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Report of the Scientific Committee of the Spanish Agency for Food Safety and Nutrition (AESAN) on the relationship between climate change and food security, and its impact on the nutritional status of the population

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Working group

Araceli Díaz Perales (Coordinator), Isabel Hernando Hernando, Gema Nieto Martínez, Ana María Rivas Velasco and María Roser Vila Casanovas

Technical management of the report AESAN: Paula Arrabal Durán

Abstract

Food security is the way to quantify the degree of access the population has to nutritious and safe food at all times. It depends on several factors, including the availability and affordability of that food. This term should not be confused with food safety, which is understood to be the discipline, process or action that prevents food from containing living organisms (bacteria, viruses and parasites) or chemical substances that could cause harm to the health of consumers.

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Climate change is the climate altering due to anthropogenic activities, which are adversely affecting the global make-up of the atmosphere as well as atmospheric phenomena. There is evidence that in a number of ways, climate change affects the degree of access the population has to nutritious and safe food worldwide. The main risks are: the loss of biodiversity in rural areas; the loss of marine and coastal ecosystems, and thus livelihoods; the loss of terrestrial ecosystems and inland waters, and livelihoods and, finally, the deterioration of food systems.

In relation to the loss of biodiversity in different ecosystems (marine and terrestrial) due to this phenomenon, we have seen a change in the distribution and phenology of both plant and animal species. This means that different species are shifting towards colder latitudes (meridionalization) and towards higher altitudes. It is expected that land degradation and loss of biodiversity will reduce crop yields, as well as the nutrient content of food.

In terms of the repercussions on food sources, the risk of known pests, as well as post-harvest losses, is increasing. The increase in temperatures not only directly affects animals, causing metabolic and immune changes, but also has indirect consequences, since the population of vectors that transmit infectious agents is increasing.

Therefore, climate change can pose a risk to the nutritional status of the population due to the reduction in food availability, access to it, use of it and the stability of the food system.

It is essential to design ways of adapting to climate change to reduce the net impact on food security and nutrition and, in this way, increase resilience to global warming. This represents a paradigm shift towards more resilient, more productive and sustainable agriculture and food systems, with the aim of guaranteeing global food security in the face of climate change.

Key words

Climate change, food security, nutritional status, biodiversity.

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1. Introduction

Food security is the way to quantify the degree of the population's access to nutritious and safe food. It depends on several factors, including the availability and affordability of that food (United Kingdom, 2022). According to the Committee on World Food Security of the United Nations (UN), food security exists when the entire population has physical and economic access at all times to sufficient, safe, and nutritious food which meets their dietary needs for an active and healthy life (FAO, 2006). This term should not be confused with food safety, which is understood to be the discipline, process, or action that prevents food from containing living organisms (bacteria, viruses, and parasites) or chemical substances that could harm consumers' health.

Recently, the One Health approach has been suggested to unify criteria in the adaptation to climate change. These policies can contribute significantly to ensuring food security, emphasising food of animal origin, extensive livestock systems, environmental sanitation, and steps towards integrated regional and global management (Zinsstag et al., 2018).

At the Conference of the Parties on Climate Change held in Dubai in December 2023 (COP28), one of the Sustainable Development Goals (SDGs) was marked as ending hunger, mitigating the vulnerabilities in food production linked to climate change, and protecting water systems. To do this, integrated and multisectoral solutions must be implemented, such as land use management, sustainable agriculture, resilient food systems, ecosystem-based approaches, and equitable access to adequate food and nutrition for all (COP28, 2023).

Climate change consists of climate modification due to anthropogenic activities that adversely affect the global composition of the atmosphere and atmospheric phenomena (United Nations, 1992). This alteration is reflected in the increase in temperatures, the decrease in rainfall, the expansion of the semi-arid climate and exotic invasive species. Its effects on flora and fauna impact food security and, therefore, people's health.

In recent years, more frequent and intense extreme weather events, such as heat waves, droughts, and floods, are being recorded, causing some natural and human systems to be displaced beyond their ability to adapt, causing irreversible damage to food security (availability, access, utilisation, and stability). For example, it is known that if the global temperature increases more than 2 ºC with respect to pre-industrial levels (currently, it has increased 1.1 ºC), the risks of food insecurity would be more severe, leading to malnutrition and micronutrient deficiencies, especially in developing regions of the planet that are highly dependent on the agricultural economy such as sub-Saharan Africa, South Asia, Central America, and South America (IPCC, 2019, 2022).

