Case study

#1 Rainbow trout in north-west Europe

#2 Rainbow trout in the eastern Mediterranean

#3 Carp in north-east Europe

Species background and economics

Rainbow trout (*Oncoryhnchus mykiss*) (Fig. 1, left) is one of the most widely introduced species worldwide. It has a long history of aquaculture, and tolerates a wide range of environmental conditions[1], with an optimum production temperature ranging from 9-20°C depending on the source and perspective, optimal for farming is considered to be below 21°C[2]. It was originally introduced from the USA to many European countries during the end of the 19th century, followed by secondary, intra-European transfers[3,4].

Figure 1: Example of Rainbow trout (*Oncorhynchus mykiss*) (left) and its traditional small-scale pond farming in Germany (right). *Credit Cornelia Kreiss, Thünen Institute*.

Within the EU28, rainbow trout is now the most produced aquaculture finfish in terms of volume and total value [5,6,7]. Production techniques range from earthen and concrete ponds to raceways, net cages and recirculation aquaculture systems. In Northwest Europe (Denmark, England, Germany) the majority of the production is portion-sized trout[3]. The firms producing are on average small and the variety of products are depending on local markets and tradition[8].

Denmark is one of the main trout producing countries in EU and the most important exporter within the EU market. In 2016, a total volume of 20,970 tons of freshwater portion-sized trout was produced with a value of €63.2 million[9]. The sector consists of 190 inland trout farms, primarily located in the mid and southern Jutland[9] (Fig. 2). While the majority is traditional production in earthen ponds, 17% of the inland farms are large and technologically advanced recirculation systems, covering almost 50% of the production volume. These new farms were introduced with the aim of reducing the environmental impact from trout aquaculture[8]. The main export market is the EU, particularly Germany[10].

Germany had a modest production of 7039 tons in 2016 with a value of €39 million and is the main EU importer of trout. The main production occurs in the south[11]

(Fig. 2). Traditional pond production is a common production technique for smaller operations (Fig. 1, right), while raceways and (partly) recirculation systems are applied by a few, larger farms[10].

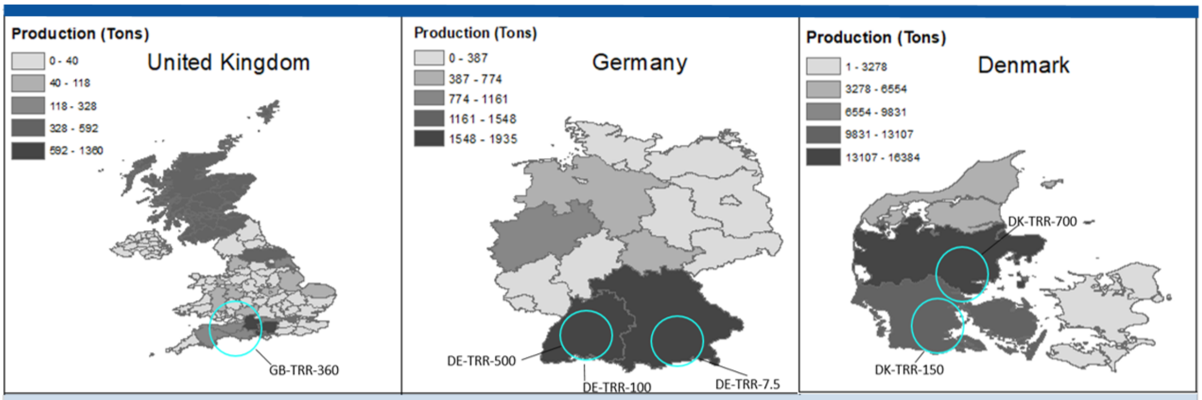


Figure 2: Rainbow trout (*Oncoryhnchus mykiss*) regional production in tons for the year 2016 and selected production countries in CERES: United Kingdom, Germany and Denmark. Locations of the typical rainbow trout farms are indicated by circles and labelled with a country-species-yearly production code. Data sources: UK Cefas Starfish database, German Federal Statistics Office, Danish Agrifish Agency.

UK has maintained a production between 12 - 17,000 tons per year (including portion-sized, restocking and on-growing production)[12] in the last two decades. Two-thirds of the production are sold on the domestic market. In 2016, England alone produced 4,852 tons corresponding to a value of €19.5 million[7,12]. The trout industry consists entirely of privately-owned business. Most of these are classified as SMEs (small and medium-sized enterprises)[13]. The farms are primarily located in the southwest and northeast of the country (Fig. 2). The farming systems used grow-out for trout farms includes the use of tanks, ponds, and raceways[14].

Expected projections under climate change

Temperature is one of the key drivers in the biological performance and health of farmed rainbow trout. 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.

