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RESEARCH ARTICLE ARAŞTIRMA MAKALESİ

Climate change awareness and potential risks in freshwater aquaculture sector in Türkiye: A survey-based evaluation

Türkiye'de tatlı su balık yetiştiriciliği sektöründe iklim değişikliği farkındalığı ve potansiyel riskler: Ankete dayalı bir değerlendirme

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Abstract: Aquaculture sector is vulnerable to climate change, which has adverse impacts on water resources such as floods, droughts, sea level rise, water scarcity and water pollution. In this study, climate change awareness of freshwater aquaculture producers and associated potential risks are investigated for Türkiye. A survey was applied to 257 trout producing plants out of 1440 active plants in 25 river basins in 2020. The results implied that 79% of producers mentioned their awareness of the negative impacts of climate change, where water quantity and quality was reported as the highest impact that would threat fish health. In terms of extreme weather events, floods and drought were experienced by 40% and 35% of respondents, respectively. Temperature increase poses a threat for the plant owners and affects trout production. One-third of the producers had a financial loss of €6500-30.000. There is water sharing problem for almost 40% of plants. Future concern on water allocation was higher than 70% and the rate of agricultural insurance was very low, i.e., 11%.

Keywords: Awareness, climate change, freshwater aquaculture, risk, survey

Öz: Su ürünleri yetiştiriciliği sektörü, sel, kuraklık, deniz seviyesinin yükselmesi, su kıtlığı ve su kirliliği gibi su kaynakları üzerinde olumsuz etkileri olan iklim değişikliğine karşı kırılgandır. Bu çalışmada, Türkiye için tatlısularda balık yetiştiriciliği yapan üreticilerin iklim değişikliği farkındalığı ve ilişkili potansiyel riskler araştırılmıştır. 2020 yılında 25 nehir havzasında 1440 aktif alabalık üreten tesisten 257'sine anket uygulanmıştır. Sonuçlar, üreticilerin %79'unun iklim değişikliğinin olumsuz etkileri konusunda farkındalıklarının olduğunu göstermiş, balık sağlığını tehdit edecek en yüksek etki su miktarı ve kalitesi olarak rapor edilmiştir. Aşırı hava olayları açısından, katılımcıların sırasıyla %40'ı sel ve %35'i kuraklık yaşamıştır. Sıcaklık artışının tesis sahipleri için bir tehdit oluşturduğu ve alabalık üretimini etkilediği belirtilmiştir. Üreticilerin üçte biri 6500-30.000 € arasında maddi kayıp yaşadığını belirtmiştir. Tesislerin yaklaşık %40'ında su paylaşımı sorunu vardır. Su tahsisinde gelecek kaygısı %70'in üzerinde çıkmış, tarım sigortası oranı ise %11 gibi çok düşük bir seviyede kalmıştır.

Anahtar kelimeler: Farkındalık, iklim değişikliği, tatlı su balık yetiştiriciliği, risk, anket

INTRODUCTION

Population growth, economic development and industrialization have induced a growing demand for natural resources. As a result, expanding emissions of greenhouse gases from burning fossil fuels have triggered the global problem of climate change. Among the consequences of climate change; global temperature rise, decreased snow cover, warming oceans, sea level rise, declining arctic sea ice, ocean acidification and extreme weather events such as floods and droughts can be listed (NASA, 2024).

One of the most noticeable impacts of climate change is perceived on the hydrological cycle and water resources. Intergovernmental Panel on Climate Change (IPCC) reports that global warming of 1.5°C and 2°C will be exceeded during the 21st century unless deep reductions in CO_2 and other greenhouse gas emissions occur in the coming decades (IPCC, 2021). One of the sectors to be adversely affected by climate change is the fisheries and aquaculture production, as they are directly linked to water.

Fisheries have an important role both in human diet and the economy. Fish provide high-quality protein, minerals and trace elements, fat-soluble vitamins and essential fatty acids (FAO, 2010). Hence, fish consumption leads to nutritional benefits. Worldwide recommended annual consumption of fish is 11.7 kg per capita (WWF, 2016). The average annual consumption of fisheries is 24.4 kg per capita in the European Union (European Council, 2024). On the other hand, with an annual consumption of 6.7 kg per capita consumption, Türkiye is below average compared to other countries and the EU (MoAF, 2021). Nevertheless, fish is expected to remain one of the highly preferred healthy foods in the human diet. With ever increasing population on earth, more fish will be required in coming years. However, due to overfishing and pollution, wild fish stocks have been decreasing, and the increasing demand has led to growth of aquaculture production (Hoque, 2021; World Bank, 2013).

Global fish production is estimated to have reached about 170 million tonnes in 2018 (FAO, 2020a, b). The latest available statistics shared by OECD demonstrate that China is the major fish producer, where more than 12 million tonnes of fish were captured in 2018. In capture, the rank is followed by Indonesia

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and USA. In addition, China has produced more than 68 million tonnes of fish by aquaculture production, followed by Indonesia and India (OECD, 2022).

Fisheries and aquaculture production occur both in seas and inland freshwaters in Türkiye. Among a total of 2139 aquaculture production plants, 432 of them are produced at sea and 1707 of them are producing at inland freshwater. These numbers indicate that aquaculture production plants are mostly dependent on freshwater. Regarding the capacities, 1118 plants have small capacity of 0-50 tons/year, corresponding to 65% of total, and 99 plants have high capacity of 500-1000 tons/year; corresponding to 6% of total. By the year 2020, 1440 out of 1707 plants are active (84%) (MoAF, 2020). The most cultivated fish species in these plants are bass, trout and bream (TURKSTAT, 2021a). About 80% of the total production of the last 10 years was obtained from seas (Figure 1). Despite the fish consumption being deficient in Türkiye, the production occurred as 785.811 tonnes in 2020, where 364.400 tonnes of the total production were from capture fisheries and 421.411 tonnes were from aquaculture production, corresponding to 46% and 54% of total production, respectively (TURKSTAT, 2021a). These data imply that in recent years, growth in the capture fishing industry has slowed down and there has been a significant increase in the level of aquaculture production.

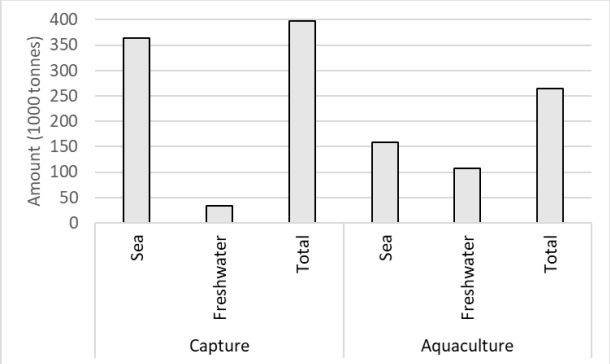

Figure 1. Fisheries and aquaculture production in Türkiye (2010-2020 average)

The fisheries and aquaculture sectors are highly vulnerable to climate change as investigated by researchers (Kainge el al., 2020; Sowman, 2020). Being located at the waterfront, fishing and fish farming communities are exposed to climate related extreme events and natural hazards, such as hurricanes, cyclones, sea level rise, ocean acidification, floods and coastal erosion (FAO, 2018). These negative impacts are not only affecting people who make their livelihood from this sector but also leading to global food insecurity. Türkiye has exported an average of 163.000 tons of aquaculture products to 80 countries worldwide from 2015 to 2019 (Figure 2). The Netherlands and Italy are the top two importing countries with an average rate of 13% (MoAF, 2020).

Climate change affects the aquaculture sector in different ways according to different countries or regions. A study on the impact of climate change on aquaculture in India reveals that the farmers in Sundarban region feels the negative impacts on the sector mainly because of the increasing frequency of cyclones and extreme weather events (Dubey et al., 2017). Similarly, another study, which investigated the possible impact of climate change on aquaculture in Indonesia shows that high density of rainfall causes decreasing water temperature and oxygen depletion that result in fish deaths (Sugama and Radiarta, 2012). There is also a case study which investigates the Mekong Delta in Vietnam. The study uncovers that climate change causes water level rise and saltwater intrusion, which creates a risk for the striped catfish production that makes huge contribution to the economy of Mekong Delta (Anh, 2014).