On the other hand, climate change also threatens the other living organisms on the planet. One-quarter of the evaluated animal and plant species are under threat of extinction (around one million species) (IPBES, 2019). This loss in biodiversity poses a threat to food security. 10 % of domesticated mammals and 3.5 % of domesticated bird breeds have already been declared extinct. The decrease in the genetic variability of species can result in increased vulnerability of agricultural systems to various threats, such as pests and pathogens, as well as climate change itself (IPBES, 2019).

In view of these considerations, the Scientific Committee of the Spanish Agency for Food Safety and Nutrition (AESAN) has been requested to review the currently available scientific evidence on the effects of climate change on food security in terms of availability and biodiversity, as well as its possible impact on access to food and the nutritional status of the population.

2. Current state of food security

Food is a fundamental human requirement, and insufficient food results in malnutrition. Due to the COVID-19 pandemic, the percentage of the world population with malnutrition went from 8.4 % in 2019 to 9.9 % in 2020 (FAO, 2021). And this percentage has not stopped increasing. The Food and Agriculture Organization of the United Nations (FAO) estimates that to meet the growing demand driven by population growth and changes in diet, food production will have to increase by 60 % by 2050 (FAO, 2009). However, increasing production alone is insufficient since enough food is currently produced, but almost 800 million people still suffer from hunger. It is also necessary that everyone has access to them, in the appropriate quantity and quality, all the time.

For this reason, the main risks induced by climate change with direct consequences for food security can be summarised in these four main points (FAO, 2015):

- The loss of livelihoods and income in rural areas.
- The loss of marine and coastal ecosystems and livelihoods.
- The loss of terrestrial ecosystems and inland waters and livelihoods.
- The effects of the deterioration of food systems.

In addition, it should be considered that climate change also has repercussions on trade flows, food markets and price stability, harming food security and human health.

The effects on food security of these risks derived from climate change are detailed below.

3. Loss of livelihoods and income in rural areas

3.1 Plant health

Climate change poses a significant threat to rural communities but also provides opportunities to implement adaptation strategies. By diversifying livelihoods, strengthening disaster resilience, promoting sustainable practices, and conserving natural resources, rural communities can meet the challenges of climate change and build a more sustainable and prosperous future.

According to the United Nations' International Fund for Agricultural Development (IFAD), at least 70 % of the very poor live in rural areas, and most of them depend partly (or entirely) on agriculture for their livelihoods. An estimated 500 million small farms in developing countries support nearly 2 billion people, and in Asia and sub-Saharan Africa, these small farms produce about 80 % of the food consumed (JRC, 2016).

Climate change is having both direct and indirect effects on agricultural production systems. Direct effects are directly caused by modifying physical characteristics, such as the levels and distribution of temperature throughout the year and the availability of water in a specific agricultural production. Indirect effects affect output through changes in other species, such as pollinators, pests, disease vectors, or invasive species.

3.1.1 Direct effects

Vulnerability indicators of the agricultural sector are associated with social and productive variables, such as soil degradation, equity in land distribution, risk levels against extreme events, percentages of water use and irrigation systems, and the degree of agricultural insurance coverage (Frieler et al., 2015).

With regard to soil degradation, the erosion process is particularly important. This phenomenon is largely a product of the expansion of the agricultural frontier as a mechanism to increase production rather than improve productivity through the appropriate use of technologies and ecological considerations (FAO, 2001).

On the other hand, the observed effects of climate trends based on crop production are already evident in several regions of the world (Porter et al., 2014). In tropical and low-latitude regions, negative effects of climate change are expected on the productivity of wheat, rice, and corn crops, on equal conditions with the agricultural areas, management levels and technology, even with low levels of warming (Lobell et al., 2011). For example, the increased frequency of unusually hot nights in most regions of the planet has a detrimental effect on most crops, with observed impacts on rice yield and quality.

