Case study

#2 Rainbow trout in the eastern Mediterranean

#3 Carp in north-east Europe

#4 Pike-perch in south-east Europe

Species background and economics

Rainbow trout (*Oncorhynchus mykiss*) is a diadromous cold-water fish species with high oxygen demand.

Rainbow trout farming is generally carried out in land-based farms using cold spring water or in natural/artificial lakes using floating cages.

According to FAO-GIGIS figures, over 187 000 tons of rainbow trout was produced in the Mediterranean countries, valued at $542 million (€488 million).

Turkey is the largest producer of rainbow trout in the Mediterranean, possessing nearly 55% of the total regional production of rainbow trout in 2017. Italy and France are the other major rainbow trout producers in the region.

In 2018, Turkey produced about 105,000 tons of rainbow trout in freshwater constituting nearly 33% of total aquaculture production in the country in over 1800 inland farms[1].

Expected projections under climate change

Climate related changes such as rise in inland water temperatures, increased frequency of extreme events (e.g. storms, floods, drought) and water stress are expected to have direct or indirect negative impacts on rainbow trout farming both in land-based and cage farms.

For instance, rising temperature in inland waters and decreasing dissolved oxygen concentrations will result in hypoxia and lower growth rates and poor feed conversion ratios (FCR).

This would not only mean an increase in production costs but would also lower harvest and income levels in rainbow trout farms.

Droughts and water stress are likely to limit freshwater water availability and quality for trout farming.

Rising water temperature will also increase incidents of diseases and parasites in trout farms resulting in higher mortalities and losses.

Air temperatures in Euphrates basin (Elazığ region-Keban dam lake) are projected to rise by about 1.5-2°C during the first half of the 21st century, and by as much as 5°C by the end of the century (2°C under RCP4.5, 4.8°C under RCP 8.5).

Projected maximum temperatures regularly exceed 40°C daily average by the end of the end of the century under RCP 8.5, whereas the present-day values are typically 32-34°C.

Minimum temperatures under RCP 8.5 rise considerably, so that some end-century years do not go below 0°C daily average.

The change in precipitation is less strong but a generally reducing trend is projected, with average annual precipitation being about 60 mm yr^{-1} less by mid-century and 100-200 mm yr^{-1} less by end-century.

The change projected for the first half of the century is within the current year-to-year variation, but the second half of the century shows greater change.

Consistent with rising temperatures and reduced precipitation, river flows are projected to decrease, by 10-25% in the first half of the century and up to 50% by end-century (Susan kay, PML)[2].

Many models and scenarios suggest a significant decline in snow water (10-60%) and in available snow-covered areas[3].

Scenarios describing future society and economy

CERES uses models to estimate economic developments in Europe´s fishery and aquaculture based on select, pre-defined physical and socio-economical future scenarios.

These future scenarios were specified by industry partners and stakeholders in the first year of CERES (e.g. fish prices, fuel prices, technological advancements, regional policy issues, etc.).

'World Markets'

- Personal independence, high mobility and consumerism
- Reduced taxes, stripped-away regulations
- Privatised public services
- High fossil fuel dependency
- Highly engineered infrastructure and ecosystems

'National enterprise'

- National isolation and independence
- Protection of national industry
- High resource intensity and fossil fuel dependency
- Low investment in technological development and education
- Low priority for environmental protection

'Global sustainability'

- High priority for welfare and environmental protection
- Cooperative local society
- Intense international cooperation
- Increased income equality
- Low resource intensity and fossil fuel dependency

'Local stewardship'

- Promotion of small scale and regional economy
- Less attention for global (environmental) problems
- Moderate population growth
- Income of industrialised and developing countries converge
- No overarching strategy to manage ecosystems

Table 1 Outline of the four social-political scenarios developed by CERES partners and stakeholders

Socio-economic effects

Four socio-political storylines are developed by CERES, based partly on the IPCC SRES (Special Report on Emissions Scenarios) framework and partly on the new system of Shared Socio-economic Pathways (SSPs) together with Representative Concentration Pathways (RCPs). The four CERES scenarios differ in their focus on consumerism versus environmental goals and their entrenched versus international outlook[4].

Turkey is the major rainbow trout producer in Europe and the Mediterranean. Farmed trout is consumed domestically and partly exported as smoked products to Northern European countries.

Therefore; rainbow trout farming sector in Turkey is competing with other producing countries and is influences by market dynamics in international markets. Both land-based and cage rainbow trout farms are spread all over the country and are important in terms of creation of income and jobs national-wide. Trout farming is also important in terms of creating other economic activities along the value chain.

Key research needs

One of the most important challenges for sustainability of inland aquaculture sector is to assess and project the direct and indirect risks associated with climate change for inland aquaculture and specifically farming of cold-water species like rainbow trout.

Inland cage farms in lakes seem to be more vulnerable to climate change more than land-based farms which use spring water for farming operations.

Results of CERES stakeholder engagements reveal that changes in physiology and growth patterns of trout, FCRs, survival rates and risks associated with incidences of fish disease and consequently productivity and profitability of trout farming operations are crucial issue to be addressed.

Accordingly; developing mitigation or adoption tools and strategies with respect to impact of climate change on physiology of trout and thus productivity and economic performance of trout farming operations would be also needed for sustainable development of the sector[5].

CERES research

Rainbow trout farms are spread all over Turkey. However; Elazığ and Muğla provinces in Turkey are among the most important rainbow trout producing regions with substantial contribution to national production of this species. For this reason, activities within CERES work packages on rainbow trout farming in the Eastern Mediterranean and climate change interactions were focused on these two provinces.