In general, temperature of the surface waterbodies within Germany, England and Denmark are projected to increase on average by around 2% under a medium emission scenario (Representative concentration pathway 4.5 = RCP 4.5) and increase by around 6% under a high emission scenario (RCP 8.5) over the course of a year within the 2040-59 time slice.

However, certain regions are projected to experience different levels of temperature change and therefore variation in the associated knock-on effects on rainbow trout production, which could be even more pronounced when considering seasonal variation.

Within England, greatest water temperature increases are expected in southern, western and eastern regions, increasing by 1.2% under RCP 4.5 and 5% under RCP 8.5 during summer months. As a consequence, temperature suitability, according to optimal growing temperature of rainbow trout, decreases for the South East.

Germany is expected to experience higher summer temperatures of 4.3% and 7.9% under RCP 4.5 and RCP 8.5, respectively, within the rainbow trout growing regions of Bavaria and Baden-Württemberg, lowering suitability substantially for these areas under RCP 8.5.

In Denmark, projections suggest that there will be less variation between different producing regions and no change in temperature suitability was predicted based on annual proportion of days within the optimal temperature range for trout. However, it has to be kept in mind that peak temperatures development is a very important factor as well.

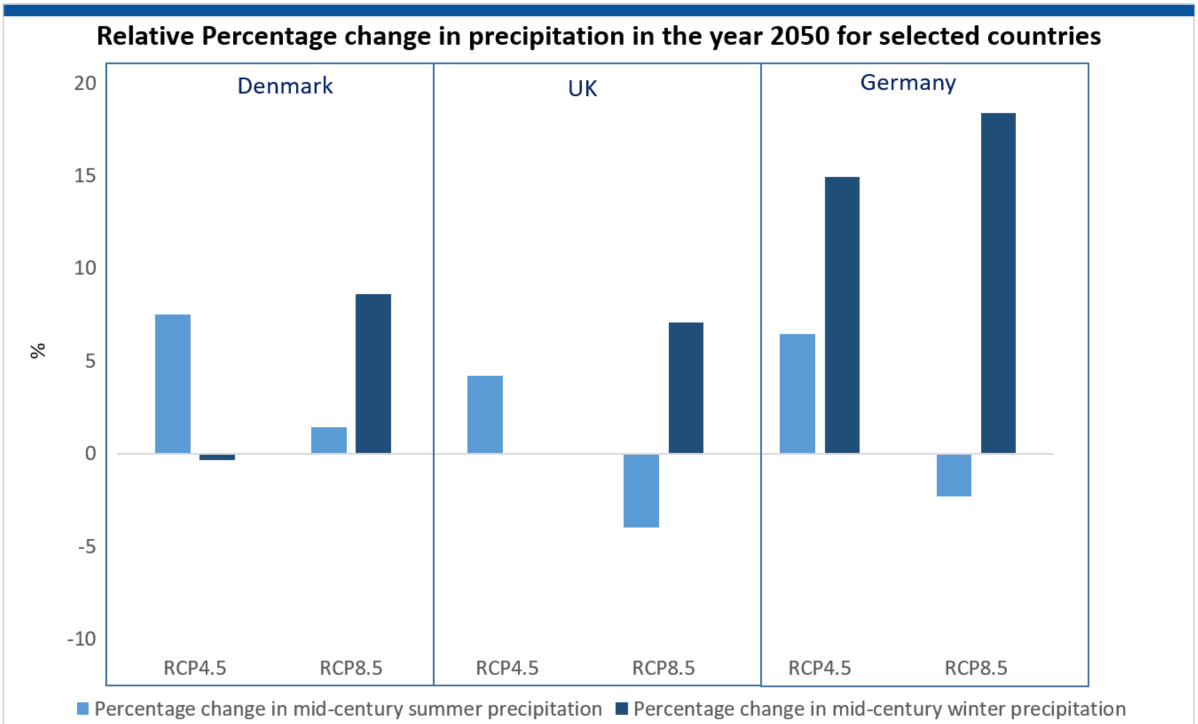


Figure 3: Relative percentage change in mid century summer (light blue) and winter (dark blue) precipitation for the selected trout producing countries Denmark, UK and Germany under RCP 4.5 and 8.5 compared to today (2000-2018).

Assessing future precipitation patterns in 2050, under RCP 4.5, Denmark the UK, and Germany are predicted to have slightly increased summer rainfall in 2050 for the overall country (Fig. 3). Denmark shows a similar trend in summer precipitation under RCP 8.5 in 2050, whereas in average a small reduction in summer rainfall in the UK and Germany is expected under this scenario. 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, which could enhance the risk of flooding[15]. However, it is also important to consider more local projections and the evaporation rate. For the south of Germany (Bavaria and Baden-Württemberg) more extreme variation in regional rainfall patterns[16,17] with potential subsequent effects on groundwater levels, was predicted for the RCP 8.5 or similar scenarios compared to the country's mean discussed above.

