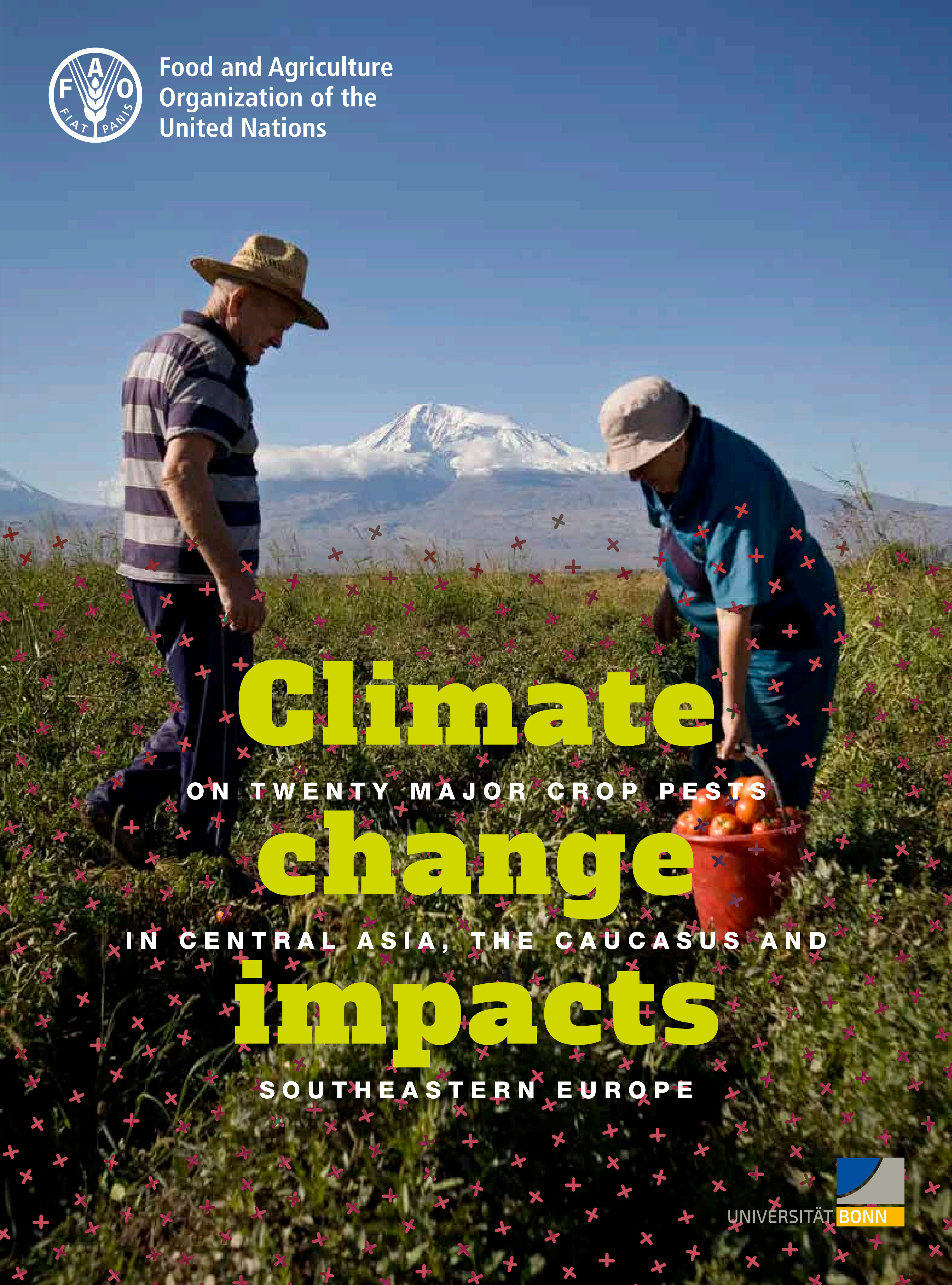
Food and Agriculture Organization of the United Nations



Climate change impacts

ON TWENTY MAJOR CROP PESTS IN CENTRAL ASIA, THE CAUCASUS AND SOUTHEASTERN EUROPE

UNIVERSITÄT BONN

Climate change impacts

ON TWENTY MAJOR CROP PESTS IN CENTRAL ASIA, THE CAUCASUS AND SOUTHEASTERN EUROPE

Food and Agriculture Organization of the United Nations
Ankara, 2021

Required citation:
FAO and University of Bonn. 2021. *Climate change impacts on 20 major crop pests in Central Asia, the Caucasus and Southeastern Europe*. Ankara, FAO. https://doi.org/10.4060/cb5954en

ISBN 978-92-5-134776-8

Cover photograph: ©FAO/Johan Spanner

Contents

Figures

Tables

Acknowledgements

This research report, produced during the course of a five-month assignment (5 October 2020 to 1 March 2021) as desk research work for a regional study on the impacts of climate change on the spread of pests, contributes to FAO's normative work. It was developed by Powell Mponela, Shova Shrestha and Lisa Biber-Freudenberger of the Center for Development Research at the University of Bonn in Bonn, Germany, under the supervision and support of Evetta Zenina, Natural Resources Officer at the FAO Subregional Office for Central Asia, and Tania Santivanez, FAO Agricultural Officer. The development of this research paper would not have been possible without the essential support and contributions provided by several colleagues, including Piotr Wlodarczyk, Agricultural Officer, and Zsuzsanna Keresztes, Specialist on Integrated Pest Management and Climate-Resilient Agricultural Practices. The researchers would like to acknowledge the support from national staff who contributed information. The report finalized and published with the support of the project "Lifecycle Management of Pesticides and Disposal of POPs Pesticides in Central Asian countries and Turkey" (GCP/SEC/011/GFF resp. GEF ID 5000).