The main agricultural producers in temperate zones, such as the European Union in the case of wheat and the United States in the case of corn, can suffer the serious negative effects of climate change due to the lower availability of water during the vegetative period, the greater frequency and intensity of heat episodes, which are more harmful during flowering (Müller and Elliott, 2015), and the acceleration of phenology, which can reduce biomass production. Agroecological projections based on climate change scenarios suggest that grain production potential in the Russian Federation, Ukraine and Kazakhstan could increase due to a combination of increased winter temperatures, extended growing seasons, and the effect of CO_2 fertilisation on agricultural crops. However, the most productive semi-arid area could suffer a drastic increase in the frequency of droughts (Lioubimtseva and Henebry, 2012).

A study of the possible effects of climate change on agriculture in Norway points out that, despite problems such as unstable winters, increased rainfall in autumn and, possibly, more weeds and diseases, a prolongation of the current short growing season, together with higher growing temperatures, can offer new opportunities for agriculture in the region. However, it will require appropriate adaptation strategies, the obtaining of new varieties of plants, changes in the planting calendar and crop rotation, etc. (Uleberg et al., 2014).

3.1.2 Indirect effects

Climate change also favours changes in the distribution and properties of pollinators and other species that contribute essentially to production through the ecosystem services they provide (FAO, 2011). Approximately 80 % of all flowering plant species are pollinated by animals, including vertebrates and mammals, with insects being the main pollinators. Pollinators such as bees, birds, and bats affect 35 % of global crop production. Their presence contributes to increasing the production of 87 of the world's main food crops and medicinal plants. Pollination was estimated to be worth 153 billion dollars worldwide in 2005 (Gallai et al., 2009) and contributes to the yield and quality of at least 70 % of the world's major food crops, especially many nutritionally important fruit and vegetable crops (Klein et al., 2003).

On the other hand, climate change is a determining factor in the appearance of new pests, being a driver of emerging phytosanitary risks (EFSA, 2024). For example, the apple snail poses a threat to the wetlands of southern Europe since extreme weather events and floods (influenced by climate change) increase the natural spread of this pest through rivers and canals (EFSA, 2014) (CABI, 2021). New pests can also arrive due to the climate-related movement of disease-carrying organisms (mainly insects and birds), known as vectors. For example, a 2023 assessment examined the risks posed by viruses transmitted to plants by the silverleaf whitefly (Naveed et al., 2023).

The increased incidence and severity of pest-associated plant disease outbreaks pose significant and increasing risks to primary productivity, global food security, and biodiversity loss in many vulnerable areas of the world. The annual loss of crop yield caused by pathogens (microorganisms that cause diseases and limit the health and productivity of the host) and pests is estimated at 220 billion dollars, which has a direct impact on food security, regional economies, and other related socioeconomic aspects (Kumar et al., 2022). This is compounded by post-harvest losses caused by pathogenic microorganisms such as *Penicillium* spp. and *Xanthomonas euvesicatoria*. It is estimated that any possible increase in production in the next five decades will be offset by altering the pressure of diseases caused by known and emerging pathogens.

Plant species or cultivars that have not co-evolved with the pathogen introduced in the new geographical location are likely to promote pathogen prevalence and disease outbreaks. An example of trade and transport as drivers of the appearance of pathogens is the wilting of bananas, also known as Panama disease, caused by the soil-borne fungus *Fusarium oxysporum* f. sp. *cubense*, which probably originated in Southeast Asia and then spread throughout the world during the twentieth century (EFSA, 2022).

Finally, climatic and ecological changes and modern land management practices, dominated by monocultures and high-density crops, likely facilitated the emergence and adaptation of plant pathogens capable of spreading beyond their normal geographic areas. For example, soybeans and wheat are grown extensively in high-density monocultures, and their yields are compromised by a plethora of pests and pathogens. Soybean rust, caused by the fungus *Phakopsora pachyrhizi*, and wheat spot, caused by the fungus *Zymoseptoria tritici*, are among the most destructive diseases of these crops, and yield losses of more than 50 % have been documented during serious epidemics (Singh et al., 2023).

Despite the complexity of natural ecosystems, climate change and the appearance and evolution of pathogens pose similar challenges for wild plant communities and their productivity. For example, the expansion of the distribution area of *Phytophthora cinnamomi* associated with global warming could have a significant negative impact on indigenous plant communities in many parts of the world. A further increase in the disease burden due to climate change could have devastating consequences for many plant species, food production, and human health (Singh et al., 2023).