Mid-century projections show river flow rates decreasing by up to 10% in Denmark. Conversely, an increase of up to > 10% is predicted for eastern and coastal Germany, with both changes being higher under the high-emissions RCP 8.5 scenario. Projections for England show decreasing flow under the moderate-emissions RCP 4.5 scenario but increasing under RCP 8.5[18]. The projections should be considered to have high uncertainty and again, regional models may add a finer scale to these projections. The prediction for summer river flow in Baden-Württemberg shows a reduction of 13-14% within the southwest to the northeast band of the county (2021-2050)[19].

In general, a study on future water resource availability projects most severe reductions for Germany compared to the other two countries for a scenario which is even below RCP 8.5 (Hagemann et al. 2013).

Socio-economic developments

Each of the medium (RCP 4.5) and "business-as-usual" emission scenario (RCP 8.5) are combined with different socio economic assumptions, the so-called "shared socio-economic pathways" (SSP) leading to four future scenarios in total: The global scenario "World Markets" (WM), based on RCP 8.5 and SSP5 and a smaller-scale scenario titled "National Enterprise" (NE), which maps onto RCP8.5 and SSP3[20].

These are complemented by two RCP 4.5 scenarios. The "Global sustainability" (GS) scenario that includes socio-economic developments of SSP1, representing a sustainable alternative to the WM scenario and the "Local stewardship scenario", which combines RCP 4.5 with SSP2.

Population growth as well as GDP are highest in the global and market-oriented WM, whereas the share of renewable energy is smallest for WM among all scenarios.

NE as well describes a scenario with intensive fossil fuel use but increased national isolation and therefore a decreasing population trend within Europe and a less thriving economy.

GS is a global scenario, characterised by a focus on renewable energy usage, trends for increasing population numbers and high GDP, but 14 % lower compared to WM for the latter.

The LS scenario is very similar to GS in terms of population growth and GDP, but focuses on local resources and strategies and uses renewable energy to a lesser amount than under GS (CERES, 2016). Based on these assumptions and suitable literature projections for fuel prices, fish prices and fish feed component prices, considering also climate change effects on agricultural yields and outputs of the fish meal/oil model, future profitability of trout farming in England, Denmark and Germany will be analysed.

Key research needs

Key research needs for rainbow trout aquaculture are the impacts of expected water temperature and quality changes combined with related oxygen levels as well as susceptibility of cultured fish to diseases.

Thereby, physiological thresholds and economic consequences (of mitigation measures), such as higher capital costs for aeration are of interest.

To develop a full picture of the future profitability of rainbow trout production under different socio-economic scenarios, future changes in feed costs, energy usage and market returns are required.

Further, the future risks of changes in the range and abundance of pathogens are very important to understand, in order to develop respective mitigation measures such as prevention, cure or change of culture species.

CERES research

- Conducted a systematic literature review, a GAP analysis and a Meta-analysis to examine direct effects of climate change (warming, acidification, deoxygenation) on survival and growth physiology.
- Projected fishmeal and fish oil prices with a global FishMeal and Fish Oil (FMFO) model to estimate future feed prices across the different CERES scenarios together with projections on other future fish feed component prices
- sourced projections on future fuel and electricity prices as well as fish prices to calculate future energy costs and returns
- Created typical farm models for rainbow trout grown in Germany, Denmark, England and projected the economic effects of climate change on these farms.
- Developed maps of disease risk and farm suitability based on changes in the probability of occurrence of important diseases across NW Europe.
- Applied a trade model to capture the direct impact on the fisheries and aquaculture sectors and the indirect impacts on associated ancillary sectors for Denmark, Germany and the UK.
- Created a conceptual (BowTie -BT) diagram including perspectives on cause-and-effect relationships between climate change (CC) and future aquaculture production of rainbow trout.
- Ranked the vulnerability of Europe's most valuable farmed finfish and shellfish to CC, including trout in the NW Europe.
- Engaged stakeholders from the rainbow trout aquaculture industry (including fish feed production and fish health inspectors) to fine tune CERES inputs and outputs for the aquaculture sector and its policymakers.

Biological consequences (WP2/WP3)

Direct effects

Based on a systematic literature review, few studies have examined direct effects of CC (warming, deoxygenation, acidification) on rainbow trout in NW Europe. Studies on other populations outside NW Europe (Canada, Turkey, Japan), reported peak growth rates at 14-18°C. Two studies were found for metabolic rates of NW European rainbow trout in response to respective warming conditions.

They revealed significantly increasing metabolic rates at 20°C in comparison to 15-16°C and even lower metabolic rates at 10-12°C. One study dealing with the effect of lowered pH on metabolism of NW European rainbow trout was included in the systematic literature review.

The mean minimum oxygen consumption slightly decreased with lowered pH conditions down to 3 (7.0-7.8 was considered ambient), yet the reductions were non-significant[21].