Our thanks to Chiara Caproni for providing the layout design and to Matthew Anderson for editing.

Abbreviations and acronyms

AR6	Sixth assessment report
CMIP	Coupled Model Intercomparison Project
CPC	Crop Protection Compendium
EVM	Ecological niche modelling
GCM	General Circulation Models
GDP	Gross domestic product
IPC	Invasive Species Compendium
IPCC	Intergovernmental Panel on Climate Change
IYPH	International Year of Plant Health
MME	Multi-model ensemble
PO	Presence only
RCPs	Representative concentration pathways
ROR	Relative occurrence rate
SSP	Shared Socioeconomic Pathways

Summary

This research report is prepared to assess the impact of climate change on the spreading of plant pests. The findings are essential for strengthening the capacities of governments and regional technical networks to improve pest monitoring and early warning systems in the agriculture sector.

The year 2020 was designated by the United Nations as the as the International Year of Plant Health (IYPH), with the aim of reducing crop loss from pests, which is estimated at 40 percent. In the current report, we define agricultural pests as any organism harmful to plants, including viruses, bacteria, fungi, nematodes, insects, etc. We include those that cause direct damage as well as disease-causing organisms. Climate change is projected to worsen crop losses by another 10–25 percent, which in some regions would emanate from associated pests. Central Asia, the Caucasus and Southeastern Europe are among the regions experiencing larger crop losses. Farmers are facing increasing uncertainty due to climatic change, which is projected to have widened the geographical range for the infestation and spread of plant pests. However, complexities in understanding pests and plants relationships and uncertainty in pest distribution patterns and modes of movement create difficulties in predicting potential pest distribution under current and future climatic conditions. Robust modelling and simulation approaches – based on information about suitable climatic conditions for major crop pests, trends of changing climatic conditions and other environmental data – to predict the possible areas of future pest invasion can guide the relevant stakeholders in their decision-making and bring awareness.

Currently, the presence of pests is estimated to be higher in the Caucasus than in Central Asia. However, predictions show that Central Asia will have optimal bioclimatic conditions and experience higher pest occurrence. The Caucasus region is projected to have an overall conducive environment for the occurrence of agricultural plant pests. This study has found that the conditions may favour microbial pests causing plant disease more than insect, nematode, etc. pests. Comparing Central Asia and Southeastern Europe, it can be seen that the predicted occurrence from past and current bioclimatic conditions is much lower for Central Asia than for Southeastern Europe, but this is projected to flip over the 20-year period.

Of the 20 major pests, habitat suitability is projected to largely shift for the pest *Blumeria graminis* and the pest *Thanatephorus cucumeris*. Significant eastward shifts are projected for the pest *Cephus pygmaeus*, the pest *Verticillium dahliae*, the pest *Ustilago maydis* and the pest *Myzus persica*e. A southward shift is projected for the pest *Puccinia graminis* and the pest *Clavibacter michiganensis*. A notable shift to central–western Central Asia is projected for the pest *Mycosphaerella graminicola*. Reductions in bioclimatic suitability are projected for the pests *Helicoverpa armigera*, *Rhopalosiphum maidi*s, *Phytophthora infestans*, *Tetranychus urticae*, *Planococcus citri* and *Loxostege sticticalis*. These pest-specific projections can be used to develop mechanisms for anticipating, forecasting and monitoring these major pests, leading to the avoidance of large crop losses of 20–55 percent in the near future. The results from this study may contribute to the better designing of suitable adaptation and mitigation measures.