3.2 Animal health

In relation to animal health, the direct effects of climate change include diseases and deaths related to temperature variations. The indirect, more complex impacts include the influence of climate on the density and distribution of microorganisms, the spread of vector-borne diseases, food and water shortages, and the increase in food-borne diseases.

Homeothermic animals respond to high temperatures by increasing heat loss and reducing their production to avoid increased body temperature (hyperthermia). This process involves increasing the respiratory rate and sweating, as well as reducing the food intake. These physiological changes contribute significantly to the appearance of metabolic disorders in animals subjected to thermal stress. Specifically, livestock in warm semi-arid environments are usually raised in extensive systems, where their productive potential is affected by their exposure to extreme climatic factors. Climate change is expected to increase animal heat stress, reducing their feed efficiency, growth rates, and reproduction rates, and therefore their production and profitability. In addition to heat, cattle grazing in warm semi-arid areas face seasonal variability in the quantity and quality of available forage and water. Animals also often have to travel long distances in search of these limited resources during the hot summer months. Therefore, grazing animals are potentially exposed to multiple stressors: thermal stress, shortage of forage and water, and physical stress due to mobility in these environments (Sejian et al., 2013). In extensive grazing systems, these stressors usually occur simultaneously rather than in isolation, which makes it essential to study the joint influence of these factors on the adaptive capacity of different species in the context of climate change.

The conservation of indigenous breeds is essential to face the modifications in extensive systems caused by climate change since they provide a rich genetic base that can be adapted to these changes. The presence of livestock species in specific ecological contexts over time, together with historical and social factors, has generated a wide spectrum of indigenous breeds specialised in the use of pastoral resources in our country. These animals, belonging to more than 163 breeds or varieties registered in the Official Catalogue of Breeds of Spain in danger of extinction (MAPAMA, 2016), are the most adapted to their territories and the most efficient in using natural resources. Over the centuries, they have made it possible to establish livestock routines that optimise this use (such as the movement of animals and the organisation of productive cycles), thus modelling agricultural and cultural landscapes and, in many cases, lands of high-natural value.

These native breeds have evolved and endured thanks to their ability to adapt to the different agrosystems of the country and their efficient use of specific pastoral systems. Without a doubt, many of them have the genetic keys for the adaptation of the livestock sector to the climate changes that Spain will face in the coming decades, which makes their conservation essential as a measure of resilience. Deepening the study of their genetic, phenotypic, and productive characteristics and their relationship with the ecological particularities of their territories would contribute to their conservation and adaptation to the new scenarios derived from climate change. In conclusion, it is essential to preserve biodiversity in rural environments and promote species diversification policies to strengthen the resilience of agroecosystems.

Birds, in particular, are the animal group for which we have the most data on the impact of climate change. In the temperate and boreal zones of the northern hemisphere, it is observed that spring is coming earlier, while autumn is delayed. It has been documented that migratory birds generally return earlier to their breeding areas, although there is no clear pattern for autumn migration (Lehikoinen et al., 2004). In Europe, an advance of approximately 2.8 days per decade in spring arrival dates has been estimated since the 1970s (Lehikoinen and Sparks, 2010).

The biological mechanisms underlying these changes in the migratory behaviour of birds are not yet fully understood (Knudsen et al., 2011). The earlier arrival in spring could be due to more favourable weather conditions and earlier food availability, facilitating faster migration across Europe and North America. This phenomenon could illustrate an adaptation by phenotypic plasticity. Alternatively, the changes observed in migratory behaviour could also reflect micro-evolutionary processes, where climate change favours the selection of earlier individuals. So far, climate changes have been moderate, but predictions indicate drastic changes in the coming decades (Solomon et al., 2007). The ability of birds to adapt to these new conditions will largely depend on the biological mechanisms involved in their adaptation (Gordo and Sanz, 2005, 2008).