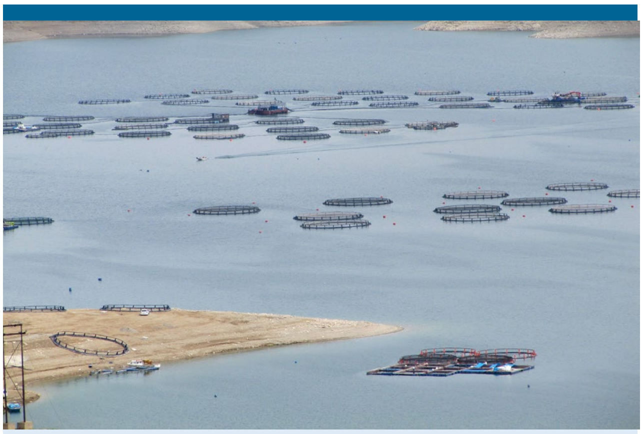


Figure 1 A Rainbow trout cage farm. *Credit: Ferit RAD, MEU*

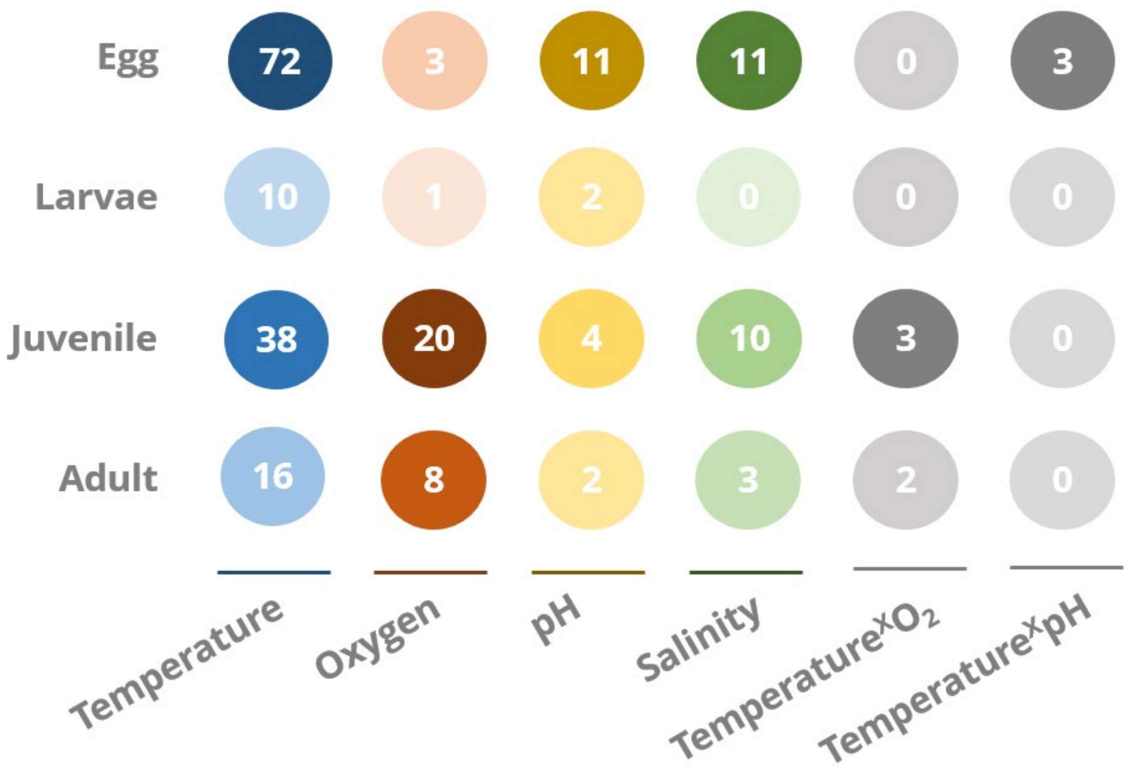
- A systematic literature review was conducted for GAP analysis and a meta-analysis to examine direct effects of climate change (warming, acidification, deoxygenation) on survival and growth physiology of European aquaculture targets.
- Surveyed and compiled data from rainbow trout land-based and cage farms in major producing regions (Muğla & Elazığ). Farmers were asked to provide information on environmental conditions, farming operations and bio-technical (e.g. growth rates, mortalities, FCR, stocking densities, diseases), structural and financial data.
- Engaged stakeholders via focus group meetings and workshops with farmers, researchers, and public administrators to increase awareness of aquaculture and climate change interactions and to regionalise CERES socio-political scenarios.
- Developed biological (WinShell and FARM) models to examine the effect of climate change (temperature, salinity, dissolved oxygen, dissolved inorganic nitrogen) on the biological production (harvestable biomass) of rainbow trout in cage farming (Elazığ

Province) in the medium- (2040-2600) and long- (2090-2100) term using an intermediate (RCP4.5) and more severe, business-as-usual (RCP 8.5) scenarios.

- Quantified changes in disease risk for key pathogens under future temperature projections for key pathogens relevant to rainbow trout across Eastern Mediterranean.
- Constructed typical farm models for Turkish rainbow trout land-based and cage farm operations and calculated financial performance under each of the CERES scenarios including trajectories of change in future prices of fuel, fish, and fish feed components and the outputs of a global fishmeal/fish oil model.
- Engaged stakeholders to verify bio-technical, structural and financial data as well as the overall model construction for 'typical' Turkish rainbow trout land-based and cage farms was assessed and verified by producers, researchers, experts through a focus-group meeting.
- Generated a conceptual (Bow-Tie) model with stakeholders to resolve the main components of risk assessment and risk management of climate change impacts on aquaculture sector.
- Ranked the vulnerability of European aquaculture to climate change including three elements: exposure, sensitivity and adaptive capacity.