Introduction

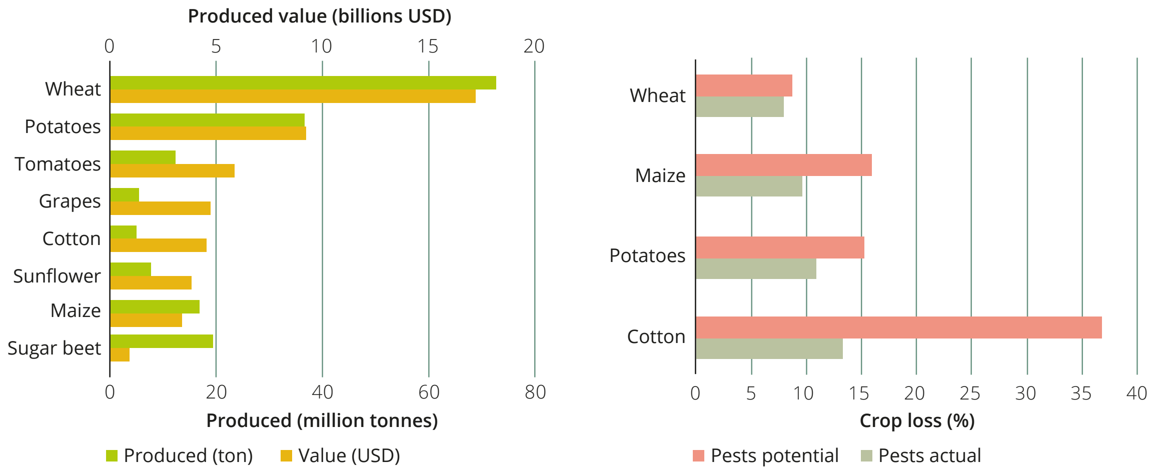
© FAO/V. Oseledko

Climatic change is projected to have significant impacts on crop yields, with 10–25 percent global yield reduction projected per degree of global mean surface warming and more crop loss expected where warming increases both population growth and the metabolic rates of insects (Deutsch et al., 2018). It is estimated that up to 40 percent of food crops are lost to pests each year. As a result, to bring awareness, the United Nations declared 2020 as the International Year of Plant Health (IYPH) (FAO, 2020c). Closing the loss of crops is among the major pathways to ending hunger, reducing poverty, protecting the environment and boosting economic development. Unfortunately, the efforts to protect plant health are still low, especially in regions where crop pests are not considered as major constraints. Yet, these regions suffer and are projected to suffer enormous losses as climate change shifts the bioclimatic zones. When out of their natural areas, pests are historically known to cause the greatest damage.

FIGURE 1. Map of the study regions: Southeastern Europe, the Caucasus and Central Asia

Source: UN, 2020.

FIGURE 2. Production and value of major crops in the study region



Source: FAO (2020b); Oerke (2016).

The global average (2000–2018) value of crops – including cereals, roots and tubers, oils, vegetables and fruits – is estimated to be around USD 1.6 trillion, of which 6.25 percent (USD 100 billion) was produced in the study region (FAO, 2020b). Of 121 crops grown in the region, eight have a production and economic value of more than USD 1 billion (Figure 2). Although there is no exact estimate of the loss of value of crops due to pests, the potential loss due to pests is estimated to vary from 26–29 percent in wheat, soybean and cotton to 31–40 percent in maize, rice and potatoes (Oerke, 2006). Where plant protection measures are not applied, the losses are much higher. Plant protection is estimated to reduce yield losses by 39 percent for pests, with actual losses ranging from 8 percent to 14.5 percent (Figure 2).

There are sharp regional differences within Central Asia and Southeastern Europe, which experience crop losses of up to 38 percent and 34 percent, respectively (Oerke, 2006). It is estimated that the current annual global expenditure on pesticides is USD 15 billion (Willis, 2017), with annual usage of 3 700 000 tonnes of pesticides (2.9 percent used in study regions) and 473 000 tonnes of fungicides and bactericides (0.7 percent in study regions) (FAO, 2020a).

General description

FOR EACH SUB-REGION:

THE **main agricultural plants**,

INCLUDING CEREALS,

VEGETABLES AND FRUITS

The three subregions – Central Asia, the Caucasus and Southeastern Europe – have diverse agroecological zones, with the differentiated capacities to produce various crops. The Caucasus region, mainly the Southern Caucasus, consists of Armenia, Azerbaijan and Georgia. The Central Asia region includes Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan, with larger populations living in rural areas. Southeastern Europe consists of Albania, Bosnia and Herzegovina, North Macedonia, Montenegro, Serbia and parts of Turkey, and geographically it covers a major part of the Balkan Peninsula area. All subregions are rich in their unique and diverse culture, ethnicity and religion (Rashidvash, 2015). Agriculture is an important sector of the economy, contributing large portions to annual national gross domestic products (GDPs) in all countries.

In all subregions, various pests have been recorded as damaging the major crops. We define pests as any organism harmful to plants, including viruses, bacteria, fungi, nematodes, insects, etc.

TABLE 1. Average annual production (tonnes) of various crops in the study region (2014–2017)

SN	Major crops	Caucasus	Central Asia	Southeastern Europe	Production
1	Wheat	2 061	23 064	24 192	78 892
2	Maize	454	1 427	13 752	43 788
3	Potatoes	1 691	7 347	6 067	43 605
4	Vegetables	2 712	12 548	18 214	41 900
5	Sugar beets	329	0	21 223	40 493
6	Barley	1 066	3 215	7 570	22 469
7	Tomatoes	873	3 944	13 082	20 444
8	Sunflower seeds	-	733	2 335	15 492
9	Fruits	848	3 257	5 549	9 654
10	Grapes	570	2 082	4 674	7 327
11	Onions	249	2 443	2 225	6 195
12	Cotton	–	3 877	1 334	5 211
13	Apples	–	–	3 298	5 180
14	Soybeans	–	–	–	4 059

Source: FAOSTAT, 2020.