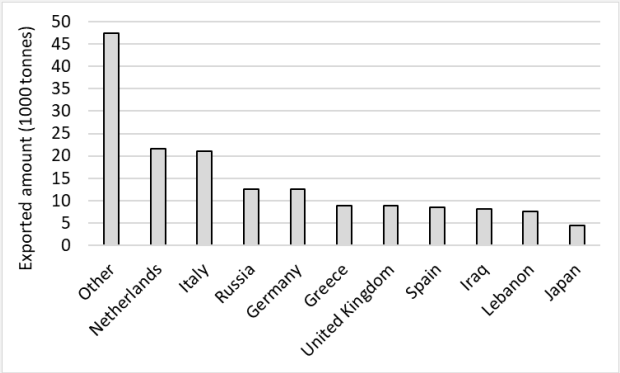

Figure 2. Aquaculture export of Türkiye (2015-2019 average) (MoAF, 2020)

Revealing the associated risks on different culture systems is important so that adaptation and resilience actions can be designed. For this, a framework was developed for assessing climate risk to aquaculture in Oman, where the overall climate risk was quantified as the combination of four risks: (1) species' temperature sensitivity, (2) flooding and storm surge exposure, (3) low-oxygen hazard and (4) disease vulnerability (Engelhard et al., 2022). They demonstrated that the framework was equally applicable at the regional, national or sub-national scale to support design of targeted resilience building actions and enhance food security.

Fisheries and aquaculture make a significant contribution to the economy of relevant countries, including Türkiye. The revenue generated by the export of fisheries and aquaculture products was about 1 billion dollars in 2020 (TURKSTAT, 2021b). The data discloses evidently that any factor that may adversely impact sustainable production will significantly harm the producers, the national economy as well as the food security of importing countries. The government has already prepared relevant adaptation strategies (MoAF, 2022). Awareness, participation and readiness of producers is vital within the context of climate change adaptation.

To contribute to the national and international strategies for adapting to climate change and in turn help sustainable production and exportation of aquaculture products, this study aims to assess the climate change awareness of freshwater aquaculture producers and associated potential risks in

Türkiye. To reach this aim, a survey was conducted with 257 production plants out of 1440 active plants from 25 river basins. Almost half of the surveyed plants were fed from rivers. The data obtained in the study was evaluated to identify river basins with high vulnerabilities. In addition, the dimensions of the threats and difficulties faced by the aquaculture sector have been revealed.

MATERIALS AND METHODS

Strategy of selecting freshwater aquaculture plants for the survey

The contact information of the freshwater aquaculture production plants was provided from the Republic of Turkey Ministry of Agriculture and Forestry (MoAF). Then, a province-based list of the plants was created based on the classification of the information in terms of the plant capacity, location, associated water resource and production model. It was aimed to sample the plants from each river basin, for which the hydrological layer of the MoAF Flood Management Information System was used. The survey was conducted in 2019. The following points were considered for plant selection:

- Different water resources such as rivers and lakes were represented.
- The distribution of plant capacities was represented; the survey covered small capacity plants to a high extent.
- The plants that use ponds on land (fed from the rivers mostly) and net cages in water bodies (reservoirs and lakes) were considered.
- The survey did not cover aquaculture production in closed loop systems and those fed by the treated drinking water (supplied by the municipality).
- In case there was a large number of plants on the same water supply, the number of plants surveyed was kept limited to avoid their impact on the results.
- For the basins whose water resources are used by different provinces or districts, it was aimed to represent producers with different economic and social conditions.

The inactive plants were eliminated and 257 active freshwater aquaculture production plants, corresponding to 18% of 1440 plants, were contacted. The number of plants to be covered by the survey was aimed to represent at least 10% of the total number of plants in each basin. As seen, the percentage of coverage varies between 11% to 100% (Table 1). The distribution of plants with respect to river basins is depicted in Figure 3.

The types of water resources used for fish production are given in Figure 4. As seen, 119 out of 257 plants use river waters (46%), followed by 61 plants fed by reservoirs (24%) and 53 plants fed by springs (20.6%). The number of plants engaged in production with water from lakes is relatively small, i.e., 23 (9%). In addition, there is only one plant that uses groundwater resource (0.4%). Considering all the plants surveyed in river basins and all types of water resources, the share of use are 11-88% for rivers, 5-56% for reservoirs, 10-100% for springs, 11-75% for lakes and 10% for groundwaters, respectively.

Table 1. Number and ratio of plants surveyed

River Basin	Number of plants surveyed	Total number of plants	Ratio (%)
01. Meriç-Ergene	10	28	36
02. Marmara	2	2	100
03. Susurluk	9	18	50
04. Northern Aegean	4	8	50
05. Gediz	6	15	40
06. Küçük Menderes	1	2	50
07. Büyük Menderes	10	43	23
08. Western Mediterranean	21	191	11
09. Antalya	26	133	20
10. Burdur	4	18	22
11. Akarçay	2	3	67
12. Sakarya	13	54	24
13. Western Black Sea	9	57	16
14. Yeşilırmak	13	82	16
15. Kızılırmak	6	50	12
16. Konya Closed Basin	3	10	30
17. Eastern Mediterranean	9	53	17
18. Seyhan	8	34	24
19. Asi	1	3	33
20. Ceyhan	7	45	16
21. Euphrates-Tigris	50	381	13
22. Eastern Black Sea	28	131	21
23. Çoruh	7	49	14
24. Aras	5	7	71
25. Van Lake	3	23	13
TOTAL	**257**	**1440**	**18**

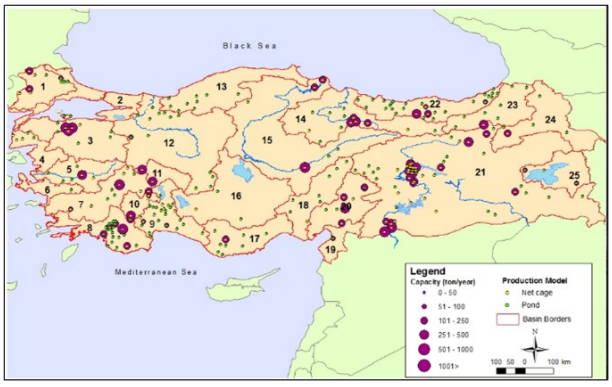

Figure 3. The distribution of plants participated in the survey with respect to river basins

Among the ones surveyed, the highest number of plants using river waters is 21 and they are in Eastern Black Sea Basin. On the other hand, the highest number of plants using reservoir waters is 28 and they are in Euphrates-Tigris Basin. This is quite expected because Eastern Black Sea Basin gets the highest precipitation compared to the country average, so the river flows are adequate for aquaculture production. On the contrary, Euphrates-Tigris Basin gets lower precipitation compared to the country average, and therefore storage of water in reservoirs becomes essential for sustainable production.

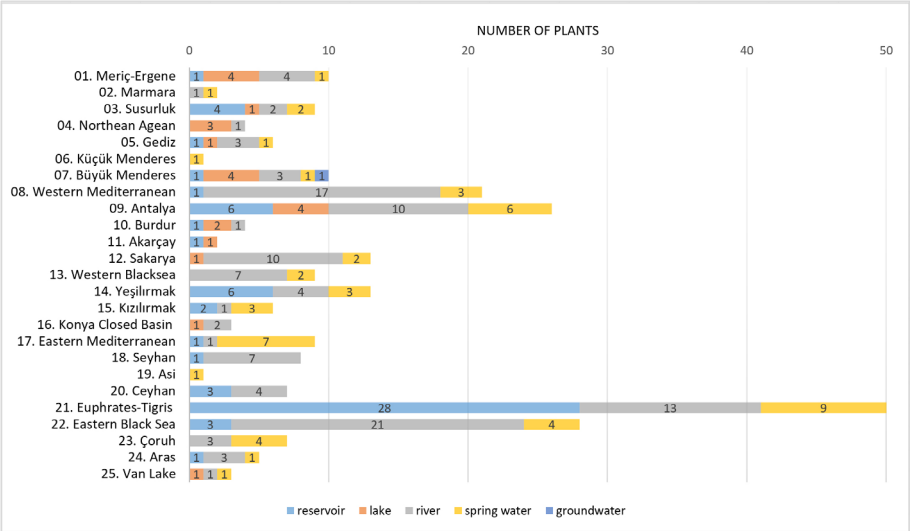

Figure 4. Types of water resources used for fish production

In this study, the production model of surveyed plants is either net cage for production in water source or ponds for inland production. Figure 5 depicts the distribution of production models; 33% of the plants were using net cages, 66% of plants were using ponds and 1% of plants were using both. As seen from Figure 6, the number of surveyed plants using ponds was highest in Antalya, Western Mediterranean, Eastern Black Sea and Euphrates-Tigris River basins.