Results

Research published on finfish in European seas



- Rainbow trout ranked 5 out of 28 European fish and shellfish genera reviewed here (18 studies).
- 3 datasets were found in the East Mediterranean (3x in Turkey). Numerous datasets are available in Storyline 1 (9), from european areas outside the storyline areas (6) and outside Europe (29).
- Most studies in storyline 1 & 2 were performing temperature experiments (8 out of 12).
- 10 out of 12 studies were performed on juveniles, others on adults
- The most common response studied on rainbow trout was growth, followed by mortality & physiology.

Biological

To assess the impact of climate change on physiology of rainbow trout and productivity of farms the individual growth model (*AquaFish*™) and the FARM model were applied to rainbow trout in cage farming in Elazığ province (Keban Dam Lake) of Turkey where trout cage farms are localized.

Cage farming of rainbow trout in Keban late is limited to certain period of the year (November-May) when water temperatures are cold and suitable for on-growing of trout.

The individual growth model for rainbow trout was developed based on the net energy balance approach.

The equations were taken or adapted from the literature and were parameterized and calibrated against different locations. The individual growth model (AquaFish) and the FARM production model were calibrated and validated against Keban lake current conditions[6]. The outputs of the Farm model are presented in Figure 3.

In terms of growth and other productivity parameters there are no significant differences between the low and the high emission scenarios until the far-future (2080-2100 time slice).

For the specific on-growing period in Keban lake which starts in November ends by May, trout seem to grow better under greater temperatures than the ones currently registered in Eastern Anatolia (Turkey) and farmers would get the greatest growth and profit in the far-future high emission scenario (Figure 3A and B) despite having more metabolic energy expenditure and requiring more feed to grow (Figure 3D and E). Profit is hereby calculated based on the present cost and returns without taking into account any future price developments.

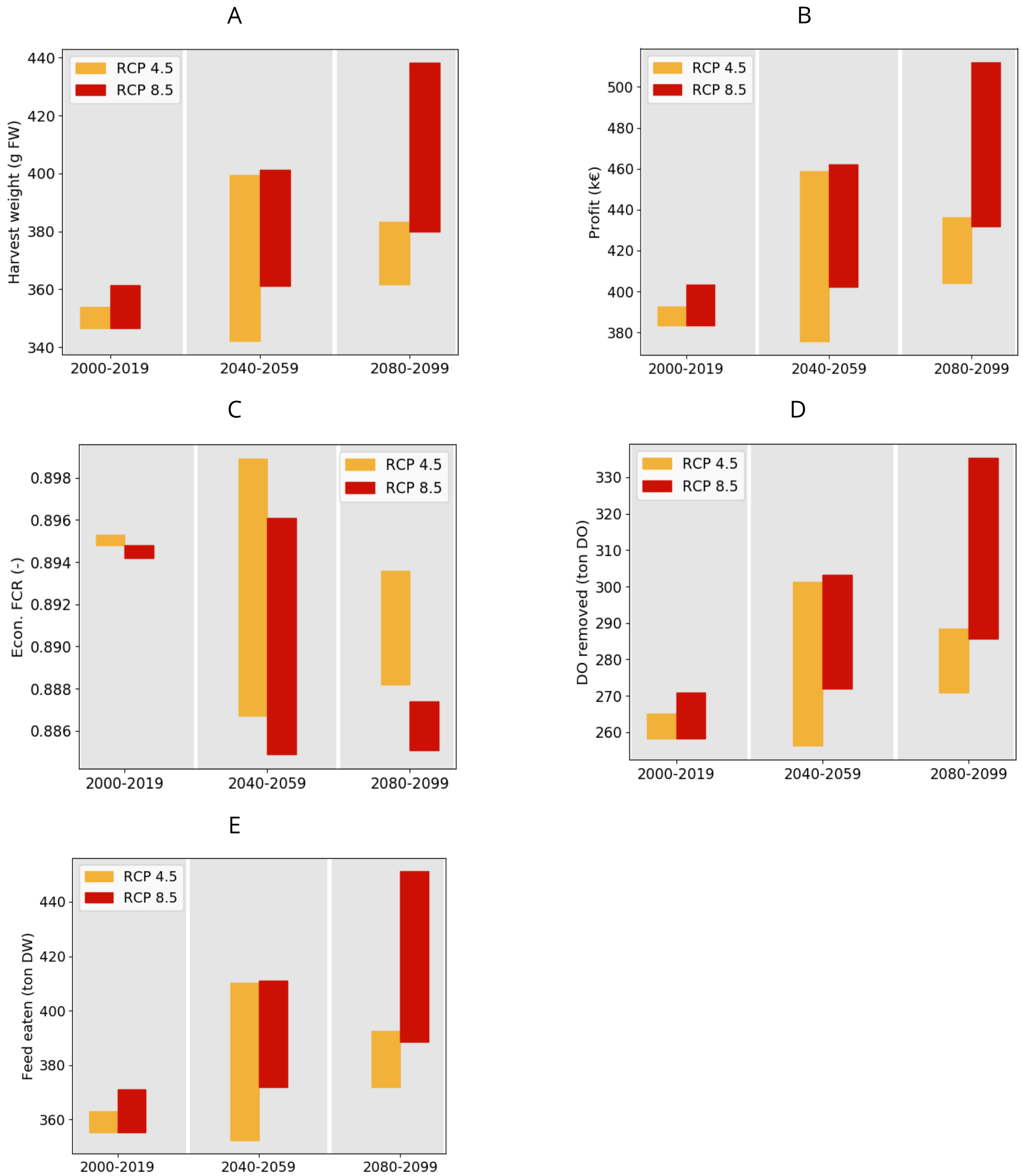


Figure 3 Range of FARM outputs for the typical rainbow trout farm in Turkey under the different climate change scenarios. Green and red bars represent the range (spread) of simulation values for the low- and the high- emission scenario, respectively. The drivers for the different climate change scenarios were obtained from the POLCOMS model as detailed in the text. LW: live weight; DO: dissolved oxygen[6].