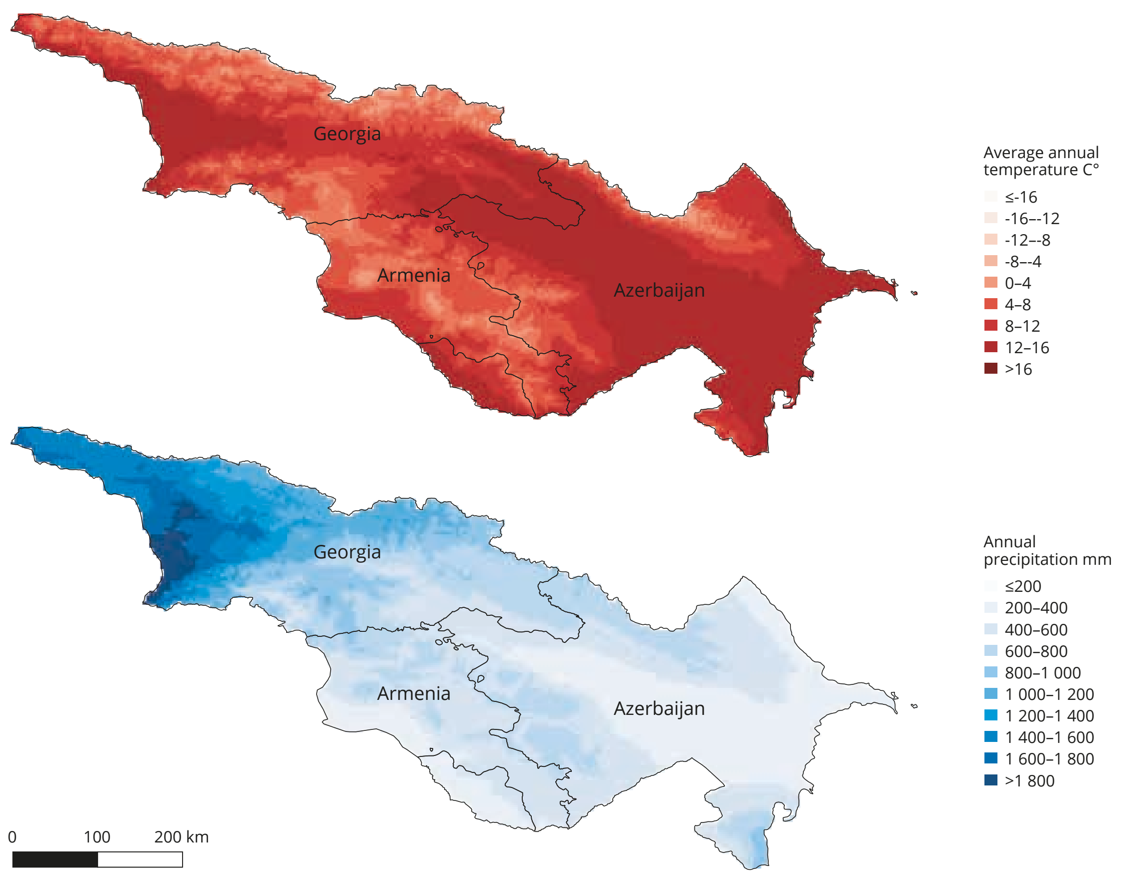
The Caucasus region

Agriculture is a major economic sector, providing more than 40 percent of total employment in the region (Ahouissoussi *et al.*, 2014). The agricultural production systems of all three countries are quite similar due to parallels in the landscapes, types of soils, water availability and climate.

MAJOR CROPS

Wheat, barley and maize are the main cereal crops grown in the Southern Caucasus region (Figure 4 and Table 2). Farmers also produce vegetables including potato, tomato, onion, cabbage and eggplant. Beans and other pulses and sunflowers and other oil crops also are grown in the region. Some farmers also produce cotton, tea, spices and fruits, including grapes, apples, oranges and citrus.

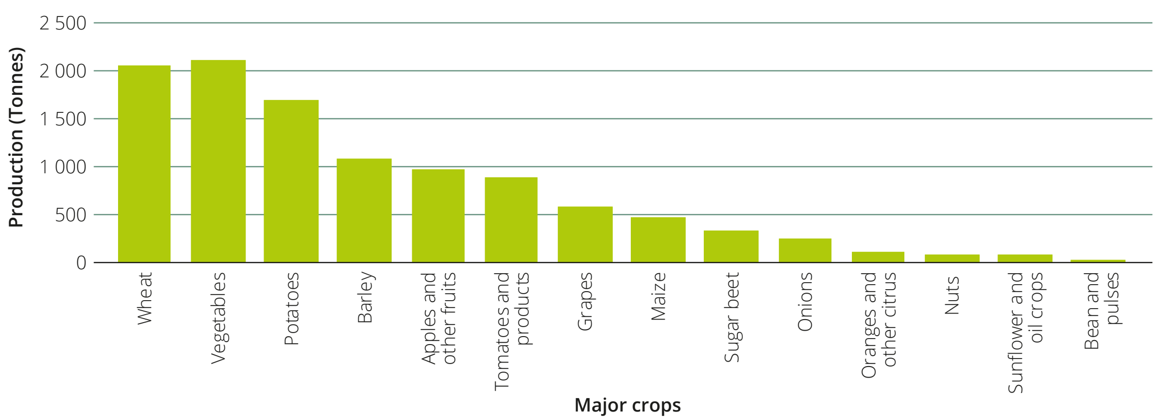
FIGURE 3. Map of the Caucasus region



Note: Average Temperature and Precipitation of Caucasus region for the years 1970 to 2000 as presented in the WorldClim.org database by Fick and Hijimans (2017). The country boundaries are from UN (2020).

Source: UN (2020); Fick and Hijimans (2017).

