern in terms of optimal growing days. As is the case with Germany, around 30% of days within the year are predicted to be in the optimal temperature range across most of the country, bar a thin strip of land across the south of the country where more optimal growing days are predicted, and a small area in the North where less are predicted. Under RCP 4.5 an increased number of optimal growing days are predicted across most of the southern half of the country. This pattern expands further under RCP 8.5 with increased growing days predicted across around 75% of the country, with only the north of the country not experiencing any substantial change.

Compared to rainbow trout which generally require a continuous flow of clean water and rapid water exchange rates, carp are generally grown in earthen ponds with little or no water exchange. This is possible as they are able to tolerate lower oxygen levels and higher levels of nitrogenous waste products and are therefore less dependent on high water exchange rates. Though summer rainfall is therefore likely to have less impact on carp than trout production, it is still important to prevent oxygen deficiency and lowered water levels that might facilitate bird predation as well as in terms of maintaining ground water levels. Future rainfall projections for 2050 predict a small increase in summer rainfall for both Germany and Poland under RCP 4.5, but under RCP 8.5, predict a small decrease in Germany compared to a small increase in Poland (Figure 3.3). A moderate increase in winter rainfall is predicted for both countries under both RCP's, with increases

predicted to be higher under RCP 8.5 than 4.5. Especially for precipitation dependent sky ponds (DE-FCP-5, DE-FCP-20) this could be beneficial as it is important to have sufficient winter precipitation in order to fill up the ponds in February/March. However, severe winter rainfall could also lead to flooding and the associated loss of stock and equipment and impair winter drainage of ponds if occurring during the fallowing period.

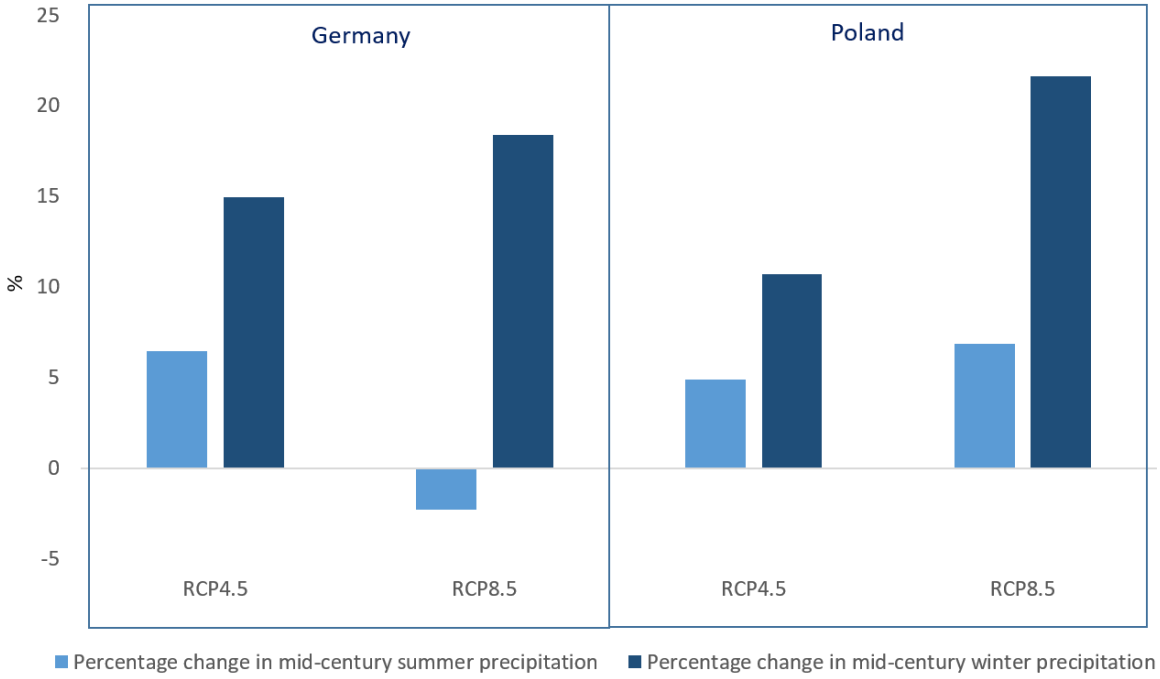

Figure 3.3. *Relative change (%) in summer and winter precipitation predicted under RCP 4.5 and 8.5 in 2050 for selected CERES Carp countries.*

Key aquaculture diseases were analysed and discussed under CERES T3.1, however for the purpose of assessing the potential economic consequence of disease on aquaculture production we model a worst-case scenario by using the diseases of most concern to each case study country. In the case of Germany, Koi herpes virus (KHV) was identified as the disease of most concern whereas Poland identified Carp Edema Virus (CEV) as their key concern. There are currently no effective control measures for either of these pathogens apart from culling and disinfecting a site. In the case of KHV there is a vaccine, however the presence of KHV or application of the vaccine can cause trade restriction on exports. Disease from both of these viruses is, however, transient, and outbreaks tend to be sporadic. Although statutory control measures may be applied to infected sites, the main impact is likely to be mortality which can occur in 30-80% of stock.

Analysing the potential number of optimal days for these pathogens reveals a similar result to that projecting optimal growing days for carp at around 30% for each country (Table 3.3). For KHV in Germany, little change is predicted under RCP 4.5, but a moderate increase is predicted under RCP 8.5, especially in the eastern part of the country in the important carp producing regions of Brandenburg and Saxony. For CEV in Poland a moderate increase is predicted under RCP 4.5 with a more substantial increase predicted under RCP 8.5.

Table 3.3. *Predicted annual proportion of days in which water temperatures are predicted to be in the optimal range for key disease of concern in Germany (KHV) and Poland (CEV) in carp under current climate and predicted percentage change under RCP 4.5 and 8.5 projections.*

Region	Present day proportion of optimal pathogen infection days	2050 RCP 4.5 proportion of optimal pathogen infection days	2050 RCP 8.5 proportion of optimal pathogen infection days	National percentage change in optimal pathogen infection days in 2050	
				RCP 4.5	RCP 8.5
Germany	0.29	0.30	0.31	0.97%	7.08%
Poland	0.30	0.34	0.37	11.25%	22.01%

3.3 Farm Level economic Consequences of Climate change

Compared to rainbow trout, the overall profit margin associated with carp farming is higher, with the overall profit margin in 2016 being similar between the four farms analysed here, at between 23% and 33.4% (Figure 3.4 & 3.5). Unlike the trout sector, however, many carp farms receive public subsidies which, in many cases, help explain the high profitability levels and face much higher opportunity costs which would lead to substantially lower long-term profit margins (see below). The two Polish farms studied in this task receive public payments of about 11-13% of their overall returns, the larger German farm 3.5% and the smaller German farm none. The profit margins without public payments obviously reduces substantially and rank respectively between 16-18% for the two Polish farms, whereas the two German farms rank between 28.7% (DE-FCP-5) and 30.9% (DE-FCP-20). Comparison of production costs between the two countries shows that stocking costs are a lot higher in Germany than Poland. This is due to higher losses in fingerlings production due to high predation. (Lasner et al. under review). This may create opportunities for secure hatchery sites to grow fingerlings to a size where predation is less of an issue to supply ongrowing sites (similar to the existing business model for UK trout).

The two German farm types studied have a similar costs structure (Figure 3.5), with the highest costs being stocking, followed by feed and, in different order, maintenance of buildings, facilities and machinery as well as diesel or minor operating equipment. The farms, however, sell to different markets with the larger German farms (DE-FCP-20) selling to wholesalers and restaurants which, when combined with public payments, allows them to achieve a higher return/kg than the smaller farms (DE-FCP-5) which sell only to wholesalers and do not receive public payments (see also Lasner et al. under review). Carp labelled as being produced under a Protected Geographic Indication (PGI) attract a greater market value and this could significantly increase the profits of both farm types but has the greatest influence on the profits of smaller German carp farms as simulated under the future scenarios.

Both Polish farms have an equal cost structure with the five most important costs categories being feed, stocking, labour, maintenance of buildings/facilities and diesel. The smaller farm does however have higher energy costs (electricity and diesel) and slightly higher fixed costs than the larger farm but has higher operating earnings as higher market returns per kg carp are achieved by selling to wholesalers, restaurants and fish farms (see also Lasner et al. under review).

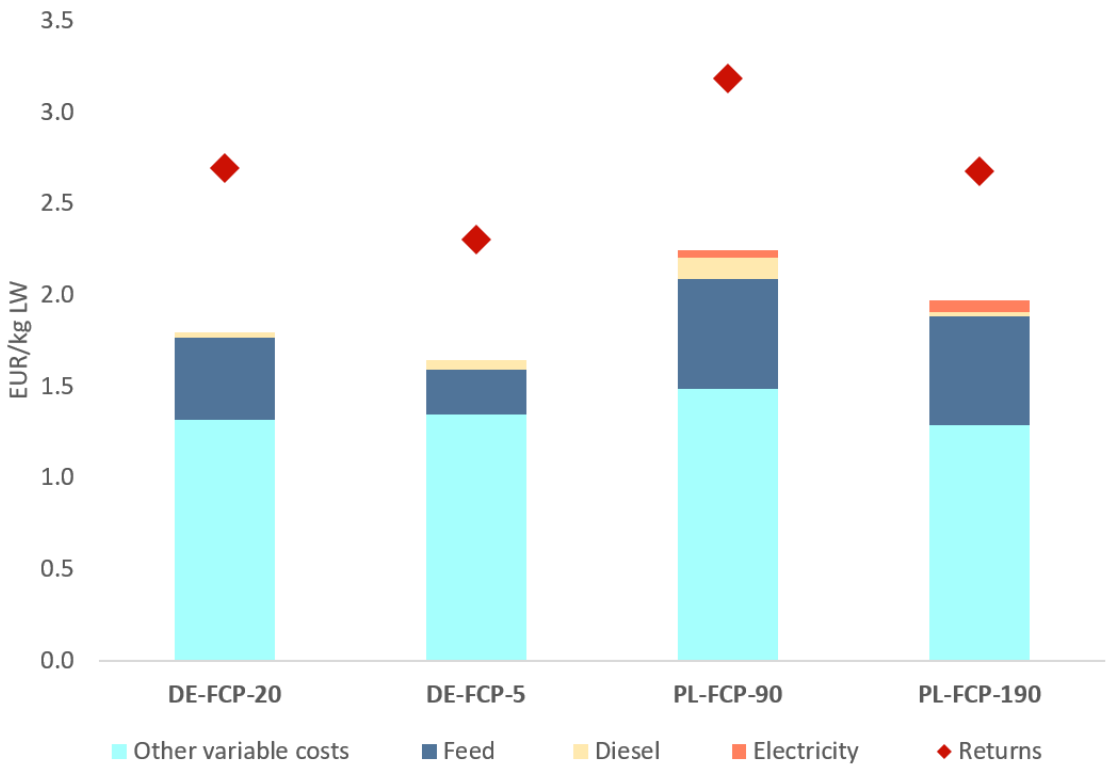

Figure 3.4. *Costs and returns from typical carp farm models showing stacked costs and returns (farmgate). The distance between the red returns point and the top of the stacked costs represents the short-term profit/loss made by a farm. DE= Germany, PL= Poland, FCP= Common carp. Numbers refer to annual production in Tons.*

DE-FCP-5	2016	DE-FCP-20	2016	PL-FCP-90	2016	PL-FCP-190	2016
Operating earnings (€/kg)	0.66	Operating earnings (€/kg)	0.90	Operating earnings (€/kg)	0.94	Operating earnings (€/kg)	0.70
Most prominent costs in % from operational costs		Most prominent costs in % from operational costs		Most prominent costs in % from operational costs		Most prominent costs in % from operational costs	
Stocking	59.15	Stocking	58.21	Feed	26.83	Stocking	30.24
Feed	14.89	Feed	24.92	Stocking	26.59	Feed	30.22
Minor operation equipment	5.85	Maintenance Build./Facilities	4.50	Labour	18.76	Labour	16.62
Maintenance Build./Facilities	5.12	Maintenance Machinery	3.40	Maintenance Build./Facilities	8.31	Maintenance Build./Facilities	8.90
Maintenance Machinery	3.84	Diesel vehicles	1.58	Diesel vehicles	5.11	Diesel vehicles	3.45

Figure 3.5. *Operating earnings and most prominent costs in percent from overall operational costs for all typical carp farms analysed in CERES. DE= Germany, PL= Poland, FCP= Common carp. Numbers refer to annual production in Tons.*

For the purpose of the future projections it was assumed that fixed public payments were paid at the same amount as today under all scenarios except for WM. Projections suggest that both types of Polish farms will be less profitable under all CERES four scenarios than today with the WM and GS scenarios having the greatest impact on profits (Figure 3.6). Under these two scenarios, the Monte Carlo simulations (which account for market variations in the prices of feed ingredients, crude oil and fish based on historic trends) suggest that these farms may no longer be profitable, whilst under the NE and LS scenarios there is a small chance profits could increase. The very low profitability of the two Polish farms under WM (which assumes no public payments) and the respective results under the other scenarios with PP (NE, GS, LS) shows clearly the dependence on the public payments and the amount paid.

The German farms also show less profitability under the two global scenarios (GS and WM), but substantial increases in profitability are predicted under the two local CERES scenarios (NE and LS). The very high profitability for the German farms under the two local scenarios is attributed to the assumption that the total production volume is marketed as PGI certified carp, which can achieve between 15% and 30% higher returns than unlabelled carp for the large (DE-FCP-20) and small (DE-FCP-5) German farms respectively. The less pronounced difference between future PGI labelled carp returns and current returns for larger farms is explained by its already higher current returns compared to the smaller farm. Additionally, the fixed additional returns due to public payments impair the delta in current and future returns for the larger farms even further. Monte Carlo simulations suggest that it may be possible for the two German farms to reach higher future profitability under optimal future price developments for the two global scenarios, though the chance of this happening is lower for smaller farms than the large farms. Higher feed costs and also higher energy costs for the Polish farms lead to slightly higher cost increases in 2050 compared to the German farms (up to 1.3 %), but the difference between future profits between the two countries is largely explained by the future cost/return ratios. These are less favourable for the Polish farms as at present they receive higher public payments, but these are not assumed to increase in the future within our analysis (Figure 3.6).

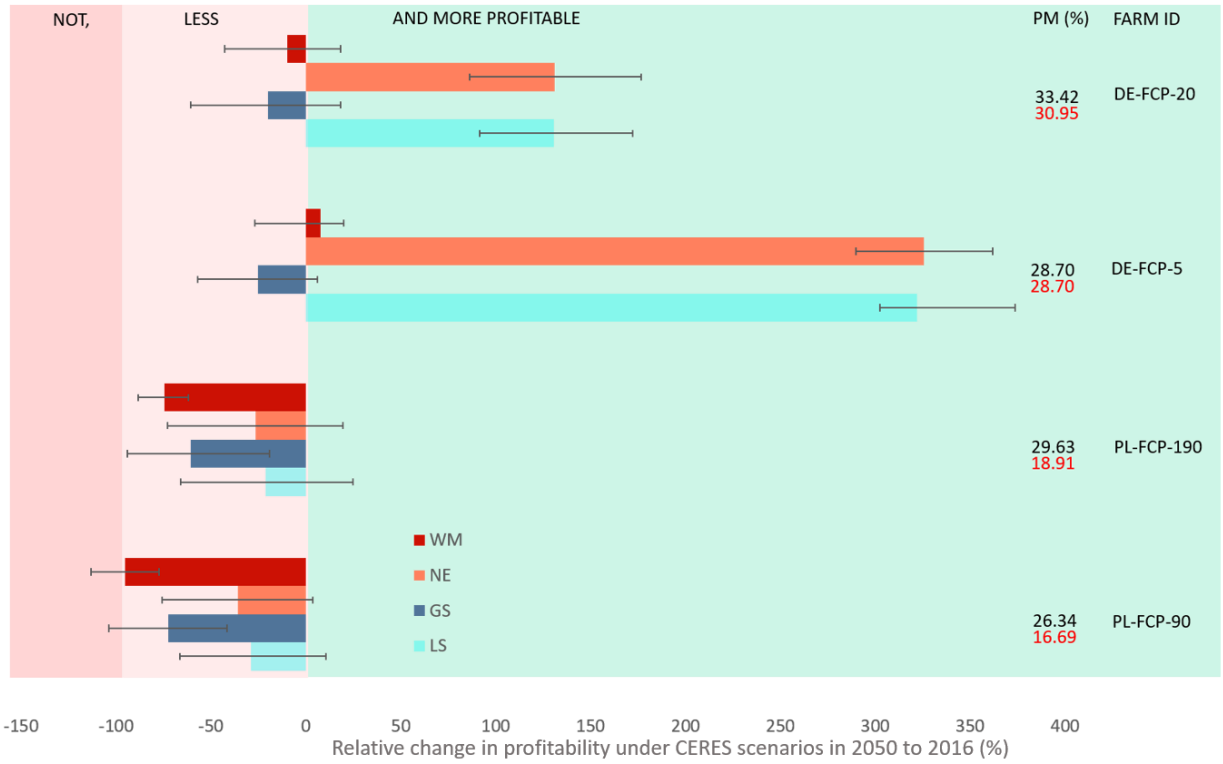

Figure 3.6. *Relative profitability change under the 4 CERES scenarios in 2050 compared to 2016 for the typical carp farms. World Market = WM, National Enterprise= NE, Global Sustainability= GS, Local Stewardship = LS. P10 = extreme cold year, P90= extreme warm year is only valid for TR-TRR-450. Error bars indicate 95% upper and lower probability ranges from Monte Carlo simulation. PM = Profit Margin in percent.*

In terms of mid- to long term costs, carp farms in Germany have high opportunity costs (Figure 3.7) relying on factors such as unpaid labour (i.e. employing family members), whereas Polish farms predominantly rely of paid labour but have relatively low interest and investment costs as these sites require little infrastructure and therefore little borrowing. Around 50% additional long-term costs (relative to operating cash costs) must be considered for the two Polish farms (PL-FCP-90, PL-FCP-190) and the larger German farm (DE-FCP-20). Polish sites are much larger than the German sites and therefore benefit from scale effects, especially PL-FCP-190. The smaller family owned German farms must also cover additional mid- and long-term costs, which may exceed current operating cash costs. These costs derive mainly from unpaid labour, but also the higher depreciation costs per kg related to the low production volume compared to the other farms (see also Lasner et al. under review).

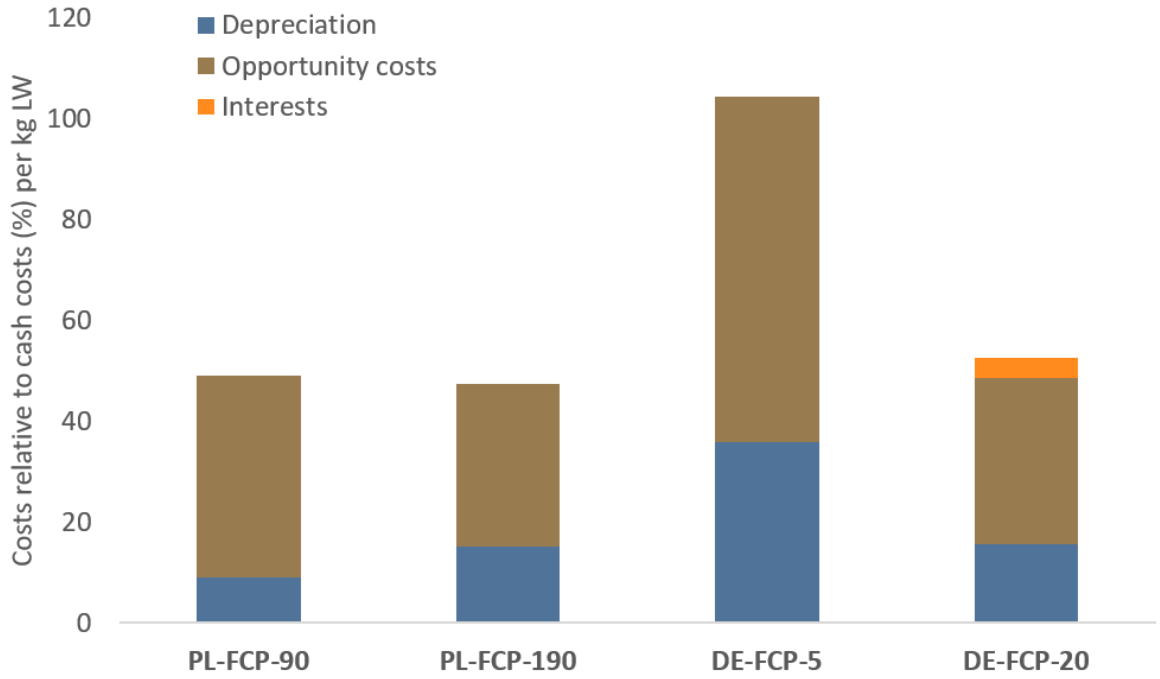

Figure 3.7. *Present day depreciation, opportunity costs and interest for all carp farms in relation to the operating cash costs (%). DE= Germany, PL= Poland, FCP= Common carp. Numbers refer to annual production in Tons.*

3.4 Regional Economic Consequences of Climate Change

Figures 3.8 to 3.11 provide maps showing the predicted change in relative profitability for a typical farm type located within a grid square within each of the countries of interest. These maps present the results of the typical farm model under the four CERES scenarios adjusted for the local effects of temperature on growth and disease occurrence on costs.

In keeping with the typical farm model results, regional analyses suggest that increased profitability in both types of German carp farm will occur across the whole country for both regional scenarios NE and LS, only a small number of isolated cells in the south of the country are susceptible to lower profits due to localized effects (Figures 3.8 to 3.11). Under the WM scenario however, localized effects are more apparent for both types of German farms. The typical farm model predicted that there would be marginal reductions in profitability for both farm types under this scenario, however when scaled up to the national level, this marginal effect means that local conditions can be important and predictions suggest that in 50% of the total country area farms could actually increase in profit. In terms of the main producing areas (see Figure 3.1) this might be most favourable for the south (Bavaria), whereas the east of Germany shows a patchier distribution of good local conditions, which are only partly present in Saxony and Brandenburg.

Although the typical farm models predicted a far greater reduction in profits under the GS scenario for both German farm types, local conditions are also predicted to be influential in the case of some of the larger German farms for which the predicted reduction in farm level profitability was less than for the small farms. For these larger farms, approximately 20% of cells, predominately in the East of Germany, may increase profits, which could be beneficial for the carp producing areas there. However, smaller farms are predicted to experience reduced profitability under this scenario across much of the country.