Indirect Affects-Fish diseases

Quantification of pathogens risk was based on the 'number of days' water temperatures across the study areas were likely to be within the permissive temperature range for each of the pathogens studied.

Under current climatic conditions, the temperature profile in Turkey provides the most days per year (47%) above the low disease threshold for PKD, and Denmark the least at 30%.

However, unlike the other pathogens, this parasite is not directly transmitted between hosts, but relies on an intermediate bryozoan host to complete its life-cycle.

This makes predicting the occurrence of the disease difficult. Although the temperature in Turkey may be most suited to the disease, that same temperature may not be conducive to survival of the intermediate host.

Of the notifiable diseases, suitability maps demonstrated that the annual water temperatures experienced in each of the trout producing countries fell within the optimal temperature ranges for Infectious Hematopoietic Necrosis virus (IHN) from 26% to 36% of days.

Turkey had the lowest suitability with, on average, 26% of days within the permissive temperature window.

The biggest increase in the proportion of suitable days for disease was also observed under RCP 8.5 but the largest increases under both RCPs were generally for PKD and Furunculosis[7].

Projections on other diseases are provided in Table 2.

Species / disease	Temperature Threshold (°C)	Mean proportion of days per year (period: 2000-2020) that temperatures fell within the species or pathogen temperature thresholds	2050 change (%) under RCP 4.5	2050 change (%) under RCP 8.5
Trout	**9-14**	**0.21**	**0.53**	**1.47**
BKD	**15-18**	**0.13**	**-4.85**	**-7.4**
EHN	**11-17**	**0.22**	**-0.98**	**-1**
IHN	**8-15**	**0.26**	**2.27**	**3.19**
VHS	**9-12**	**0.12**	**1.4**	**3.36**
ERM	**15-17**	**0.1**	**0.44**	**0.4**
Furunculosis	**19-25**	**0.28**	**3.2**	**4.46**
PKD	**>15**	**0.47**	**5.43**	**7.72**
SAV	**12-15**	**0.11**	**-0.77**	**-0.44**

Table 2 Eastern Mediterranean – Turkey. Values highlighted in red highlight highest suitability value for present day but also indicate the biggest increase in the suitability for a pathogen under the two climate projections. Green values highlight smallest change in the suitability for a pathogen under the climate projections[7].

Economic consequences

To examine the impact of CC on productivity and economic performance of rainbow trout farming in East Mediterranean (Turkey), Typical Turkish rainbow trout land-based and cage farms were constructed based on collected data, farm visits, interviews with producers and consultation with experts and public administration.

A Typical Turkish land-based and cage farms were defined as a 500 tons full-cycle (TR-TRR-500) in Muğla province and 450 tons grow-out farm (TR-TRR-450) in Elazığ province (Keban Lake) respectively[8].

Land-based TR-TRR-500 includes hatchery and nursery facilities next to grow-out and produces from egg to portion-sized trout, whereas the cage farm TR-TRR-450 is solely concentrating on grow-out production.

For both farms feed cost are the major costs making up around 50% of total costs. However, stocking costs, being the second important cost factor, are 56% higher for the vertically integrated TR-TRR-500 than for TR-TRR-450. The remaining costs are allocated to other operational costs.

Both trout farms are profitable on the long term, with TR-TRR-450 being in a better position.

Future profitability is calculated by considering feed conversion ratio and total harvestable biomass under RCP 4.5 & 8.5 environmental conditions from physiological models as well as literature projection ranges of energy prices (fuel, electricity) fish prices and fish feed price assumptions under all four of the CERES scenarios, namely; World markets (WM), Global sustainability (GS), National enterprises (NE) and Local stewardship (LS) in the year 2050[8].

Both Turkish farms (Figure. 4 and 6) have equal returns per kg live weight, but TR-TRR-500 has higher cash costs compared to the dam lake farm. Among other things, these trace back to higher diesel (almost 3 times higher) and stocking costs (1.5 times higher) per kg fish.

Especially the price for diesel is projected to increase significantly in the future and the overall cost increase under all CERES scenarios is >3 % higher than for TR-TRR-450.

Model predictions suggest that Turkish land-based farms (TR-TRR-500) had a 2016 profit margin of around 7% will not be profitable under any of the four future scenarios.