Among the plants surveyed, 199 had small capacity of 0-50 tons/year, corresponding to 76%, followed by 10% of plants having a capacity of 101-250 tons/year. Only eight plants had a high capacity of 500-1000 tons/year, corresponding to 3% (Figure 7). These ratios well represented the situation in the country.

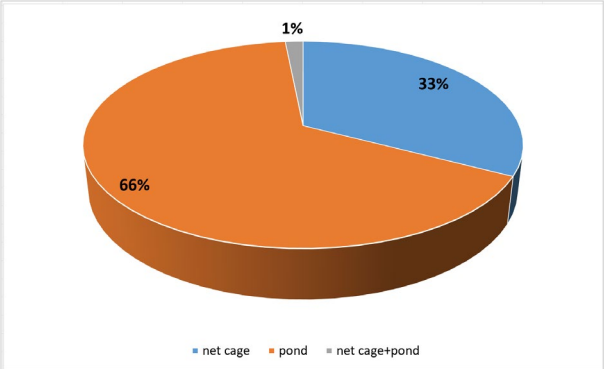

Figure 5. Share of production models

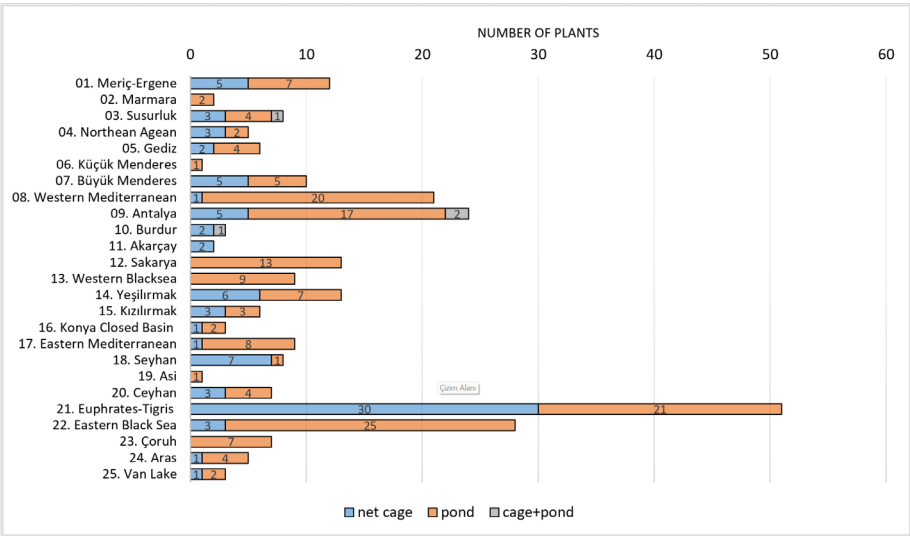

Figure 6. Distribution of production models among the river basins

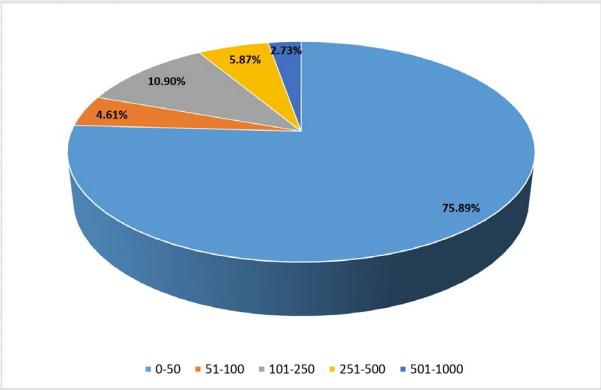

Figure 7. Capacity of plants surveyed (tons/year)

Content of the survey

The survey included one open-ended, three multiple responses and six multiple-choice questions (Table 2). The interviews were conducted by phone call and questions were answered by plant owners or authorized engineers. The results were evaluated on a basin basis.

Table 1. Survey questions

No	Question
1	Do you think that climate change affects the water resource that you use? If so, what is the severity of the impact? 1. No effect 2. Little effect 3. Some effect 4. Severe effect 5. No idea
2	In which of the following do you observe the impacts of climate change the most? 1. Production period and harvest 2. Water quality/quantity 3. Fish health 4. Reproduction performance 5. No idea
3	Have you experienced extreme weather events in the last five years? If so, which ones? 1. Storms 2. Drought 3. Flood 4. Frost 5. Others
4	Have you had any financial loss related to extreme weather events? Can you give a range for your approximate loss? 1. € 0-600 2. € 600-3500 3. € 3.500-6.500 4. € 6.500-30.000 5. € 30.000 and more
5	Do you have agricultural insurance? Yes/No
6	Do you have any problems with other sectors sharing water? Yes/No
7	Are you concerned with possible future problems on water allocation in the basin you are located? Yes/No
8	How would you be affected by a possible temperature increase of 1°C in the water supply? 1. Positive 2. Negative 3. No effect
9	Which of the following are the factors that you consider as a risk for the sustainability of your business? 1. Fish feed 2. Share of water 3. Climate change 4. Economy 5. Others
10	What is the most important problem that you think the freshwater aquaculture sector will face in the future?

RESULTS

Perceptions on the impacts of climate change on water resources and fish production stages

The respondents were asked whether the water resources they were using were negatively affected by climate change (Figure 8). The analysis of the answers on the basin level is shown in Figure 9.

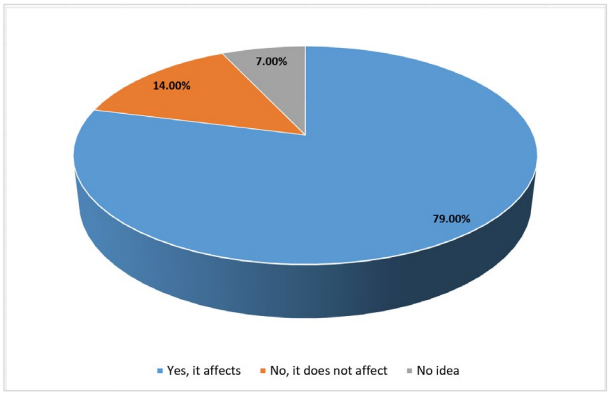

Figure 8. Producers' perception of climate change impacts on water resources

To figure out the fish production stages which were mostly affected by the climate change, the second question was directed to the respondents. They were allowed to give multiple answers (Figure 10).

Extreme weather events

The producers were asked which extreme weather events they have faced in the last five years (Figure 11). The occurrence of extreme weather events in each river basin is given in Figure 12.

Financial losses and agriculture insurance

The range of financial losses of the plants surveyed in this study are given in Figure 13 and their distribution with respect to the river basins is given in Figure 14.

Water sharing problems

The distribution of responses on water sharing problems with respect to river basins is given in Figure 15.

Impact of temperature increase

The distribution of producers' perceptions on 1°C temperature increase is shown in Figure 16 for all river basins.

Future risks

The future risks were asked to the respondents, and the results are given in Figure 17 and Figure 18. The distribution of possible risks is given in Figure 19.

The summary of all the responses is listed in Table 3.