FIGURE 4. Major crop productions (tonnes) of the main crops in the Caucasus region (2014–2017)



Source: FAO (2020b). FAOSTAT.

TABLE 2. Average annual production (tonnes) of various crops in the Caucasus region (2014–2017)

SN	Major crops	Armenia	Azerbaijan	Georgia
1	Vegetables	918	1 654	140
2	Potato	614	869	208
3	Wheat	307	1 654	100
4	Tomato	288	531	54
5	Grapes	240	149	182
6	Fruits	216	546	86
7	Barley	167	860	40
8	Sugar beet	59	270	0
9	Onions	51	183	15
10	Maize	18	220	216
11	Nuts	4	50	35
12	Bean	5	10	7

Note: The annual average production numbers of each crop of each individual country are summed to get the total regional production of the crops.
Source: FAOSTAT, 2020.

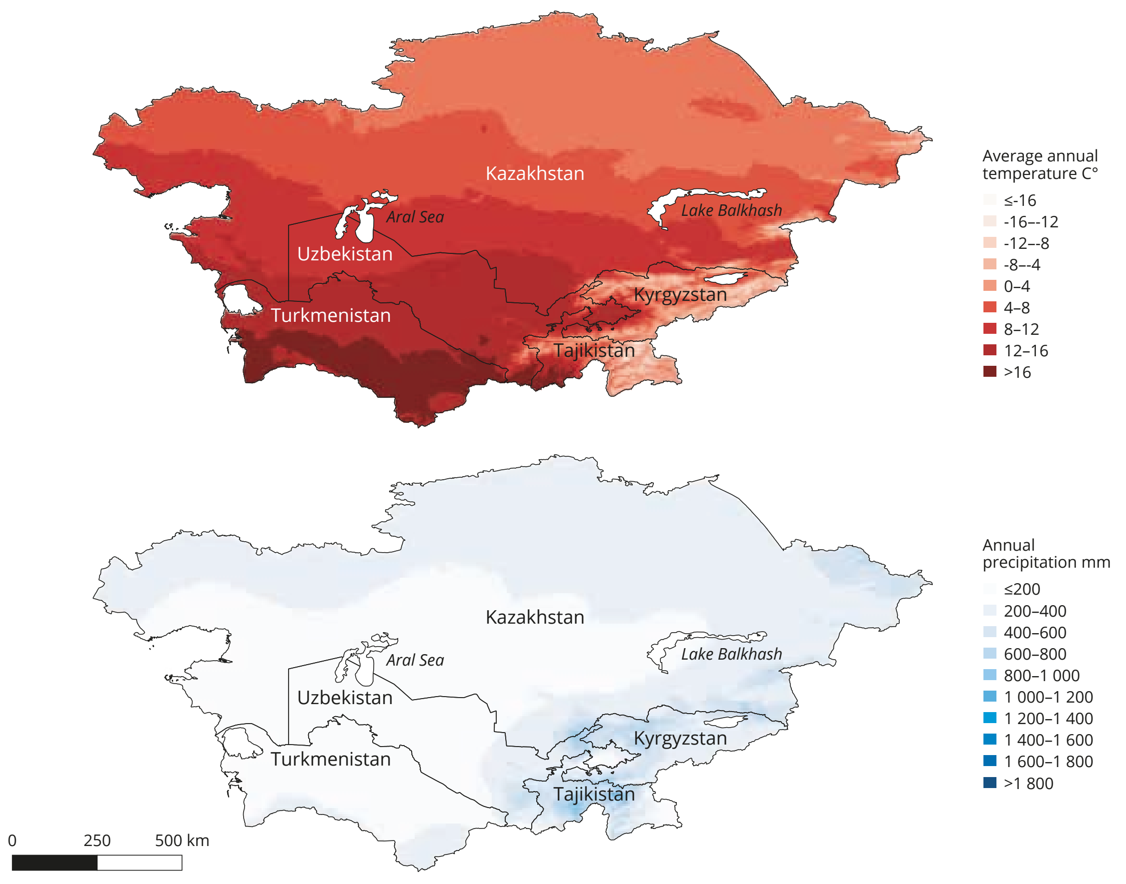
Central Asia

The agricultural sector is climate sensitive, and potential adverse changes in temperature, precipitation and the frequency of extreme events (i.e. droughts, heat waves and floods) are likely to increase the vulnerability of poor rural communities. A slight change in such climatic factors as temperature, precipitation and extreme events can potentially adversely impact the crop production systems. Moreover, locally present and emerging pests cause irrecoverable damages to crop production, which severely affects the economy of the rural communities and compels the farmers to use chemical or biological pesticides to control pests, diseases and weeds.