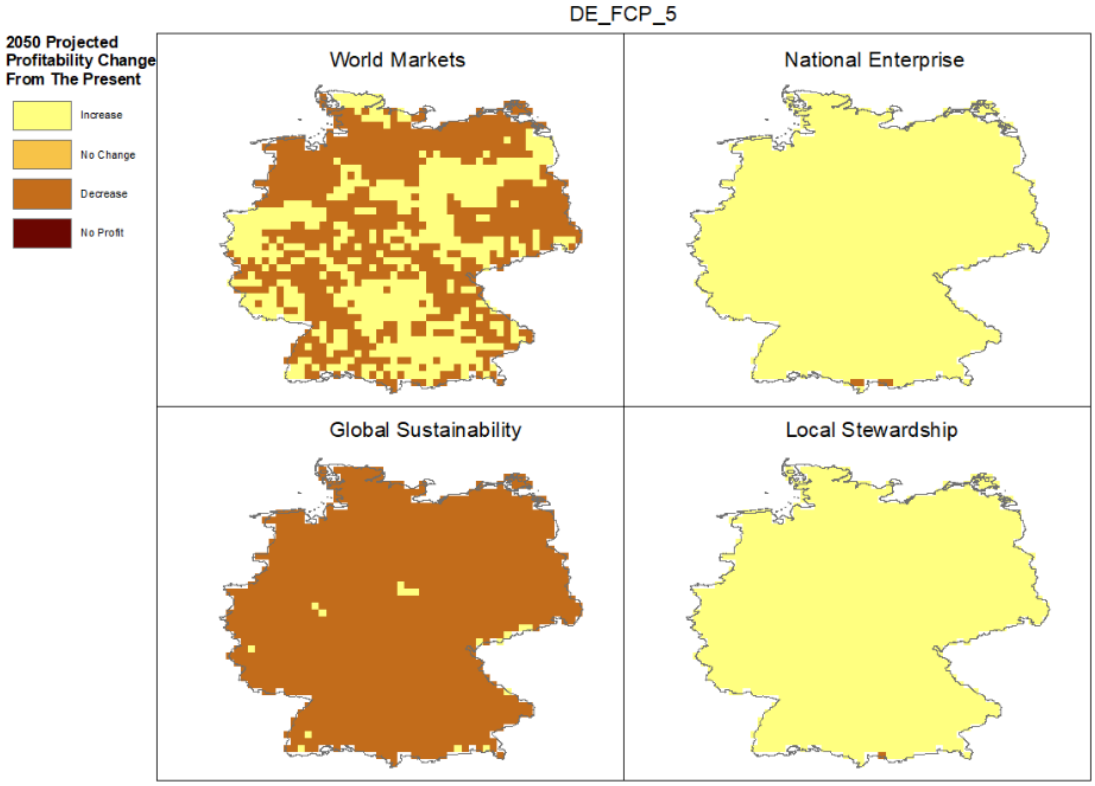

Figure 3.8. *Predicted consequences of the four CERES climate change scenarios on the profitability of small German carp farms (DE-FCP-5).*

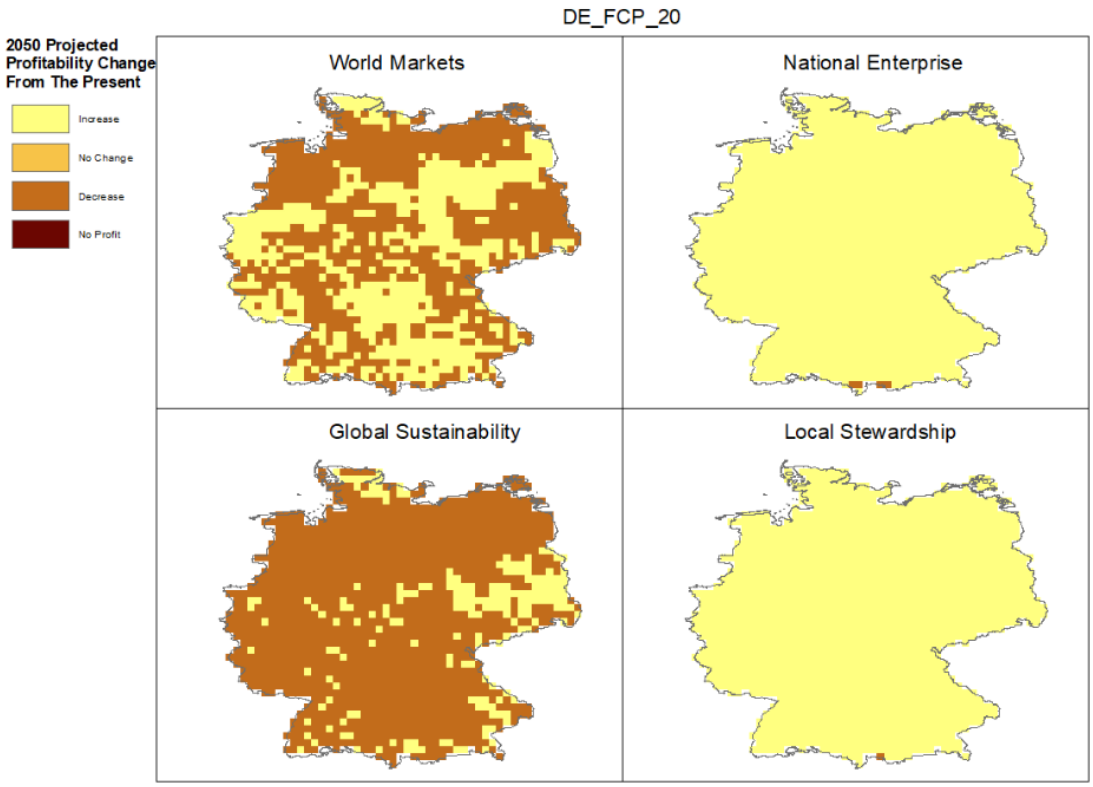

Figure 3.9. *Predicted consequences of the four CERES climate change scenarios on the profitability of large German carp farms (DE-FCP-20).*

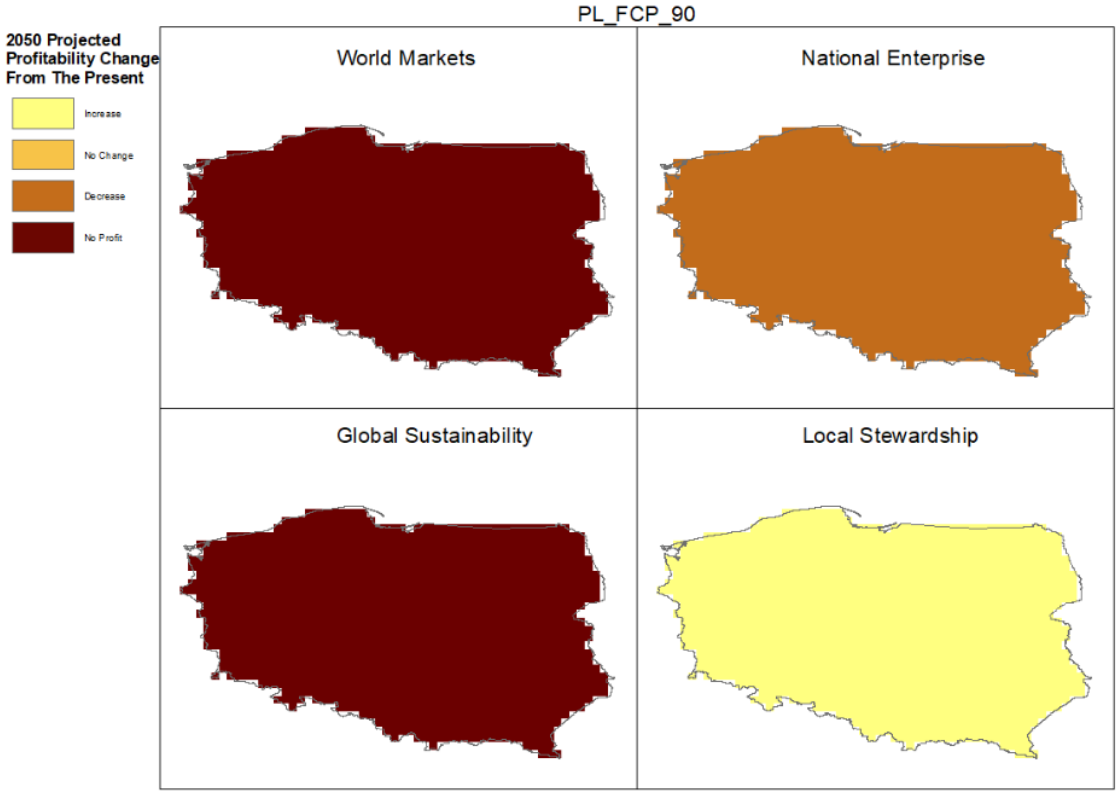

Figure 3.10. *Predicted consequences of the four CERES climate change scenarios on the profitability of small polish carp farms (PL-FCP-90).*

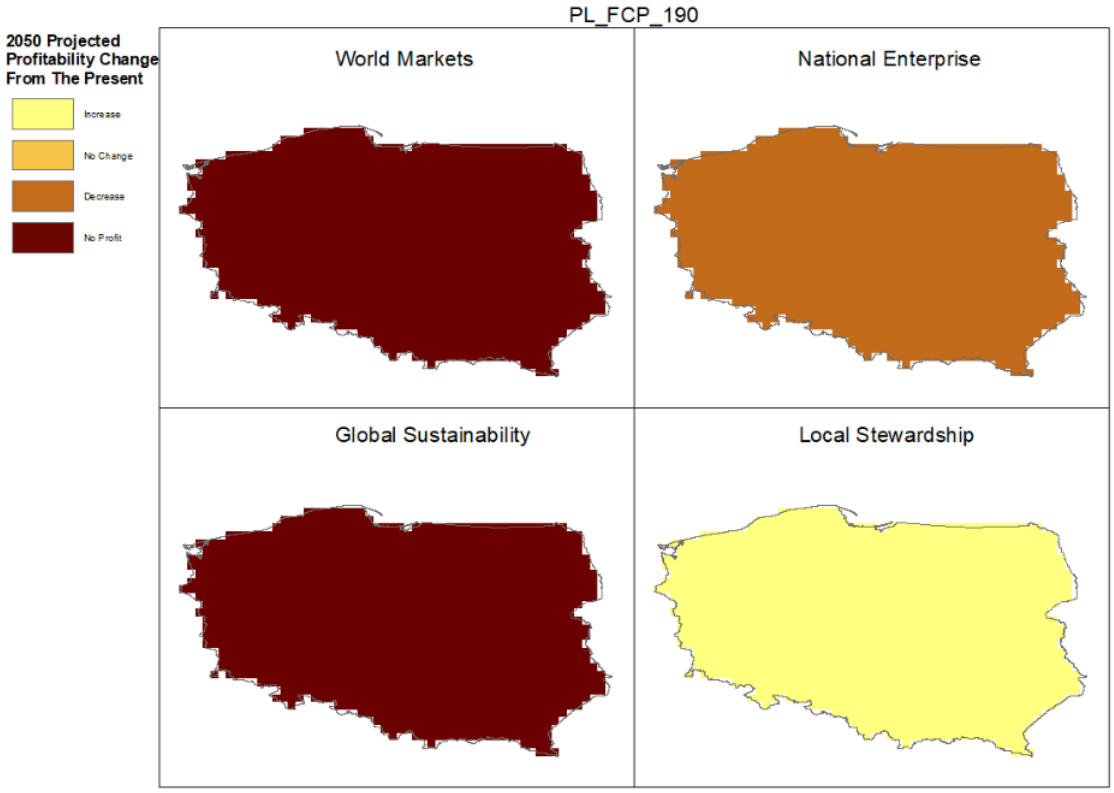

Figure 3.11. *Predicted consequences of the four CERES climate change scenarios on the profitability of larger polish carp farms (PL-FCP-190).*

In the case of both types of Polish carp farms, profitability predictions are consistent across the country under all four scenarios (Figures 3.10 and 3.11). However, the temperature related effects associated with carp growth and disease are influential as they accentuate the predictions of the typical farm models. For both farm types, the WM and GS scenarios substantially reduced profitability, but both farm types were predicted by the typical farm model to retain some profit. However, the national level analysis suggests that once the relative temperature effects (on both the target species and the associated diseases) are accounted for, both farm types are likely to operate at a loss across the entire country. Under the NE scenario the regional findings agree with the typical farm results, predicting reduced profitability across the country for both farm types. However, under the LS scenario for which the typical farm models predicted marginal losses, the regional model predicts the effects of temperature change to be beneficial and could subsequently result in increased profitability nationally.

3.5 Conclusions, Opportunities and Challenges for Carp Production

Within Europe, carp constitute the second most commonly produced freshwater aquaculture species after rainbow trout. This is, in part, due to their wide-ranging

environmental tolerance and their ability to be produced in low technology systems with limited water supply. At present, the profitability of carp production within the typical farm sites is greater than for rainbow trout on the short-term. In many cases, however, this high profitability can be attributed to the contribution of EU public payments, which are paid for by the ecosystem services carp farming provides as well as higher occurring long-term costs compared to other species' production that were not included in the main analysis (mainly opportunity costs, see also Figure 3.7). To remain profitable in the future, it is important that public payments continue, and their importance is clear through the reduced profitability of farms under the WM scenario where public payments are assumed to cease. As a consequence of this, the WM scenario is especially detrimental to many of the polish carp farms as these currently receive the greatest payments. The WM scenario is however likely to be less detrimental to German production as they are less dependent on these payments, and this scenario may increase opportunities to export carp to Poland in the face of the challenges to the sector in this country in case the German production could be increased. This, however, would require a large-scale increase in production as Germany is currently a net importer itself.

The price that carp can be marketed is obviously an important factor in determining the profitability of a site. Analysis of the German farms has shown there to be a demand for PGI labelled carp which allows them to attract a greater price in local markets than non-labelled. As Poland is so dependent on imports of carp to meet demand, it may be that Polish farms could obtain better prices for locally produced fish through the adoption of labelling and certification schemes, which may help offset some of the negative consequences of the future scenarios to Polish carp aquaculture. However, the Polish carp market is national rather than regional as in Germany, which implies more success for the labelled carp if more localised markets are not developed in response to the impacts of climate change (see Lasner et al under review). Compared to other countries, production in Poland is low given the land area available, given the large domestic market and dependence on imports and there is an opportunity to increase production through increasing the number for farms and the production efficiency and intensity. The challenge to this will be the increased infrastructure costs required, which in Poland are currently low. Also, intensification and certain production practices may make sites ineligible for public payments or certification schemes, so these trade-offs would need to be considered before changing practices. The German best practice site does however show that changing practices can improve the profitability of a site and make it more resilient to climate change impacts.

For the German sites, changes in practice could also be beneficial. Currently many of the sites have very low production and moving practices towards those adopted by the larger German sites is predicted to be beneficial, however as sites increase in size and production intensity staff costs are likely to increase which may offset some of the opportunity cost currently realised by small farms thought the use of family labour. The main cost to German production comes from stocking due to high predation rates at the fry stage. Obviously improving anti-predation measures should be a priority and this

would also have biosecurity benefits which may help prevent disease incursions. Carp production in the region of Saxony was found to be sensitive to KHV outbreaks, also due to difficulties in deterring predators in the very large pond systems of this region and a practice of high exchange in stocking fish. Following an increase in KHV induced losses since 2006 a programme to combat KHV ("KHV Tilgungsrichtlinie") associated with the EU2006/88 directive was adopted (Füllner et al. 2010, 2016). The recommended sanitizing measurements such as sufficient fallowing periods, disinfection of ponds and single way stock-exchange of disease-free fish seem to be effective (Füllner et al. 2010, 2016) and will be of even more importance in the future. There may also be opportunities for dedicated fingerling producers as currently seen in the UK trout sector. Dedicated producer could make use of indoor recirculating systems to remove predation threats and reduce disease risks, hatching eggs and growing them to a size that is robust enough for stocking into outdoor pond and cage systems. Though the running and infrastructure costs of such systems can be relatively high, this can be offset by the low predation and disease impacts and the achieve optimal growth throughout the year due to the ability to manipulate temperature. Such systems allow the provenance of fingerlings to be assured and due to their bio-secure nature may allow assurances relating to disease freedom that may open access to export markets.

Under both RCP's a greater number of optimal production days are predicted for in Poland which provides opportunities to increase production due to improved growth rates. This benefit of climate change may however be offset by increased disease concerns and the risk of flooding in winter. In the case on many pond sites, especially those that have low dependence of river water, little investment would be required to improve biosecurity, and this could be of great benefit. For both Polish and German farms, robust biosecurity measures and the ability to source disease-free stock will be key to mitigating disease concerns.

As the profitability of German sites is less dependent on public payments than the Polish sites, local climate change effects are of greater importance to Polish farms and this was especially apparent under projections for WM and GS. Under all scenarios, increased production through improved growth due to greater temperature suitability could be realised, however, as so much of the German production is in very small farm sites, it may be difficult to realise this opportunity without the ability to upscale towards the nature of the larger best practice farms. Though intensification may increase staff and infrastructure costs, the increased production is likely to offset this.

For both countries, the relatively simple nature of carp production systems and feed as well as the relocation of costs to mid- and long-term (e.g. unpaid labour) is currently a key factor in achieving the better short-term profitability of this species compared to rainbow trout. However, these factors also mean that production intensity and efficiency are low. Through investment in infrastructure, there are opportunities to increase production volumes through the application of technology and more high-tech systems. Recirculating systems are more suited to carp production than rainbow trout and by

maintaining good water quality in the absence of low external water source, fish can be farmed at higher densities. Such systems also often provide the ability to control temperature to a certain extent which can improve growth rates and efficiency. Indoor recirculating systems also have the advantages of helping to mitigate the impact of flooding, predation and disease. Improved growth rates, efficiency and water quality can also be achieved through the use of better feeds, however under future scenarios the associated increased feed costs would make the sector more susceptible to the impacts in changes in world markets. Though there appears to be some good opportunities for the future of carp farming in both countries, these are not without challenge and changes in systems and practices will be required to realise opportunities and increase resilience in the face of climate change under all scenarios. Evaluations will be required at the business level to determine the best way forward for each venture and assess whether increased feed, infrastructure and possibly staff costs, especially when the work load cannot be covered any longer by unpaid labour, can be offset by improved growth, increased production volumes and reduced disease and predation impacts. Though not as critical as it is to the trout sector, future water availability should be considered as though nationally this may not be of great concern, regional projections for the carp sector in eastern Germany predict risks of water shortages (Ballmann et al. 2017). Therefore, potential investment into additional wells, water pumps or pipelines in vulnerable areas should also be considered. In addition to preserving the sector it is also important that pond systems are maintained for their ecological role in biological conservation, ecosystem services and climate change mitigation (Céréghino et al. 2013).

Chapter 4 European Salmon Aquaculture

4.1 Introduction

Atlantic salmon (*Salmo salar*) is the most important European aquaculture finfish species, both in terms of volume and value of production. The industry structure reflects the anadromous life cycle of this species, with separate and specialised facilities for breeding, hatching and smolt production as well as grow-out. While fish are reared in freshwater until smoltification, the grow-out production takes place in seawater, predominantly in near shore open sea pens (cages). Environmental challenges associated with this production system are currently driving innovation towards more closed systems and offshore and onshore technologies. Within CERES we concentrated on Norway and Ireland as case study examples, covering the two respective leading countries in both conventional and organic production.

Globally Norway is the most important salmon producer with a total volume of 1.2 million metric tons in 2016, which is equal to 82% of Europe's total production, with an overall value of €6.5 billion (OECD stats, FEAP 2017). Aquaculture operations are distributed along the entire coastline of Norway, except around the Oslo fjord and a few other areas due to the presence of other industries or environmental protection. The most important production region is the coast of Nordland, followed by the northern adjacent county Troms and the more southern located regions Hordaland and Sør Trøndelag (statbank no) (Figure 4.1). The large proportion of salmon is exported and in 2016 the export volume accounted for 81 % of total production (1million tons) (Norwegian Seafood Council seafood.no) of which 75% were sold to the EU with main importers being Poland and France, followed by Denmark and the US (Norwegian Seafood Council seafood.no). Although the sector is characterized by a high degree of consolidation, with only 6 large companies accounting for 61% of total revenues in 2016 (Norwegian aquaculture analysis 2017), there are currently several hundred companies holding licenses for salmon and trout (eurofish.dk). Within CERES models were based on a typical grow-out farm site located in the county of Nordland and with 3680 tons of production was defined (NO-SAL-3680) (Figure 4.1).

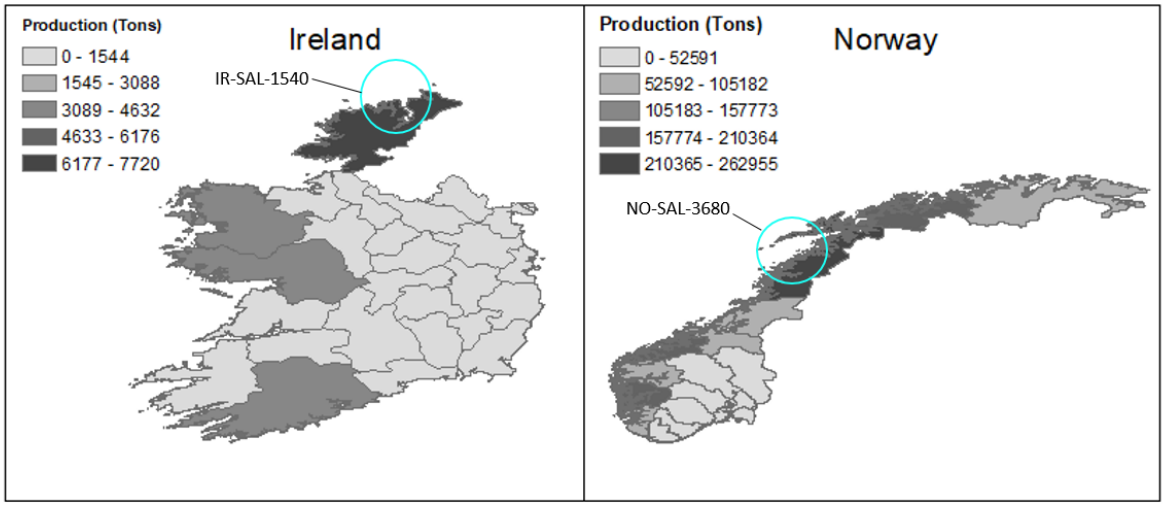

Figure 4.1. *Atlantic salmon (Salmo salar) regional production in tons for the year 2016 and selected production countries in CERES: Ireland and Norway. Locations of the typical salmon farms are indicated by circles and labelled with a country-species-yearly production (t) code. Data sources: Ireland's Seefood Development Agency, Norwegian Directorate of Fisheries.*

Despite being a much smaller producer of only 16300 metric tons in 2016, Ireland is the EU's leading producer of organic salmon (EUMOFA 2017). In total, there were 16 grow-out production units and seven for smolt that held licences in 2016 with the majority of production taking place in the Northwest of the country (Donegal), and other significant production regions being located further south along the Westcoast (Mayo, Galway) and in the South (Cork) (BIM Annual Aquaculture Survey 2017). The vast majority of salmon farms in Ireland are owned by Mowi Ireland, however a number of smaller independent units also exist. Such sites are typically located in more peripheral rural areas along the North, West and South West coasts of Ireland (Grealis et al. 2017). The whole of Ireland's salmon is produced according to organic standards following a diet of organic approved feed, low stocking densities and being mostly located at high energy exposed sites (for EU organic certification see EC 834/2007, EC 889/2008). The value of the Irish salmon production for 2016 was estimated at €105 million (BIM Annual Aquaculture Survey 2017; DAFM Report, 2017, Mid-Term Assessment National Strategic Plan for Sustainable Aquaculture Development) and the majority is exported (65 % in 2017), mostly to France, Germany and recently a high market share went to Poland, whereas imports originate largely from the UK (EUMOFA database: eumofa.eu). The Irish Salmon typical farm defined in CERES is located in Donegal and produces 1540 tons (IE-SAL-1540) (Figure 4.1).

4.2 Climate Change Effects on Habitat Suitability for Salmon

As is the case with other salmonid fish species, Atlantic salmon require good water quality and have a relatively limited temperature threshold with optimal growing temperatures being between 10 and 16°C. The average water temperature for the coastlines surrounding Ireland and Norway is within the lower portion of this range (Table 4.1) with

Ireland being around 1°C warmer than Norway at 11.44 and 10.45°C respectively. Thereby, the Norwegian data concentrates on the waters of the southern part of the country. Under both RCP's average temperatures are projected to increase by a small amount, but the increase is predicted to be marginally larger for Norway than Ireland. It should, however, be remembered that the temperature data used to make these calculations relates to off-shore data, and it is likely that inshore waters will be warmer, however given that these temperatures are at the lower end of the optimal threshold, they are unlikely to exceed the upper threshold.