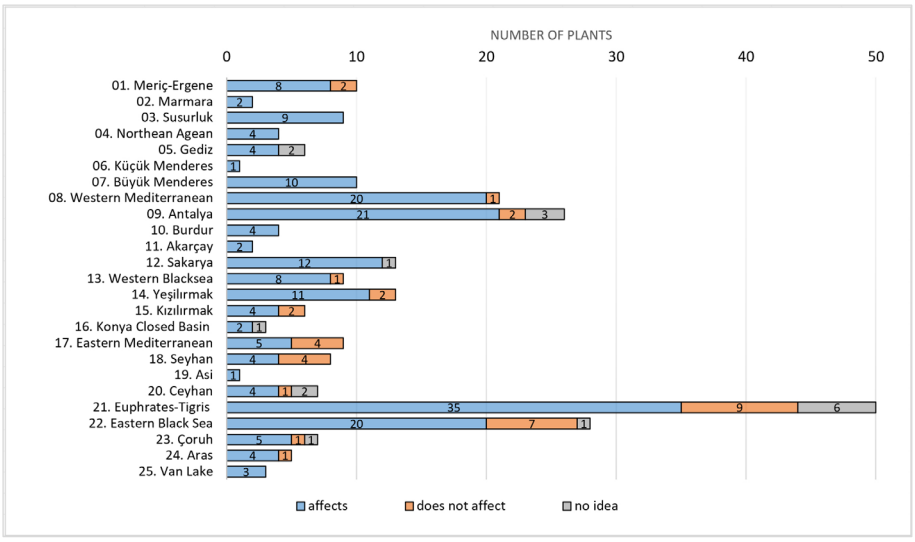

Figure 9. Replies for awareness on climate change impacts with respect to river basins