Studies on deoxygenation effects were not found for NW Europe. A study from Canada indicated reduced mean growth rates for rainbow trout eggs under lowered oxygen concentrations (5.7 mg l-1) in comparison to saturated oxygen conditions[22].

According to another experiment, conducted on French rainbow trout, mean body mass of juvenile specimens exposed to hypoxic conditions (from 11 mg l-1 to 2.5 mg l-1) in their embryonic phase were not negatively affected at the end (after 24 weeks) of the experiment[23].

To conclude, a general scarcity in data hampers a differentiated risk assessment for NW European rainbow trout facing climate change effects especially about potential ontogenetic sensitivity changes. In order to increase predictive significance of climate change effects on rainbow trout in NW Europe more studies are needed.

Apart from the direct temperature effect on marine and inland water bodies, the impact of indirect climate change effects, such as of temperature on the changes in the distribution of pathogens, may have severe consequences for aquaculture operations as well. Thereby, pathogens can have significant impact on infected sites due to high mortality rates of infected fish and the control measures that are imposed on infected farms, which often persists for a longer time horizont[15,25].

In the medium-term (2040-59), the suitability of habitats and seasonal window for several diseases and pathogens known to impact European trout farms is projected to increase across Germany, Denmark and England.

Increased suitability generally expands northwards in responses to increasing temperature that are above the minimal thresholds of occurrence. Some pathogens are projected to show greater suitability to temperatures associated with RCP 4.5 in the year 2050 (e.g. Infectious Hematopoietic Necrosis Virus (IHN) suitability across the UK) whereas others show greatest suitability increases under RCP 8.5 (e.g. Proliferative Kidney Disease (PKD) suitability across Germany, Fig. 3). For PKD it has to kept in mind that the infecting parasite relies on an intermediate host, whose temperature optimum was not included in the present analysis.

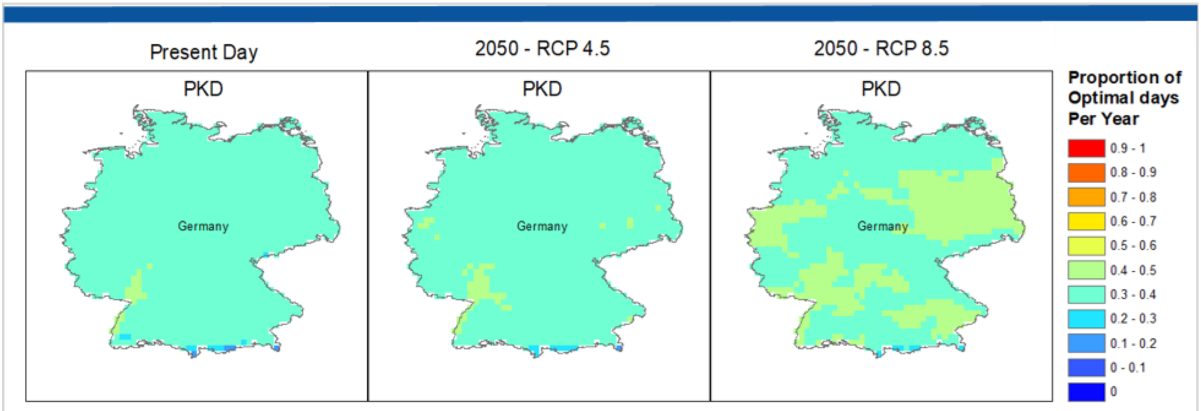


Figure 4: Temperature suitability maps for Proliferative Kidney Disease (PKD) occurence in trout (>15°C) in Germany under present-day surface water temperatures and the projected mid-century temperatures (2050) under RCP4.5 and RCP 8.5 scenarios.

However, there are exceptions, where suitability does not change in relation to projected temperature increases (e.g. Bacterial Kidney Disease suitability across Denmark) and occasions where suitability decreases in responses to the future scenarios (e.g. Enteric Redmouth Disease across the UK and Germany in response to both RCPs).

Despite such decreases, some suitability remains and the potential for infections persists with risk potentially increasing if fish health was to decrease in response to other environmental changes.

In the event of decreasing oxygen levels, extreme precipitation events and general thermal stress, cultured finfish are known to become more susceptible to the diseases and pathogens discussed above[23] and the potential future distributions of pathogens will dictate the impacts and management to trout farms across Europe.

Economic consequences

Typical farms representing the main trout production regions and systems in Germany, Denmark and England were defined together with experts and stakeholders from the operational business and analysed for their cost structure as well as profitability (see [10] for more information on the method).

With the majority of trout producing farms in NW Europe being traditional and small operations, this sector was represented by 2 farms (7.5- 150 tons/year) in typical trout producing regions of Bavaria in Germany and southern Denmark (DE-TRR-7.5; DK-TRR-150).