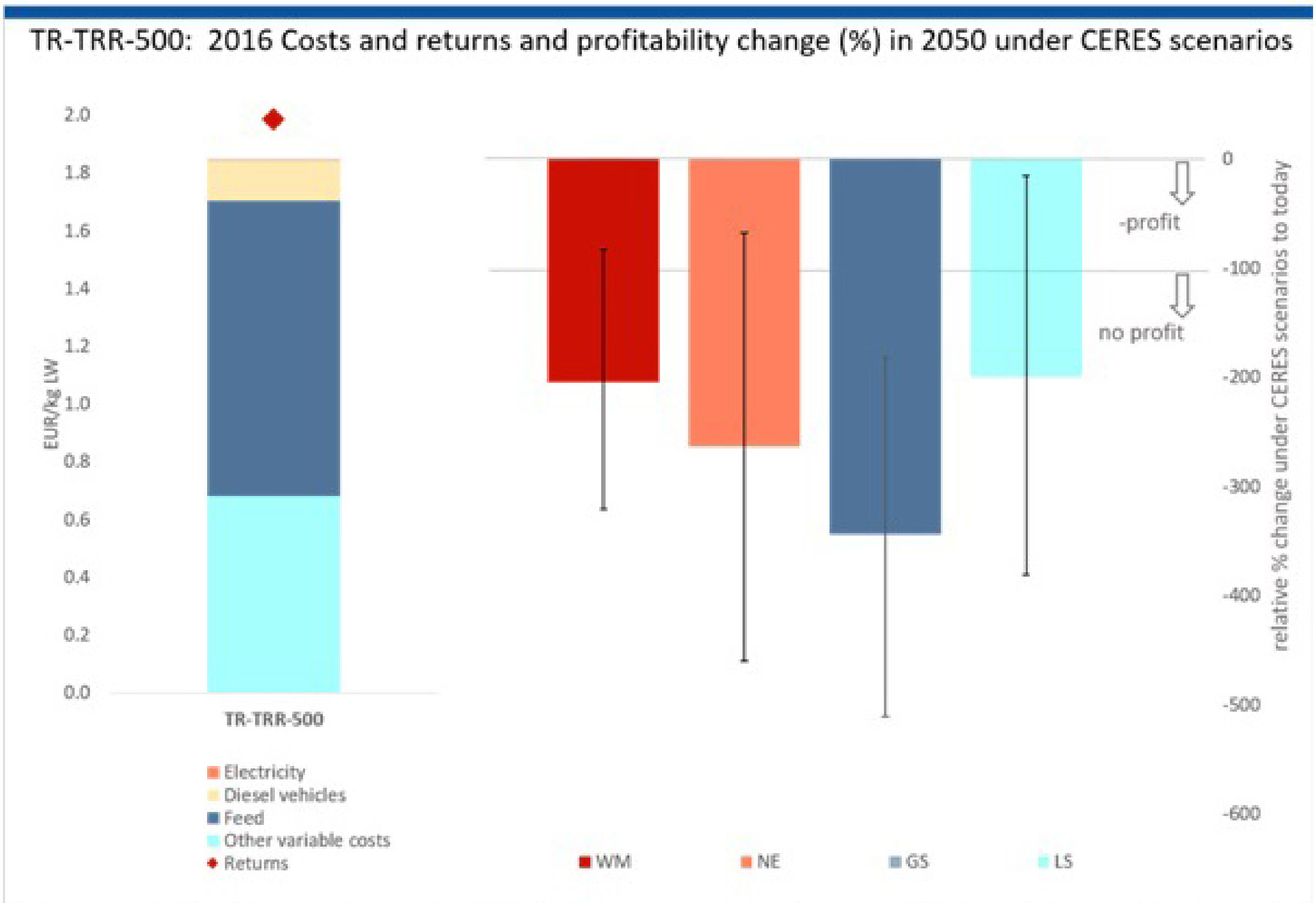


Figure 4 Stacked plot of cost and returns of typical Turkish rainbow trout farm (TR-TRR-500) in 2016 (left) and relative changes in profitability (returns against costs) in the year 2050 under the CERES scenarios World Market = WM, National Enterprise= NE, Global Sustainability= GS, Local Stewardship = LS compared to today (right). Error bars indicate 95% upper and lower probability ranges from Monte Carlos simulation results. Grey lines indicate higher or lower profitability compared to 2016.
Credit: Cornelia Kresis-Thünen Institute

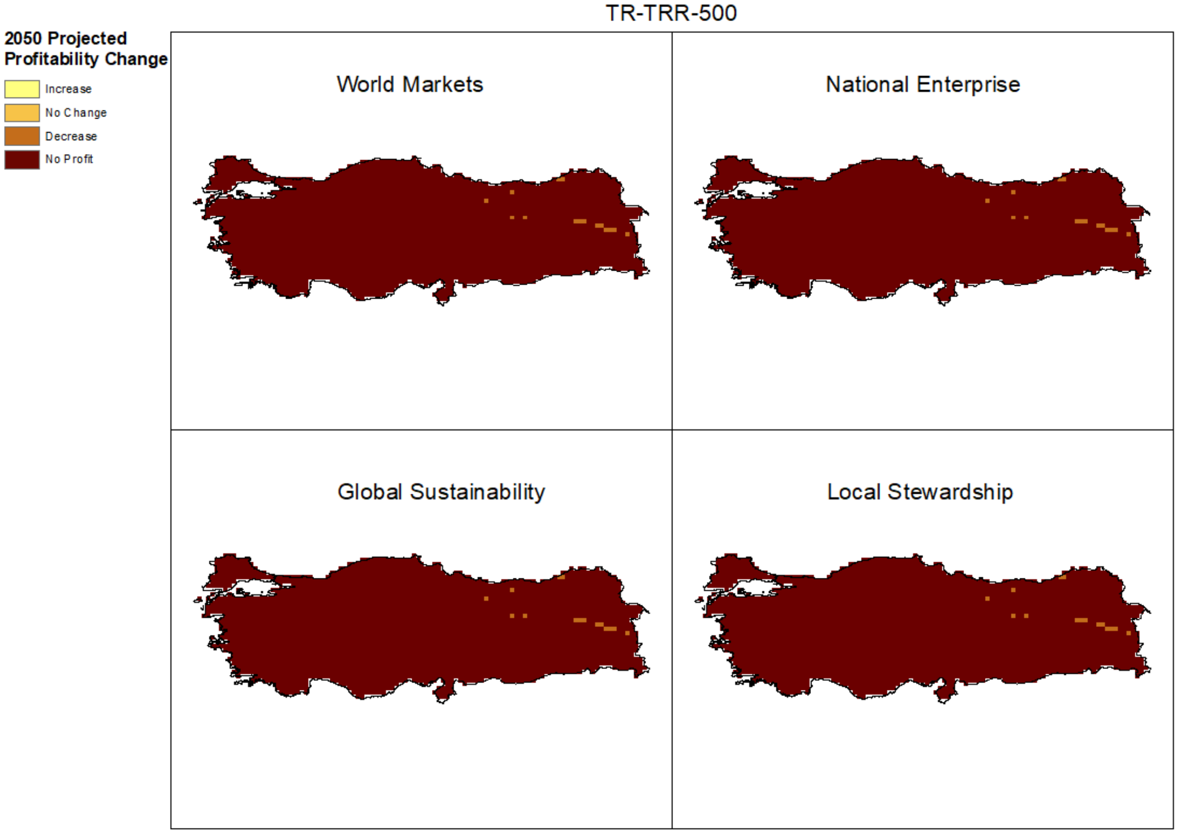


Figure 5 Map of projected profitability of land-based rainbow trout farming in Turkey under four CERES scenarios[8].