There is evidence that changes in the routes and times of migration of birds due to global warming and seasonal changes affect the distribution of infectious diseases, and facilitate the appearance of new zoonotic diseases that can have an impact on humans and livestock (Gilbert et al., 2008). As their migratory patterns are modified, the possibility increases for the spread of pathogens (viruses, bacteria, parasites) carried by birds and for these pathogens to find new habitats and vectors. This is especially important in the case of vectors such as mosquitoes and ticks, which can establish transmission cycles in new geographical areas and threaten public and animal health (Ogden and Robbin, 2016). The West Nile virus is a clear example of a mosquito-borne disease that has expanded its scope through the migration of birds, affecting both humans and domestic and wild animals (Chancey et al., 2015). Another increasing risk is the transmission of zoonotic diseases, as changes in migratory routes increase the likelihood of interaction between migratory birds and other species, including farm animals. This increases the risk of transmission of zoonotic pathogens such as avian influenza (bird flu) viruses (H5N1, H7N9), which can sometimes jump from birds to humans and cause outbreaks with significant repercussions on public health and the livestock industry (Kilpatrick et al., 2006). Wild birds can, in turn, transmit the virus to poultry, affecting livestock production and generating considerable economic losses. Overall, an indirect impact on food safety is also observed since the introduction of diseases in livestock can reduce their productivity and generate additional costs in health control measures, which has repercussions on the availability and price of animal products, especially in vulnerable areas (Jones et al., 2012). In conclusion, changes in migratory patterns of birds represent a challenge for public health and livestock production in the context of climate change. The implementation of monitoring and prevention systems in areas of passage of migratory birds and their proximity to livestock facilities could be an essential measure to anticipate and mitigate zoonotic outbreaks related to these changes. Scientific evidence underlines the need to integrate disease surveillance into wildlife monitoring programs to better understand and manage emerging risks (Altizer et al., 2013)

4. Loss of marine and coastal ecosystems, and livelihoods

From a marine biodiversity perspective, the main effects of climate change are sea warming, increased climate variability leading to more frequent extreme events, and changes in sea level, sea ice, thermal stratification, and ocean circulation. In addition, both warming and altered ocean circulation influence the reduction of oxygen concentrations in the inner layers. CO_2 emissions, which largely drive anthropogenic climate change, also cause sea acidification. All these processes can act on biodiversity directly (e.g., when the local temperature exceeds the physiological tolerances of individual species) or indirectly (e.g., by altering habitat availability, species interactions, or productivity). Potentially complex interactions can occur between climate change and other aspects of global change, especially those due to fishing, eutrophication, habitat destruction and zoonotic diseases (Worm and Lotze, 2021).

The marine environment is home to enormous biodiversity, which supports economic activities with a long tradition, such as fishing. This activity not only plays a fundamental role in healthy eating but is also the livelihood of many communities. Ensuring sustainable fishing is crucial to securing the future of fishing activity. The world population is expected to far exceed 9 billion people by the middle of the 21st century, and the latest edition of the FAO report already reflects the extent to which fishing is decisive in achieving the global goal of a world without hunger and malnutrition (Pérez, 2020). Spain ranks 20th in the world in marine fisheries and is the fourth-largest importer of aquatic products (FAO, 2022). Therefore, any change in global fishing and aquaculture production can affect the consumption of marine products by the population, affecting its nutrition. At present, the biggest threat to fishing is climate change. For this reason, there has been a growing interest in adapting fisheries and aquaculture to climate change in recent years.

The most important fishing areas in Spain are the North-East Atlantic (FAO sub-area 27), where cod, hake, herring, and mackerel are mainly caught; the Mediterranean and Black Sea (FAO sub-area 37), where the most important catches are sardines, anchovies, cuttlefish, shrimp, and prawns, and the Mid-West Atlantic (FAO sub-area 47), where giant squid, hake, and scallop are the main catches.

As a result of climate change in the northern hemisphere, a northward movement of cephalopods and fish such as sardines, anchovies, and mackerel has been reported. Specifically, in FAO sub-area 27, a greater abundance of European bass and some squid species has been detected in the North Sea, and an increase in cod and mackerel in the Norwegian Sea (Nottestad et al., 2015). These changes in the abundance and distribution of species can affect fishing catches both in number and in type of species, not only in that area but also in adjacent fishing areas.