The fewer, more professional farms, which operate in raceways and partly recirculating systems, are represented by a total of 4 farms (100- 700 tons/ year) covering the region of Baden-Württemberg in Germany, the southwest of England and Mid-Jutland in Denmark (DE-TRR-100, DE-TRR-500, GB-TRR-360, DK-TRR-700).

Cost structure analysis for the reference year of 2016 reveals that feed costs account for the largest cost share in all production systems with 42-61% of total costs. However, other cost categories differ more pronounced between the different farms and countries, such as market returns. For example, energy costs are much lower for smaller traditional farms than for the highly automated recirculation systems.

All farms are at present profitable in the medium term, whereas most of the large farms are also profitable in the long-term.

Future fish feed prices, electricity and diesel price development as well as projected fish prices under the different emission and socio-economic assumptions have varying impacts on the operating margin (short-term profitability) of our typical farms (Figure 4).

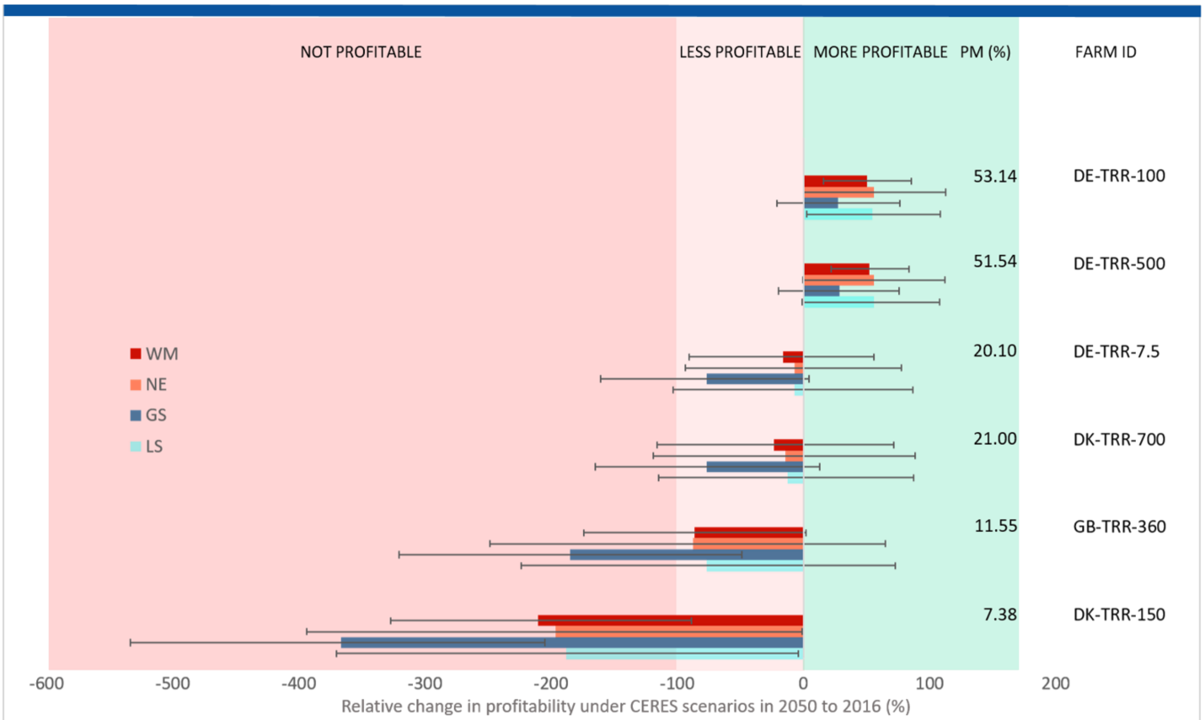


Figure 5: Relative profitability change under 4 CERES scenarios in 2050 to 2016 according to the relation of the profit margin (operating earnings/returns) in 2016 for all typical trout farms. World Market = WM, National Enterprise= NE, Global Sustainability= GS, Local Stewardship = LS. Error bars indicate 95% upper and lower probability ranges from Monte Carlo simulation results in relation to operating earnings from today (2016). PM = Profit Margin in percent.

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. Model predictions suggest that the smaller Danish farm (DK-TRR-150), which had a profit margin of around 7%, in 2016, 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 around 20% 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 adaptations are made to practices or supply chains and markets.

Predictions averaged across the trout sector as a whole show that overall cash costs will increase more than returns under all four CERES scenarios 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. This leads to the observed results distribution with farms being least profitable under the GS scenario, but most profitable under LS (Fig. 4). The reason for this are amongst others the comparably low fish prices under GS. Fish prices are derived from SSP-specific changes in population, income, international trade, agricultural expansion and technological change as major drivers for long-term changes in world food prices[25].Thereby GS shows lowest demand for agricultural commodities, resulting in more rapid growth in agricultural productivity and globalized trade[26].