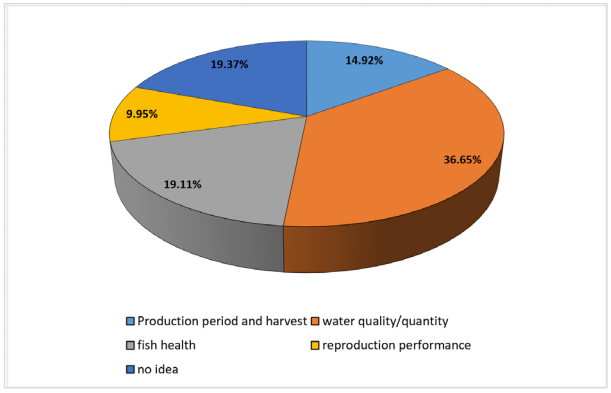

Figure 10. Impacts of climate change on fish production stages

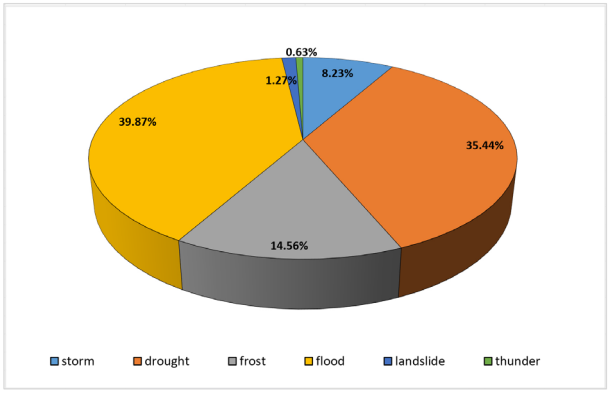

Figure 11. Extreme weather events that plants had faced in the last 5 years

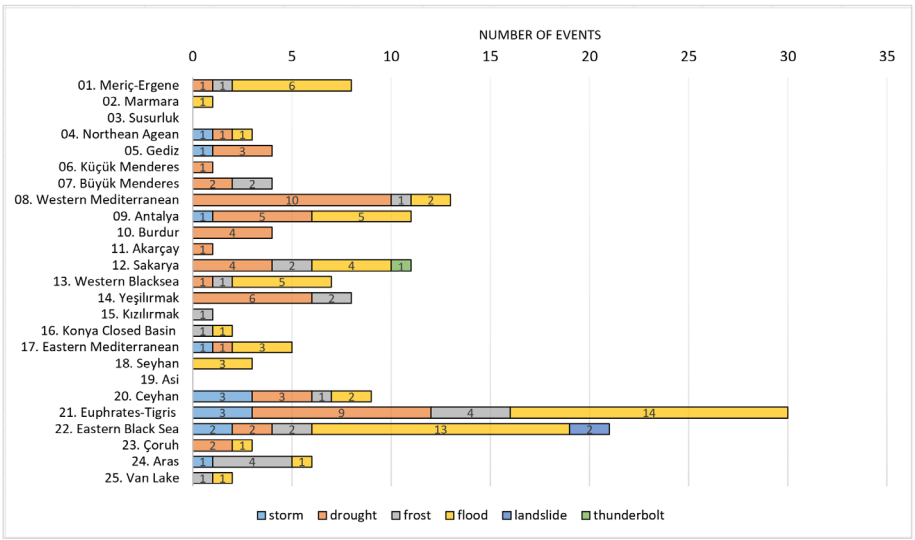

Figure 12. Occurrence of extreme weather events in river basins

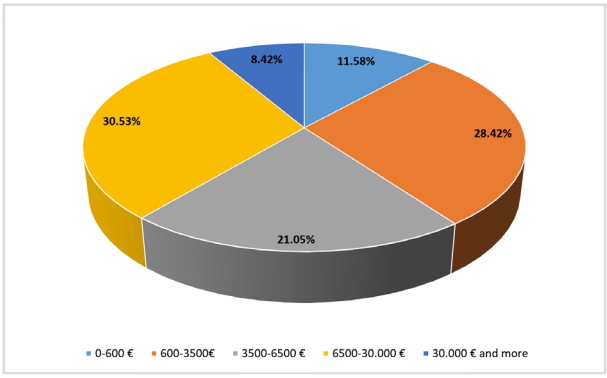

Figure 13. Financial losses of the plants

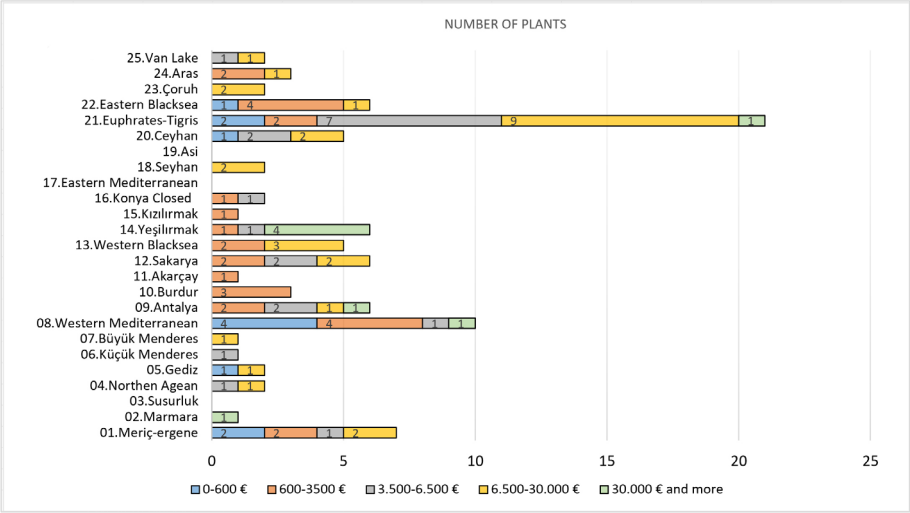

Figure 14. Distribution of financial losses among river basins

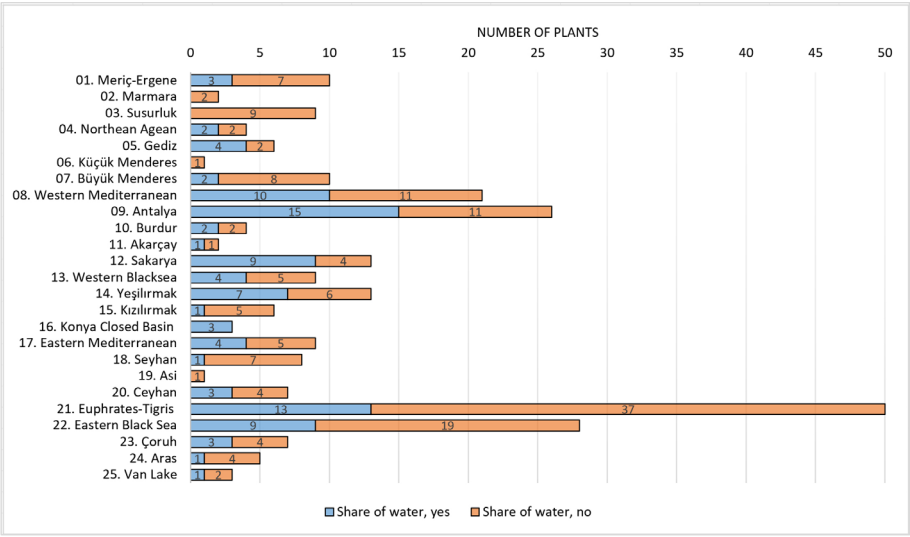

Figure 15. Distribution of responses on water sharing problems in river basins

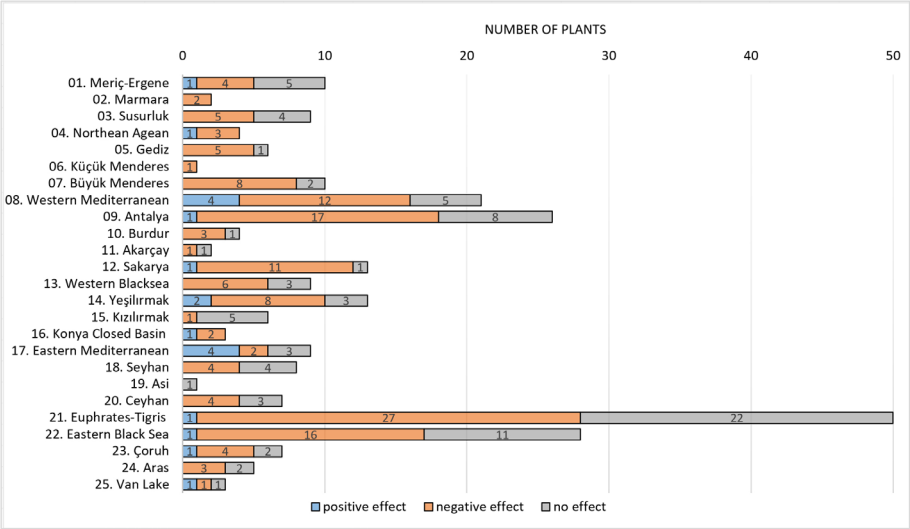

Figure 16. Distribution of producers' perceptions on 1°C temperature increase

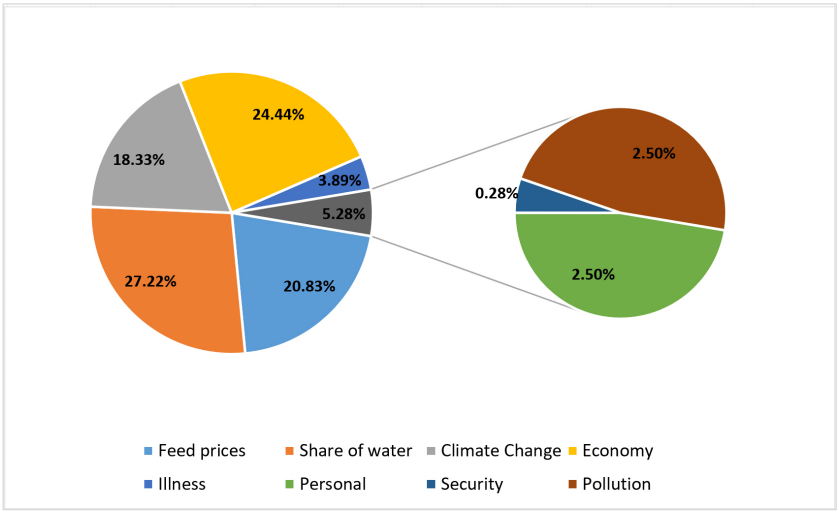

Figure 17. Possible future risks for the aquaculture sector

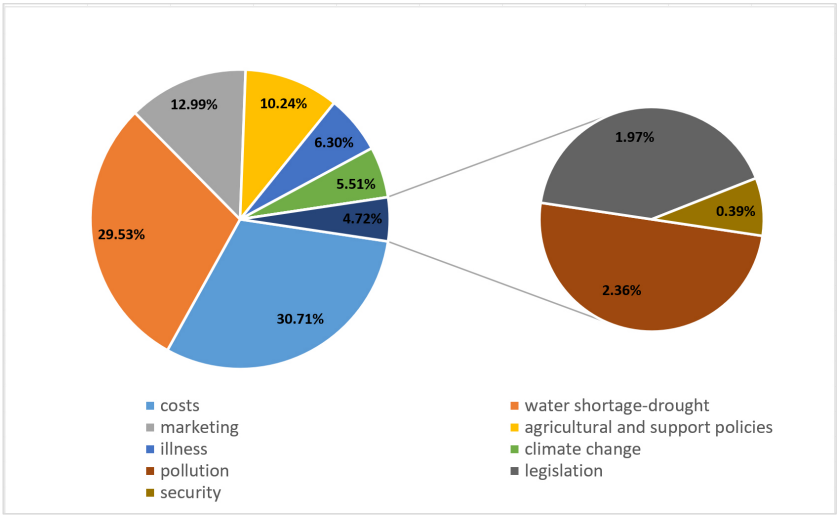

Figure 18. Future problems of aquaculture sector

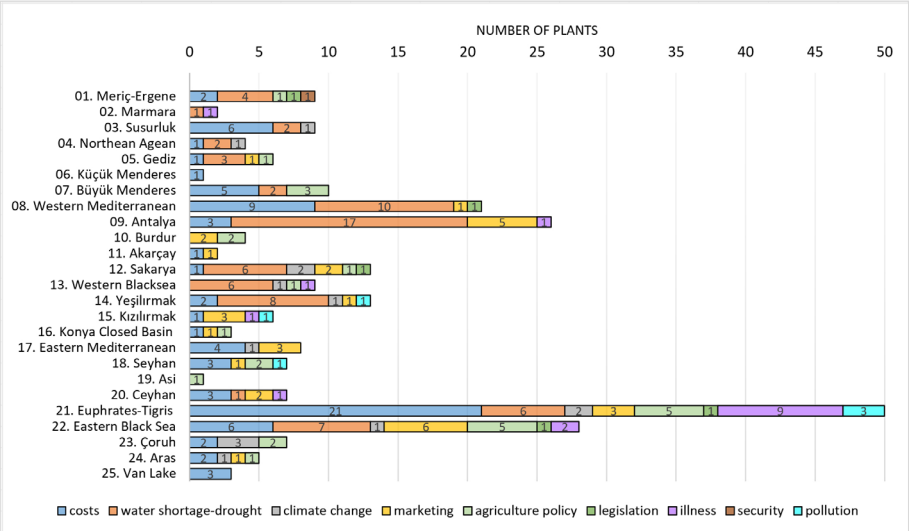

Figure 19. Distribution of future problems among river basins

Table 3. Summary of all the responses

Question	Result	Response	Most affected river basin
Climate change awareness	High	79%	All basins
Impact of climate change on production stages	Water quality/quantity Fish health	37% 19%	All basins
Extreme weather events	Floods Drought	40% 35%	Floods; Eastern Black Sea, Western Black Sea, Meriç-Ergene
Financial losses	€6500 - €30.000 €600 - €3500	31% 28%	Yeşilırmak, Euphrates-Tigris
Agricultural insurance	Low	11%	Euphrates-Tigris
Problem of water sharing	There is conflict	38%	Konya, Euphrates-Tigris and Antalya
Future concern on water allocation	High	> 70%	Sakarya and Konya
Temperature increase	Negative impact expected	58%	Western Mediterranean, Antalya, Euphrates-Tigris and Eastern Black Sea
Possible future risks and problems	Costs Water shortage/drought	31% 30%	Costs; Çoruh, Küçük Menderes and Susurluk Water shortage/drought; Western Black Sea,

DISCUSSION

Perceptions on the impacts of climate change on water resources and fish production stages

As evidenced from the survey study, 79% of the respondents said that the water resources they were using were negatively affected by climate change (Figure 8). These data imply that aquaculture producers are aware of the climate change and its impacts on water resources. This is quite expected since recent studies point to the fact that Türkiye, being in the Mediterranean Basin, is predicted to be severely affected by the adverse effects of global climate change, particularly in terms of water resources (Aktaş, 2014; ClimaHydro Project - MoAF, 2016a). According to ClimaHydro projections, temperature increase of at least 1-2,5C° is expected in Türkiye. Annual precipitation rates are expected to decrease except Black Sea Basin. All projection periods predict a serious water deficit in Euphrates-Tigris and Konya Closed Basin while excess water is predicted in Eastern Black Sea and Çoruh Basins (MoAF, 2016a).