In the specific case of the Mediterranean (FAO sub-area 37), a clear warming and increase in the salinity of the Mediterranean waters surrounding the Spanish coasts has been confirmed. These variations in temperature and salinity have been evaluated from 1945 to 2016. In the case of intermediate and deep waters, the temperature has increased at a rate of between 0.2 and 0.3 ºC/100 years and, in surface waters, the trend is around an increase of 2 ºC/100 years. As for salinity, it increases at a rate of between 0.1 and 0.3 ups/100 years (Vargas et al., 2019). Other factors to consider are, on the one hand, drought, which can cause rivers to contribute more or less nutrients to the sea and also more or less flow; and, on the other hand, torrential rains, which affect rivers that flow into the ocean and can carry away many sediments that contain nutrients. These changes that are taking place in the Mediterranean have an impact on fishing catches. For example, it has been observed that there are a lot of anchovies and sardines during some years, but there are few examples of these species for other years (Vargas et al., 2019). It has also been seen that thermophilic species such as lemonfish or serviola (*Seriola dumerili*) have experienced an increase in their abundance, as well as an increase in their distribution to the north and that species of boreal fish such as the chanquete (*Aphia minuta*) or the swordfish (*Sprattus sprattus*) are increasingly scarce. This effect, known as "southernisation", has been evident in the catches of some commercial species (Benigno and Almodovar, 2010).

As for future forecasts in marine systems, it is expected that the effects of climate change will vary by region and that the warming of the oceans will force fish populations to migrate toward the poles, so the extinction of some local species in warmer areas can be expected. However, this does not necessarily imply an increase in the biological diversity of the polar seas, given the rapid retreat of sea ice and the increase in acidification of the cold waters. In coastal areas, the proliferation of extreme weather events, sea level rise, and coastal development are expected to intensify fragmentation and habitat loss (IPBES, 2019). All this can have a long-term impact on fish catches and the availability of seafood for consumers' food.

5. Loss of terrestrial ecosystems and inland waters

Land and aquatic ecosystems are very vulnerable to climate change. Currently, species extinction is accelerating: more than 60 % of the world's wild species have become extinct in the last 50 years (Thomsen and Thomsen, 2021). Biodiversity loss is expected to spread as global warming increases, with greater repercussions in northern South America, southern Africa, most of Australia, and the high latitudes of the north. According to the Red List of the International Union for the Conservation of Nature, 16.2 % of terrestrial and freshwater species listed as endangered, critically endangered, or extinct in nature include climate change or extreme weather conditions as one of their threats (Parmesan et al., 2022).

The impact of climate change on biodiversity affects the distribution and phenology of both plant and animal species. In relation to plants, many European species have shifted towards the north and higher altitudes. By the end of the 21st century, the distribution is expected to have shifted several hundred kilometres to the north, with the consequent expansion of forests in the north and contraction in the south, with 60 % of mountain plant species in danger of extinction. The rate of change exceeds the capacity to adapt, with which the composition of many plant communities is changing. Thus, in Western and Central Europe, broadleaf species are replacing conifers. One of the species limited by climate is the holly (*Ilex aquifolium*), which has expanded in southern Scandinavia due to the increase in winter temperatures (Walther et al., 2005) (Feehan et al., 2009).

Regarding the distribution of animal species, almost half (47 %) of endangered terrestrial mammals, excluding bats, and a quarter (23 %) of endangered birds have already been negatively affected by climate change in at least part of their distribution area (IPBES, 2019). In Europe, birds, insects, and mammals are moving north and to higher altitudes in response to climate change. However, many species, including butterflies, do not move as quickly as expected with the current rate of climate change (Warren et al., 2013), perhaps due, at least in part, to habitat fragmentation.

On the other hand, global warming has led to advances in the life cycles of many groups of animals, including the spawning of frogs, the nesting of birds, and the arrival of migratory birds and butterflies. Seasonal advance is particularly strong and rapid in the Arctic. The breeding seasons are lengthening, which allows additional generations of temperature-sensitive insects, such as butterflies, dragonflies, and pest species, to be produced during the year (Feehan et al., 2009).

Hybridisation between closely related species has increased in recent decades as one species shifts the boundaries of its distribution area and positions itself closer to the other. Thus, for example, hybrids between polar bears and brown bears in northern Canada have been documented (Kelly et al., 2010), while in North American rivers, hybridisation between invasive rainbow trout (*Oncorhynchus mykiss*) and native cutthroat trout (*Oncorhynchus clarkii*) has increased in frequency as rainbow trout have expanded to warmer waters (Muhlfeld et al., 2014).