Taking the results one step further, information on future temperature suitability and disease risk under the two RCPs 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 (Fig. 6 and 7). The local effects of temperature suitability is thereby only marginal for the land-based trout farming across Turkey (Fog. 6). Only a small number of grid cells retaining the potential to make profit, all be it a lower levels than currently observed, particularly if the land in these areas is not suitable for trout farming (e.g. urban area).

For the cage-based trout farming (TR-TRR-450), the World Markets and Local Stewardship scenarios revealed a small number of grid squares where increased profitability could occur (Fig. 7) compared to the economic analysis displayed in Fig. 5. in case it is possible to locate cage sites within these locations.

In general, 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. To offset some of the increasing costs, it may be possible for Turkish trout farming sector to target new markets that will pay premium prices to achieve higher market returns. This has been occurred and 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[8].

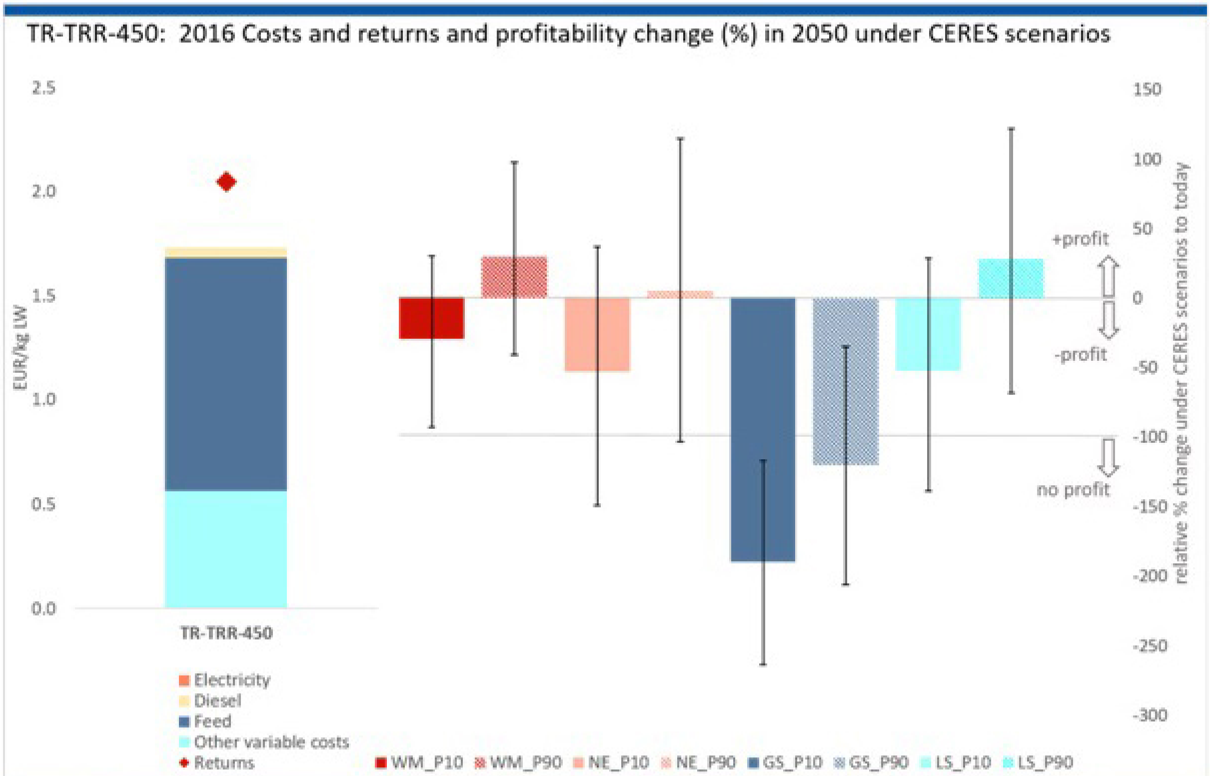


Figure 6 Stacked plot of cost and returns of typical Turkish rainbow trout farm (TR-TRR-450) in 2016 (left) and relative changes in profitability (returns against costs) in the year 2050 under P10 and P90 of the CERES scenarios World Market = WM, National Enterprise= NE, Global Sustainability= GS, Local Stewardship = LS compared to today (right). Error bars indicate 95% upper and lower probability ranges from Monte Carlos simulation results. Grey lines indicate higher or lower profitability compared to 2016.
Credit: Cornelia Kresis-Thünen Institute