The analysis of the answers on the basin level shows that 50-100% of the plants in all river basins realize the climate change impacts on water resources; where 100% reply belongs to the producers from Northern Agean, Susurluk, Burdur, Marmara, Büyük Menderes, Küçük Menderes, Akarçay, Van Lake and Asi basins (Figure 9). The ratio of respondents who said that climate change had no effect on their water resources was as high as 44-50% in Eastern Mediterranean and Seyhan basins. The corresponding number of plants in this category was 4 out of 9 and 8, respectively. The numbers were even higher in Euphrates-Tigris and Eastern Black Sea basins, i.e., 9 out of 50 plants and 7 out of 28 plants, respectively, had the idea that no impact of climate change was observed. However, most respondents in these

basins also agreed with the impact of climate change on water resources.

Regarding the evaluation of water resources with respect to the level of impact; 40% of the respondents indicated that they were moderately affected while 37% said that they were strongly affected. The remaining stated that there was little effect. By the analysis of the answers on river basin level, Burdur is the only river basin that all respondents indicated that the water resources were strongly affected by climate change (Tatma, 2020). The climate change related future projections support this information as it was revealed that water resources of Burdur basin currently cannot meet the water demand and the basin is expected to have the worst scenario in terms of gross water availability in all periods from 2015 to 2100, where 80-90% decrease is expected (Burdur Report - MoAF, 2016b).

As seen from Figure 10, the most preferred answers were water quality/quantity (37%) and fish health (19%) as the production stages mostly affected by climate change in almost all river basins. On the other hand, reproduction period/harvest option was preferred more by producers from Aras, Sakarya, Antalya, Euphrates-Tigris and Western Mediterranean River basins. It is interesting to note that the ratio of those who have no idea was as high as 19%. On the other hand, only 7% of respondents had no idea about the impact of climate change on water resources. This difference may imply that some producers are aware of water-related problems but not aware of the production problems in their plants. On the other hand, it is also known that some producers having water related problems have been trying to find different water resources and make changes in their production plans. These efforts seem to lessen the possible negative effects on production stages.

Extreme weather events

According to recent research, the severity and number of extreme climatic and meteorological events such as storms, heavy rains, floods, tornadoes, heat waves and forest fires are expected to increase in Türkiye in relation to the climate change (Demircan et al., 2017). In the current state, 54% of the respondents in this study stated that they had faced extreme weather events in the last five years (Tatma, 2020).

The producers were mostly exposed to floods (40%) and drought (35%) (Figure 11), which may indicate evidence of a change in precipitation patterns. Frost, by 15%, is the third most observed extreme event. The respondents also indicated that there had been an increase in the number of days without rain and extreme precipitation rates after severe drought and this situation resulted in floods, especially for the last three years. Some of the respondents claimed that another reason for the floods was the structures which prevent rainwater from reaching rivers and watersheds. In addition, producers in Eastern Black Sea River basin stated that the construction of dams reduced floods by regulating flow regimes.

The number of extreme weather events was reported to be between 15-30 in Euphrates-Tigris and Eastern Black Sea River basins, with a majority of floods. This was followed by 10-15 extreme weather events in Western Mediterranean, Antalya and Sakarya river basins, with a majority of drought. This outcome is supported by the findings of ClimaHydro project, where Western Mediterranean is among the basins that is expected to have the highest decrease of precipitation (25-30%) in the period of 2071-2100 (MoAF, 2016a). The survey results show that the occurrence of frost was highest in Aras and Euphrates-Tigris River basins (Figure 12). Floods were also observed in Meriç-Ergene, Antalya and Western Mediterranean basins. All these information need to be handled carefully since extreme weather events due to climate change might severely harm the sector in Türkiye.

Financial losses and agriculture insurance

The plants' authorized staff were asked whether they had any financial loss in the last five years due to extreme weather events and 95 out of 257 plants (37% of the respondents) replied positively. The amount of losses was grouped into five ranges (Figure 13). It was noticed that the producers did not consider the decreased production capacity (due to drought) as a financial loss. This means their financial losses are very likely to be higher than the reported values. As seen from Figure 13, 8% of the plants had the highest loss of €30.000 or more, whereas 31% of them had losses between €6500-30.000, followed by 21% of plants with losses of €3500-6500 and 28% of them with losses of €600-3500.

The interviews showed that most of the financial losses were caused by floods and drought. By its nature, production plants are located nearby water resources, and they are exposed to danger of floods. Overflow of the production pools results in both fish stocks to escape to the natural environment and turbidity problem. Floodwater causes blockage of fish gills and fish deaths. It can lead to a complete loss of the production season and significant financial losses. The financial losses are high in Yeşilırmak and Euphrates-Tigris River basins (Figure 14). The financial losses were mostly due to droughts and floods (Figure 12). The total financial loss of all affected plants was estimated as €950.000. This is equivalent to the income that can be earned from almost 300 tons of trout, given that one kg of trout costs approximately €3. This amount of fish can be produced in six small sized plants (0-50 tons/year).

Although the sensitivity of the aquaculture sector to extreme weather events and natural disasters was shown explicitly by the survey, it has been observed that the number of plants which had agricultural insurance is very low, i.e., only 28 out of 257 (11%).

Some of the respondents stated that they had tried but failed to meet the requested conditions for insurance. Some of them who had insurance indicated that they had to use a loan to complete the process for agricultural insurance. In addition, a large part of the plants which had insurance were the ones that had large production capacities and using reservoirs as the water resource. The plants located in/nearby rivers stated that

the required conditions for insurance were too hard and it was not possible for them to fulfill.

Kızılırmak river basin, with a number of 5 insured plants out of 6, had the highest level of agriculture insurance. On the other hand, Euphrates-Tigris River basin, having intense aquaculture production at high-capacity plants shows the least number of insured plants, that is 3 out of 50. Insurance seems to be an option for producers in talking the climate related risks, however it is not valid for most plants due to financial issues.

Water sharing problems

Türkiye is a water-stressed country with a water potential of around 1300 m3/cap/year and 77% of water resources are used for agricultural production. Therefore, fair water allocation for all sectors at river basin scale is of utmost importance. According to the Regulation on Water Allocation (Official Gazette of the Republic of Turkey, 2019), sectors are ranked with respect to their priority. The first two are human consumption and environmental flow requirement. Irrigation and aquaculture production are in the third row, followed by energy and industry sectors. However, in some basins problems may occur in allocating water according to the priority rank as sectors compete for the same water resource. Water is generally not used efficiently in agriculture as modern irrigation techniques cannot be applied widely yet.

In relation to this issue, the respondents were asked if they were having any conflicts about the share of water resources with other sectors. A total of 159 respondents (62%) answered that they had not had any conflicts and 98 of them (38%) answered that they had conflicts. They also stated that they mostly had conflicts with irrigation unions, municipalities and the people in the region. Besides, the producers had conflicts with the energy sector. Water shortage and controlled release of water during and after the construction of hydroelectric power stations aggrieve the producers and they are forced to reduce their capacity to overcome this problem, which in turn causes economic losses.

All producers in Konya closed basin stated that they had problems while all producers from Marmara, Susurluk and Asi River basins indicated that they had not had any conflict about sharing water resources (Figure 15).

Although 62% of the plants did not report any problem on share of water, 54% of the respondents had concerns about possible problems in the future on water allocation. They had primarily cited drought periods as the reason for their concern. The producers also had concerns about the water allocation priority of other sectors such as drinking water, agriculture, energy and industry. This issue is a good example to recall the work of Zeitoun (2011) on the web of water security, where it is mentioned that water security for some rests on the water insecurity of others.

The analysis of the answers on the basin level demonstrates that there is a concern about water allocation in 23 out of 25 river basins, excluding Marmara and Asi. The concerns were high; 70-77% in Çoruh, Yeşilırmak, Sakarya, Western Mediterranean and Meriç-Ergene river basins, and as high as 85% and 100% in Sakarya and Konya closed river basins, respectively. Although the rate of concerned plants was 34% for Euphrates-Tigris basin, it is among the three basins that are projected to have water deficiency in 2071-2100 period, followed by Eastern Mediterranean and Konya Closed basins (MoAF, 2016a, b). These results clearly imply that reduced water availability in the future due to pressures such as population growth and climate change will most probably lead to serious risks for the aquaculture sector.

Impact of temperature increase

Water temperature has a great influence on the initiation and course of several fish diseases. The immune system of most fish species has an optimum performance at water temperatures of about 15°C (Svobodová et al., 1993). While warm climate species naturally grow better between 20ºC and 28ºC, their ability to live decelerates as they approach 0ºC. Cold climate species show better development at water temperatures below 20°C, and when the temperature rise above 25°C, they can die (Dikel, 2009).