In Europe, climate change has caused a displacement of agroclimatic areas to the north and an earlier start of the growing season (Ceglar et al., 2019). Since 1990, there have been reductions in wheat and barley yields and increases in corn and sugar beet (Moore and Lobell, 2015). Likewise, warming has caused increases in the yield of cultivated fruit vegetables, decreases in tubers, tomatoes, and cucumbers (Potopová et al., 2017) and earlier flowering of olive trees (García-Mozo et al., 2015). Also, climate change has affected wine quality (van Leeuwen and Darriet, 2016) (Bednar-Friedl et al., 2022).

Cold water habitats and associated obligate species, such as salmonids, are especially vulnerable to these changes (Santiago et al., 2016) (Merriam et al., 2017). Thus, the average return time of Atlantic salmon to the Newfoundland and Labrador rivers increased between 12 and 21 days in recent decades, associated with generally warmer conditions (Dempson et al., 2017). On the other hand, tropical lakes, which are home to thousands of animal species that are not found elsewhere and that support important fisheries, are prone to the loss of deep-sea oxygen due to warming, with adverse consequences for productivity and biodiversity (Sterner et al., 2020) (Parmesan et al., 2022).

The increase in water temperatures, the reduction in ice cover, and the decrease in oxygen in deep waters cause changes in freshwater ecosystems consistent with changes in terrestrial systems: earlier development of phytoplankton and zooplankton, and advanced spawning of fish in spring, as well as extension of the growing season (de Senerpont Domis et al., 2013) (Adrian et al., 2016). Ectotherms like fish and invertebrates are particularly susceptible to thermal and oxygen stress. In the lakes of Wisconsin (United States), abnormally high water temperatures due to warmer summers caused a large fish mortality. These phenomena are expected to double by 2041-2059 and quadruple by 2081-2099 compared to historical levels (Till et al., 2019). This expected increase in mortality can make it easier for warm-water fish species to displace cold-water species (Hansen et al., 2017).

Spain has the greatest diversity of continental aquatic systems in Europe, with unique and very specific floras and faunas. These systems are generally small, included in very large river basins, often depend on groundwater, and experience intense water fluctuations that affect their ecological functioning. Climate change will likely cause some of these ecosystems to go from permanent to seasonal; some will even disappear, and the biodiversity of many will be reduced (Alvarez Cobelas et al., 2005). For example, in riverbank vegetation, tarayes (*Tamarix*) are expected to increase compared to *Salicaceae* (*Salix*) and poplars (*Populus*), and oleander (*Nerium oleander*) is likely to expand. In the emerging vegetation of wetlands, clearly amphibious species may be favoured over genuinely aquatic ones; thus, for example, *Phragmites* and *Scirpus* may dominate over *Typha* or *Cladium* (Alvarez Cobelas et al., 2001).

Likewise, larger river fish (barbels and bogues) develop migratory strategies to tolerate the pronounced drought, either going upstream to find permanent waters or descending to the confluence with the main rivers. The most peculiar endemic fish are small in size (*Squalius alburnoides, Chondrostoma lemmingii, Iberocypris*), and their basic adaptation consists of resisting the summer in isolated pools under overcrowded conditions (Carmona et al., 1999). Due to the increased water temperature, the salmonid habitat will be reduced, and native trout populations will be fractionated as their habitat is reduced (Alvarez Cobelas et al., 2005).

6. The effects of the deterioration of food systems

Understanding the food system as the set of activities involved in the production, processing, transport, consumption, and management of food waste (MITECO, 2020), its relationship with climate change, food security, and human health is dynamic and multisectoral (Schnitter and Berry, 2019). Existing evidence suggests that climate change can cause disturbances in the stable supply of resources needed for processing operations and that extreme weather events can cause physical damage to processing and facilities (Ziska et al., 2016). It can also disrupt food distribution networks through acute crises such as extreme weather conditions (Palko and Lemmen, 2017).

Therefore, climate change can pose a risk to the nutritional status of the population due to the reduction in food availability, access to it, use of it, and the stability of the food system, which, combined with the high demand, increases food prices. An unstable food system, with a scarce supply of unprocessed foods and high prices, increases the search for ultra-processed and processed foods, which brings to light another aspect of food and nutrition insecurity: overweight or obesity (Raiten and Aimone, 2017). This means that climate change directly influences poor nutrition and food and nutrition insecurity: malnutrition/nutritional deficit and overweight/obesity, reinforcing the need for intersectoral public policies that understand the determining factors that influence the food choices of the population and their consequences on poor nutrition, giving answers beyond the health sector (de Moura Ariza et al., 2022).