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 simulation of possible future price variation (Monte Carlo Simulation) considering historical price changes for feed ingredients, diesel and electricity and fish (returns) was conducted. The respective results illustrate that farms with "medium profit margin" (around 20%) could get even more profitable under optimal price development of costs and returns for WM, NE and LS scenario. In the worst case they will no longer be 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 Fig. 4). The farm DK-TRR-150, could be profitable, but with lower operational earnings compared today under the two local scenarios.

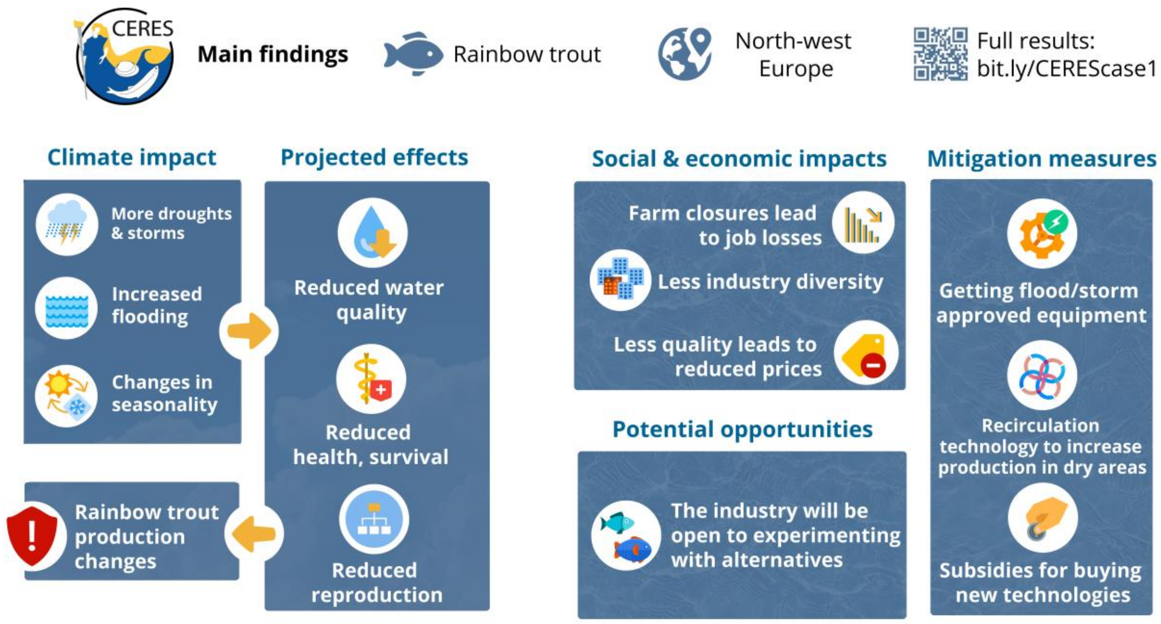
Taking the results one step further, information on future temperature suitability and disease risk under the two RCP's were considered to include local effects of temperature on growth and disease occurrence and costs. Thereby, the typical farms were placed across their original countries in order to identify the most and least suitable regions in combination with future price projections under the four scenarios.

Though environmental conditions are important in terms of the viability of a rainbow trout farm, the regional level analyses suggest they have comparably little impact on the profitability of the sector when considering the average annual proportion of days within the optimal growing temperature as well as disease suitability to various pathogens and parasites. This is in comparison to the impact of the projected price changes on profitability.

Besides temperature and disease suitability, future water availability is another very important factor, which could not be included within the present economic analysis. However, based on the projected precipitation patterns and as the external local climate studies for southern Germany show, rainfall patterns will be increasingly varying and there is a trend to dryer summers and more rainfall in the winters. Especially farms with already limited assess to water inlet are at risk and may face significant losses. During the drought in 2018 there were examples of farms which existence was at risk due to lack of water supply within the German sector, including large professional production systems (comparable to DE-TRR-100)[27,28].

Climate-ready solutions

A BowTie (BT) conceptual model was developed to improve our cause-and-effect understanding of the relationship between the potential impacts of CC on rainbow trout production and the mitigation measures that could reduce those impacts (Fig. 6).



Expected changes in precipitation and an increase in surface water temperature for NW Europe are pushing towards or exceeding the thresholds for water temperature and/or quality of rainbow trout. Consequently, declines in fish health and potentially reduced survival are expected to negatively impact rainbow trout production. Increased winter precipication and regional increase in river flow could cause an increased frequency of flooding and damaging farms. Adaptation measures will increase operational costs (e.g. energy costs to increase aeration) and, if these measures are not sufficient or exceed profit, relocation of aquaculture with reduced local employment could be the consequence (Fig. 6, red boxes). Mitigation measure options from governmental site include subsidies to enable the adoption of new technologies to overcome increased droughts, floods and/or decreased water quality. In case that physiological thresholds of the cold water species rainbow trout are exceeded alternative rainbow trout strains, e.g. selected for higher thermal tolerance could be an option.