There are a number of studies investigating the impacts of climate change on cold-water fish. Williams et al. (2015) investigates the existing and future impacts of climate change on salmonids in North America. Native salmonids in western North America are facing mounting stressors because of climate change and the resulting warmer streams, higher variability in precipitation, and reduced snowpack (Westerling et al., 2006). Similarly, a study evaluating the impacts of climate change on brown trout in Central Europe shows an increase of temperature-related risk for proliferative kidney disease and a decrease of suitable thermal habitat for brown trout (Borgwardt et al., 2020).

The optimum temperature for the growth of *oncorhynchus mykiss* is 16.5°C and maximum temperature for taking the feed is 19.5°C. Regarding the temperature tolerance, it can be said that the critical lower limit is 5°C, the optimum temperature is 10-16°C and the critical upper limit is 20-22°C. Besides its impact on fish growth and death, global warming may impose severe risks for aquatic animal health if increasing water temperature leads to an increase in the incidence of parasitic diseases (Karvonen et al., 2010).

According to the ClimaHydro project, at least 1°C temperature rise is expected for all river basins in Türkiye after the year 2050, which is projected to be even higher; 2-6°C in 2091-2100 period (MoAF, 2016a). The survey shows that 1°C temperature increase in water supply would negatively affect the aquaculture production plants. Among all the respondents, 58% of them thought that they would be negatively affected by a possible temperature increase of 1°C while 34% of them said they would not be affected. On the other hand, 8% of them mentioned that they would be positively affected. Regarding the responses with respect to river basins, it was seen that plants in Western Mediterranean, Antalya, Büyük Menderes,

Küçük Menderes, Gediz, Sakarya, Yeşilırmak, Euphrates-Tigris and Eastern Black Sea River basins mentioned they had low tolerance to temperature increase (Figure 16).

Considering the importance of trout production in Turkish aquaculture sector, it is inevitable that a possible temperature increase will negatively affect the producers because of the thermal tolerance of trout and increased costs for the aquaculture production sector. Because in such a case, the temperature in the ponds might need to be reduced by providing cooling. Furthermore, oxygen deficiency might need to be compensated by providing oxygen to the ponds to maintain optimum growth conditions. These practices would increase the costs of fish production, which in turn would increase the fish prices on the market.

Future risks

As the study aims to assess the possible future risks, the respondents were asked which factor(s) they considered as risk(s) to their businesses for the future (multiple answers allowed). The most preferred answer was the share of water with a rate of 27%, followed by the economy with a rate of 24% and feed prices with a rate of 21%. Climate change was in the fourth raw among the expected risks (Figure 17).

Considering the basin-based assessment of operating risks, producers in Antalya, Gediz, Küçük Menderes and the Western Black Sea basins consider the share of water as a risk in the future, while the risk for producers in the Akarcay, Van Lake and Küçük Menderes basins is the climate change and that for producers in Asi and Burdur basins is the economy.

In the last question, the participants were asked "What is the most important problem that you think the freshwater aquaculture sector would face in the future?" Although the question was open-ended, the answers were very similar. For that reason, the answers were grouped after the survey was completed.

According to the respondents, the major problems that the producers expect are the high production costs (31%) and water shortage-drought (30%) (Figure 18). Since feed prices are high, it also affects the production costs. As seen, climate change is ranked as 6th in the list of nine problems asked to the producers. Indeed, the second most voted problem, that is water shortage-drought is also related to climate change. The data shows that most of the producers don't expect marketing, legislative issues and illness as high risks.

Producers in Western Black Sea, Antalya and Yeşilırmak river basins were mostly concerned about water shortage and drought while the producers in Çoruh, Küçük Menderes and Susurluk river basins were mostly concerned about costs (Figure 19).

As given in Table 3, climate change awareness is high in the sector. The major impact of climate change on production stages is mentioned as water quality and quantity. The front runner extreme weather events are floods and droughts. The highest financial losses belong to Yeşilırmak and Euphrates-Tigris River basins, where the agricultural insurance is also low. The conflict of water sharing was pronounced in Konya, Euphrates-Tigris and Antalya River basins. And finally, the future water allocation risks were mentioned highest for Sakarya and Konya River basins.

CONCLUSION

This study has carried out a survey for the freshwater aquaculture producers in Türkiye to assess their level of awareness on climate change and possible risks for their businesses. The results showed that producers have a high awareness on climate change and its impacts on water resources. Producers find production costs and water sharing problems as the most likely future challenges.

From the river basin perspective, producers from all river basins have common views about the impacts of climate change on water resources. In terms of extreme weather events, floods occurred in Eastern Black Sea, Western Black Sea and Meriç-Ergene river basins, droughts in Western Mediterranean and frost in Aras basin. More than half of the attendees have been exposed to extreme weather events in the last five years. Total financial losses of the plant owners as a result of the extreme weather are estimated as €950.000. Although the fact that more than half of the plants have been exposed to extreme weather events, there is only a small number of plants which have insurance. Insurance should be regarded as part of the possible solutions in tackling the risks associated with climate hazards.

The survey shows that most of the plants did not have problems with water allocation in the past. However, 54% of the plant owners have concerns about water allocation problems that may occur in the future.

At least 1.0 – 2.5^{o}C temperature increase in Türkiye is expected in the future. Increasing temperature is also expected to affect fish health and especially trout production which holds an important place in Turkish aquaculture sector. As a result of temperature increase, 30% of the attendees think that water shortage/drought will be a future problem.

The study clearly figures out that aquaculture sector in Türkiye needs immediate action to build capacity for climate resilience. The future of the sector is important for the national economy as well as international trade in relation to food security. Some recommendations and adaptation options are given below:

- There are still few studies in Türkiye on the impact of climate change on aquaculture sector and determining the sectoral vulnerability is the most priority issue.
- It should be determined which impacts climate change will have on the aquaculture sector (water temperatures, drought, floods, heat waves, etc.) and which stage of production is more sensitive to it. Aquaculture production takes place in different types of water sources such as

lakes, streams, dams, and spring water. For this reason, priorities will vary according to the different water resources. Pollution may be a priority for still-waters while drought may be a priority problem for streams.

- The applicability of production systems that will enable more efficient use of water resources in aquaculture should be evaluated such as closed-circuit production.
- The rate of insurance should be increased via legislative and financial instruments.

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AUTHOR CONTRIBUTIONS

Ayşe Tatma has collected data, conducted the survey in 2019 and evaluated the results. Gökşen Çapar has supervised the study (as the master thesis of Ayşe Tatma), evaluated the results, wrote the manuscript.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

ETHICAL APPROVAL

Ethical approval is not required for this study. This study was conducted in 2019. The journal requests an ethical approval document for studies conducted as of 2020.

DATA AVAILABILITY

The corresponding author should be contacted regarding any questions.

REFERENCES

Aktaş, Ö. (2014). Impacts of climate change on water resources in Turkey. *Environmental Engineering and Management Journal, 13*(4), 881-889. https://doi.org/10.30638/eemj.2014.092

Anh, N.L. (2014). *Climate proofing aquaculture: A case study on pangasius farming in the Mekong Delta, Vietnam* (Print ISBN 978-94-6257-221-8) [Doctoral dissertation, Wageningen University]. The Netherlands.

Borgwardt, F., Unfer, G., Auer, S., Waldner, K., El-Matbouli, M., & Bechter, T. (2020). Direct and indirect climate change impacts on brown trout in Central Europe: How thermal regimes reinforce physiological stress and support the emergence of diseases. *Frontier Environmental Science, 8*, Article 59. https://doi.org/10.3389/fenvs.2020.00059

Dikel, S. (2009). Effects of the water temperature on fish production. *Alinteri Journal of Agriculture Science, 16*(B), 42-49. ISSN: 1307-3311.

Demircan, M., Türkoğlu, N., & Çiçek, İ. (2017). Climate change: From model to sectoral applications (in Turkish with English abstract). In A. Ertek, İ. Çiçek, N. Türkoğlu, E. Yılmaz, & M. Süzer (Eds.), *International Congress on the 75th Anniversary of Turkish Geographers Society, November 8-10, 2017* (pp. 572-585). Ankara, Türkiye: Proceedings Book.