Table 4.1. *Average predicted water temperatures in case study countries and predicted change under RCP 4.5. and 8.5.*

Country	Average national present-day water temp	Average national 2050 water temp – RCP4.5	Average national 2050 water temp – RCP8.5	Percentage change in national average water temperature in 2050	
				RCP 4.5	RCP 8.5
Ireland	11.44^{0}C (SD= 0.73^{0}C)	11.89^{0}C (SD= 0.73^{0}C)	11.94^{0}C (SD= 0.75^{0}C)	3.97%	4.36%
Norway	10.45^{0}C (SD= 0.31^{0}C)	10.93^{0}C (SD= 0.33^{0}C)	11.12^{0}C (SD= 0.28^{0}C)	4.58%	6.46%

Assessing the proportion of days within a year where water temperatures are predicted to be in the optimal growing range for salmon suggests a greater amount of difference in the suitability between the two countries, with Ireland predicted to have 64% of days in the optimal temperature threshold and 53% of days in Norway (table 4.2). Again, under both RCPs the suitability is predicted to increase, however whilst the predicted increase is similar for both countries under RCP 8.5 being between 7.8 and 7.4% for Ireland and Norway respectively, there is a larger predicted difference under RCP4.5 at 8 and 4.6% respectively.

Table 4.2. *Predicted annual proportion of days in which water temperatures are predicted to be in the optimal growing temperature range for Atlantic Salmon (10-16°C) under current climate and predicted percentage change under RCP 4.5 and 8.5 projections.*

Region	Present day proportion of optimal days per	2050 RCP 4.5 proportion of optimal days per	2050 RCP 8.5 proportion of optimal days per	Annual national average change in temperature suitability for Atlantic Salmon in 2050	
				RCP 4.5	RCP 8.5
Ireland	0.64	0.69	0.68	8.01%	7.80%
Norway	0.53	0.55	0.57	4.62%	7.40%

Visual representations of the distribution of these predicted temperatures and changes under the RCPs (Figure 4.2) shows an area of relatively high suitability near the south west of Ireland, and an area of relatively low suitability towards the South West of Norway. The maps show the temperature suitability to be generally higher around the coast of Ireland than Norway. The observed patterns and differences between regions become more extreme compared to present day under both RCP's but there is little predicted difference in suitability between the two of them.

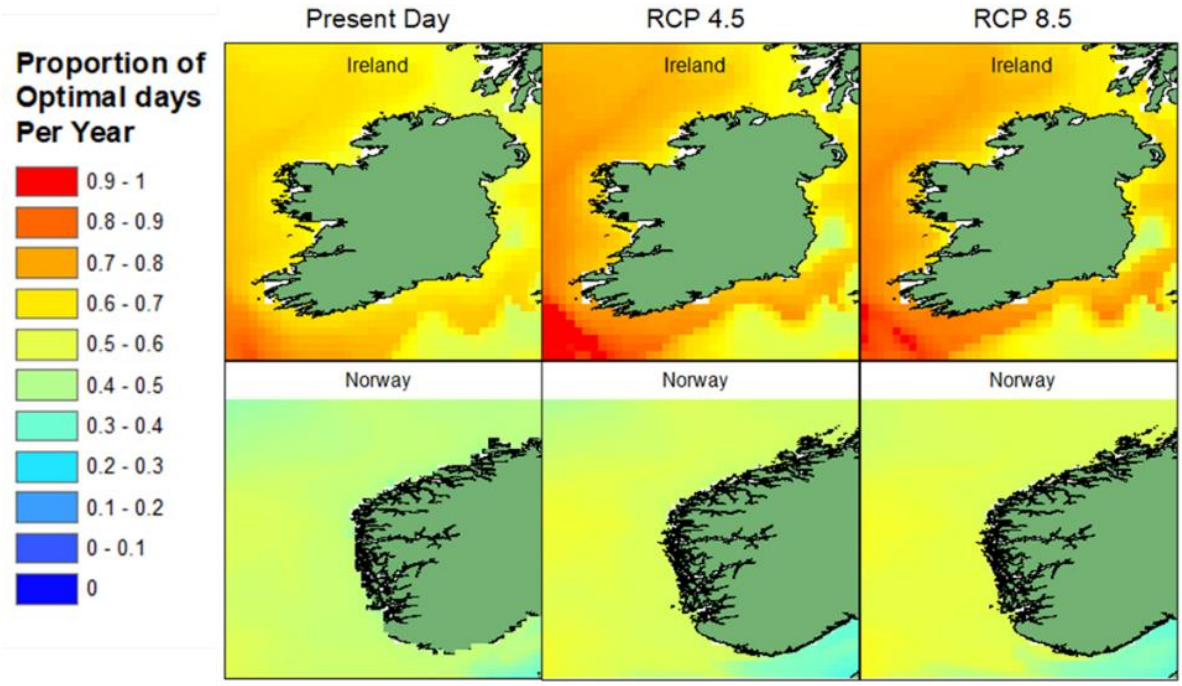

Figure 4.2. *Predicted annual proportion of days water in which temperatures are predicted to be in the optimal growing temperature range for Atlantic Salmon (10-16°C) under current climate and RCP 4.5 and 8.5 projections.*

Similar to all aquaculture species, disease is of great concern to salmon farming, causing reputational concerns, direct impacts through mortality and veterinary costs and potentially leading to statutory control measures (such as culling, fallowing and movement restrictions). For illustrative purposes we have picked Infectious Salmon Anaemia (ISA) as a disease to understand how scenarios of climate change may influence the risk posed by this pathogen. This is a viral disease that is notifiable under EU law, as there is currently no effective treatment or prophylactic measures. Ireland has recognized freedom from this pathogen, but Norway is currently undergoing a control and eradication programme for this pathogen. Predictions for the proportion of days in the optimal suitability range for this pathogen (table 4.3), suggest that though free of the disease Ireland is at greater risk of disease impact than Norway should it be introduced, with 59% of days in the optimal range compared to 49% for Norway. Going forwards it will be key for Ireland to maintain good biosecurity measures into the future to prevent introduction of this pathogen and eradicate it quickly should there be an incursion.

Under both RCP's this risk is likely to increase for Ireland by around 4% but decreases slightly in Norway under RCP4.5 and increase slightly under RCP8.5.

Table 4.3. *Predicted annual proportion of days in which water temperatures are predicted to be in the optimal range for a key disease of potential concern for Atlantic Salmon under current climate and predicted percentage change under RCP 4.5 and 8.5 projections.*

Region	Present day proportion of optimal pathogen infection days	2050 RCP 4.5 proportion of optimal pathogen infection days	2050 RCP 8.5 proportion of optimal pathogen infection days	National percentage change in optimal pathogen infection days in 2050	
				RCP 4.5	RCP 8.5
Ireland	0.59 (ISA)	0.62	0.62	4%	4.4%
Norway	0.49 (ISA)	0.49	0.50	-1.19%	1.95%

4.3 Farm Level Economic Consequences of Climate Change

Typical farm model assessments (Figure 4.3 and 4.4) shows the Norwegian typical farm to have a much higher profit margin (27.5 %) than the Irish one (17.4%), making them more able to buffer increasing costs. It should be noted that, in order to be comparable to the other typical finfish farms, costs and returns for non-gutted fish were displayed in this assessment, which are lower than for gutted fish. However, it must be acknowledged that the cost of salmon that is sold gutted is greater due to processing costs and other associated factors.

Feed costs are the most substantial cost for both countries but, although their absolute cost per kg fish is very similar (differ by 4 cents/kg), the percentage of total costs is 1.3 times higher in Norway than Ireland. The higher cost in Norway traces back to the overall higher cash costs. Further, the share of stocking costs of total cash costs is more than 2 times higher for Norway than Ireland. Labour costs are, however, a lot higher for the Irish farm than the Norwegian farm, both in absolute costs per kg fish produced as well as allocation of total cash costs. Although producing less than half of the production volume of NO-SAL-3680, the Irish farm IE-SAL-1540 has more labour and an overall 19 times greater labour costs per kg fish produced amongst other due to less opportunities to contract services, but also a lower level of automation. However, the Norwegian farm has today 16 times higher diesel costs and higher licence costs, though as Norway is transferring to electric power supply and reducing fossil fuel dependency, diesel costs will be less important in the future than today. Veterinary costs are important and similar for farms in both countries.

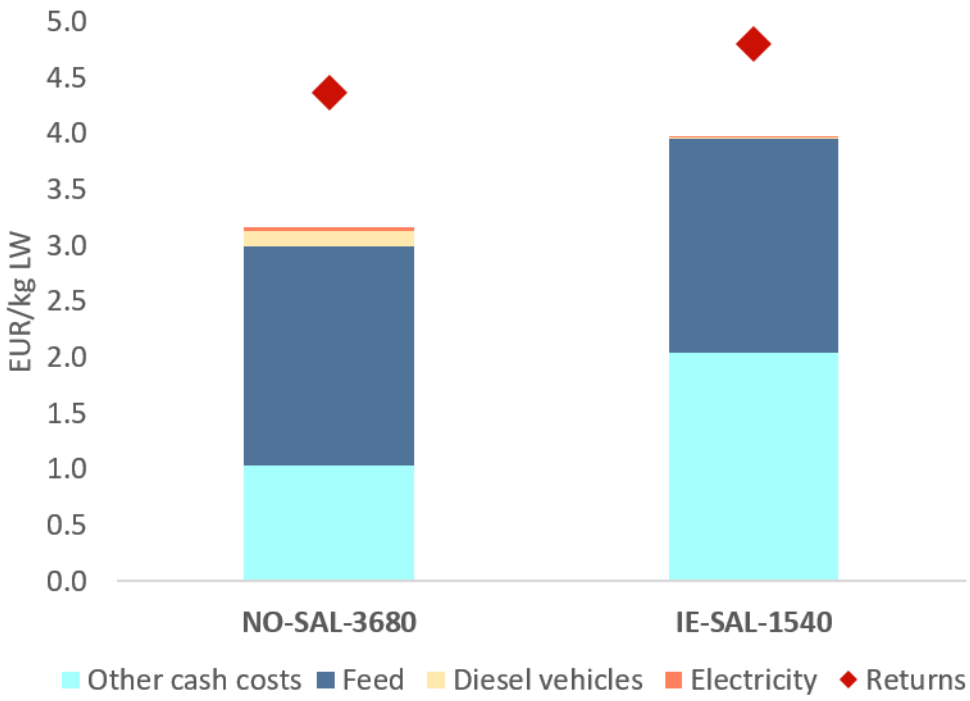

Figure 4.3. *Costs and returns (farmgate) from typical Atlantic salmon farm models showing stacked costs and returns. The distance between the red returns point and the top of the stacked costs represents the short-term profit/loss.*

IE-SAL-1540	2016	NO-SAL-3680	2016
Operating earnings (€/kg)	0.83	Operating earnings (€/kg)	1.20
Most prominent costs in % from operational costs		Most prominent costs in % from operational costs	
Feed	48.29	Feed	68.17
Other variable costs	21.06	Stocking	13.08
Labour	7.86	Lease and water charge	9.89
Veterinary	6.64	Veterinary	6.72
Stocking	5.22	Diesel vehicles	4.41

Figure 4.4. *Operating earnings and most prominent costs in percent from overall operational costs for all typical salmon farms analysed in CERES.*

Under future price scenarios, Irish salmon farms are likely to suffer reduced profits under GS, NE and LS scenarios, with the reductions being most severe under GS. Norwegian salmon farms are also projected to experience reduced profitability under the GS

scenario, although the impact is predicted to be around half that projected for Ireland, however, conversely profits are projected to increase in Norway under the NE and LS scenarios. Farms in both countries are predicted to have increased profits under the WM scenario, which is different to the freshwater aquaculture species, trout and carp (Figure 4.5). The reasons for this are the comparably high feed costs per kilograms of fish produced for both countries, and the predicted changes in this under the different scenarios. Feed costs are lowest under the WM scenario for the Irish production compared to the other scenarios, and lowest under GS and WM (% difference to GS) for the Norwegian. In combination with the better fish price development under WM than GS this explains why WM is the most favourable scenario.

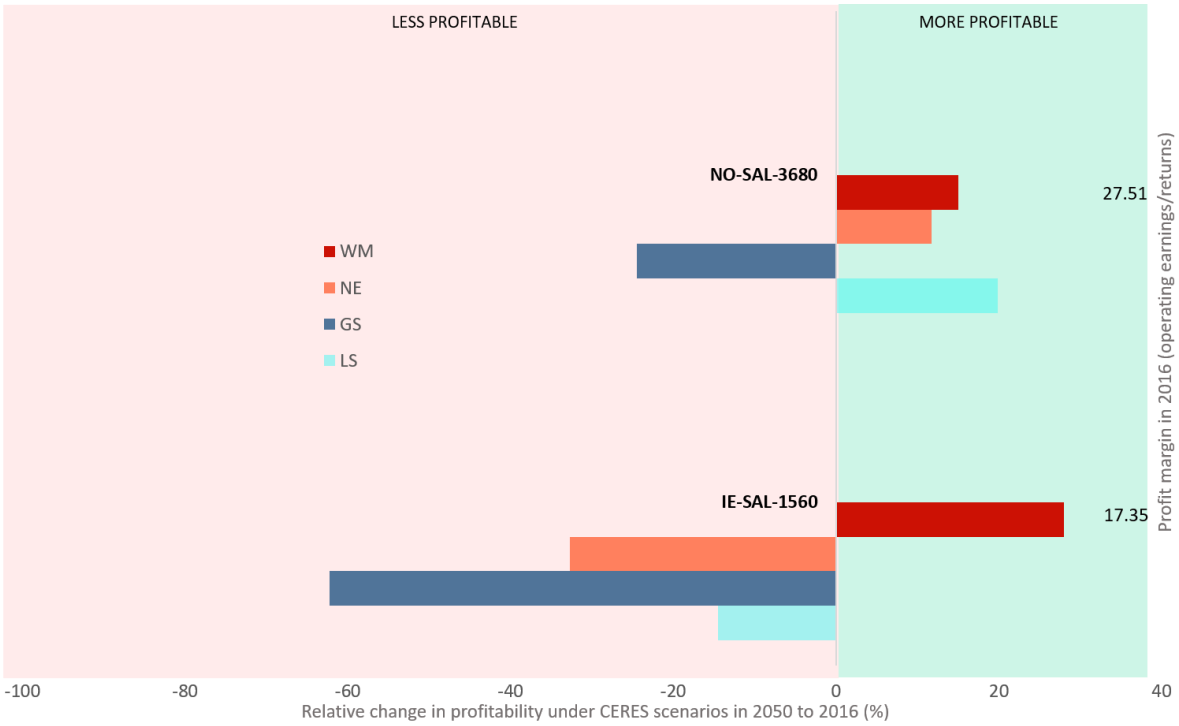

Figure 4.5. *Relative change in profitability under the four CERES scenarios in 2050 compared to 2016 profit margin for all typical Salmon farms without considering future harvest weight and FCR. World Market = WM, National Enterprise= NE, Global Sustainability= GS, Local Stewardship = LS.*

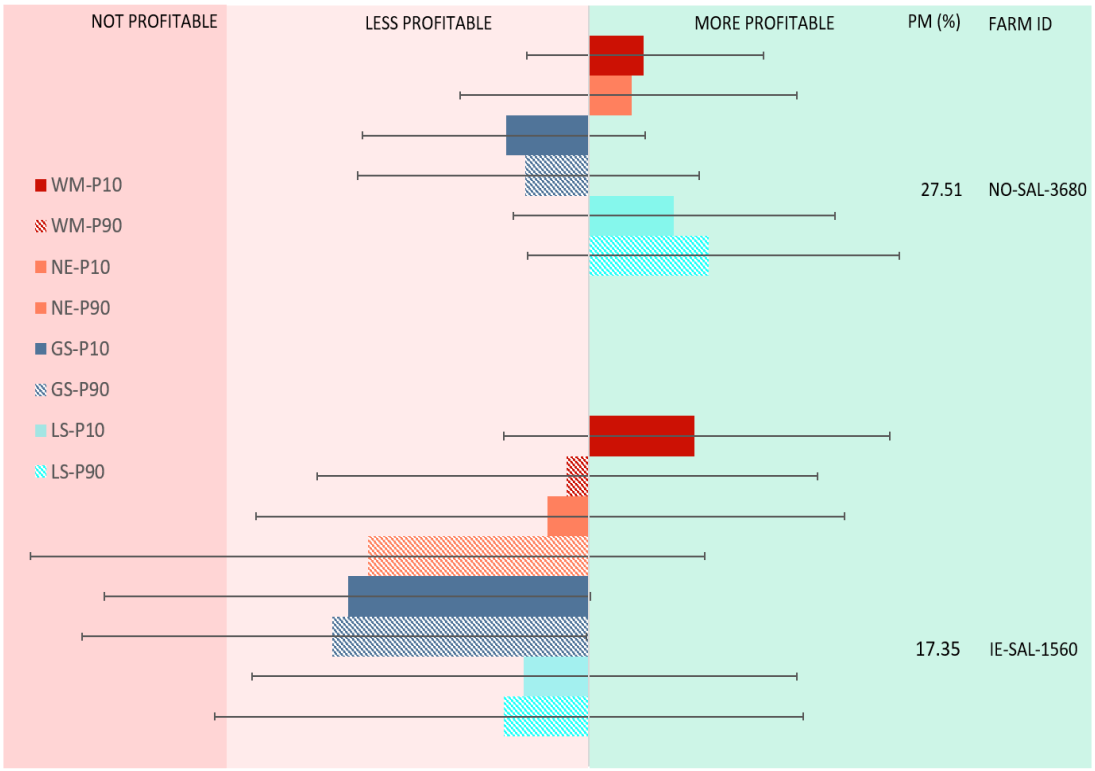

Figure 4.6. *Relative profitability change under the 4 CERES scenarios in 2050 compared to 2016 for the typical salmon farms. World Market = WM, National Enterprise= NE, Global Sustainability= GS, Local Stewardship = LS. P10 = extreme cold year, P90= extreme warm year is only valid for TR-TRR-450. Error bars indicate 95% upper and lower probability ranges from Monte Carlo simulation. PM = Profit Margin in percent.*

When considering the changes in feed conversion ratio (FCR) and harvest weight under RCP 4.5 for the respective areas where the typical farms are located, the Norwegian waters show much more variation between extreme cold and extreme warm years for FCR and harvest weight by 2050 (Figure 4.6). Whereas for the extreme cold year FCR and harvest increase in parallel for both farms, the extreme warm year has a stronger effect on FCR than harvest weight for the Irish farm and the counteractive effect for the Norwegian farm. This pattern explains the more favourable future profitability under the GS and LS scenario for Norway compared to Ireland. Whereas the latter shows decreased profitability compared to the pure cost/return developments without considering FCR and weight changes, NO-SAL-3680 can even increase its profitability due to higher harvest weight. The temperature development for Irish waters under RCP 8.5 shows strong variability. Extreme cold years (P10) with a more pronounced decrease in FCR than harvest weight has a positive effect on profitability for the NE scenario, where feed costs are highest. Extreme warm years lead to unfavourable development of FCRs in relation to harvest weight and concomitantly a strong pronounced decrease in profitability under NE scenario. In general, the typical Irish salmon farm has less capacity to buffer potential additional climate change related investments or expenditures (e.g. storm-related) than the Norwegian farm. Conditions in an extreme cold year under the WM scenario,

however, lead to a profit increase, which could be used to balance less favourable conditions in warmer years.

Even considering future potential price variation, the Norwegian farm shows a higher probability of remaining profitable under all scenarios tested. Monte Carlo simulations also show the chance of being more profitable than today for all scenarios, though reduced profitability is likely under the P10 and P90 for the GS scenario. For the Irish farm there are three scenarios where there is a risk of not being viable - P10 and P90 of GS and P90 of the NE scenario. Otherwise (with the exception of the GS scenarios) there is the chance of higher future profitability than today.

Additional mid- and long-term costs (not included in operating earnings) are lower for our typical salmon farms (Figure 4.7) than for the freshwater aquaculture operations (i.e. trout and especially carp). For the Irish farm around 20% of the cash costs, mostly depreciation would have to be invested on a long-term scale, whereas for the typical salmon farm in Norway only around 5 % of overall cash costs have to be expected in addition.

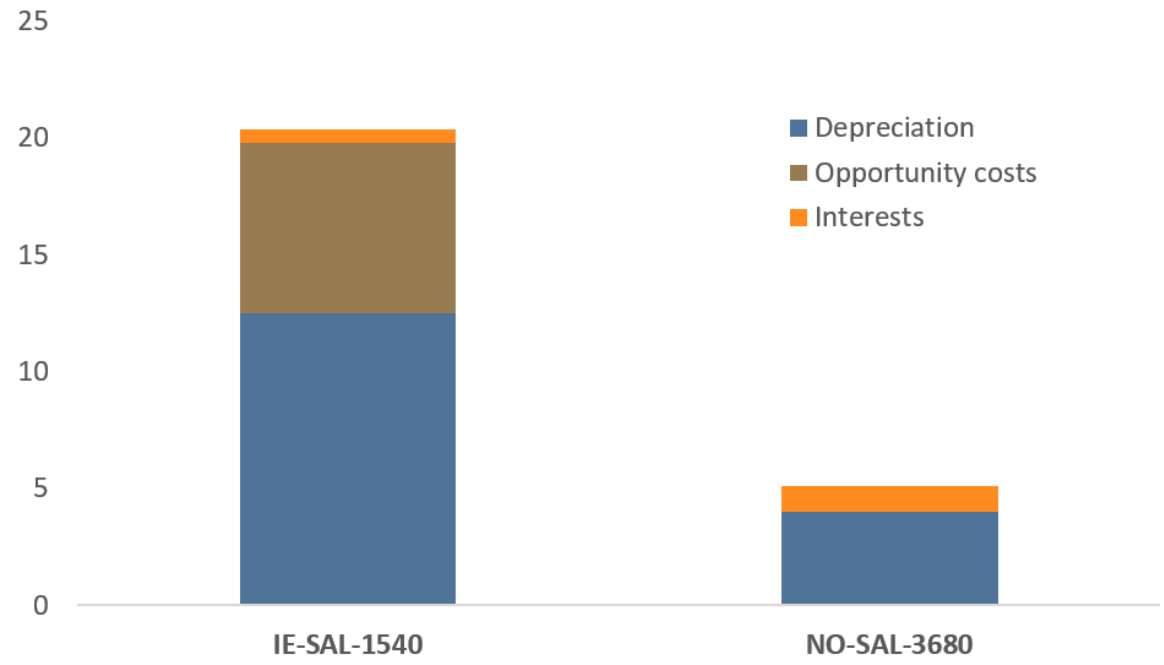

Figure 4.7. *Additional mid- and long-term costs - Present day depreciation, opportunity costs and interest for all Atlantic salmon farms in relation to the operating cash costs (%).*

4.4 Regional Economic Consequences of Climate change

Combining average typical salmon farm model results with spatial projections relating to temperature for optimal growing temperatures and pathogen risk provides a means to

visualise the relative change in profitability (Figures 4.8 and 4.9). The regional results reflect the farm-level results with little changes in the classifications of profitability observed across the two countries studied, revealing that future price trends have a more pronounced effect than regional changes in temperature and temperature induced disease suitability. In Ireland, increased profits are projected across the mapped region under the WM scenario. In contrast, decreased profits are predicted across the mapped region under the NE and GE scenarios. This is also largely the case for the LS scenario, however, there are some areas that have the potential to realise increased profits when considering the regional influence of temperature and disease risk changes, but these are largely offshore where it is currently not feasible to farm due to limitations in the culture technology and conflicts with shipping. In the case of Norway WM, NE, and LS scenarios all show increased profits across the range except for under the WM and NE scenarios where areas in the South of the mapped range are predicted to experience reduced profits, however this is not a main salmon producing area today (Otero et al. 2011). Profits are predicted to reduce across the whole region under the GS scenario. Further, it has to be kept in mind, that the typical farm was defined for the region of Nordland, whereas the regional mapping concentrates on the southern waters of the country (due to data limitations) where farms today, are more severely affected by sea-lice (Jansen et al. 2012) with respective associated costs that would increase cash costs even further. Depending on the future development of sea-lice abundance, the available treatments and avoidance strategies might be a factor that adds up on the future price and regional temperature predictions discussed here.