Policy recommendations

According to current estimations, the EU's climate commitments are insufficient and consistent with warming between 2°C and 3°C until the end of the century[29], which would be closer to the RCP 8.5 scenario than RCP 4.5. Among the rainbow trout producing countries discussed within this storyline, Denmark has set the most ambitious goals with aiming at reducing greenhouse gas emissions by 70 % until 2030 and being emission neutral by 2040. Germany has set lower goals of aiming at -55% until 2030 and being emission neutral in 2050[30]. However, the current adopted German climate package[30] is according to expert analysis not sufficient to reach this goal[30]. Some analyses comes to the result that the prevention to exceed an 1.5 °C increase until end of the century (within 90% variation of RCP 4.5 scenario) requires a lot more ambitious emission reduction goals than -55%, especially if no technology for negative emissions is successfully developed[32].

The UK has already reduced GHG emissions more efficiently than the other two countries (44% since 1990 compared to 35% DK & 32% DE) and committed to be emission free until mid of the century, but 2030 goals have to be re-defined.

All together, within this storyline especially Germany might have to review and revise its climate package in order to assure that the required national emission reductions to limit global warming to 1.5 °C until 2100 are fulfilled.

Besides the overall climate goals there are very little aquaculture adaptation plans for the rainbow trout producing countries being part of this storyline. For Denmark the environmental parameters discussed above are most stable compared to the other two countries and production in the new RAS systems is less temperature sensitive as the larger recirculation farms in Denmark use underground wells for water supply and not surface water.

For Germany a current adaptation agenda for agriculture, forestry, aquaculture and fisheries does exist[33], but this is so far only a baseline to develop more specific measures and it would be important to investigate if some of these measures could be put into action sooner rather than later. Thus, the development of adapted technologies and a review of the existing regulatory frameworks are crucial. Especially adaptations towards an altered availability of water resources are important, including additional aeration and (partly) recirculating production systems.

The use of more renewable energy within the sector would be beneficial. Furthermore, supporting breeding of more climate resistant rainbow trout strains could address some of the problems. The extreme summer in 2018 showed that farmers in the area of North-West Germany predominantly reacted with increasing aeration leading to additional electricity costs of 20% on average[27]. Furthermore, reduced stocking densities as well as applications for groundwater extraction were seen as future adaptation measures[27].

Further reading

CERES publications

[15]Taylor N (2019) CERES deliverable 4.2 Report on minimising economic losses, opportunities and challenges for aquaculture in Europe. Available from https://ceresproject.eu/deliverables/

[18]Kay S (2017) CERES deliverable 1.4 Synthesis of projected impacts of climate and anthropogenic change on European river flows. Available from https://ceresproject.eu/deliverables/

[20]Pinnegar JK, CERES deliverable 1.1 Exploratory socio-political scenarios for the fishery and aquaculture sectors in Europe. Available from from https://ceresproject.eu/deliverables/

[23]Doyle T (2019) Tools (statistical/probabilistic early warning tools) allow industry to prevent and mitigate indirect effects of CC.

CERES (2017) Synthesis of projected impacts of climate and anthropogenic change on European river flows (Ed. Kay, S.) CERES Deliverable D1.4.

Other publications

[1]Molony B (2001) Environmental requirements and tolerances of Rainbow trout (*Oncorhynchus mykiss*) and Brown trout (*Salmo trutta*) with special reference to Western Australia: A review. Fisheries Research Report No. 130:1-28

[2]http://www.fao.org/fishery/culturedspecies/Oncorhynchus_mykiss/en

[3]Crawford SS, Muir AM (2008) Global introductions of salmon and trout in the genus Oncorhynchus: 1870–2007. Reviews in Fish Biology and Fisheries 18 (3): 313-344

[4]Stanković D, Crivelli AJ, Snoj A (2015) Rainbow Trout in Europe: Introduction, Naturalization, and Impacts. Reviews in Fisheries Science & Aquaculture 23:39–71

[5]FEAP European Aquaculture Production Report 2008-2016. Prepared by the Federation of European

[6]European market observatory for Fisheries and Aquaculture Products (EUMOFA) https://www.eumofa.eu/

[7]Eurostat database: https://ec.europa.eu/eurostat/data/database

[8]Nielsen R, Asche F, Nielsen M (2016) Restructuring European freshwater aquaculture from family-owned to large-scale firms – lessons from Danish aquaculture. Aquaculture Research 47 (12): 3852–3866

[9]Statistics Denmark https://www.dst.dk/en

[10]Lasner T, Brinker A, Nielsen R, Rad F (2017) Establishing a benchmarking for fish farming– Profitability, productivity and energy efficiency of German, Danish and Turkish rainbow trout grow-out systems. Aquaculture Research 48(6): 3134-3148