MAJOR CROPS

Central Asia is an important agricultural region, where crops such as cereals, wheat, cotton, barley, fruits (e.g. grapes), vegetables, tomatoes and onions are produced. Although Central Asian countries produce a large variety of different crops, with large differences among the individual countries in terms of production quantity, the main cereal crops of the region are wheat, barley, maize, rice and oats (Figure 6 and Table 3). Potatoes, tomatoes, onions, and other vegetables also are grown on a large scale. Cotton is cultivated for commercial purposes. Sugar beets, beans, peas, soybeans and other pulses take a significant share of the overall

FIGURE 5. Map of the Central Asia region

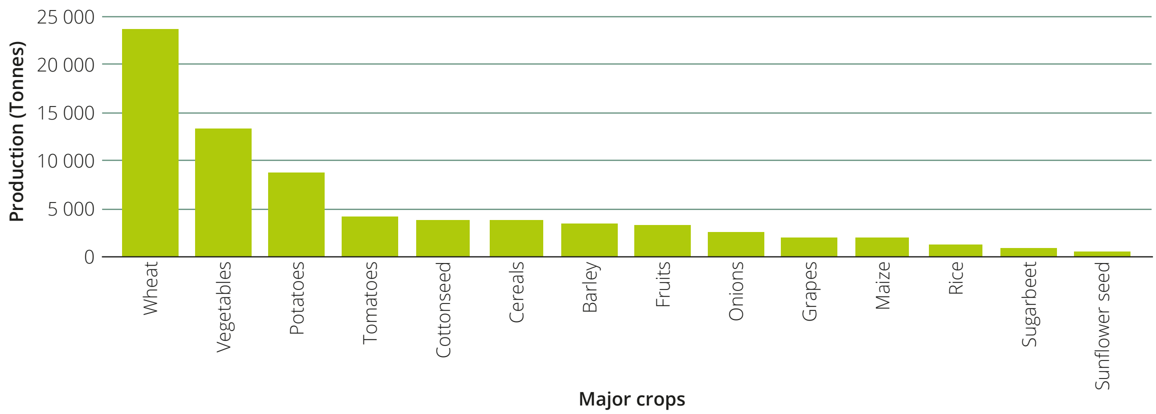


Note: Average Temperature and Precipitation of Caucasus region for the years 1970 to 2000 as presented in the WorldClim.org database by Fick and Hijimans (2017). The country boundaries are from UN (2020).

Source: UN (2020); Fick and Hijimans (2017).

production. Sunflowers, rapes, mustards and other oil crops are grown for oil production. Farmers cultivate fruits such as grapes, oranges, mandarins and other citrus. Among all types of crops, wheat occupies the largest portion of the regional production, followed by vegetables and potatoes.

FIGURE 6. Major crop production (tonnes) of the main crops in the Central Asia region (2014–2017)



Source: FAO (2020b). FAOSTAT.

TABLE 3. Average annual production (tonnes) of various crops (products) in the Central Asia region (2014–2017)

SN	Major crops	Kazakhstan	Tajikistan	Turkmenistan	Uzbekistan
1	Wheat	14 133	895	1 302	6 734
2	Vegetables	4 289	1 508	509	6 242
3	Potatoes	3 507	856	301	2 683
4	Tomatoes	706	373	340	2 525
5	Cottonseed	167	181	385	3 144
6	Fruits	76	104	96	2 982
7	Barley	2 906	135	26	148
8	Onions	699	514	94	1 136
9	Grapes	72	209	234	1 567
10	Maize	739	205	50	433
11	Rice	434	90	130	679
12	Sunflower	676	12	0	44

Note: The annual average production numbers of each crop of each individual country are summed to get the total regional production of the crops.
Source: FAOSTAT, 2020.

Southeastern Europe

The agricultural sector in Albania is economically important, contributing 23 percent to the national GDP of the country. The agricultural sector has been identified, however, as a vulnerable sector due to climate change impacts such as exposure to more pests and diseases and water scarcity, with altered crop yields and growing cycles.

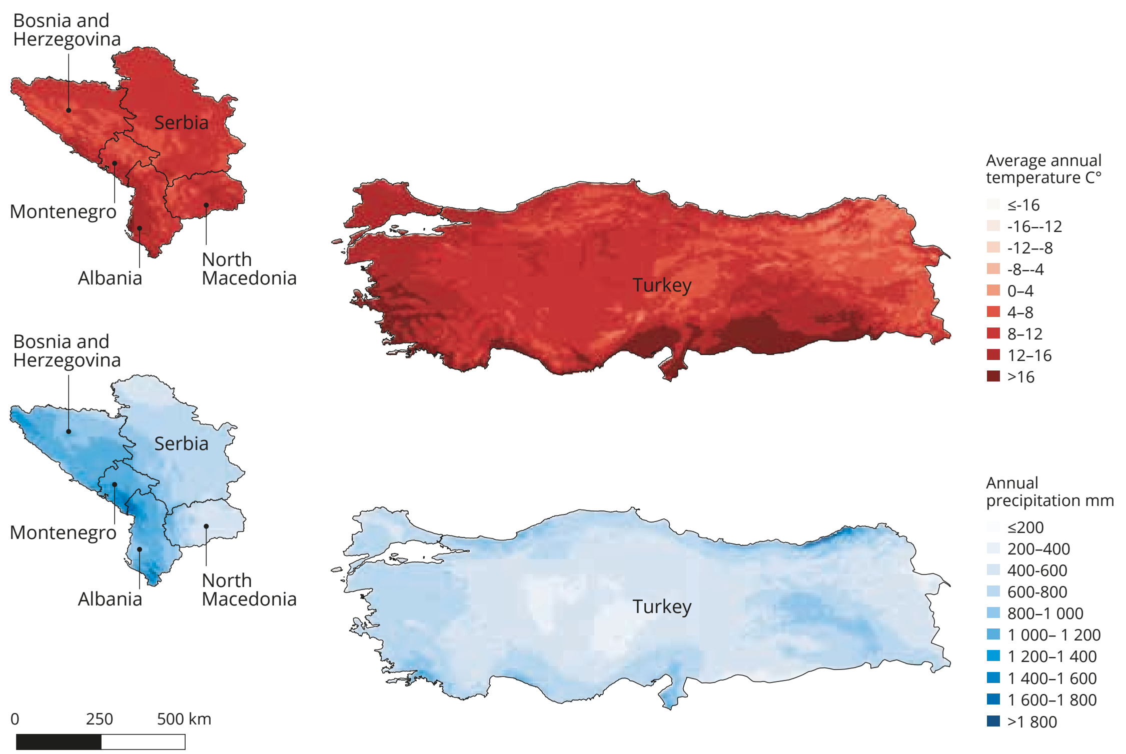
The agricultural sector in Bosnia and Herzegovina is important for the national economy, contributing around 7 percent to the national GDP (2010) and accounting for about 19 percent of the total employment generation, mainly in rural regions (UNFCCC, 2013). This sector also has been identified as the most vulnerable to climate change, including water resources, forestry and biodiversity, ecosystems and human health. In the past few decades, Bosnia and Herzegovina has experienced many extreme climate events due to changing climate (Zurovec *et al.*, 2015) and is threatened by water scarcity, yield reduction, exposure to agricultural pests and diseases, and, ultimately, food insecurity, due to climate change (UNFCCC, 2013).