IE-SAL-1540

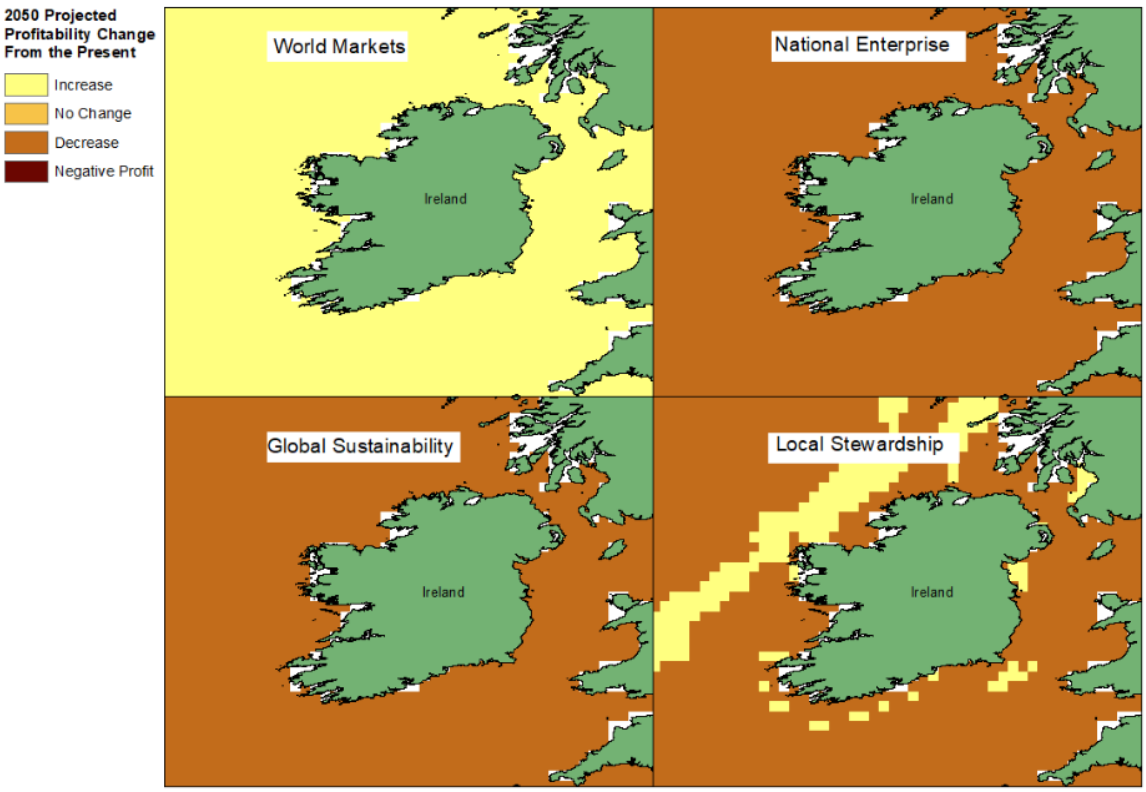

Figure 4.8. *Predicted consequences of the four CERES climate change scenarios on the profitability of typical Irish Atlantic Salmon farm (IE-SAL-1540).*

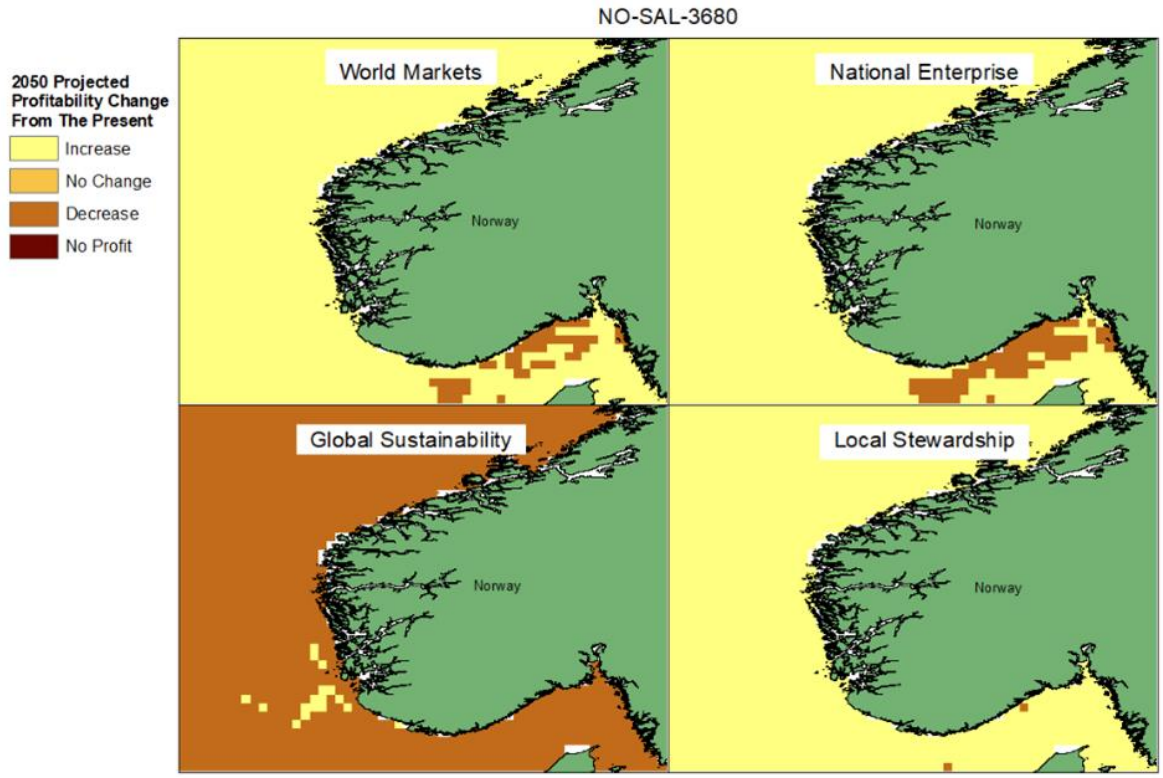

Figure 4.9. *Predicted consequences of the four CERES climate change scenarios on the profitability of typical Norwegian Atlantic Salmon farm (NO-SAL-3680).*

4.5 Conclusions, Opportunities and Challenges for Atlantic Salmon

Atlantic salmon currently constitute the most important European aquaculture species in terms of volume produced and, although currently a highly profitable industry, there are many challenges moving forward in a future climate. Currently, there is a large export market for Atlantic salmon and few countries in Europe are able to produce salmon (due to a lack of suitable coastline or environmental conditions). Competition in terms of supply from outside of Europe is increasing. To overcome this challenge, the European industry will need to adapt to future changes to ensure sale prices remain competitive and costs sufficiently low to retain good profitability.

Feed constitutes the dominant cost to the sector and, consequently, the overall profitability of a farm is greatly influenced by changes in feed price. Whilst the projections made in CERES generally show these costs to go up, besides considering the market influence of fish meal and fish oil alternatives according to the different scenarios, it was assumed there would be no change in the composition of feeds in general. Substituting marine ingredients with alternatives such as insect meal, single cell protein, animal protein or marine algal oil as well as gene-modified plant oil, the (partly) replacement of other ingredients with respective impacts on future feed prices is conceivable. However, challenges associated with new ingredients include consumer acceptance, the ability to produce the quantities required and assure their provenance, to ensure any labelling or certification standards the salmon industry wishes to adhere to are not affected.

Fuel costs are also an important cost, especially in Norway, however conversion to electric energy and non-fossil fuel sources is a priority in Norway and across Europe. Though transitioning to this technology is likely to incur significant initial investment costs, it will make the industry less susceptible in to changes in global oil prices. In Ireland, labour costs are more important than Norway, due to less external services available as the industry is a lot smaller and expansion of the industry could mitigate such costs. Any measures adopted in Ireland, however, would need to be carefully evaluated to ensure that they do not jeopardize the organic status associated with their product as this is an important marketing tool for the Irish sector allowing them to achieve good market prices.

The future supply of smolts to the sector is critical. This depends on the ability to maintain freshwater production systems which face many of the same challenges as the trout sector. To help overcome these, the salmon industry is starting to adopt recirculating systems to produce smolts. However, there is some evidence that these fish are not as fit as those grown on flow through systems and there is a large body of research that is currently on-going to understand and overcome this. If done correctly there are however excellent opportunities for the freshwater production side of operations to improve

growth and profitability in the marine environment. Selective breeding experiments are being conducted to try and establish lines of salmon that will grow faster and be more disease resistant, and some smolt units are now producing larger 'super-smolts' that have better survival at sea and shorten the marine on-growing phase.

Compared to future price trends, local climate effects have little meaningful influence on the profitability of a site, though they may affect a sites viability. The direct temperature effects associated with climate change are however still important and the positive side of climate change is the predicted increase in number of optimal growing days for both Norway and Ireland, which may help shorten production cycles and improve profitability. However, this change in temperature may also increase disease risks and impact, and in open cage systems the adoption of effective preventative biosecurity measures against vectors and waterborne transmission of pathogens is challenging. Land based pump ashore systems and careful siting of cage sites may help mitigate some disease concerns. Another concern associated with increasing temperature is that though there may be an increased number of optimal growing days, the likelihood of exceeding the maximum physiological threshold for salmon becomes a possibility. This possibility may also be higher for the inshore waters, fjords, lochs and loughs in which production is predominantly based, obviously moving production off-shore and into deeper waters may help this, but there may also be greater opportunities to produce rainbow trout instead of salmon in these inshore waters. Although the optimal growing temperatures for rainbow trout are very similar to Atlantic salmon, they are able to tolerate a higher maximum temperature of 27°C for short periods compared to 22°C for Atlantic salmon. Fresh water rainbow trout are also less susceptible to sea lice infections than Atlantic salmon (Fat et al. 2002) and attract a high market value in both countries (STECF 2018), so provide a useful alternative species under some circumstances.

For the industry to expand and realise the opportunities and overcome the above challenges associated with temperature changes, new farming locations need to be found. Given current technologies, conflicts with other sectors and regulatory factors, only a limited number of new inshore areas exist. Again, land-based pump ashore systems may provide and alternative, but land availability, infrastructure and running costs are a concern associated with such systems. New cage and holding technologies are required to realise the opportunities that are available offshore, however due to this being a high energy environment, the challenge is to build systems that can withstand this and develop the mean to monitor, maintain and harvest such systems. Moving further off-shore may also help overcome some of the public concerns associated with salmon aquaculture and make it easier to manage some of the conflicts with other industries, both of which may allow a reduced regulatory burden which is currently a big barrier to new investments.

In summary, the future climate scenarios investigated within CERES pose mostly opportunities for Norway (3 out of 4 scenarios suggest increased future profit), but substantial challenges to the Atlantic salmon industries for Ireland (3 out of 4 scenarios

suggest decreased future profit). In general, there are opportunities to expand production and retain profitability, but this will require significant investment and the development and adoption of new technologies. The advantage of the Atlantic salmon sector over others is its high technological progress and maturity. As the sector is mainly comprised of large multi-site companies that are often, vertically integrated, they have higher investment potential to realise new opportunities and overcome challenges more readily than sectors comprised of small independent concerns, such as the trout and carp sectors.

Chapter 5 European Sea Bass and Sea Bream Aquaculture

5.1 Introduction

Gilthead sea bream (*Sparus aurata*) and European sea bass (*Dicentrarchus labrax*) are the two most widely and intensively cultured marine finfish species in Southern Europe. They are often farmed together as part of the same operation, though in separate cages of mostly coastal net pen facilities. The majority of sea bass and sea bream is consumed in Southern European countries. Markets for these species are relatively integrated, although the market for sea bream has been less stable and generally achieves lower prices than for sea bass (Globe fish market report 1/2017). Research in CERES concentrated on Turkey for seabream and sea bass production and Spain, with focus on the Canary Islands as important sea bass producer.

Turkey, being the major European producer in 2016, reached volumes of 67,612 metric tons of seabream and 72,342 metric tons of sea bass within that year (FEAP 2017) with an overall value of €655 million (OECD statistics). Currently there are 426 Turkish farms (BSGM 2018), which are pre-dominantly localized at the Aegean and Southern Aegean coastline with main producing regions in Muğla and Izmir (Figure 5.1). Economies of scale is a crucial determinant of profitability of sea bass and sea bream farming, and an overall annual capacity of 2000 metric tons is regarded as the minimum capacity for a viable farming operation in Turkey. The sector is well consolidated with large-scale and vertically integrated enterprises dominating the production (BSGM 2019). This export-oriented business concentrates on fresh, chilled fish but markets for filleted fish are also developing. Export volumes were around 30,000 metric tons for sea bream and over 40,000 metric tons for sea bass in 2016, with the EU (especially Italy and the Netherlands) being the most important markets (Globe fish sector report 1/2018). Within CERES, a typical farm was defined for the region of Muğla producing equally 1000 metric tons of each species (TR-BSS-200).

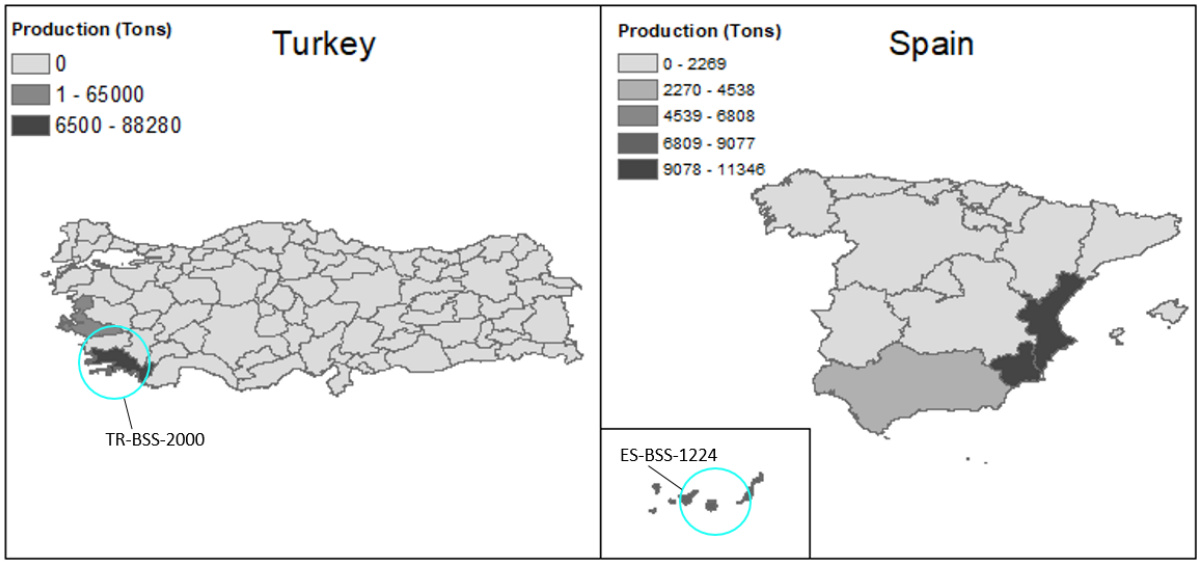

Figure 5.1. *Sea bass (Dicentrarchus labrax) and sea bream (Sparus aurata) regional production in tons for the year 2016 and selected production countries in CERES: Turkey and Spain. Locations of the typical carp farms are indicated by circles and labelled with a country-species-yearly production (t) code. Data sources: Turkish Ministry of Agriculture/Forest, Spanish Aquaculture Association (APROMAR).*

Spain harvested volumes of 13740 metric tons of sea bream and 23445 metric tons of sea bass in 2016 and thereby ranked third within European production for that year (FEAP 2017, APROMAR 2017). Murcia and Valencia are the two main producing regions, with the Valencian community being the main producer of sea bream (41%) and Murcia sea bass (35%). Other important production regions are the Canary Islands and Andalusia (APROMAR 2017, Figure 5.1). In Andalusia, a number of farms produce for the local market in traditional and extensive estuary aquaculture systems, but it is the circa 40 sea cage farms along the coast of Spain and the Canary Islands that account for over 90 % of the domestic sea bass and sea bream production (Globefish, APROMAR 2017). Overall the value of the Spanish sector was around €221 million in 2016 (OECD statistics) with around 35% of both species being exported, mainly to Portugal and France (emofa.eu). With Spain being one of the main markets for sea bream and sea bass (ranking second after Italy), an additional 8000 metric tons of sea bream and 2000 metric tons sea bass were imported in 2016, mainly from Turkey and Greece (eumofa.eu). Within CERES, a typical sea bass farm was defined for the Canary Islands with an annual production of 1224 metric tons (ES-BSS-1224). Due to the insularity location of the Canary Island, European subsidies for ultraperipheral regions are granted for agricultural/aquaculture production on this island group (POSEICAN programme for Canary Islands), which was also considered in the economic analysis.

5.2 Climate Change Effects on Habitat Suitability for Sea Bass and Sea Bream

Sea bass and Sea bream have similar temperature tolerances and optimal growing temperature of between 2-33°C and 17-25°C respectively. Comparing average water temperatures for the two growing areas of interest in this study show that they both sit within the optimal growing range (table 5.1), with Eastern Mediterranean waters being around 2°C warmer (note: it is important the region mapped for the Western Mediterranean is much larger and includes south Atlantic waters). Under RCP4.5, the average temperature in both regions is predicted to rise by around 0.5°C, under RCP8.5 an increase of around 0.8°C is predicted. Under both RCPs, average water temperatures are projected to remain within the optimal growing threshold for each species.

Table 5.1. *Average predicted water temperatures in case study regions and the predicted change under RCPs 4.5 and 8.5.*

Country	Average national present-day water temp	Average national 2050 water temp – RCP4.5	Average national 2050 water temp – RCP8.5	Percentage change in national average water temperature in 2050	
				RCP 4.5	RCP 8.5
East Mediterranean (Turkey)	20.43°C (SD= 0.98°C)	21.05°C (SD= 1.0°C)	21.31 °C (SD= 0.99°C)	3.02%	4.33%
West Mediterranean and south Atlantic waters (Spain)	18.38°C (SD= 2.06°C)	18.82°C (SD= 2.15°C)	19.11°C (SD= 2.25°C)	2.42%	3.98%

The average number of optimal growing days across each of the mapped regions is similar with a slightly higher proportion of optimal days in the Eastern region compared to the Western, at 0.64 and 0.61 respectively (Table 5.2). Under RCP4.5 a small increase of <1% is predicted for the eastern region and around 1.6% for the western region. Under RCP8.5, this increase remains similar in the western region (circa 1.4%), but a reduction on around 4.6% is predicted in the eastern region, due to an increased number of days exceeding the upper optimal growing threshold. However, when the proportion of optimal days is mapped across each of the study regions (rather than averaged across them as presented in table 5.2), it becomes apparent that conclusions based on averages across the regions are misleading, and a more useful interpretation can be derived from the spatial analysis (Figure 5.2).

Table 5.2. *Predicted annual proportion of days in which water temperatures are predicted to be in the optimal growing temperature range for Sea bass and Sea bream (17-25°C) under current climate and predicted percentage change under RCP 4.5 and 8.5 projections.*

Region	Present day proportion of optimal days per	2050 RCP 4.5 proportion of optimal days per	2050 RCP 8.5 proportion of optimal days per	Annual national average change in temperature suitability for Sea Bass and Sea Bream in 2050	
				RCP 4.5	RCP 8.5
East Mediterranean	0.64	0.64	0.61	0.85%	-4.56%
West Mediterranean and South Atlantic	0.61	0.62	0.62	1.58%	1.38%

The spatial projections show that at present, in the eastern Mediterranean around 70 to 80% of days in a year are in the optimal growing range, particularly in waters off the western Turkish coasts. Under both RCP's the percentage of days in the optimal growing range is predicted to increase to 100% off the South west coast of Turkey and this pattern expands towards Greek waters. The range of this optimal growing area is predicted to be of similar size and extent similar under both RCP's.

In the Western Mediterranean region, little change is predicted for the pattern of optimal growing days under either of the RCPs compared to the present-day time slice. Optimal growing days are predicted for around 60-70% of the year along the southern coast of Spain and southwest tip of Portugal. However, as you move down the west coast of North Africa and around the Canary Islands, optimal growing days increase to 100% and this does not change under either of the RCPS.

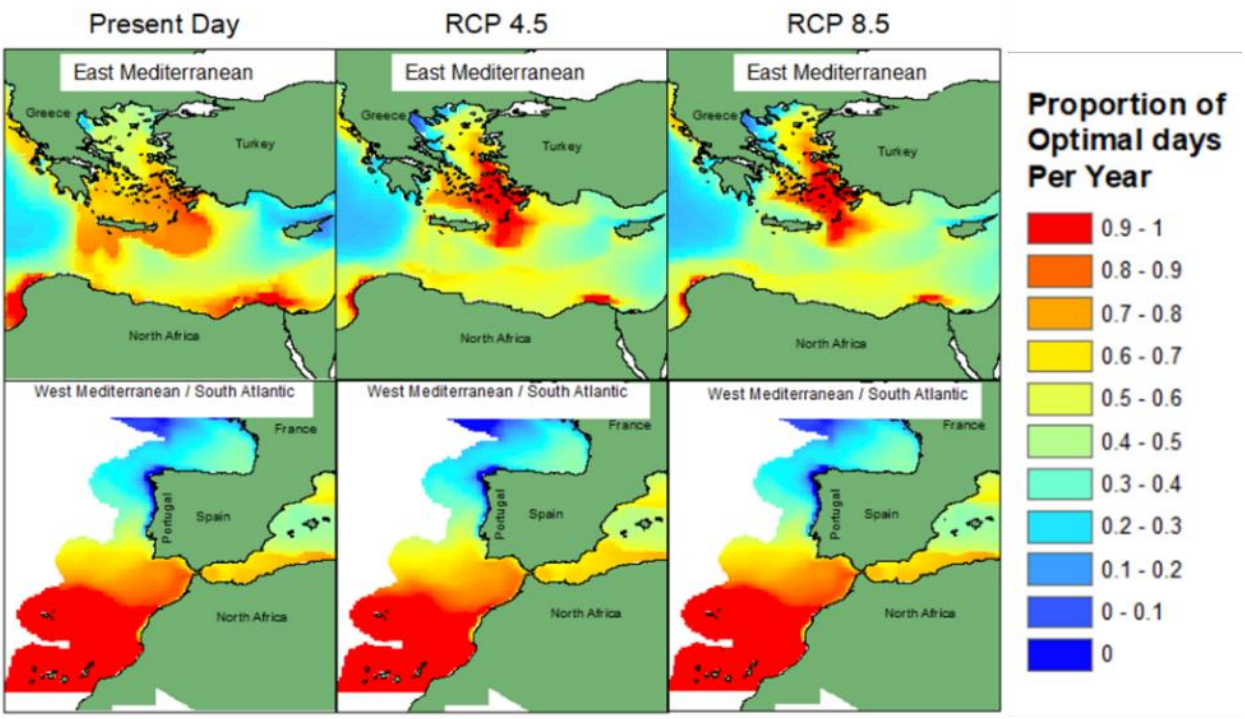

Figure 5.2. *Predicted annual proportion of days in which water temperatures are projected to be in the optimal growing temperature range for Sea Bass and Bream (17-25°C) under current climate and RCP 4.5 and 8.5 projections.*

Disease concerns relating to this sector are discussed in detail within the CERES WP3 deliverables, but the impacts of an important production disease called viral nervous necrosis on regional farm economics is included here. As the viral infection can cause disease and high mortality at a wide range of temperatures (from 15 to 30°C), the proportion of days in this temperature range in both of the mapped regions is high, being 81% in the western Mediterranean and 95% in the eastern Mediterranean. In the Western Mediterranean a 4 to 5.4% increase is projected under RCP 4.5 and 8.5 respectively compared to 2.3 and 2.7% for the Eastern Mediterranean (Table 5.3). These temperature-based analyses suggest that, although there may be opportunities for improved growth in the Eastern Mediterranean and parts of the Western Mediterranean, the disease risk will also increase so good biosecurity practices will be required to realise additional profits from improved growth.