[11]Destatis Erzeugung in Aquakulturbetrieben (2017) Fachserie 3, Reihe 4.6 Land und Forstwirtschaft, Fischerei (transl. Production of aquaculture farms 2017. National Agency for Statistics)

[12]Cefas FHI's STARFISH database - non-public cross-government database

[13]McKenzie JM, Wyness L (2013) Review of Nutritional & Health Benefits for the British Trout Association. Queen Margaret University, Edinburgh, British Trout Association Client Report, Edinburgh: p.30

[14]http://britishtrout.co.uk/trout/farming-trout/

[16]Klimawandel in Baden-Württemberg – Fakten, Folgen, Perspektiven (2016) Ministerium für Umwelt, Klima und Energiewirtschaft Baden-Württemberg (transl. Climate change in Baden-Württemberg – Facts, Impacts, Perspectives by the Ministry for Environment, Climate and Energy Baden-Württemberg)

[17]Klimaanpassung Bayern 2020 – Der Klimawandel und seine Auswirkungen-Kenntnisstand und Forschungsbedarf als Grundlage für Anpassungsmaßnahmen (2008), Bayerisches Landesamt für Umwelt (transl. Climate adaptation Bavaria 2020 – Climate change and its impacts – state of knowledge and research needs as basis for adaptation measures, Bavarian State Ministry of the Environment)

[19]Strategie zur Anpassung an den Klimawandel in Baden-Württemberg (2015) Ministerium für Umwelt, Klima und Energiewirtschaft Baden-Württemberg

(transl. Strategy for climate change adaptation in Baden-Württemberg by the Ministry for Environment, Climate and Energy Baden-Württemberg)

[21]Ultsch GR, Ott ME, Heisler N (1980) Oxygen Tension, and Aerobic Scope for Spontaneous Activity of Trout (*Salmo Gairdneri*) and Carp (*Cyprinus Carpio*) in Acidified Water. Comparative Biochemistry and Physiology 67A: 329–335

[22]Miller SC, Reeb SE, Wright PA, Gillis TE (2008) Oxygen concentration in the water boundary layer next to rainbow trout (*Oncorhynchus mykiss*) embryos is influenced by hypoxia exposure time, metabolic rate, and water flow. Canadian Journal of Fisheries and Aquatic Sciences 65: 2170–2177

[24]Liu J, Dias K, Plagnes-Juan E, Veron V, Panserat S Marandel L (2017) Long-term programming effect of embryonic hypoxia exposure and high-carbohydrate diet at first feeding on glucose metabolism in juvenile rainbow trout. The Journal of Experimental Biology 220: 3686–3694

[25]Gubbins M, Bricknell I, Service M (2013) Impacts of climate change on aquaculture. MCCIP Science Review 2013: 318-327

[26]Popp A, Calvin K, Fujimori S, Havlik P, Humpenöder F, Stehfest, E, Bodirsky BL, Dietrich JP, Doelman JC, Gusti M, Hasegawa T, Kyle P, Obersteiner M, Tabeau A, Takahashi K, Valin H, Waldhoff S, Weindl I, Wise M, Kriegler E, Lotze-Campen H, Fricko O, Riahi K, van Vuuren DP (2017) Land-use futures in the shared socio-economic pathways. Global Environmental Change 42: 331-345

[27]Knoepfel T, Brummer B, Wessels S (2019) Efficiency of rainbow trout production in North-West Germany. Aquaculture Europe Talk 2019

[28]person.communication

[29]https://climateactiontracker.org

[30]Klimaschutzprogramm 2030 der Bundesregierung zur Umsetzung des Klimaschutzplans 2050 (2019), Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit (transl. 2030 climate protection programme (2019) Federal Ministry for the Environment, Nature Conservation and Nuclear Safety)

[31]Edenhofer O, Flachsland C, Kalkuhl M, Knopf B, Pahle M (2019) Bewertung des Klimapakets und nächste Schritte- CO_2-Preis, sozialer Ausgleich, Europa Monitoring (transl. Evaluation of the climate package and upcoming steps- CO_2 price, social compensation, Europe monitoring)

[32]Höhne N, Emmrich J, Fekete H, Kuramochi T (2019) 1.5 °C: Was Deutschland tun muss. (transl. 1.5°C: What Germany needs to do) http://newclimate.org/publications/

[33]Agenda Anpassung von Land-und Forstwirtschaft sowie Fischerei und Aquakultur an den Klimawandel (2019) Bundesministerium für Ernährung und Landwirtschaft. (transl. Agenda for climate change adaptation of agriculture, forestry, fishery and aquaculture, German Federal Ministry for Food and Agriculture)

CERES Climate change and European aquatic RESources

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