Agricultural production in North Macedonia is sufficient to meet the national food demand, but the prevailing crop production practices are highly dependent on rainfall, increasing the country's vulnerability to future climate change.

Turkey, with a total area of 783 562 sq. km and belonging partly to Europe and partly to Asia, is 30 percent arable land; 3 percent orchards, olive groves and vineyards; and 26 percent forest area.

In Serbia in 2017, agriculture, forestry and fishing accounted for around 6 percent of the national GDP, and about 1.6 percent of registered employment is provided by the agriculture, forestry and fishing sector. Crop production amounted to 62 percent of the total agricultural production, with the remaining 38 percent provided by livestock production.

FIGURE 7. Map of the Southeastern Europe region



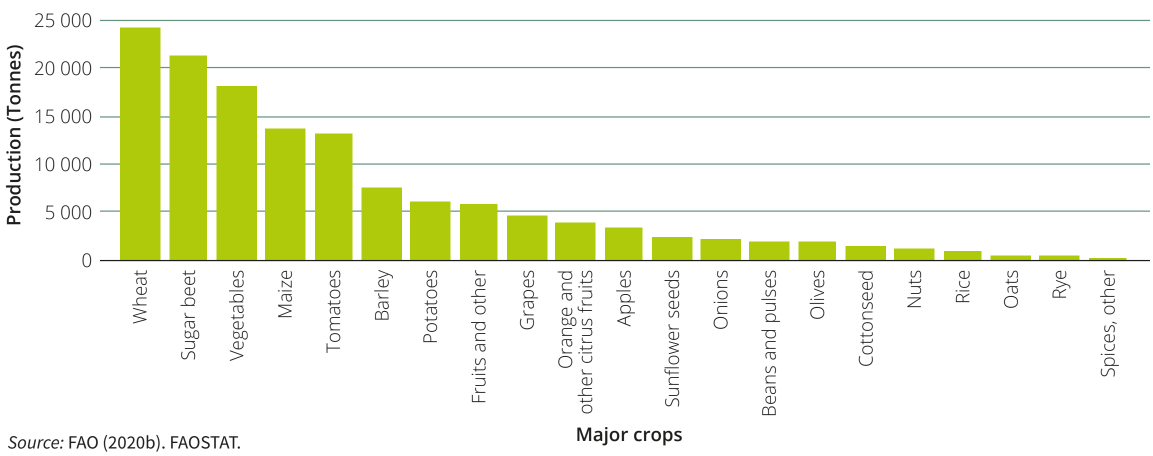
Note: Average Temperature and Precipitation of Caucasus region for the years 1970 to 2000 as presented in the WorldClim.org database by Fick and Hijimans (2017). The country boundaries are from UN (2020).

Source: UN (2020); Fick and Hijimans (2017).

MAJOR CROPS

Cereal crops – mainly wheat, maize, barley, rice and oats – dominate the crop production system of the region (Figure 8). The major vegetable crops are tomatoes, potatoes and onions. Grapes and apples are the common fruit crops in the region, and large amounts of sugar beets also are produced. Sunflowers, beans, olives and nuts are grown as well. Wheat accounts for most of the production, followed by sugar beets and vegetables (Table 4).