Table 5.3. *Predicted annual proportion of days in which water temperatures are predicted to be in the optimal range for a key disease of potential concern for Sea bass and bream under current climate and predicted percentage change under RCP 4.5 and 8.5 projections.*

Region	Present day proportion of optimal pathogen infection days	2050 RCP 4.5 proportion of optimal pathogen infection days	2050 RCP 8.5 proportion of optimal pathogen infection days	National percentage change in optimal pathogen infection days in 2050	
				RCP 4.5	RCP 8.5

East Mediterranean	0.95	0.97	0.97	2.32%	2.67%
West Mediterranean and South Atlantic	0.81	0.85	0.86	4.0%	5.4%

5.3 Farm Level Economic Consequences of Climate Change

Within the sea bass and sea bream sector, sea bass achieves a better market price, and these are higher for fish produced in Spain compared to Turkey (Figure 5.3). Due to this fact, the typical sea bass farm for the Canary Islands (ES-BSS-1224) achieves the highest profit margin among the farms analysed for this sector (39%), however, transport costs to the Spanish mainland for first sale would be 34% higher, leading to a minimum profit margin of 29%. The Turkish production usually combines both sea bream and sea bass in the same operation, but the two species are analysed separately so that the separate biological model projections of future harvest weight and FCR deriving from D3.3 can be assessed in terms of species-specific impact and opportunity. With lower production costs in Turkey (8 to 15% for sea bass and sea bream respectively), a sustained depreciation of the Turkish lira versus the Euro, and subsidies that were granted by the Turkish government in the past (Bjørndal et al. 2019), Turkish sea bass and bream could be marketed at lower prices than other producing countries such as Spain. Aquaculture production on the Canary Islands, however, also receives subsides to balance higher costs of the insularity location as costs for supplies from the mainland are expensive and competition on the export market is hampered by high transport costs.

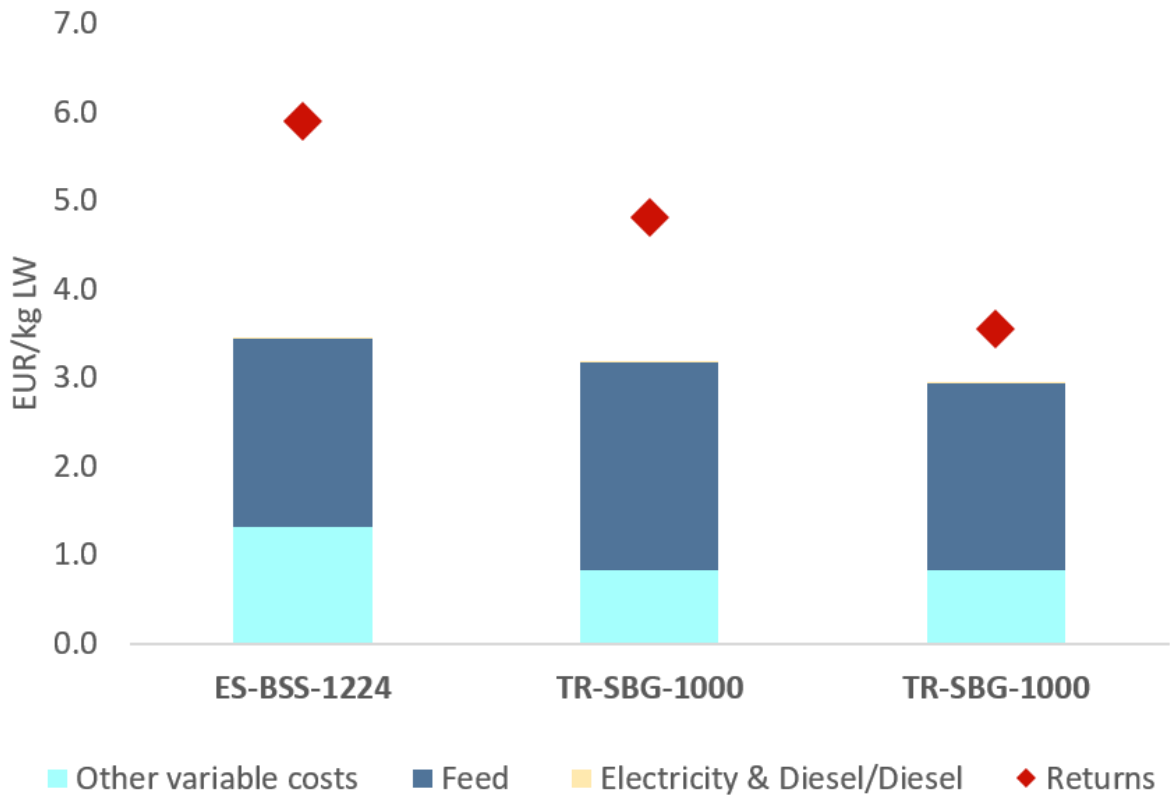

Figure 5.3. *Costs and returns (farmgate) from typical sea bass and sea bream farm models (TR=Turkey, ES= Spain) showing stacked costs and returns. For ES-BSS-1224 Electricity and Diesel is a merged cost category, for the other two farms only Diesel costs are occurring within cash costs. The distance between the red returns point and the top of the stacked costs represents the short-term profit/loss.*

The main cost factors are similar for all typical farms in both countries (Figure 5.4). Feed costs are most prominent (62-74% of overall cash costs) and here even more pronounced than for salmonid farms due to the higher FCR (i.e. the system is less efficient), especially for the Turkish production. The second important cost factor is stocking for typical farms of both countries (13-18%) and labour costs also rank within the five main cost factors for both production countries. In addition, maintenance of buildings and facilities, veterinary costs (TR) and insurance as well as other variable costs (ES) are important, whereas overall energy costs account for less than 0.5 % of the overall cash costs in both countries.

ES-BSS-1224	2016	TR-SBG-1000	2016	TR-BSS-1000	2016
Operating earnings (€/kg)	2.44	Operating earnings (€/kg)	0.60	Operating earnings (€/kg)	1.60
Most prominent costs in % from operational costs		Most prominent costs in % from operational costs		Most prominent costs in % from operational costs	
Feed	61.67	Feed	71.49	Feed	73.68
Stocking	18.13	Stocking	13.90	Stocking	12.83
Labour	9.16	Other variable costs	4.32	Other variable costs	3.99
Maintenance Build./Facilities	4.86	Veterinary	3.76	Veterinary	3.47
Insurances	2.24	Labour	3.28	Labour	3.03

Figure 5.4. *Operating earnings and most prominent costs in percent from overall operational costs for all typical SBSB farms analysed in CERES.*

Both sea bass farms show increased profit under all scenarios when considering the future cost and price changes only, even if subsidies are no longer granted for the typical farm on the Canary Islands under the WM and GS scenarios as assumed within the analysis (Figure 5.5). This removal of subsidies does, however, explain the lower profits under these two scenarios compared to the Turkish farm, despite the higher profit margin for the Spanish farm. Thereby WM is the most favourable scenario for TR-BSS-1000 and the LS scenario is the most favourable for ES-BSS-1224. Sea bream production in Turkey has currently almost half the profit of sea bass production (17%) and concomitantly less buffer to balance increasing future costs under the different climate change scenarios. Lower profits for three out of four scenarios are the consequence, with 45% reduction compared to today's operating earnings under the worst scenario, which is GS. However, for WM an increase in profitability of 30% can be achieved, predominately due to a more favourable future cost-return combination of fish feed, diesel and fish prices.

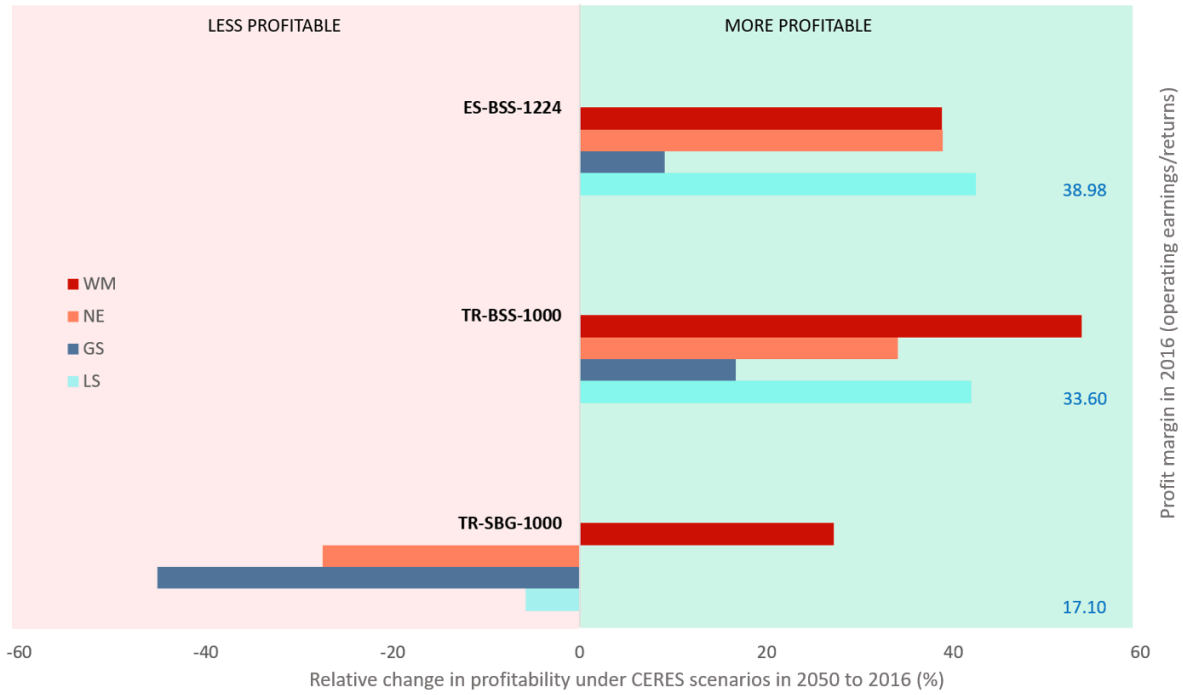

Figure 5.5. *Relative change in profitability under the four CERES scenarios in 2050 compared to 2016 for the typical Sea bass and Sea bream farms without considering future harvest weight and FCR. World Market = WM, National Enterprise= NE, Global Sustainability= GS, Local Stewardship = LS.*

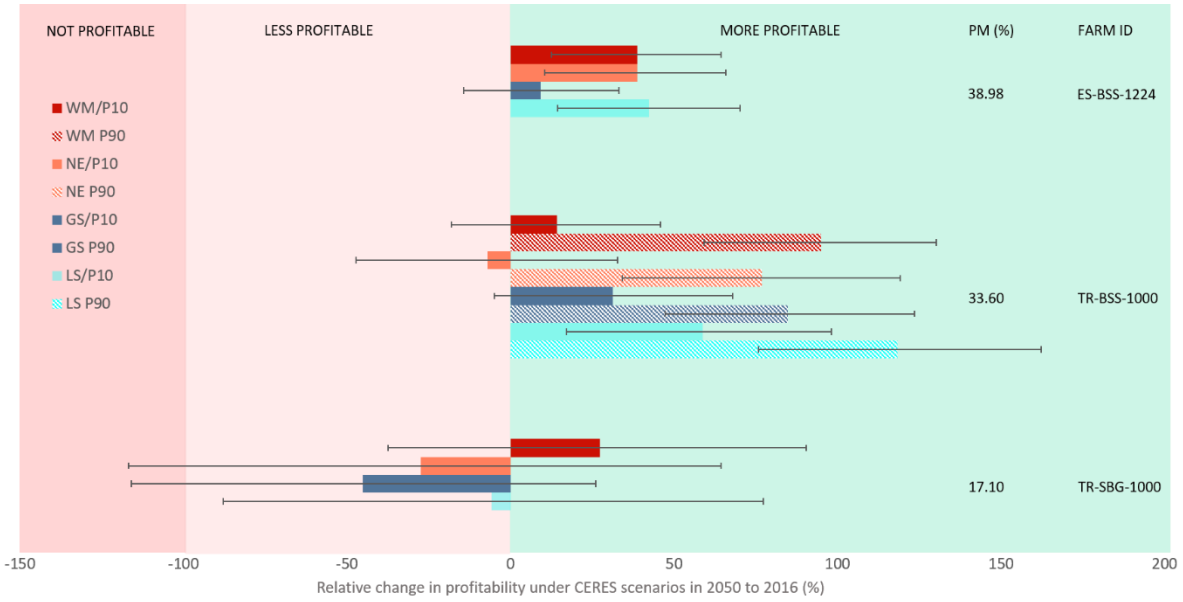

Figure 5.6. *Relative change in profitability under the four CERES scenarios in 2050 compared to 2016 for the typical Sea bass and Sea bream farms. World Market = WM, National Enterprise= NE, Global Sustainability= GS, Local Stewardship = LS, P10 = extreme cold year, P90= extreme warm year. Error bars indicate 95% upper and lower probability ranges from Monte Carlo simulation results in relation to operating earnings from today (2016). PM = Profit*

Margin in percent. PM = Profit Margin in percent, black numbers indicate PM with public payments, red numbers without.

When considering the changes in FCR and harvest weight under RCP 8.5 (WM and NE scenario) and RCP 4.5 (GS and LS scenario) for the Turkish sea bass production (D3.3), future profitability develops differently. A reduced harvest weight of around 9% combined with a slightly increased FCR under RCP 8.5 for extreme cold years leads to a slight loss in profitability under NE P10 and a clear reduction in profit increases for WM P10 compared to the results without considering harvest weight and FCR changes (Figure 5.6). For extreme warm years under RCP 8.5 however, harvest weight and FCR increase simultaneously compared to today and thereby also future profits increase further. For both, extreme cold and warm years under RCP 4.5, harvest weight increases more pronounced than FCR, which leads to further increased profits being maximal for warm years under the LS scenario.

When considering future potential price variation of the uncertainty analysis, the Turkish sea bream farm has the potential to increase future profits under all four scenarios in the case of favourable price and cost developments but would be no longer viable under the NE and GS scenario in the worst case. ES-BSS-1224 has an overall >95% probability to increase profits under the WM, NE and LS scenarios when taking potential future price changes into account. However, under the GS scenario there is a chance of reduced profits, down 23% on today's operating earnings when the future price development is unfavourable. For the Turkish sea bass production this risk occurs for most of the cold year scenarios (WM P10, NE P10, GS P10), but only with a low probability for the GS scenario. The most pronounced is this risk under NE P10 with a loss of 50% of today's operating earnings under most unfavourable future price developments. All other scenarios, and especially those for extreme warm years, show a >95% probability of increased profitability compared to today. As sea bream are marginally less tolerant of cold-water temperatures than sea bass (Ökte 2002, Dülger et al. 2012), the impact of extreme cold years could lead to even more severe declines in profitability for this species, especially considering today's already lower profit margin of around 17%. However, the Canary Islands might have a production advantage due to today's more stable water temperature conditions (18-24°C throughout the year) than in the Mediterranean, however this would require further exploration before reliable conclusions could be drawn.

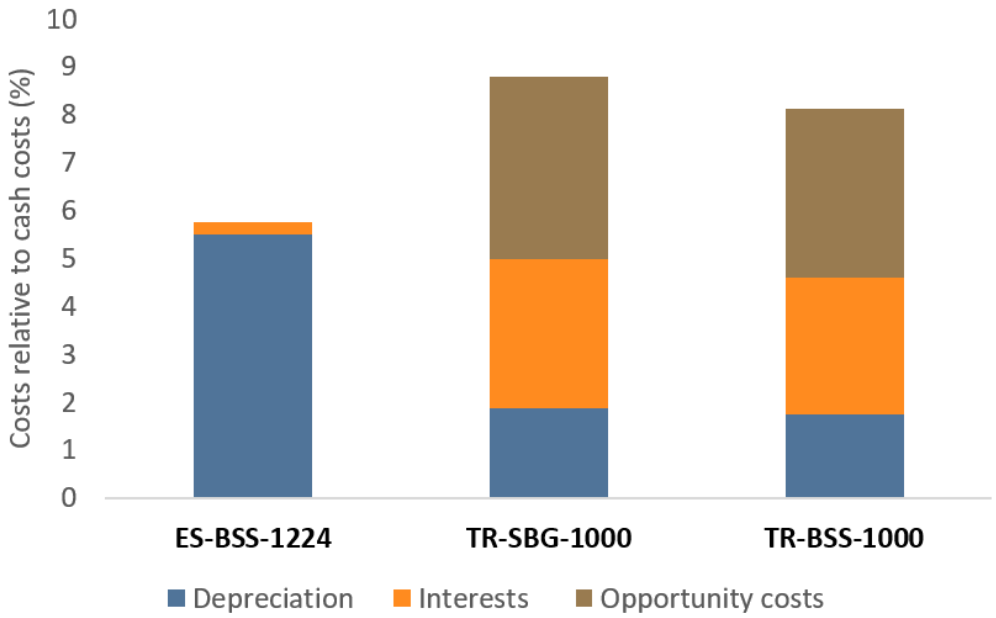

Figure 5.7. *Additional mid to long-term costs - Present day depreciation, opportunity costs and interest for all Sea bass and Sea bream farms in relation to the operating cash costs (%).*

When considering additional mid- to long-term costs, they are most pronounced for the Turkish production with about 9% of overall cash costs allocated to mostly opportunity costs, but also Interests and depreciation (Figure 5.7). Opportunity costs derive from unpaid labour, which is unusual for the typical Spanish farm (ES-BSS-1224). The majority of additional mid- and long-term costs for the Spanish farm is allocated to depreciation and although investment in equipment, farming systems and buildings is substantially higher than for the Turkish farm. Costs for interests in Spain are only marginal compared to the typical sea bass and sea bream production in Turkey. In conclusion, ES-BSS-1224 has more additional economic buffer on a long-term scale than the Turkish farms, which could for example be used to balance potential higher investments that might become necessary under future climate change impacts. These could include investments in more robust equipment that endures extreme weather events or allows further automation of feeding and maintenance of the marine cage farms to reduce maintenance effort by staff. However, due to the ultraperipheral location of the Canary Islands, higher transport costs to the buyers' market must be taken into account as well. These costs are partly balanced by subsidies, but in case they are no longer granted, for example under a WM scenario, this could lead to a locational disadvantage.

5.4 Regional Economic Consequences of Climate Change

Regional analyses presented in Figures 5.8 to 5.10 largely reflects the conclusions of the typical farm models relating to profitability, though some local effects are visible in the

case of the eastern Mediterranean. In the case of Spanish sea bass, no local effects are predicted and the whole of the mapped region is predicted to have potentially increasing profits under all four scenarios (Figure 5.8).

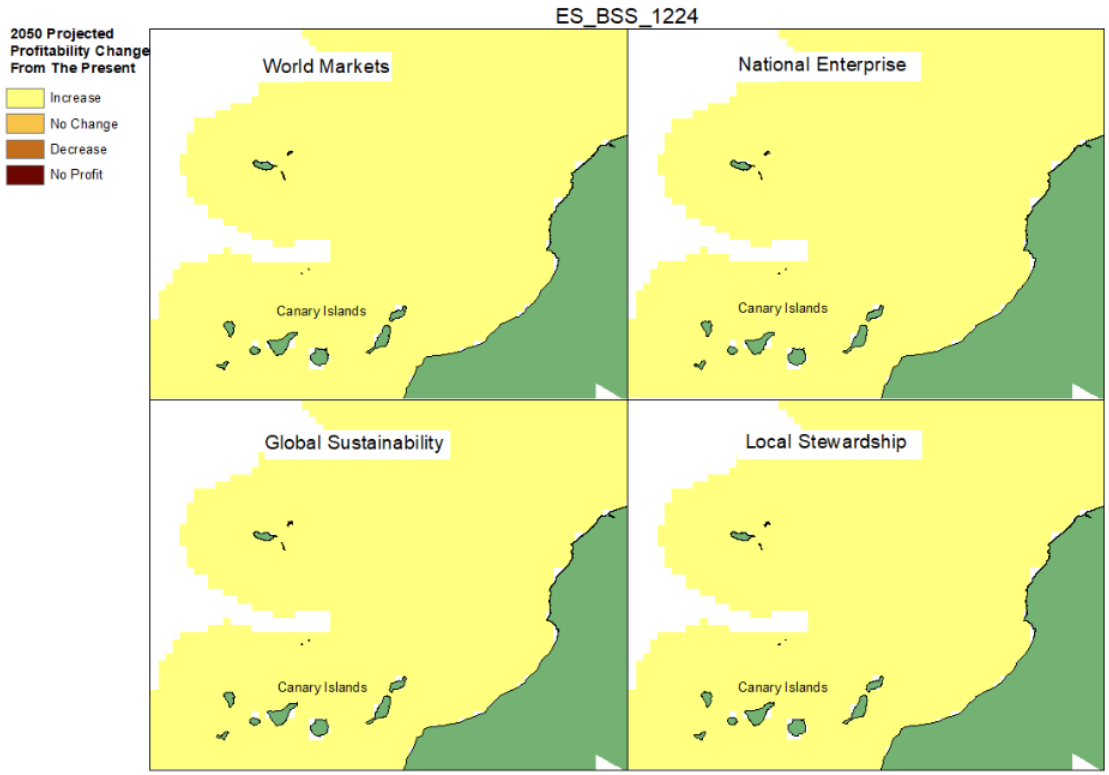

Figure 5.8. *Predicted consequences of the four CERES climate change scenarios on the profitability of typical Spanish Sea Bass farms (ES-BSS-1224).*

A similar pattern is also predicted for sea bass in the Eastern Mediterranean, with the potential for increased profits across the vast majority of the mapped region under all four scenarios (Figure 5.9). For the latter it has to be kept in mind, that although the averaged future temperature projections are positive, extreme cold years might lead to decreased profitability as shown for the region of Muğla as discussed above (6.3). However, under the NE and GS scenarios some local effects can be seen, with areas to the east of Turkey predicted to suffer reduced profitability. This observation is far less pronounced under the WM and LS scenarios

In the case of Turkish sea bream production reduced profitability is predicted across the whole mapped area under the NE and GS scenarios (Figure 5.10). Under the WM scenario however the majority of the mapped area is predicted to experience increased profitability, with waters to the east of Turkey predicted to experience decreases in profitability. Under the LS scenario most of the Turkish coastline and large amounts of the offshore environment are predicted to have the potential to experienced increased profits.