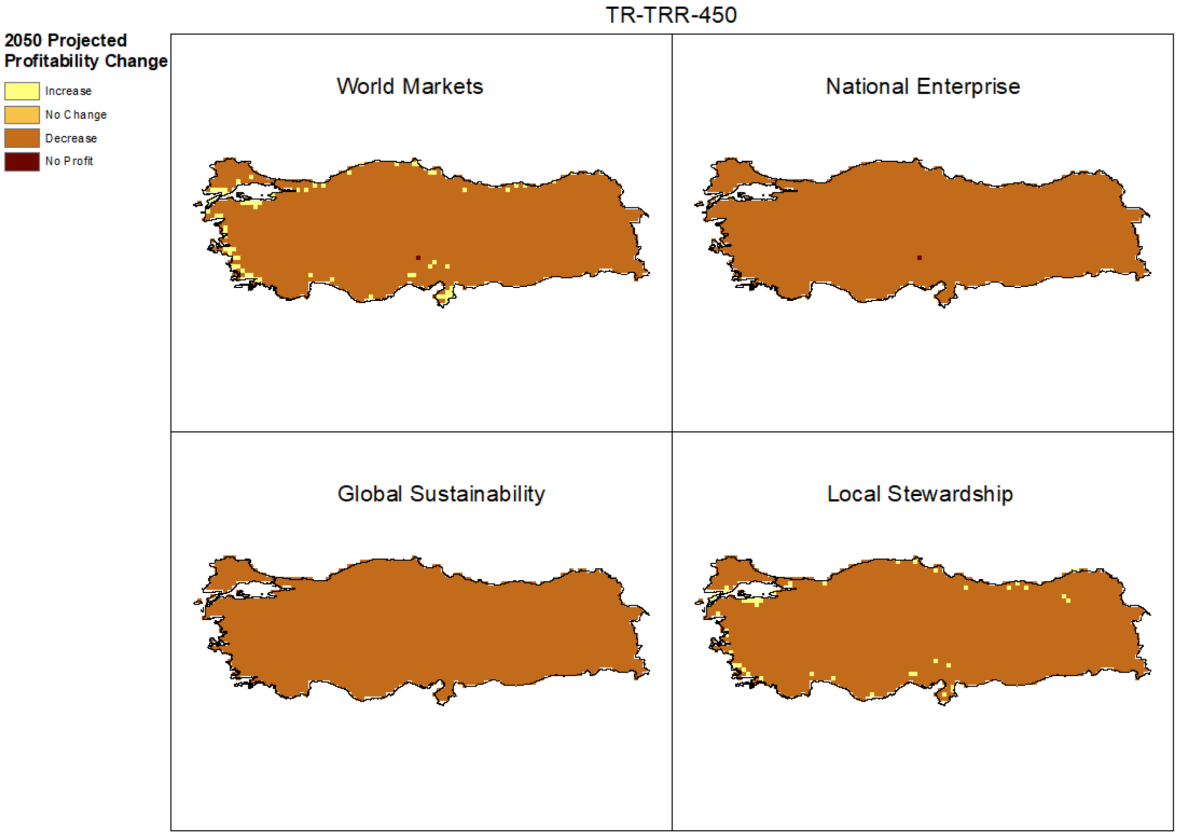


Figure 7 Map of projected profitability of rainbow trout farming in cages in Turkey under four CERES scenarios[8].

Fish meal and Oil Model

The fishmeal and fish oil model have been run under an initial parameterisation of the CERES scenarios.

These first run results show that under the "Global Sustainability" future scenario, fishmeal production increases by 19% by 2032, fish oil production increases by 31% and there is a relatively modest price increase (56% and 39% respectively).

In contrast, under a "National Enterprise" scenario, fishmeal production decreases by 34%, fish oil production decreases by 26% and there is a relatively significant price increase (68% and 83% respectively).

The "World Markets" scenario produces results that show fishmeal and fish oil production could potentially decrease by 94% and 92% respectively and is coupled with an exponential increase in price of 477% for fishmeal and 522% for fish oil[9].

Climate-ready solutions

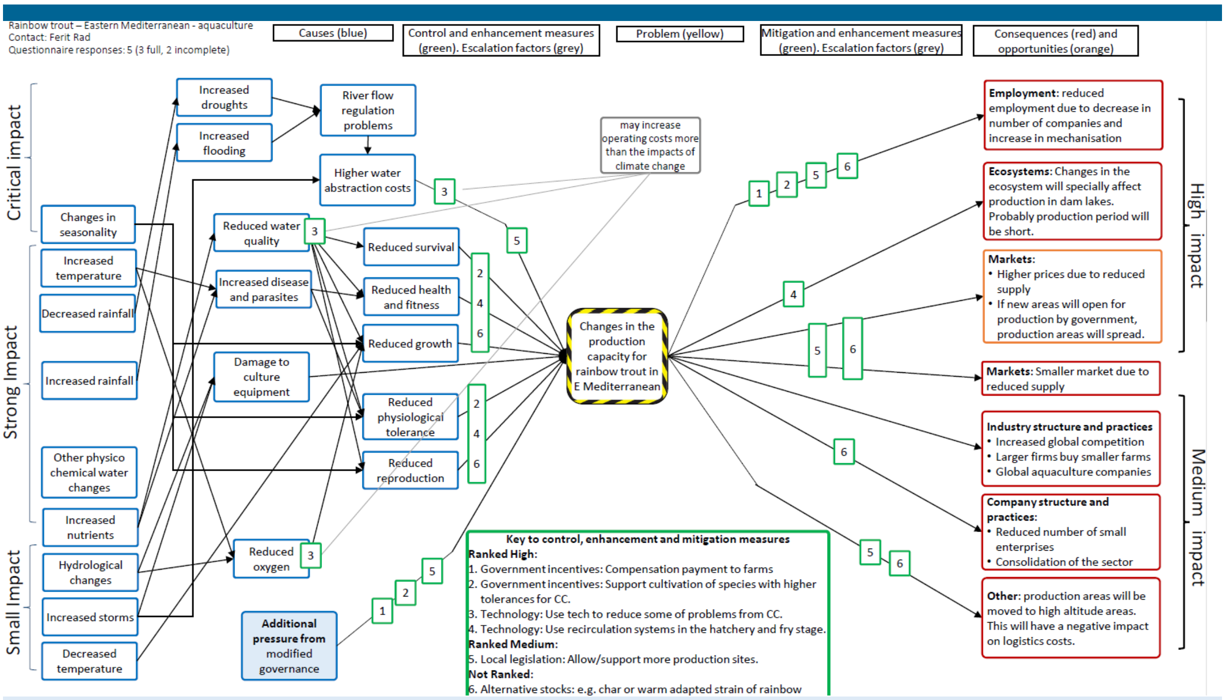


Figure 8 BowTie analysis based on stakeholder feedback. All full BowTies available http://bit.ly/CERESbowties2020 *Credit: Katie Smyth, Hull*

According to Bow-tie analysis key to control, enhancement and adaptation measures are as following[10]:

Ranked High:

1. Government incentives: Compensation payment to farms
2. Government incentives: Support cultivation of species with higher tolerances for CC.
3. Technology: Use technology
4. to reduce some of problems from CC.
5. Technology: Use recirculation systems in the hatchery and fry stage.