To deal with the negative effects of climate change, there is an urgent need to restructure the food system and the global agricultural profile, as well as change the food and consumption profile of the population.

7. Reduction of the impact of climate change on food security

7.1 Changes in the weather patterns

Rural communities depend on climate conditions for agriculture, livestock, and other economic activities. Climate change has caused variations in rainfall patterns, more frequent droughts, and extreme temperatures, affecting water availability, agricultural production, and livestock health. This, in turn, impacts the food security and livelihoods of rural communities.

To adapt, the communities must diversify their sources of income and adopt sustainable agricultural practices. This can include the promotion of climate-resilient crops, implementing water conservation techniques, adopting healthy soil management practices, and exploring non-agricultural income options, such as rural tourism or renewable energy production (Erezi et al., 2023).

7.2 Risk of natural disasters

Rural communities are often located in areas prone to natural disasters, such as floods, droughts, wildfires, and intense storms. Climate change has exacerbated these risks, increasing the frequency and intensity of extreme events.

To adapt, these communities must strengthen their capacity for disaster response and preparedness. This involves developing effective early warning systems, improving climate-resilient infrastructure, promoting disaster risk management practices, and training residents in measures of security and evacuation. In addition, land use planning and the conservation of natural ecosystems can help to reduce risks. For example, the reforestation of vulnerable areas can prevent floods and landslides, while conserving wetlands favours their behaviour as natural buffers against storms (LI, 2014).

7.3 Shortages of natural resources

Climate change can also exacerbate the scarcity of natural resources in rural communities, such as water and food. Droughts and rising temperatures can reduce water availability for irrigation and human consumption, directly affecting agricultural production and the quality of life.

In response, it is essential to implement water conservation measures, such as rainwater harvesting, the construction of efficient irrigation systems, and the sustainable management of local aquifers. Promoting crop diversification and introducing climate-resistant varieties can also help ensure food security in changing environments (Nikolaou et al., 2020).

7.4 Biodiversity loss

Climate change contributes to the loss of biodiversity, affecting both natural ecosystems and the economic activities of rural communities, such as fishing and tourism. Biodiversity loss reduces an ecosystem's ability to adapt to changes and ultimately directly impacts humanity negatively.

To adapt, it is essential to promote conservation practices and sustainable management of natural resources. This includes establishing protected areas, encouraging responsible fishing, regulating tourism to minimise environmental impact, and promoting environmental education to raise awareness about the importance of biodiversity conservation.

Conclusions of the Scientific Committee

There is evidence that climate change affects in many ways the degree of access the population has to nutritious and safe food worldwide. The main risks are the loss of biodiversity in rural areas, the loss of marine and coastal ecosystems and livelihoods, the loss of terrestrial ecosystems and inland waters and livelihoods and, finally, the deterioration of food systems.

In relation to the loss of biodiversity in different ecosystems (marine and terrestrial) due to climate change, we have seen a change in the distribution and phenology of both plant and animal species. This has caused different species to shift towards colder latitudes (southernisation) and higher altitudes. It is expected that land degradation and loss of biodiversity will reduce crop yields, as well as the nutrient content of food.

In terms of the repercussions of climate change on food sources, the risk of known pests, as well as post-harvest losses, is increasing. The temperature increase directly affects animals, causing metabolic and immune changes, and has indirect consequences since the population of vectors that transmit infectious agents is increasing.

Therefore, climate change can pose a risk to the nutritional status of the population due to the reduction in food availability, access to it, use of it and the stability of the food system.

As FAO states, understanding the cascade of risks derived from climate change and the vulnerabilities to these risks is essential to designing ways of adapting to reduce the net impact on food security and nutrition. Increasing resilience to climate change can require multiple interventions, from social protection to agricultural practices and risk management, within the framework of strategies that must be based on risk and vulnerability assessments and that consider the different dimensions (social, economic, and environmental).

It is essential to design ways of adapting to climate change to reduce the net impact on food security and nutrition and, in this way, increase resilience to global warming. This represents a paradigm shift towards more resilient, productive, and sustainable agriculture and food systems, aiming to guarantee global food security in the face of climate change.

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