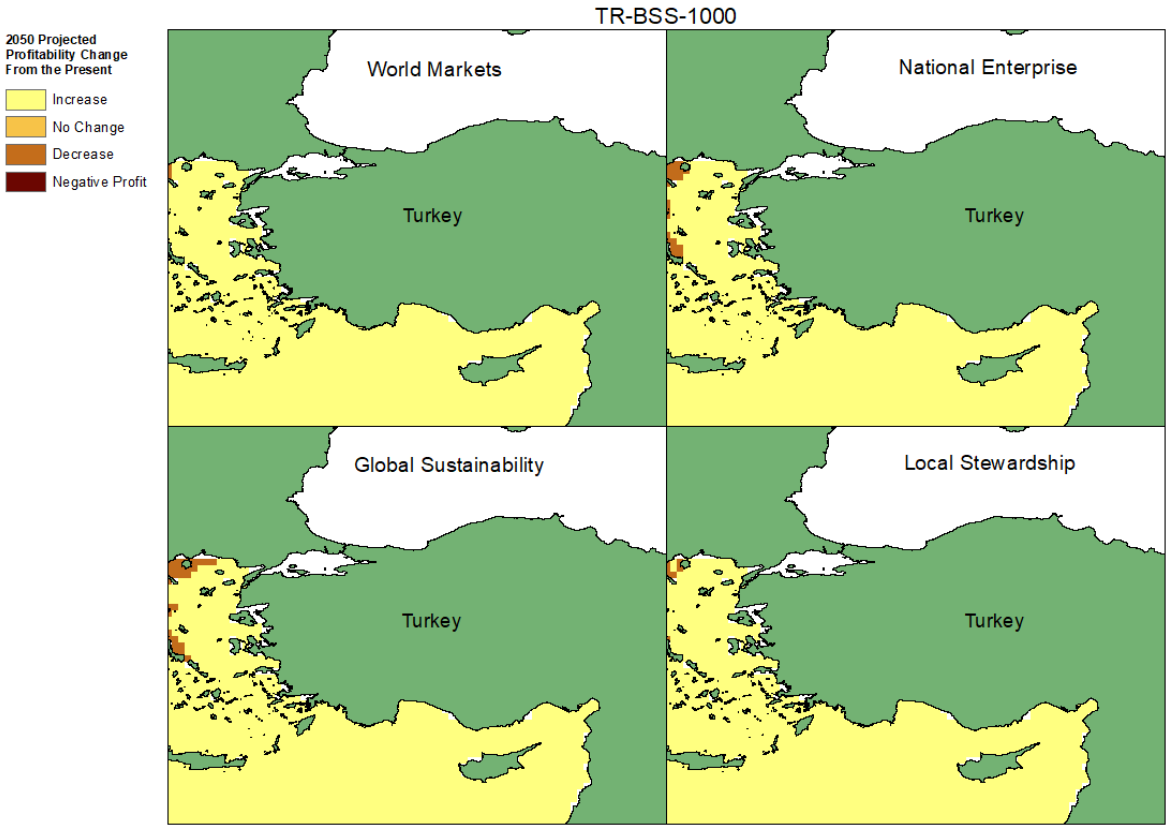

Figure 5.9. *Predicted consequences of the four CERES climate change scenarios on the profitability of typical Turkish Sea Bass farms (TR-BSS-1000).*

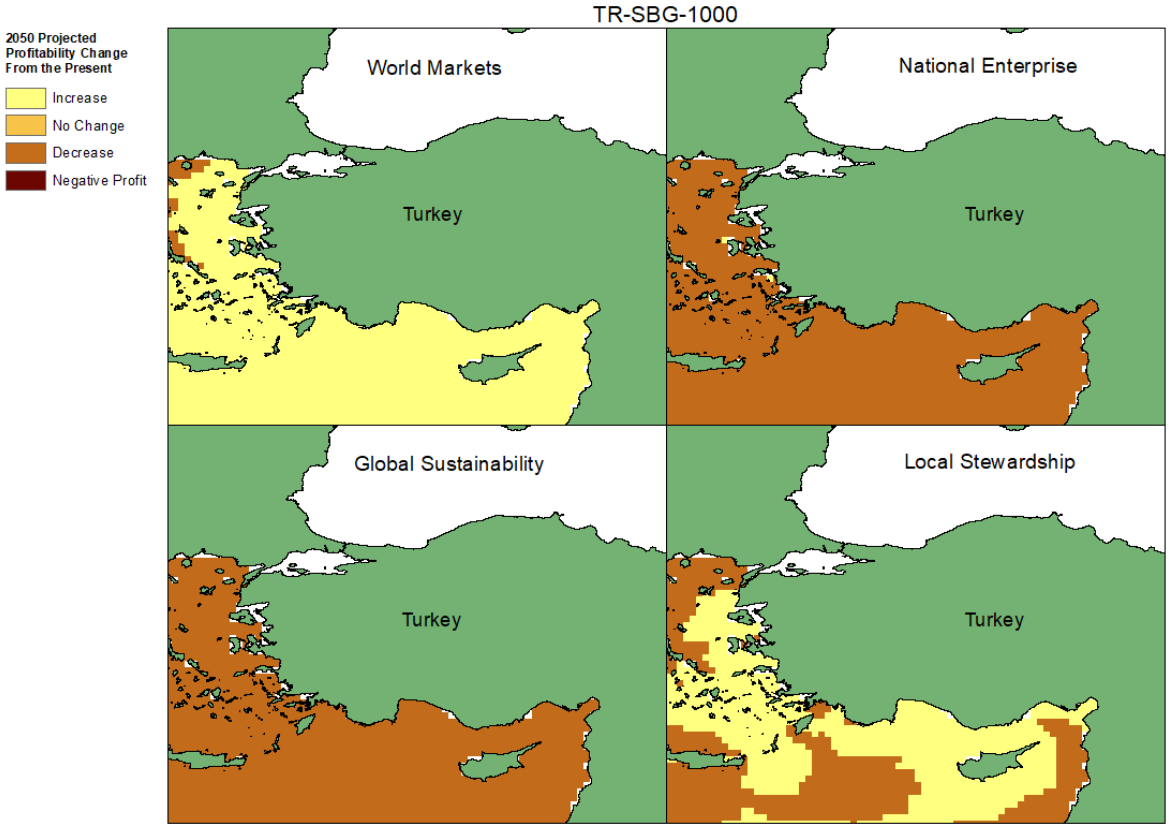

Figure 5.10. *Predicted consequences of the four CERES climate change scenarios on the profitability of typical Turkish Sea Bream farms (TR-SBG-1000).*

5.5 Conclusions, Opportunities and Challenges for Sea Bass and Sea Bream

The production of sea bass and sea bream in the Eastern and Western Mediterranean Sea has many parallels to the European Atlantic Salmon sector in terms of production technique and is also a lot closer in terms of professionalisation to salmon production than the other species analysed within CERES. For sea bass especially, there are many opportunities to increase profitability under all four climate change scenarios, however the picture for sea bream is more challenging as the profit margin for this species is, at present, considerably smaller than for sea bass. On average, more optimal growing days around Turkey and the coast of southern Spain for both species may improve growth rates and allow increased production. In the event of a growing industry off the Spanish coasts, it will be important for the Canary Islands to continue to receive public payments as their remoteness increases transport costs, which could mean that Spanish product is cheaper.

Despite the potential benefits in terms of growth associated with warmer temperatures, there are well founded stakeholder concerns relating to increased stock losses at higher temperatures due to reduced oxygen, increased stress and the occurrence of harmful algal blooms and disease. As is the case with salmon, improved technologies may help keep oxygen levels high, but if this is not possible it may be necessary to reduce stocking densities which is likely to offset any gains achieved through improved growth. Harmful algal blooms are challenging, and better early warning systems would be of benefit to this and other aquaculture sectors, which would allow contingency plans to be implemented in good time. Again, submersed cage technology could be deployed further offshore and changes in cage depth may provide a means to help cope with blooms, but this would involve significant development and investment. Disease is another challenging concern, and robust farm area and national level biosecurity plans will be needed for all producing countries. The ability to move offshore may also allow greater spacing between farms reducing pathogen spread. Where disease does become an issue and appropriate vaccines and treatments are not available, in addition to investing in their development, there may be opportunities to produce resistant lines of bass and bream or move to producing other species. Thereby the fast growing Meagre (*Argyrosomus regius*) or greater amberjack (*Seriola dumerili*), both with promising market acceptance, could be a good opportunity if production bottlenecks can be overcome (Duncan et al. 2013, Sinanoglou et al. 2014, Mylonas et al. 2016)

Stocking is a major cost to the industry, and access to good hatchery production units will not only be critical to meeting demand, but also important to help prevent and mitigate disease issues. As the marine on-growing sector grows, there will be opportunities for growth in hatchery-based production. Hatchery units provide the ability to provide safe

stock that can be assured as disease free as animals can be produced in bio secure conditions. The facilities also allow a point where vaccination programmes can be applied and allow the potential for the production of lines of fish resistant to disease or environmental change. Developments in hatcheries and their technology will be key to helping realise the opportunities on offshore production and will be critical if new aquaculture species are going to become available on a large scale.

Locating farms and availability of new aquaculture areas is another key concern to both the Spanish and Turkish sectors. There are great concerns over the frequency and severity of storms under future scenarios given the resilience (or lack) of current technologies to high-energy conditions. This is especially of concern to the Turkish industry that currently must produce further offshore than may be required by other countries. Obviously, the development of robust new cage and culture systems that can tolerate harsh sea states and offshore conditions is needed, but new aquaculture areas are also needed. The development of new aquaculture areas needs to be tackled in partnership between industry and government. An aquaculture strategy needs to be developed by national and regional governments that takes into account the benefit of production in terms of food provision, export value and livelihoods at a regional level, balanced against potential conflicts with the environment, other industries and the public. The availability of areas for land-based culture should also be considered in such plans, as should investments in research and development and the provision of subsidies where required to allow the sector to develop, become self-sustaining and support some of the wider benefits of aquaculture. For the Canary Islands government support was seen as especially important to improve approval procedures and facilitate increases in production volume. At the industry level, it will be key to invest further in developing practices and technologies that helps to improve fish welfare, reduce environmental impacts and allow the exploitation of new areas and environments. For the sector on the Canary Islands improved technology has also been identified as being especially important, with better systems and increased automation required to improve the efficiency and sustainability of the sector.

Finally, as is the case with salmon and trout production, feed constitutes the single biggest cost to the industry and brings with it, environmental concerns due to its dependence on wild capture fisheries. The search for new sustainable sources of raw materials is critical not only to offset some of the price changes predicted under the future CERES scenarios, but also to increase flexibility in formulating highly nutritious feeds and low environmental impact. The feed sector is already working hard to do this and has been able to reduce the proportion of fish meal and fish oils with vegetable oils and other products, of which insect meal could be one (Arru et al. 2019). However, as sea bass and sea bream are carnivorous species and need proteins of animal origin in their feed, there are concerns that as fish meal and oils are further replaced there will be subsequent declines in feed quality, fish growth rates and FCR. Stakeholder feedback highlighted the

need to develop new cost-effective alternatives for fish meal, as, at present, considering that feed cost constitutes about 65% of total production costs in sea bass and bream farming, prices and availability of fish meal and oil remain a crucial issue for the future economic sustainability of the industry.

Chapter 6 European Blue Mussel Aquaculture

6.1 Introduction

Mussels of the genus *Mytilus* are the most important European aquaculture species in volume (Eurostat, 2016). The blue mussel (*Mytilus edulis*) ranks third in the list of cultured European species (Eurostat, 2016) and is mainly produced within the North Sea area in extensive on-bottom or off-bottom systems. Culture is currently dependent on wild spat, and thereby on the availability of natural stocks (Wijsman et al. 2019) as well as environmental factors such as food supply, temperature and salinity. Blue mussels are pre-dominantly marketed as live fresh product with main consumption concentrating on very few European countries (Monfort 2014). The production has declined since the late 1990s (Globefish 2014) and net profit margins decreased again since 2013 (STECF report 18-19, p. 84), but value-added strategies such as organic certification and other labelling are developing (Globefish 2014), which can lead to price premiums up to 20% (EUMOFA 2017). Within CERES we concentrated on the main European blue mussel producer, the Netherlands (OECD statistics) and Denmark (Figure 6.1).

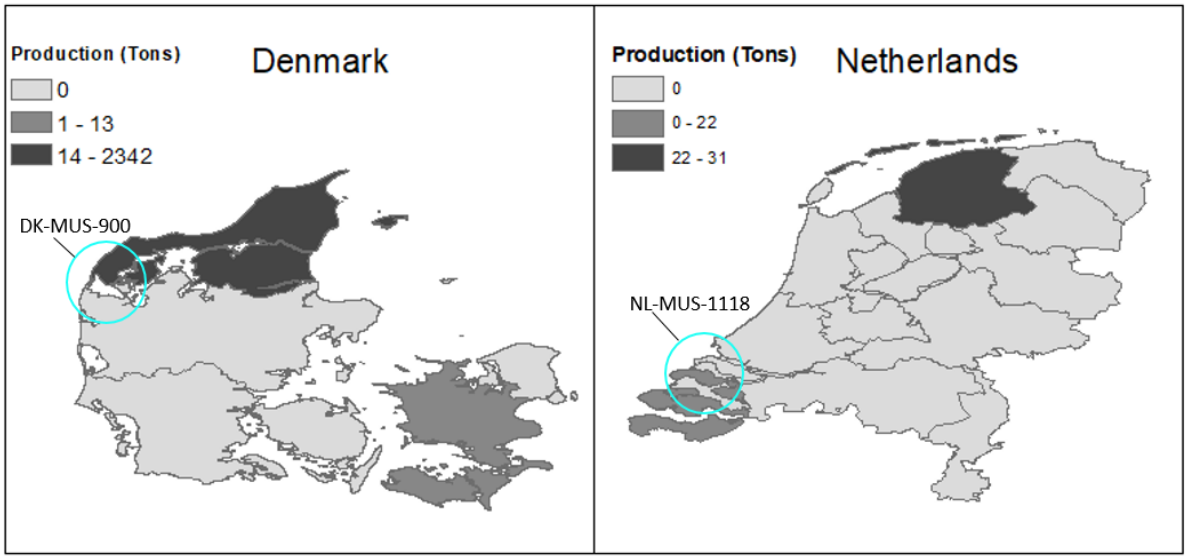

Figure 6.1. *Blue Mussel (Mytilus edulis) regional production in tons for the year 2016 and selected production countries in CERES: Denmark and the Netherlands. Locations of the typical farms are indicated by circles and labelled with a country-species-yearly production (t) code. Source: Danish Agrifish Agency, Dutch Mussel Producer organisation.*

With a blue mussel production of over 5,400 metric tons in 2016, equal to a value of €44.8 million (STECF report 18-19), the Netherlands is the largest blue mussel producer in Europe. The main technique culture method is bottom culture, and production occurs mostly in the western Wadden Sea in the North of the country and the Oosterschelde

estuary in the Southwest of the Netherlands (Figure 6.1). Seed is collected from natural beds in the Wadden Sea and by spat collectors in both the Wadden Sea and the Oosterschelde estuary. The mussel sector in the Netherlands is comprised of 51 companies and is primarily dominated by small farms with less than 5 employees. Dutch mussels are largely exported fresh, and the key destination for mussels from the Netherlands is the Belgian market, which made up 50% in volume and 55% in value of all mussel exports in 2016 (STECF 18-19). The second largest market is France (29% of volume and 23% of value), followed by Germany, United Kingdom and Luxembourg. The Netherlands are also a main significant seafood importer, bringing in 36000 metric tons of *Mytilus spp*. from mainly Germany, Denmark, Ireland and the UK in 2016 (EUMOFA). These are sold together with the Dutch mussels at the mussel auction in Yerseke, the world's only trading centre specialised in mussels (Eurofish 2017). For the economic analysis in CERES a model mussel bottom culture farm was defined for the Oosterschelde region producing 1118 tons a year (NL-MUS-1118) (Figure 6.1).

Denmark has a much smaller production with a volume of 2234 metric tons in 2016 achieving a turnover of €1.4 million (Danish Fishery Agency, https://fiskeristyrelsen.dk/). Main production technique is long line culture, which is concentrated in the area of Limfjorden, with few production enterprises existing in other coastal areas (Figure 6.1). The long-line mussel sector in Denmark is mainly represented by three large mussel long-line companies, employing 3 to 8 people in the Limfjorden. Around 90 percent of live mussels were exported, mainly to The Netherlands, then Germany and France. Within CERES a model mussel long line farm was defined for the region of Limfjorden producing 900 tons (DK-MUS-900) (Figure 6.1).

6.2 Climate Change Effects on Habitat Suitability for Blue Mussel

Blue mussel has a physiological temperature range of 2 to 27°C, but optimal growing temperatures are between 8 and 18°C (https://longline.co.uk/meta/list). Average sea water temperatures across the North Sea study region is 11°C which is in the lower quartile of the optimal growing range (table 6.1). Under RCP 4.5 and 8.5 increases in average temperature of 0.45°C and 0.64°C are predicted.

Table 6.1. *Average predicted water temperatures in the North Sea case study region and the predicted change under RCPs 4.5 and 8.5.*

Region	Average national present-day water temp	Average national 2050 water temp – RCP4.5	Average national 2050 water temp – RCP8.5	Percentage change in national average water temperature in 2050	
				RCP 4.5	RCP 8.5

North Sea	11.11˚C (SD= 0.71˚C)	11.56˚C (SD=0.71˚C)	11.75˚C (SD= 0.73˚C)	4.06%	5.80%

When assessing sea water temperatures in terms of the proportion of days in a year where optimal growing temperatures are likely to be experienced, results show that under current climate conditions, 73% of days would be within this range (table 6.2). Under RCPs 4.5 and 8.5 the proportion of days per year within the optimal growing temperature range would increase by 6.12% to 78% of days and 9.44% to 80% of days respectively.

Table 6.2. *Predicted annual proportion of days in which water temperatures are predicted to be in the optimal growing temperature range for Blue Mussel (8-18°C) under current climate and predicted percentage change under RCP 4.5 and 8.5 projections.*

Region	Present day proportion of optimal days per	2050 RCP 4.5 proportion of optimal days per	2050 RCP 8.5 proportion of optimal days per	Annual national average change in temperature suitability for Blue Mussel in 2050	
				RCP 4.5	RCP 8.5
North Sea	0.73	0.78	0.80	6.12%	9.44%

Mapping days within the optimal growing temperature range shows a confusing picture that suggests very few days per year would occur along the coast of the Netherlands or Denmark (Figure 6.2). The map suggests that under current conditions the coastline of the South Coast of England is highly suited to optimal production as are offshore waters around the Shetland Islands. Under RCPs 4.5 and 8.5, the coastline around Netherlands and Denmark retain very low suitability and the suitability along the south coast of England drops marginally, whilst the suitability off the Shetland Islands increases. Though this analysis suggests that temperatures in the growing waters of the coast of the Netherlands and Denmark are not suited to Blue Mussel production, this is clearly not the reality given the production levels in these countries. It is likely that as this analysis is based on 5km grid squares which capture water temperatures off-shore and is not representative of the in-shore water temperatures where mussels are produced.

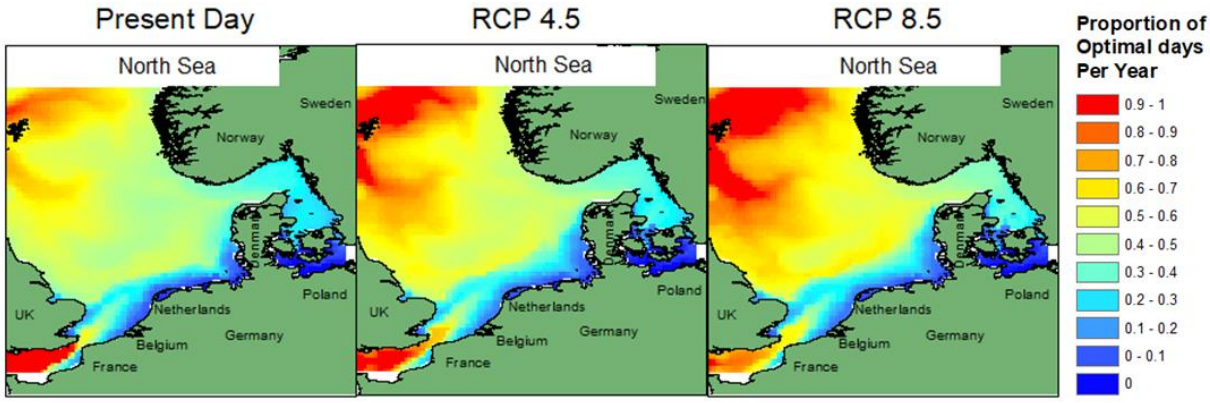

Figure 6.2: *Predicted annual proportion of days in which water temperatures are predicted to be in the optimal growing temperature range for Blue Mussel (8-18°C) under current climate and RCP 4.5 and 8.5 projections.*

The key disease affecting mussel culture are discussed in detail within two CERES WP3 deliverables, but, for the purpose of inclusion in the economic analysis, the parasitic disease cause by *Marteilia refringens* has been chosen as a key pathogen of concern in terms of regional farm economics. This parasite causes clinical signs of disease which can reduce growth and cause significant mortality at temperatures in excess of 17°C. As this is a relatively warm water disease, our analysis predicts that only 5% of days under current climate conditions exceed the 17°C disease causing threshold, however it is likely that the in-shore waters where culture occurs regularly exceed this threshold (Table 6.3). Under RCPs 4.5 and 8.5 large increases in the number of days are predicted, suggesting this disease will become a bigger concern to production in the future.

Table 6.3. *Predicted annual proportion of days in which water temperatures are predicted to be in the optimal range for a key disease (Marteilia refringens) of potential concern for Blue Mussel culture under current climate and predicted percentage change under RCP 4.5 and 8.5 projections*

Region	Present day proportion of optimal pathogen infection days	2050 RCP 4.5 proportion of optimal pathogen infection days	2050 RCP 8.5 proportion of optimal pathogen infection days	National percentage change in optimal pathogen infection days in 2050	
				RCP 4.5	RCP 8.5
North Sea	0.05	0.06	0.07	29.11%	43.44%

6.3 Farm Level Economic Consequences of Climate Change

As blue mussels are not fed, there are no feed costs associated with their production. The highest cost for both farms is seed collection, making up around a third of overall cash costs (Figure 6.3). It is however difficult to estimate seed costs exactly, as seed is not marketed. Costs come from a range of factors that includes labour costs, maintenance of vessels and equipment for seed collection, which might be depreciated over several years and thereby not occur within the operating cash costs. The second most important cost factor for both farms is labour for mussel grow-out production (23-30 %). Overall energy costs range from around 5 % for the Danish farm (3 % diesel, 2 % electricity) to 8 % for the Dutch farm (mostly diesel). The model mussel farm for the Netherlands has higher cash costs per kg, which is partly explained by the costs for sea area lease which constitutes around 12 % of the overall cash costs, which are not incurred for Danish mussel farms.

In addition, market returns are higher for Danish than Dutch mussels, resulting in a lower profit margin for NL-MUS-1118 than for DK-MUS-900 (6 % vs. ca. 40%) (Figure 6.4). One reason for this, could be the high quality of Danish mussels, that have a shorter production cycle and a higher meat content (around 30% meat content) (Wijsman and de Mesel 2008) compared to Dutch bottom-culture (Nguyen 2011). Furthermore, Dutch mussel producers are facing more market competition in recent years (e.g. from Germany) and experiencing increasing tetrodotoxin occurrence in waters around Oosterschelde (Gerssen et al. 2018). Other factors that will be important in determining profitability will be post-harvest depuration or relaying which will be required for waters of lower microbial water quality which are more prevalent in the Netherlands compared to Denmark.

DK-MUS-900	**2016**	**NL-MUS-1118**	**2016**
Operating earnings (€/kg)	0.61	Operating earnings (€/kg)	0.04
Most prominent costs in % from operational costs		Most prominent costs in % from operational costs	
Seed allocated costs	30.10	Seed allocated costs	33.55
Labour grow-out	30.10	Labour grow-out	23.55
Other variable costs	16.70	Sea area use	11.84
Minor equipment	11.67	Maintenance machinery	12.16
Maintenance machinery	3.93	Diesel for vehicles	7.77

Figure 6.3. Present operating earnings and most prominent costs in percent from overall operational costs for all model mussel farm analysed in CERES.