Ranked Medium:

5. Local legislation: Allow/support more production sites.

Not Ranked:

6. Alternative stocks: e.g. char or warm adapted strain of rainbow trout, that are tolerant to the changing conditions.

Vulnerability assessment

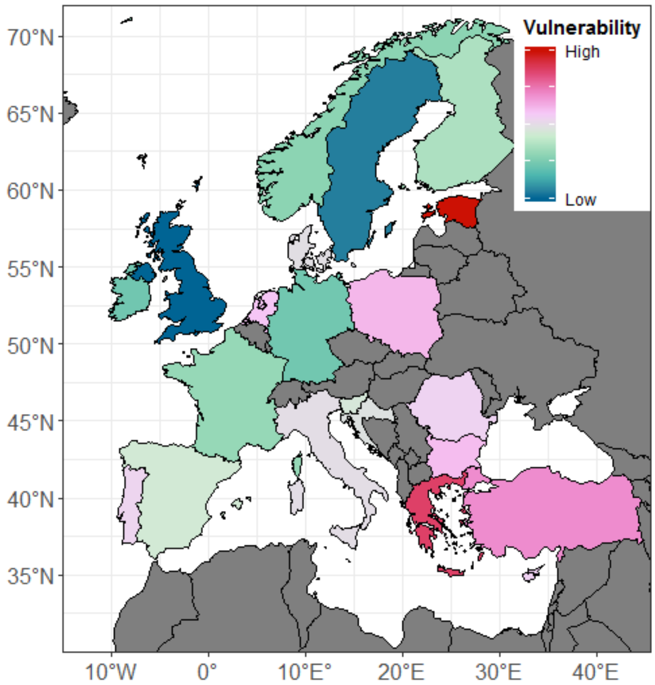


Figure 6 Climate vulnerability assessment for Europe. Colour scale is linear in the value of the corresponding score, but is presented without values, as they have little direct meaning. *Picture credit: Myron Peck*

- A climate vulnerability assessment (CVA) was conducted on the European aquaculture sector using the FAO model of Exposure + Sensitivity + Adaptive Capacity.
- The CVA included the physiological and farming methods of seven species (Atlantic salmon, sea bass, sea bream, trout, carp, mussels, oysters and clams) representing > 95% of the value for the region.
- Based on available economic data, the vulnerability of 22 countries – the top producers in the Europe28 as well as Norway and Turkey – was ranked and relative values are shown (right)
- By 2050 in RCP8.5, warming caused little change in the suitability of culture conditions for most species in most regions, including trout in the eastern Mediterranean. Direct effects of warming were small. Although not included in this analysis, projected declines in rainfall across southern Europe would have negative impacts on farms relying on river water.
- Many countries growing freshwater fish such as trout were relatively vulnerable to climate change due to the small size of firms (low adaptive capacity), and the lack of control associated with farming conditions.
- Nation-level vulnerability in the eastern Mediterranean was relatively high due to the economic importance of aquaculture and slow progress in implementing national climate adaptation plans.

Policy recommendations

An aquaculture-specific action plan addressing the risks associated with impact of climate change on both inland and marine aquaculture (cage farming) accompanied with mitigation and adaptation measures need to be developed by public authorities. Producers do not perceive climate change an urgent issue to deal with. It is seen as a challenge which needs to be addressed in future by public institution e.g. research institutes.

Awareness and capacity building actions regarding climate-change and aquaculture interactions should not be limited to private sector but needs to include technocrats/policy-makers at administrative level. Allocation of new sites for rainbow trout farming for both land-based and cage farms need to be in line with climate change scenarios to mitigate potential negative impact of CC.

Research and technology development focusing on CC and aquaculture interactions and targeting mitigation and adaptions measures (e.g. recirculation aquaculture system for fry production stage-hatchery) should be actively supported by public in close collaboration with aquaculture producers.

Public Universities and specifically faculties of Fisheries need to be more active in this domain.

Stakeholder engagement

A series of stakeholder meetings (focus-group, interviews and seminars) were conducted in Elazığ and Ankara with external stakeholders namely, rainbow trout farmers, researchers and policy makers. These events were often co-sponsored by the aquaculture industry and public institutions.

These events have substantially contributed to the awareness-building of inland aquaculture producers on how climate change will potentially impact their sector and business.

Focus-group meetings also shed light on perceptions of Turkish stakeholders regarding climate change and on four socio-political scenarios and their regionalisation.

As far as regionalization of CERES socio-political scenarios are concerned, stakeholders from the Turkish aquaculture sector identified '**World Markets**' (RCP 8.5, SSP5) as the most likely future pathway of the four CERES socio-political scenarios.

Based on growth patterns, characteristics and market dynamics, this scenario was believed the best match to the economic growth and regional socio-political environment that the marine aquaculture sector has developed in.

What has been evident from interviews with producers regarding their perception on climate change and aquaculture interactions is that Turkish producers see climate change as a long-term challenge which needs to be dealt with in future. For this reason, only few producers have any mitigation strategy to meet this challenge[11].

Further reading

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Climate change and European aquatic RESources

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