Dubey, S.K., Trivedi, R. K., Chand, B.K., Mandal, B., & Rout, S. K. (2017). Farmers' perceptions of climate change, impacts on freshwater aquaculture, and adaptation strategies in climatic change hotspots: A case of the Indian Sundarban delta. *Environmental Development, 21*, 38-51. https://doi.org/10.1016/j.envdev.2016.12.002

Engelhard, G.H., Howes, E.L., Pinnegar, J.K., & Le Quesne, W.J.F. (2022). Assessing the risk of climate change to aquaculture: A national-scale case study for the Sultanate of Oman. *Climate Risk Management, 35*, Article 100416. https://doi.org/10.1016/j.crm.2022.100416

European Council. (2024, October 28). Management of the EU's fish stocks. https://www.consilium.europa.eu/en/policies/eu-fish-stocks/

FAO. (2010). *Report of the joint FAO/WHO expert consultation on the risks and benefits of fish consumption* (FAO Fisheries and Aquaculture Report No. 979). Wold Health Organization, Food and Agriculture Organization of the United Nations. https://www.fao.org/4/ba0136e/ba0136e00.pdf

FAO. (2018). *Impacts of climate change on fisheries and aquaculture: Synthesis of current knowledge, adaptation and mitigation options* (FAO Fisheries and Aquaculture Technical Paper 627). Food and Agriculture Organization of the United Nations. https://openknowledge.fao.org/server/api/core/bitstreams/9aeb8ade-a623-4954-8adf-204daae3b5de/content

FAO. (2020a). *The state of world fisheries and aquaculture 2020: Sustainability in action* (The State of the World series). Rome, Italy. Food and Agriculture Organization of the United Nations. https://openknowledge.fao.org/server/api/core/bitstreams/170b89c1-7946-4f4d-914a-fc56e54769de/content

FAO. (2020b). *FAO Yearbook: Fishery and Aquaculture Statistics 2018*. Food and Agriculture Organization of the United Nations. https://openknowledge.fao.org/server/api/core/bitstreams/f138370c-cd94-4bfb-8767-34b7e952c9d6/content

Hoque, M.Z. (2021). Sustainability indicators for sustainably-farmed fish in Bangladesh. *Sustainable Production and Consumption, 27*, 115-127. https://doi.org/10.1016/j.spc.2020.10.020

IPCC, (2021). *Sixth Assessment Report Working Group I: Climate Change 2021: The Physical Science Basis*. Intergovernmental Panel on Climate Change. https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_FullReport.pdf

Kainge, P., Kirkman, S.P., Estevao, V., van der Lingen, C.D., Uanivi, U., Kathena, J.N., & van der Plas, A. (2020). Fisheries yields, climate change, and ecosystem-based management of the Benguela Current Large Marine Ecosystem. *Environmental Development, 36*, Article 100567. https://doi.org/10.1016/j.envdev.2020.100567

Karvonen, A., Rintamaki, P., Jokela, J., & Valtonen, E.T. (2010). Increasing water temperature and disease risks in aquatic systems: Climate change increases the risk of some, but not all, diseases. *International Journal for Parasitology, 40(13)*, 1483-1488. https://doi.org/10.1016/j.ijpara.2010.04.015

NASA. (2024, October 28). Climate change: How do we know? https://climate.nasa.gov/evidence/

OECD. (2022). Aquaculture production [Data]. https://data.oecd.org/fish/aquaculture-production.htm#indicator-chart

Official Gazette of the Republic of Türkiye. (2019, December 10). Regulation on Water Allocation. Issue 30974. https://www.tarimorman.gov.tr/SYGM/Belgeler/D%C4%B0%C4%9EER%2002.01.2024/Su%20Tahsisleri%20Hakk%C4%B1nda%20Y%C3%B6netmelik.pdf

MoAF. (2016a). *The Impacts of Climate Change on Water Resources (ClimaHydro) Project*. The Ministry of Agriculture and Forestry. General Directorate of Water Management. https://www.tarimorman.gov.tr/SYGM/Belgeler/H%C4%B0E-Ta%C5%9Fk%C4%B1n-Son/%C4%B0klim%20De%C4%9Fi%C5%9Fikli%C4%9Finin%20Su%20Kaynaklar%C4%B1na%20Etkisi%20SYGM.pdf

MoAF. (2016b). Burdur River Basin Water Allocation Plan. The Ministry of Agriculture and Forestry. General Directorate of Water Management. https://www.tarimorman.gov.tr/SYGM/Belgeler/burdur%20nhyp%20nihai%20rapor/BUN_NHYP%20Nihai%20Raporu.pdf

MoAF. (2020). *Production Report: Aquaculture*. The Ministry of Agriculture and Forestry, Institute of Agricultural Economics and Policy Development (TEPGE). https://arastirma.tarimorman.gov.tr/tepge/Belgeler/Yay%C4%B1n%20Ar%C5%9Fivi/2017-2022%20Yay%C4%B1n%20Ar%C5%9Fivi/Yay%C4%B1nno317.pdf

MoAF. (2021). *Fisheries and Aquaculture Statistics*. The Ministry of Agriculture and Forestry. https://www.tarimorman.gov.tr/BSGM/Belgeler/Icerikler/Su%20%C3%9Cr%C3%BCnleri%20Veri%20ve%20D%C3%B6k%C3%BCmanlar%C4%B1/Su-Urunleri-%C4%B0statistikleri-temmuz-2021-1.pdf

MoAF. (2022). *Climate change and agriculture workshops declaration of results*. The Ministry of Agriculture and Forestry, General Directorate of Agricultural Reform. https://www.tarimorman.gov.tr/TRGM/Belgeler/IKLIM%20DEGISIKLIGI%20VE%20TARIM%20DEGERLENDIRME%20RAPORU.pdf

Sowman, M. (2020). Participatory and rapid vulnerability assessments to support adaptation planning in small-scale fishing communities of the Benguela Current Large Marine Ecosystem. *Environmental Development, 36*, Article 100578. https://doi.org/10.1016/j.envdev.2020.100578

Sugama, K., & Radiarta, N. (2012). Brief study on possible impact of climate change on aquaculture in Indonesia. In *APEC Seminar on Sharing the Experiences of Mitigating the Impact of Extreme Climate on Aquaculture and Fisheries, 21-23 March 2012* (pp. 120-126). Chinese Taipei, Taiwan: Proceedings Book. https://www.researchgate.net/publication/275833186

Svobodová, Z., Lloyd, R., Máchová, J., & Vykusová, B. (1993). *Water quality and fish health* (EIFAC Technical Paper No. 54). Rome, Italy: FAO.

Tatma, A. (2020). Basin-based investigation of impacts of climate change on inland aquaculture in Turkey [Master's Thesis, Ankara University]. Türkiye.

TURKSTAT. (2021a). Fishery Products, 2020. Turkish Statistical Institute. https://data.tuik.gov.tr/Bulten/Index?p=Su-Urunleri-2020-37252

TURKSTAT. (2021b). Export Statistics. Turkish Statistical Institute. https://biruni.tuik.gov.tr/disticaretapp/menu.zul

Westerling, A.L., Hidalgo, H.G., Cayan, D.R., & Swetnam, T.W. (2006). Warming and earlier spring increase western U.S. forest wildfire activity. *Science, 313*(5789), 940–943. https://doi.org/10.1126/science.1128834

Williams, J.E., Isaak, D.J., Imhof, J., Hendrickson, D.A., & McMillan, J.R. (2015). Cold-water fishes and climate change in North America. *Reference Module in Earth Systems and Environmental Sciences*. https://doi.org/10.1016/B978-0-12-409548-9.09505-1

World Bank. (2013). *Fish to 2030: Prospects for Fisheries and Aquaculture* (Agriculture and Environmental Services Discussion Paper No. 3). Washington D.C. http://documents.worldbank.org/curated/en/458631468152376668/Fish-to-2030-prospects-for-fisheries-and-aquaculture

WWF. (2016). *Fishing for Proteins: How Marine Fisheries Impact Global Food Security up to 2050. A Global Prognosis*. Hamburg, Germany: WWF Germany; International WWF Centre for Marine Conservation. https://www.worldwildlife.org/publications/fishing-for-proteins-how-marine-fisheries-impact-global-food-security-up-to-2050

Zeitoun, M. (2011). The global web of national security. *Global Policy, 2*(3), 286-296. https://doi.org/10.1111/j.1758-5899.2011.00097.x