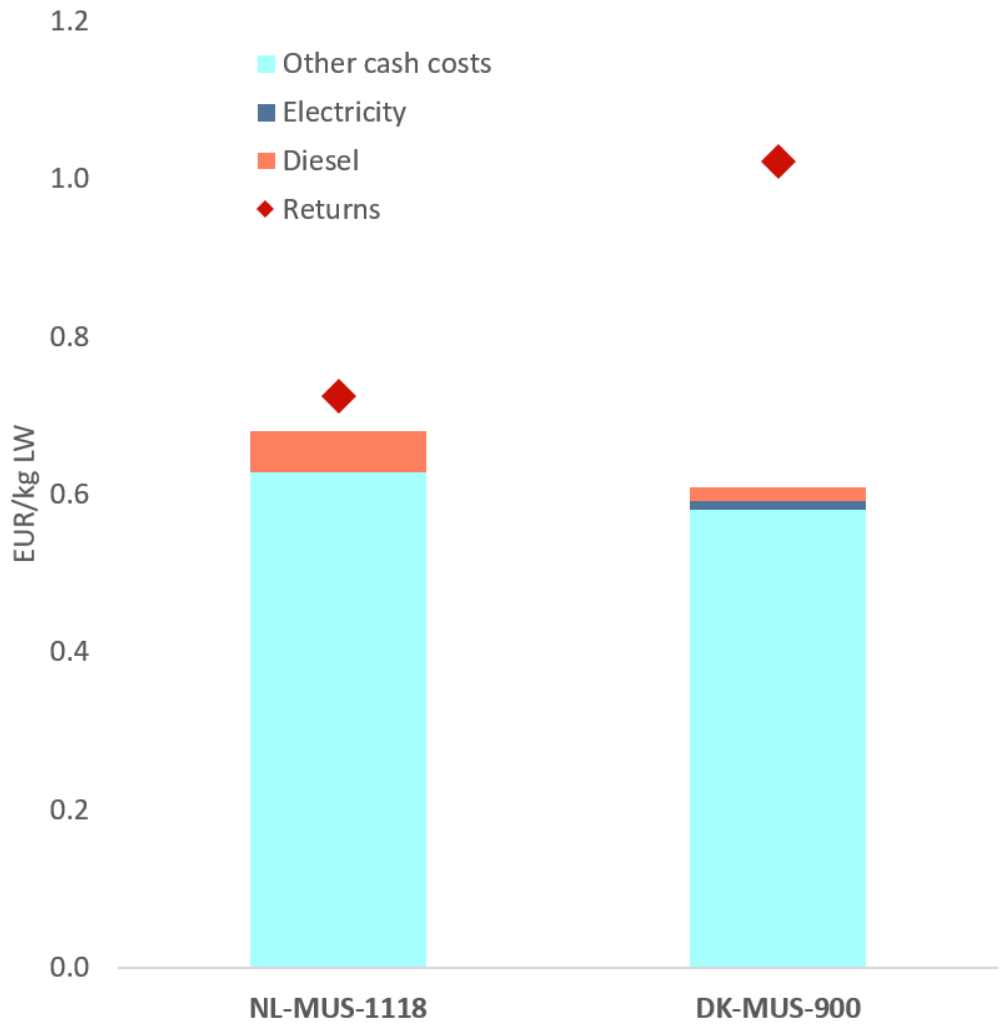

Figure 6.4. *Costs and returns (farmgate) from model blue mussel farms (NL=Netherland, DK= Denmark) showing stacked costs and returns. The distance between the red returns point and the top of the stacked costs represents the short-term profit/loss.*

Based on the predicted profit margin, the Danish farm has much more capacity to buffer future increased costs or variations in harvest weight compared to the Dutch farm. When considering only future price trends the Danish farm shows increased profits under all scenarios except for GS, where a slight decrease in profits (-4.5%) is observed. The Dutch farm with its very low present operating earnings, however, would no longer be viable under any scenario based on future price trends (Figure 6.5). This picture changes significantly when taking future changes in harvest weight into account. Both farms show most favourable future profits under the LS scenario, but different patterns under the remaining scenarios. DK-MUS-900 is less profitable under the worst production years and, thereby, most pronounced under the WM scenario (up to -70% operating earnings). NL-MUS-1118 is less profitable than today under all scenarios except for LS in best production years and would not be viable in most cases (Figure 6.6).

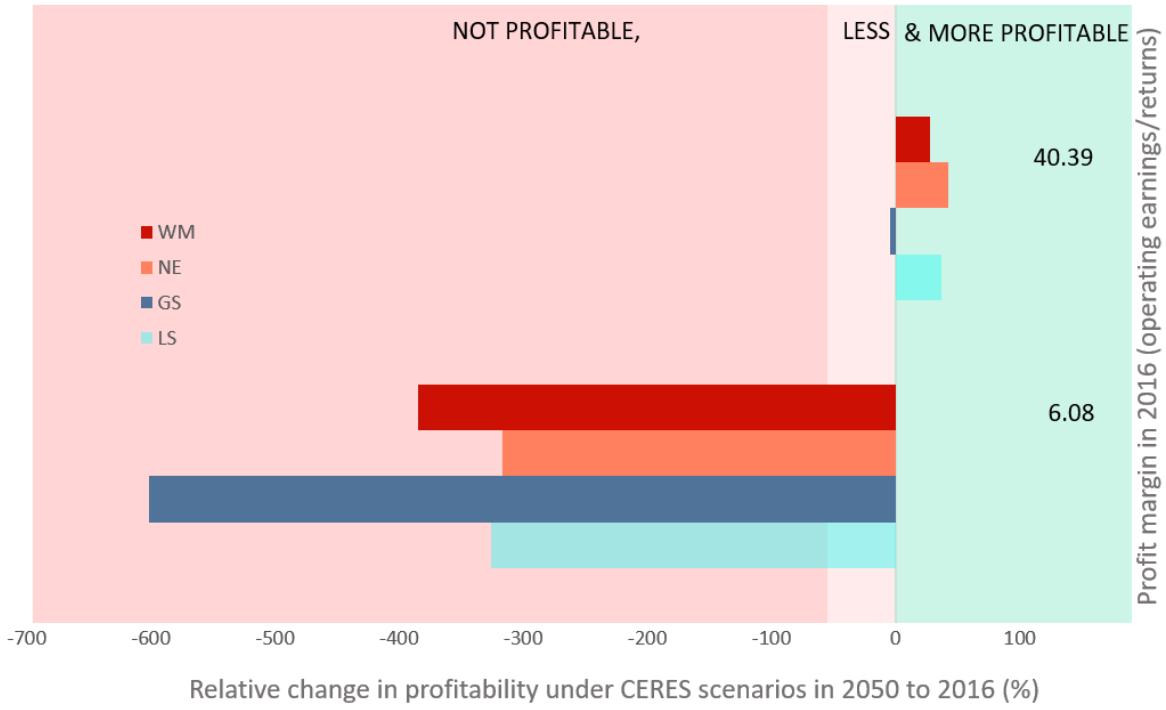

Figure 6.5. *Relative change in profitability under the four CERES scenarios in 2050 compared to 2016 profit margin for all model mussel farms without considering future harvest weight. World Market = WM, National Enterprise= NE, Global Sustainability= GS, Local Stewardship = LS.*

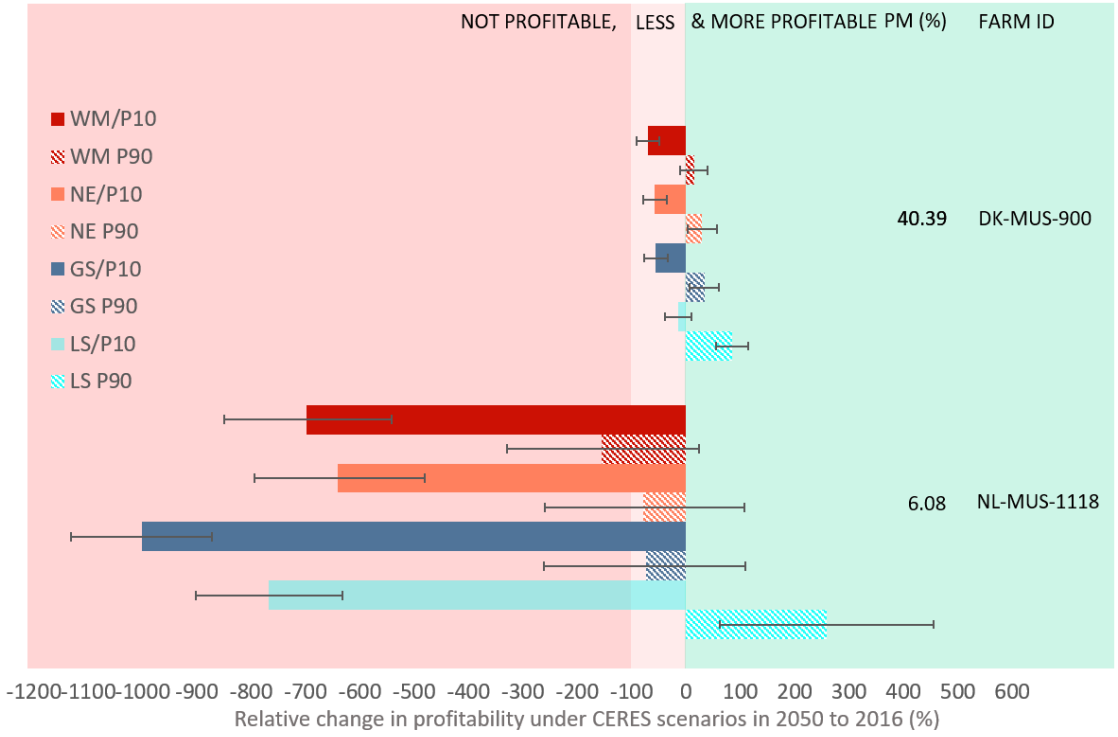

Figure 6.6. *Relative change in profitability under the four CERES scenarios in 2050 compared to 2016 for all model mussel farms. World Market = WM, National Enterprise= NE, Global*

Sustainability= GS, Local Stewardship = LS, P10 = worst production year, P90= best production year. Error bars indicate 95% upper and lower probability ranges from Monte Carlo simulation results in relation to operating earnings from today (2016). PM = Profit Margin in percent, black numbers indicate PM with public payments, red numbers without.

Differences between future profitability trends of the two farms were related to developments in future harvest weights (Figure 6.6). Variation in harvest weights between best and worst production years is highest under RCP 4.5 (GS and LS scenario) and changes in harvest weight are very similar for best and worst production years under RCP 8.5 and highest production years under RCP 4.5 for both farms (D3.3). However, for worst production years under RCP 4.5, expected mussel harvest weight for Danish mussels in the year 2050 is very similar to today, but reduces by 15% for the Dutch model mussel farm. This explains the unfavourable cost/return ratio that occurs under the GS P10 (RCP 4.5 min) scenario for the Dutch farm, whereas WM P10 leads to the lowest profitability for the Danish farm (RCP 8.5 min).

When considering future potential price variation, the Danish model mussel farm shows a high probability of remaining profitable under all best production year scenarios and also for worst production years under the LS scenario. Less profit than today is expected for worst production years under all scenarios, but even under least favourable price variation the farm remains profitable. For the Dutch farm, there is a chance for profit increase under best production year scenarios (P90), but for WM, NE and GS scenarios this would only occur under most favourable price developments. Worse production years are expected to lead to non-profitable Dutch mussel farms even if the future cost/price variation is favourable.

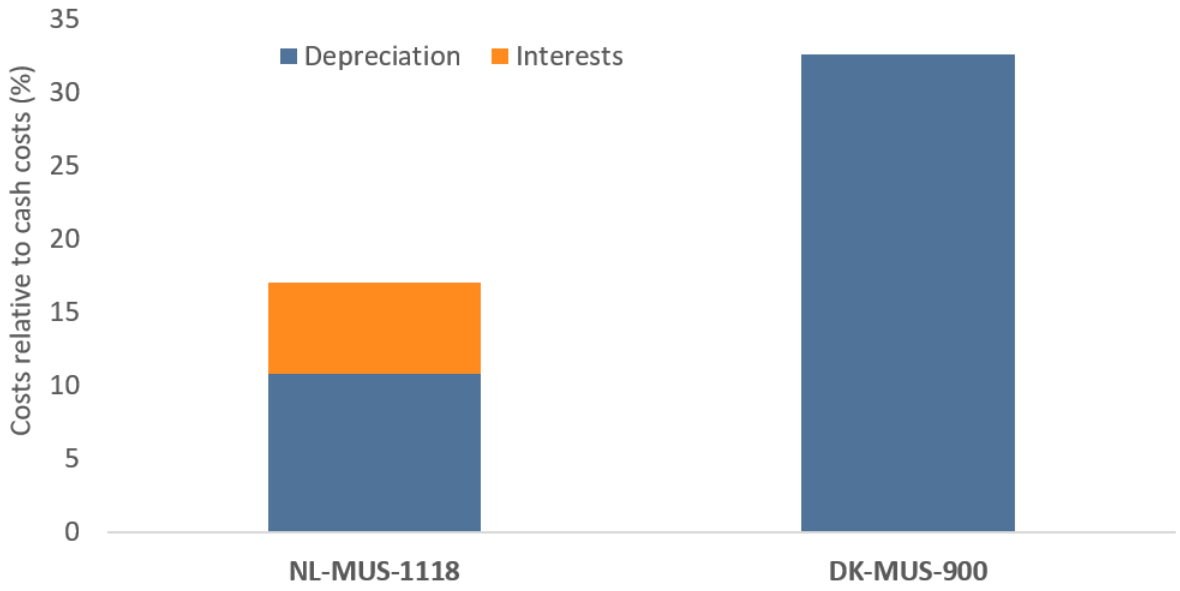

Figure 6.7. *Additional mid- and long-term costs - Present day depreciation, opportunity costs and interest for all blue mussel model farms in relation to the operating cash costs (%).*

Additional mid and long-term costs for mussel farms are mainly allocated to depreciation costs of farm systems, equipment and buildings (Figure 6.7). Both farms have similar farming system investment costs, whereas the Danish mussel farms has a higher vessel usage and higher equipment investment demand. Opportunity costs are not relevant for our model mussel farms, but interests should be taken into account for the Dutch farm. Overall, for the Danish farm, around 32% of the cash costs would have to be invested on a mid- to long-term scale, whereas for the model mussel farm in the Netherlands, only around 17 % of overall cash costs should be expected in addition.

6.4 Regional Economic Consequences of Climate Change

As the combination of future price trends with harvest weight change under extreme cold and warm years has shown, local temperature effects may have a large influence on profitability of mussel production. Predicted changes in profitability based on the model mussel farm results, the optimal growing days and disease risk for each of the case study countries are presented in Figures 6.8. and 6.9. For Danish mussels, profitability is predicted to increase under all four scenarios (Figure 6.8) and thereby lead to increased profits (Figure 6.5). Contrastingly the entire mapped area relating to the Netherlands, predicts that mussel farming across this whole region will no longer be viable under any of the four CERES scenarios (Figure 6.9). Lack of evidence of local effects in the spatial analysis may be a result of the temperature projections, which as discussed are possibly not representative of in-shore waters and patterns may change in the event of extreme warm and cold years.

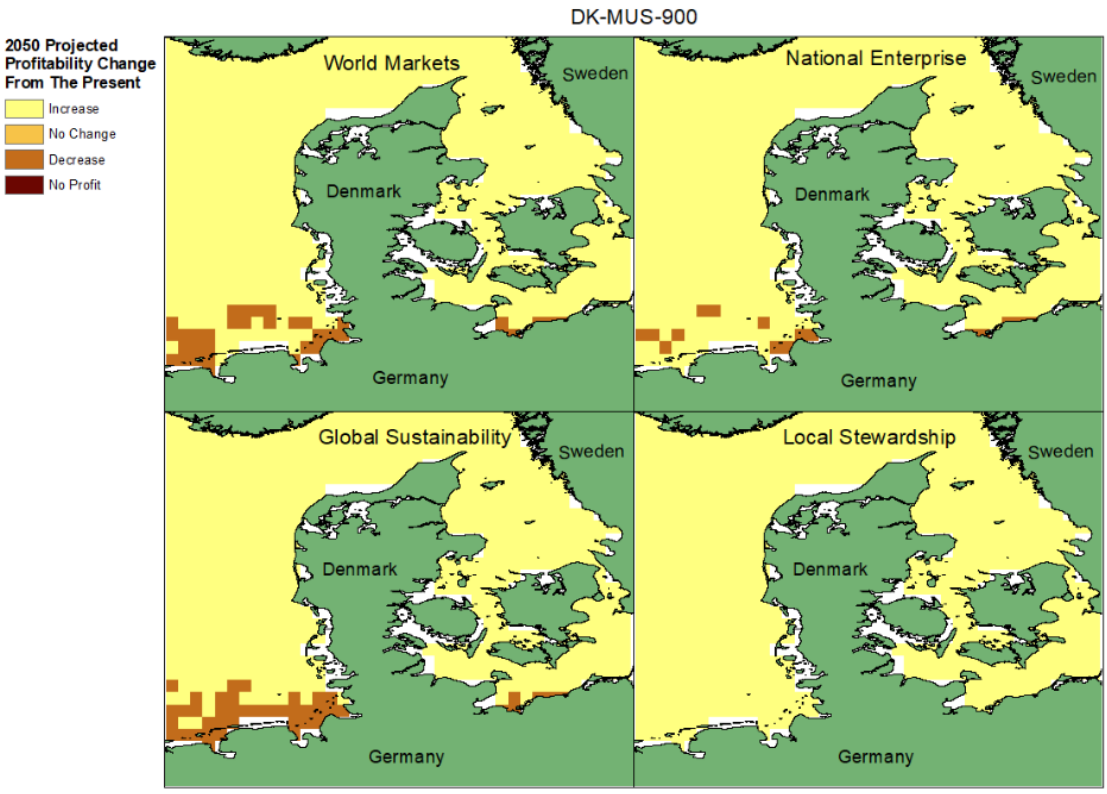

Figure 6.8. *Predicted consequences of the four CERES climate change scenarios on the profitability of typical Blue Mussel farms (DK-MUS-900).*

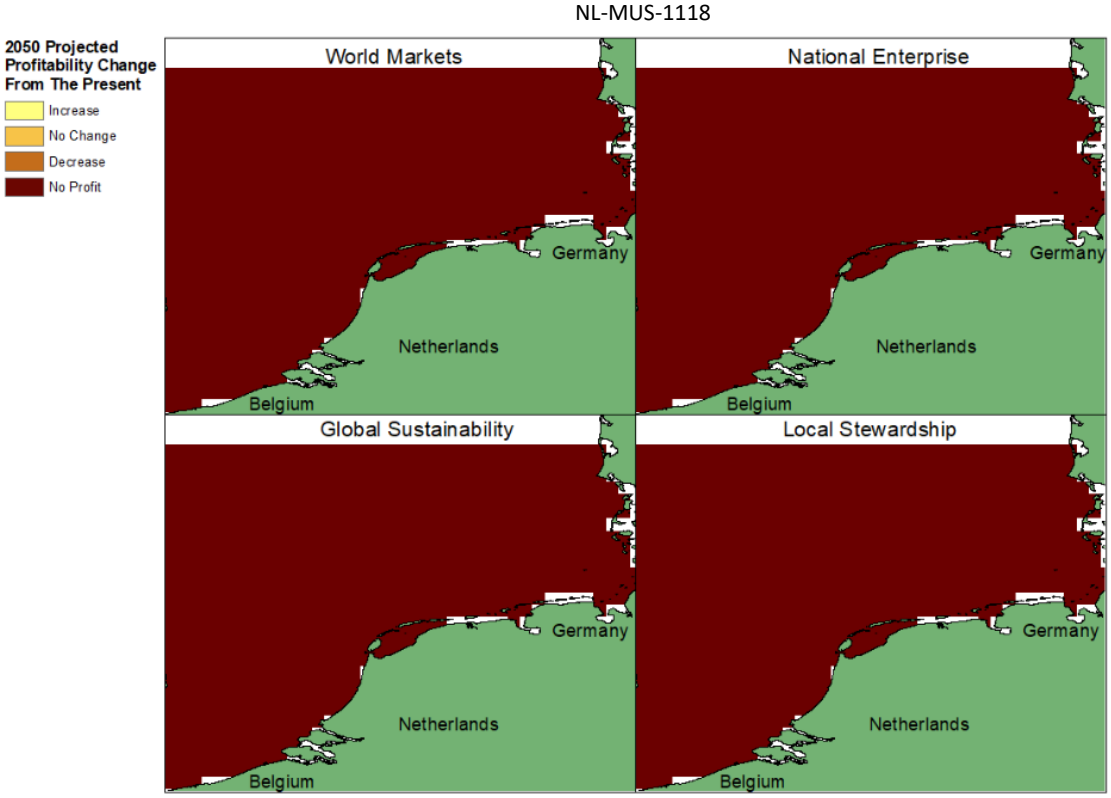

Figure 6.9. *Predicted consequences of the four CERES climate change scenarios on the profitability of typical blue mussels farms (NL-MUS-1118).*

6.5 Conclusions, Opportunities and Challenges for Blue Mussel Production

Future projections of climate change suggest increased opportunities for Danish mussel production. This sector already has a relatively high profit margin compared to Dutch production, partly because of product quality but also due to the culture means and the larger business model used in Denmark. The profitability of the Dutch mussel sector has been in decline in recent years, driven by a considerable fall in prices received at auctions. The fall in prices is attributable to a number of factors, such as size and quality of the mussels and import competition. The quality of German import mussels has improved in recent years, and the availability of German mussels has become far more stable due to changes in production methods. This has also allowed German mussels to be exported earlier in the year and these two factors have led to the competition from German mussel production being much more important for the Dutch farmers than before. Additionally from the cost perspective, the scaling back of bottom seed fishing and changes in production practices have put pressure on workload and production cost in the sector, increasing the total national annual cost of mussel seeds by an addition €6m to €9m over the 2014-2016 period (Oostenbrugge et al. 2018). Due to the low profits, the small independent businesses may benefit from forming co-operatives and sharing some of the equipment costs. For shellfish culture generally there may be opportunities for greater integration with finfish farming, taking a multitrophic (e.g. IMPTA) approach as practiced in many parts of Asia, which helps balance nutrient impacts of finfish and provides an efficient means to produce shellfish. Within Denmark, bio-mitigation and the use of biofilters such as seaweeds and shellfish are already being considered in combination with licences for new marine fish farms (Chopin et al. 2008)

In general, extreme warm years provide the best opportunity for increase production and profit for both, Danish and Dutch farms. The risk of disease and toxic algal blooms, however, also increase with temperature (Danovaro et al. 2009). Disease causes economic loss through mortality and reduced growth. Disease control in shellfish is extremely challenging as pathogens circulate in the water and are concentrated by these filter feeders, therefore containment and isolation of infected areas through control zones and movement restrictions is normally the only means by which to limit impacts. Sourcing of safe seed produced in biosecure hatcheries would help reduce risk significantly but given the dependency on wild seed, this is not currently possible. Not moving shellfish or equipment between areas is also beneficial in terms of reducing pathogen spread, but in areas where a pathogen is circulating, minimising stress via culture and husbandry practices is the best option.

Although algal toxins do not normally affect shellfish directly (though toxicity to the shellfish is possible), beds will be closed for consumer safety reasons, meaning that harvesting cannot take place until toxin levels are found to have returned below safe limits. Closures can occur for long periods, meaning harvesting and supply cannot take place, and this can have significant impacts on production volumes, as tetrodotoxin (TTX) in known to cause significant closures and low production volumes in the Netherlands (Turner et al. 2017). Also, of concern to human health, is the risks associated with microbial water quality. As bivalve shellfish such as mussels are filter feeders, they can rapidly bioaccumulate organisms such as bacteria and virus that may pose a human health risk. These organisms can be high in waters that have received high levels sewage inputs or land run off from river catchments with high levels of animal production or wildlife. All shellfish harvesting waters throughout the EU must be classified based on microbial indicator levels detected in shellfish. Class A waters are best quality and shellfish can be harvested directly for consumption. Class B waters are of lower quality and shellfish from these areas must either be depurated or relayed to a class A water for a period of time before they can be marketed which adds to the costs of production. Class C waters are of poor quality and no shellfish grown in these areas may be placed on the market. Water quality is likely to become a bigger barrier to production in the future as population densities increase, but also increased storm events can cause significant increases in untreated sewage inputs and agricultural run-off. Moving production further off-shore using long-line culture or other suitable systems may help overcome this, but it is important that appropriate monitoring and assessments are conducted prior to production to ensure offshore sites of sufficient environmental quality.

Despite the challenges to shellfish aquaculture, there are opportunities to be realised with warming temperatures, but this will rely on changing business models and possibly moving culture further offshore. Due to the investment requirements required for this to happen, it is likely that business models will need to move towards larger companies or co-operatives that manage multiple sites and can allow cost sharing between sites so that equipment and staff costs can be reduced. Where only low profit margins per kg can be achieved, production volumes will need to be high enough to make site profitability worthwhile, and this could require the development and utilization of intensive production systems. Integration of culture with finfish production may also allow increase efficiency in production and allow cost savings. Finally, progressive governments with a strong environmental agenda should evaluate the ecosystem services that can be provided by shellfish culture, which may offset some of the environmental impacts of terrestrial agriculture and land management. It may be that in some areas subsidized shellfish culture should be considered for the purpose of bioremediation.

Chapter 7 Synthesis: Economic Impacts, Opportunities and Challenges of Climate Change on European Aquaculture

This CERES task aimed to help understand the present-day costs and profit levels for key aquaculture species produced across Europe and determine how and why costs and profits may change under the four CERES socio-political scenarios that were associated with the RCP climate projections. Six species (rainbow trout, carp, Atlantic salmon, sea bass, sea bream and blue mussels) farmed across a total of ten European countries (Germany, Denmark, Ireland, Norway, United Kingdom, Netherlands, Spain, Poland and Turkey) were investigated to understand the opportunities and challenges associated with future production with a view to making recommendations on how aquaculture practices may adapt to the consequences of climate change. For four of these countries' (Germany, Turkey, Poland and Denmark) multiple species and/or farm types were investigated allowing within country comparisons to be made. In the previous chapters within this deliverable, the profits, costs opportunities and challenges have been discussed at the species level. This chapter aims to draw together information from

across the species and between countries to identify the potential winners and losers under the four-climate change scenarios and identify common challenges and opportunities for aquaculture as a whole.

7.1 Current Profitability Between Farm Types, Species and Countries

Across the species investigated, there was substantial variability between the profitability of the different farm types investigated. However, if we take the most profitable example from each farm type, that was studied, then the species rank as follows in terms of operator earnings (€/Kg): Rainbow trout = 2.60 (German 500T), Sea Bass = 2.44 (Spanish), Salmon = 1.20 (Norwegian), Carp = 0.94 (Polish 90T), Blue Mussel =0.61 (Denmark) and Sea Bream = 0.60 (Turkey). Conversely, if we take the least profitable farms, the species rank as follows: Blue Mussels = 0.04 (Netherlands), Trout = 0.14 (Turkish 500T), Carp = 0.66, Salmon = 0.83 (Irish), Sea Bass = 1.60 (Turkey).

This analysis shows high variability between farm types within species (reasons for these are discussed within each species chapter) and between species. Trout profits were highly variable between farm types, with best practice German farms being highly profitable and attracting a profit per kg live weight (LW) over double that of Norwegian Atlantic salmon, which can be considered as a baseline comparator due to the massive production volumes of this species. However, in the worst case, Turkish land-based trout ranked the second lowest in terms of profit margin after Dutch blue mussels. Both farm types for sea bass attracted high profits that were up to double that of Norwegian salmon per kg LW and, thereby, ranked third most profitable, and around a third more profitable than Irish salmon production. Carp profitability was between 25 and 50% lower than Norwegian salmon production, and best-case blue mussel and sea bream profitability was around half the profitability of Atlantic Salmon. At its worst, blue mussel only attracted €0.04 per Kg. Obviously within this study, only a relatively small number of typical finfish and model mussel farms could be investigated, but the results give an indication of the profit variations that can occur both between and within species and countries.

Trout profitability ranged between €0.94 and €2.60 per Kg and Carp between €0.66 and €0.90 per Kg. In both cases the smallest farms were the least profitable. This pattern was also true for Danish trout with profits in small farms being €0.21 per Kg compared to €0.59 per Kg in larger farms which is a similar profit margin compared to Danish mussel production which generates a profit of €0.61 per Kg. In the case of Polish carp culture, the opposite was true with smaller farms attracting a profit of €0.94 per kg compared to €0.70 per Kg for larger farm types. This pattern was also observed in Turkish trout where smaller cage farms attracted a profit of €0.31 per Kg and larger land-based farms attracted only €0.14 per Kg. Turkish Sea bream profits were double the most profitable

trout production at €0.60 per Kg, however Turkish Seabass profits were much greater at €1.60 per Kg.

7.2 Future Profitability among Farm Types, Species and Countries

As a general rule, analysis of present-day profitability showed that in the absence of public payments and subsides, larger more vertically integrated farm types were more profitable than smaller independent enterprises. When looking at the projections for future profitability, this pattern also held true, and the analysis suggests that such businesses are more resilient to the effects of climate change and for certain farm types, may benefit from some or all future scenario (Figure 7.1). Five typical farm types were predicted to be more profitable under all four climate change scenarios: the two large best practice German trout farms, the Spanish and Turkish farms producing high value Sea Bass, and the Danish Blue Mussel farm. For all farm types, the trade focussed WM and the national NE scenario appeared to provide the greatest potential opportunities to increase profits with more environmentally friendly GS scenario the lowest. Both the small and large German carp farms could benefit greatly under the LS and NE scenarios where domestic markets become increasingly important, under which they were predicted to see the biggest increase in profits compared to any other sector due to PGI certified and marketed products, but under the WM and GS scenarios their profits were predicted to undergo little change. The biggest European finfish sector, Norwegian aquaculture profits are projected to remain relatively stable under all four future scenarios, with minor losses under the GS scenario, but marginal increases in profits under the other three scenarios. With the exception of Irish salmon and Turkish sea bream under the WM scenario, all other farm types were predicted to experience reduced profits under all four scenarios, with small Danish trout farms, land based Turkish trout farms and Dutch mussel production all being projected to no longer be viable under any of the four scenarios. UK trout was also predicted to no longer be viable under the GS scenario.

The future projections assume the status quo in terms of production practices, management and feed compositions. Obviously in the face of negative predicted changes, sectors and farm types will need to adapt and there are opportunities for change. The outputs of this task provide a tool by which different farm types can identify and understand factors that could lead to future vulnerabilities in terms of profitability in the future. The results also provide farms with benchmark competitors from which they can compare their existing practises with a view of adapting their production methods and business models to make them more resilient into the future.

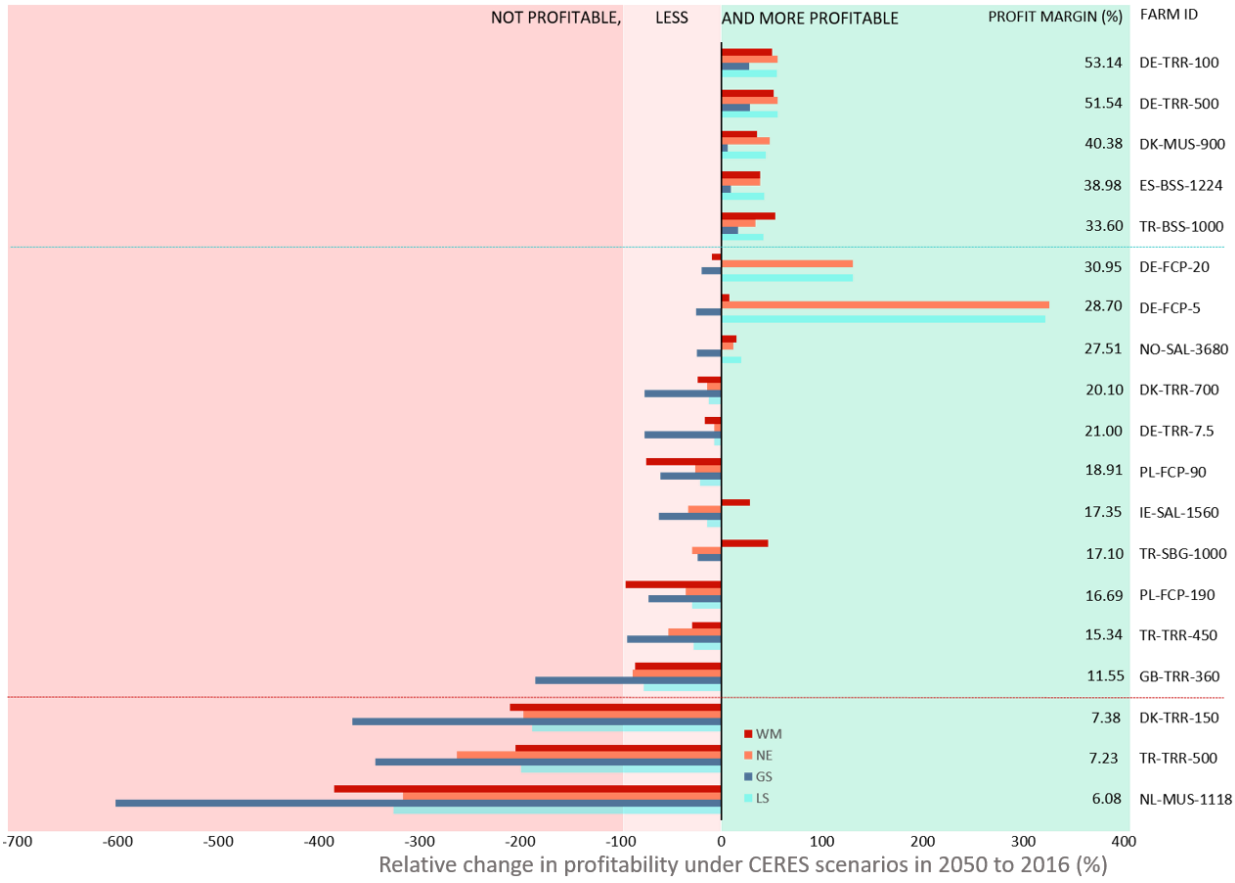

Figure 7.1. *Future profitability projections (% change) for all typical farm models under the four CERES scenarios. Farms above the blue line make profit under all scenarios. Farms below the pink line are no longer profitable under any scenario. Blue shaded areas = increased profit, light pink = reduced profit, dark pink = loss.*

7.3 Common Concerns and Potential Solutions Across the Sectors

Throughout the analyses conducted within this Task, several common key factors emerged for many of the sectors. These included how feed ingredients, fuel and energy are influenced by global market forces, whereas others such as disease or growth rates are influenced by local conditions. In this analysis, we found that, the main impacts of climate change on aquaculture profitability acted through the effects on global markets, rather than direct local effects associated with temperature changes. A summary of the concerns relating to each of these key factors with suggestions for potential solutions is provided below.

Feeds: With the exception of Blue Mussels, which are not fed, and traditional carp production which are less depended of commercial diets, feed was the most significant cost in all other farm types. Despite a large reduction in the dependence on the inclusion

of fish meal and oil in modern commercial diets, at present they still provide the most cost-effective means by which to produce an efficient diet. Fish oil and meal is however subject to global price variations and because it is such a large outgoing for a farm, this is the key factor in determining profitability. Figure 7.2 shows the predicted changes in feed prices for each of the typical farms, which shows substantial increase (minimum of 50%) under all four scenarios, but particularly under the NE scenario.

Alternative ingredients such as insect meal, single cell protein, marine algal oil or gene modified plant oil are receiving a lot of interest and it is felt that these could provide viable substitutions for marine ingredients, however, at present production is in early stages, meaning prices are high and it would be challenging for existing producers to reliably meet demand. Increasing fish oil and fish meal prices could improve opportunities to these sectors as this is likely to drive investment in larger scale more efficient cost-effective production. Inclusion of alternative feed ingredients will help improve the sustainability of aquaculture through removing the current reliance on harvesting wild capture fisheries, which will help improve the environmental image of aquaculture. The efficiency of feeds containing fish meal, fish oil alternatives does however remain a concern and more research to optimise future diets will be needed. There are also questions relating to the traceability of such ingredients to ensure the criteria of various certification schemes such as organic status can be met.

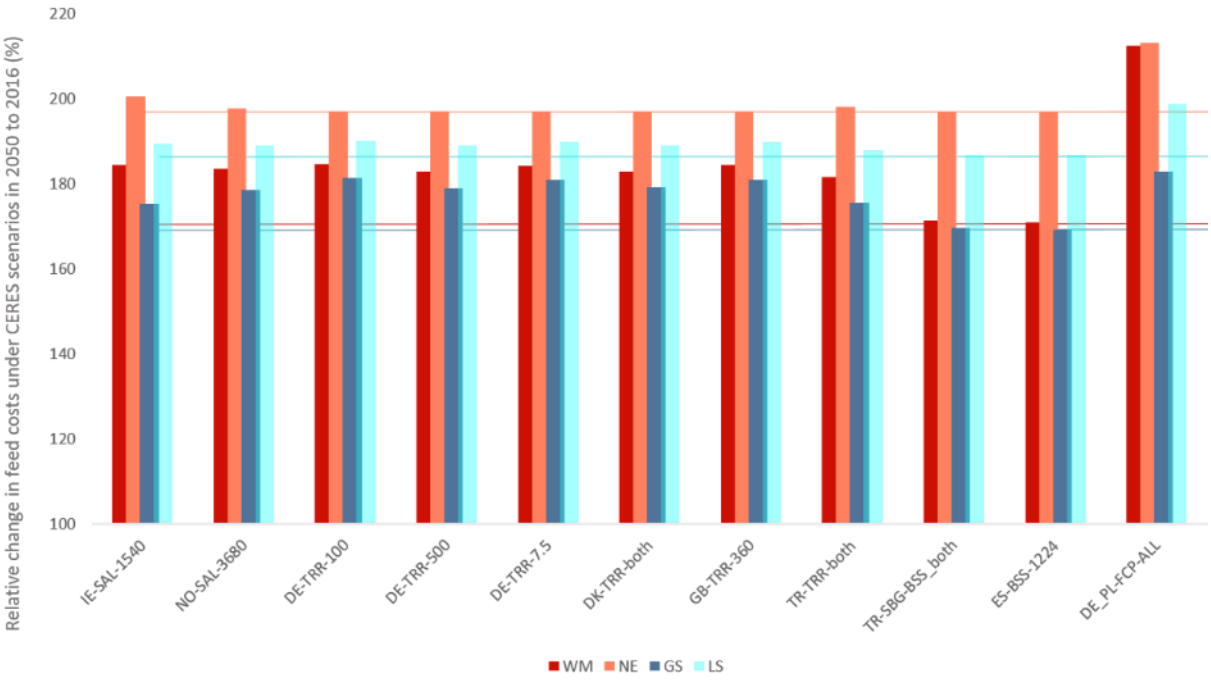

Figure 7.2. *Predicted relative future feed cost changes for each typical farm type under each of the CERES future scenarios from 2016 to 2015 per kg. WM= World Market, NE = National Enterprise, GS = Global Sustainability, LS = Local Stewardship.*

Stock: For all sectors, provision of high-quality seed and fingerlings is critical. Unfortunately, this phase of an animal's lifecycle is very vulnerable to water quality issues, disease and predation, and consequently this can interrupt supply which can inflate prices due to high market demand. Additionally, transport costs and post transfer survival can have a significant impact on prices. These factors can have large knock-on consequences to on-growing productions and profits.

Different sectors approach juvenile production in different ways. Mussel farming relies on the availability of wild spat, which though usually plentiful is subject to natural variation and is of unknown disease status. Many trout farms rely on supply from professional hatcheries. This provides assurance of provenance and disease status, but if a hatchery goes out of business or has movement controls placed on it, supply changes are highly vulnerable and many on growing sites can be adversely impacted. Salmon farms tend to be vertically integrated having their own hatcheries. This gives them the advantage of being able to manage their own supply and be self-assured in the provenance of their stock but requires investment in separate specialist infrastructure in addition to their on-growing facilities.

There are opportunities for specialist hatcheries as demand for supply of high-quality stock will always be in demand. Hatcheries can also play a big role in determining the success and profitability of the on-growing sector, not just through keeping production cost low, but also through the production of particular strains of animal that may be disease resistant or exhibit better growth rates than other strains.

Labour and fuel costs: The level of labour and fuel costs varies greatly between farm types and sectors. Diesel and electric costs tend to increase as farms increase in size and technological complexity. Under the four CERES scenarios, significant increases in fuel costs are predicted, but the larger sectors such a as Norwegian salmon are already starting to adapt by moving away from the use of fossil fuels to renewable electrical energy. Currently, in addition to moving towards electric land vehicles. Norway is investing in electric and hydrogen powered boat technologies, which will not only be more environmentally friendly, but will also aim to offset some of impacts the future price changes.

Labour costs appear to be particularly important to smaller farm types with less automation. Future wage costs are likely to rise, especially if countries introduce or raise minimum wages. Obviously, automating processes can significantly reduce labour costs, indeed due to automation, a 4000T salmon farm can be run by the same number of people as it takes to run 100T trout farm. However, this can substantially increase investment costs, depreciation and fuel/energy costs and will not be feasible for many small-scale farmers. The formation of co-operatives that share staff and equipment may be an option in some cases but brings with it risks of disease transfer that need to be managed.

Availability of aquaculture areas: One of the key factors in limiting increases in future aquaculture production is the availability of suitable locations. In the freshwater environment, especially in the case of trout which have more constrained environmental tolerance, the availability of water in sufficient volumes and of sufficient quality is a key limiting factor. Here, the use of more technologically advanced recirculating systems that reduce new water requirements whilst maintaining good water quality may provide a solution, but investment costs are high, and the technology still requires further developments.

In the case of marine aquaculture, regulatory burden, conflicts and suitable coastline are key concerns. As coastlines are often heavily utilised there are often many competing interests and environmental concerns affecting aquaculture, especially in the more sheltered areas suited to current production technologies. This needs to be tackled within national and regional level aquaculture plans which take a holistic approach the utilisation and exploitation of marine space. Where this is not possible, exploitation of under-utilised environments will be key. One option is to move further off-shore, but this will require the development of more robust culture systems that can cope with the off-shore energy levels, do not cause conflicts with shipping and can be serviced and maintained easily. Another option is to use more land-based systems that either employ pump-ashore or recirculating technologies. If suitable land is available, this brings with it many advantages such as better disease and environment controls that can allow the culture of novel marine and freshwater species. Examples of the application of land-based systems for European marine species include barramundi, shrimp, turbot, tilapia, sole and octopus. Some of these, such as octopus are in the early experiment phase, but this diversity demonstrates the potential of and interest in such systems.

Water quality: Linked to the availability of suitable aquaculture areas is the availability of good quality water which may be affected by environmental, climate and anthropogenic factors. Environmental factors such as the occurrence of harmful algal blooms (HABs) can cause issues, particularly in shellfish culture (largely due to food safety concerns), which lead to restrictions on harvesting and marketing of affected product. Bloom occurrence is currently difficult to predict, but the development of early warning systems may allow sectors to take actions such as emergency harvesting before aquaculture areas are affected. Ocean acidification is another area of major concern to the shellfish sectors and is a concern that cannot be addressed by the sector and must be through international interventions.

Changing temperatures bring both opportunities and challenges. Increasing temperatures will benefit some regions by allowing more optimal growing days, improving production and potentially allow new species to be farmed. The flip side of this is that in some regions, temperatures will exceed physiological thresholds for existing species which, combined with reduced oxygen levels and increased metabolic rates at increased temperatures, can cause stress and mortality. Counter measure that may help reduce stress caused through increasing temperatures, such as reduced stocking

densities, may also have a negative impact on profits. Where this becomes a frequent concern, moving to producing alternative species may be the most sensible way to progress.

One of the key anthropogenic water quality concerns is that of microbiological contamination occurring through sewage discharges and terrestrial land management practices. This is the major limiting factor to shellfish production as production is prohibited in areas with high levels of microbiological contamination, and post-processing such as depuration is required prior to sale of shellfish harvested from moderately contaminated which can have a significant impact on profitability.

Agent based mortality and impacts include competitive effects from non-native species, jellyfish blooms and disease impacts. Of these concerns, disease is the most commonly cited and is one of the biggest limiting factors for production. Notifiable pathogens listed in European law and for which there are no cure, may trigger statutory control measures to be implemented. Such measures usually include culling and eradication of sites, fallowing and movement restriction. The measures can impact sites and areas for many years but. at a national level. may allow a country to maintain international aquatic animal trade. Production diseases not listed in law are for the industry to control. As relatively few pharmaceutical treatments are licenced for use in aquaculture, preventative measures are of great importance. Biosecurity plans should be developed at the farm, regional and national levels, which lay out a surveillance programme and action plan in the event of a detection. Preventative measures such as vaccination and immunisation are important tools, and reduction measures such as resistant strains of animal and habitat and environmental manipulation to reduce disease impacts. Control measures co-ordinated across areas hosting epidemiologically connected sites are of great benefit in terms of rapid detection and effective control, and local aquaculture committee groups are a beneficial measure.

Sale price: At the end of the production cycle the key concern to farmers is the price they can attract for their product. Market forces governed by supply and demand dictate price, but there are steps farmers can take to try and attract best prices. The ability to produce where and when supply is low, such as common species or particular times of year may help a product stand out in the marketplace. Understanding consumer preferences is key: does the buyer want whole fish or fillets, is the demand for fresh or frozen product. Targeting specific markets is also important and assessing whether local markets will attract a better price and have sufficient demand for product compared to global export markets is a critical point. Generally speaking, the more directly you can market to the consumer the better the price that can be achieved, i.e. farm gate and restaurant sales compared to selling to a wholesaler or distributer. Finally having a unique selling point can help improve the prices achieve. This can either be through producing interesting species, colour morphs or unusual sizes, or through labelling and certifications schemes that show the product to be from a particular region or meet a particular stand such as organic standards or sustainability criteria. However, high value markets are often only

required in limited supply, meaning that evaluations should be made as to whether to supply small amounts to a high value markets, or large quantities to lower value markets or somewhere in between.

7.4 Opportunities for the Future

Although there are doubtless challenges associated with climate change for the aquaculture sector, the sector is witnessing increased importance and an exciting phase of development that will offer many opportunities if industry and governments are able to work together and embrace change. With a growing population that is beginning to recognise the health benefits of eating fish and the fact that many wild capture fisheries are now exploited to their limit, there is increasing demand for aquaculture species, and there are many opportunities to increase production and diversify. As land availability reduces with growing populations and demand for protein increases, there is the possibility of increasing investment opportunities to produce new species and develop technologies to exploit alternative farming environments, both on land and offshore. However, to exploit these opportunities and overcome the challenges of climate change, business models will need to evolve, and the formation of co-operatives or larger vertically integrated business is likely to be needed in order to exploit global markets and allow the required investments in infrastructure and technology.

Often when people think of aquaculture, finfish such as Atlantic salmon and their associated issues spring to mind, however shellfish, sea weeds and other taxa will be key to the success of aquaculture moving forwards. Aquaculture is likely to benefit from taking a more holistic integrated approach where finfish, seaweeds, shellfish and sea urchins are farmed together under an ecosystems approach that will maximise production whilst offsetting environmental impacts both from finfish, but potentially also nutrient inputs from terrestrial agricultural practices. Indeed, seaweed and shellfish aquaculture could be used to benefit the environment, acting as a means by which to offset carbon, nitrogen and phosphorus inputs from the land. In turn, where such production has little food value on human markets it could be used in animal feeds, fertilisers or cosmetic products where appropriate risk assessments have been conducted. To incentivise such opportunities, environmentally minded governments may offer incentives or subsidies to landowners who use such systems to offset their inputs to the marine environment. Such seaweed and shellfish culture areas may, in themselves, act as natural reefs and spawning grounds further contributing back to the environment. Done sensibly aquaculture should take the pressure off wild stocks and not add to it.

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