FIGURE 8. Major crop production (tonnes) of the Southeastern Europe region (2014–2017)



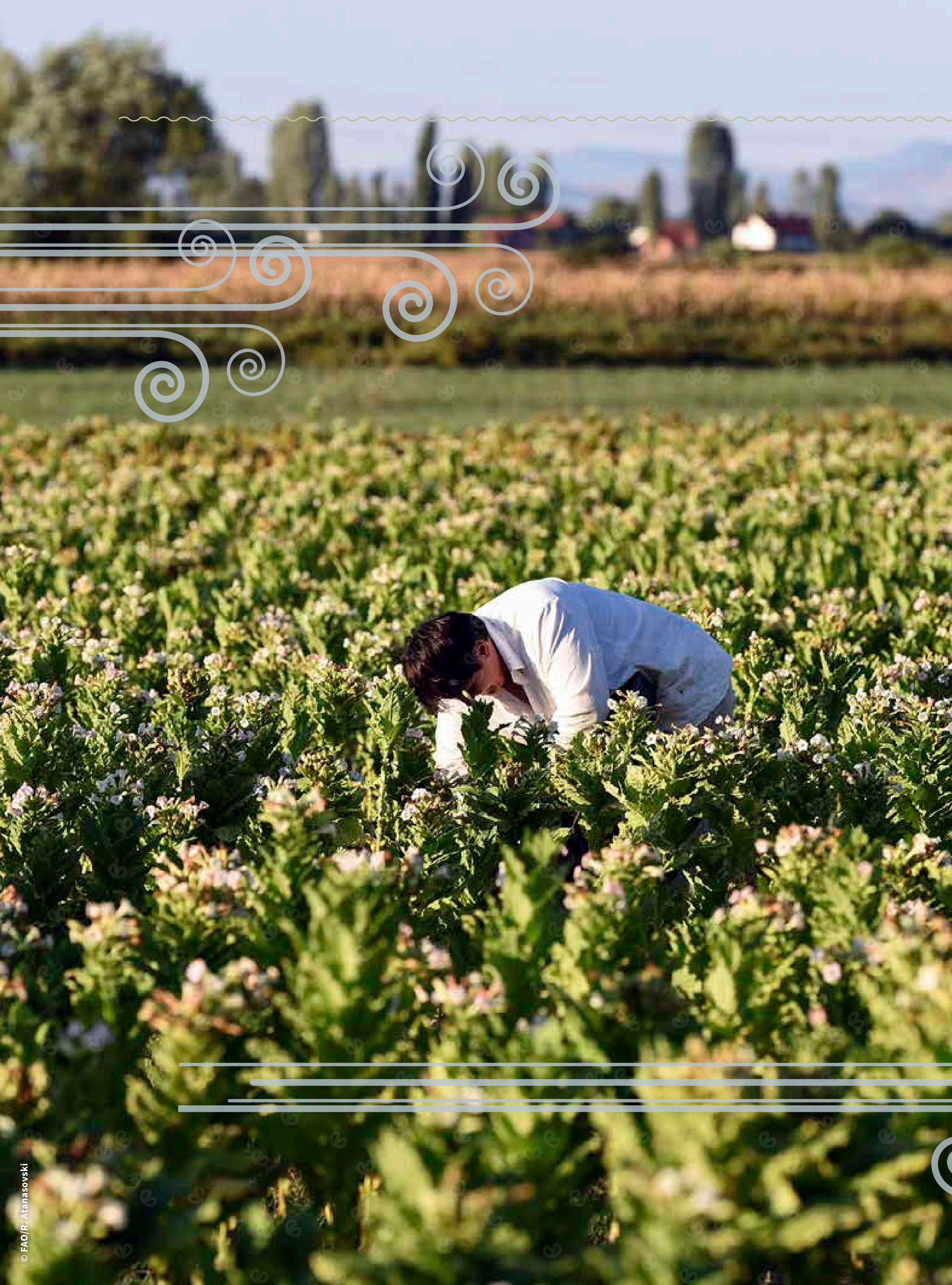
Source: FAO (2020b). FAOSTAT.

TABLE 4. Average annual production (tonnes) of various crops (products) of the countries in Southeastern Europe (2014–2017)

SN	Major crops	Albania	Bosnia and Herzegovina	North Macedonia	Montenegro	Serbia	Turkey
1	Wheat	276	246	249	2	2 494	20 925
2	Sugar beet	35	1	10	0	2 722	18 455
3	Vegetables, other	697	694	618	36	946	15 223
4	Maize	380	868	137	3	6 201	6 163
5	Tomatoes	266	43	164	3	152	12 454
6	Barley	8	66	124	1	347	7 025
7	Potatoes	243	352	192	27	634	4 619
8	Fruits, Other	149	173	78	22	854	4 273
9	Grapes	204	31	259	23	151	4 006
10	Apples	93	64	-	2	387	2 752
11	Oranges, mandarins	29	-	-	12	-	3 122
12	Sunflower seed	2	61	7	-	527	1 739
13	Onions	103	37	59	1	45	1 981
14	Nuts and products	15	5	6	1	18	1 009
15	Sunflower seed oil	1	0	-	-	218	800

Note: The annual average production numbers of each crop of each individual country are summed to get the total regional production of the crops.
Source: FAOSTAT, 2020.

IDENTIFICATION OF THE **top 20 pests** THAT CAUSE THE **greatest damage** TO MAJOR CROPS



Large number of crops are damaged due to different types of crop pests causing great financial damage to farmers. Many pests have been identified that affect the crops in different stages and are presented in the full version of this report. In order to emphasize main threat for the plant production in the investigated region, a structured inclusion or exclusion criteria was employed to identify the top 20 most dangerous pests for the major plants (Table 5). First, the importance of crops in terms of product volume and their economic value was averaged for the period 2000 to 2018. Then, a review of damage caused by the pest and associated diseases as catalogued in CABI's Crop Protection and Invasive Species

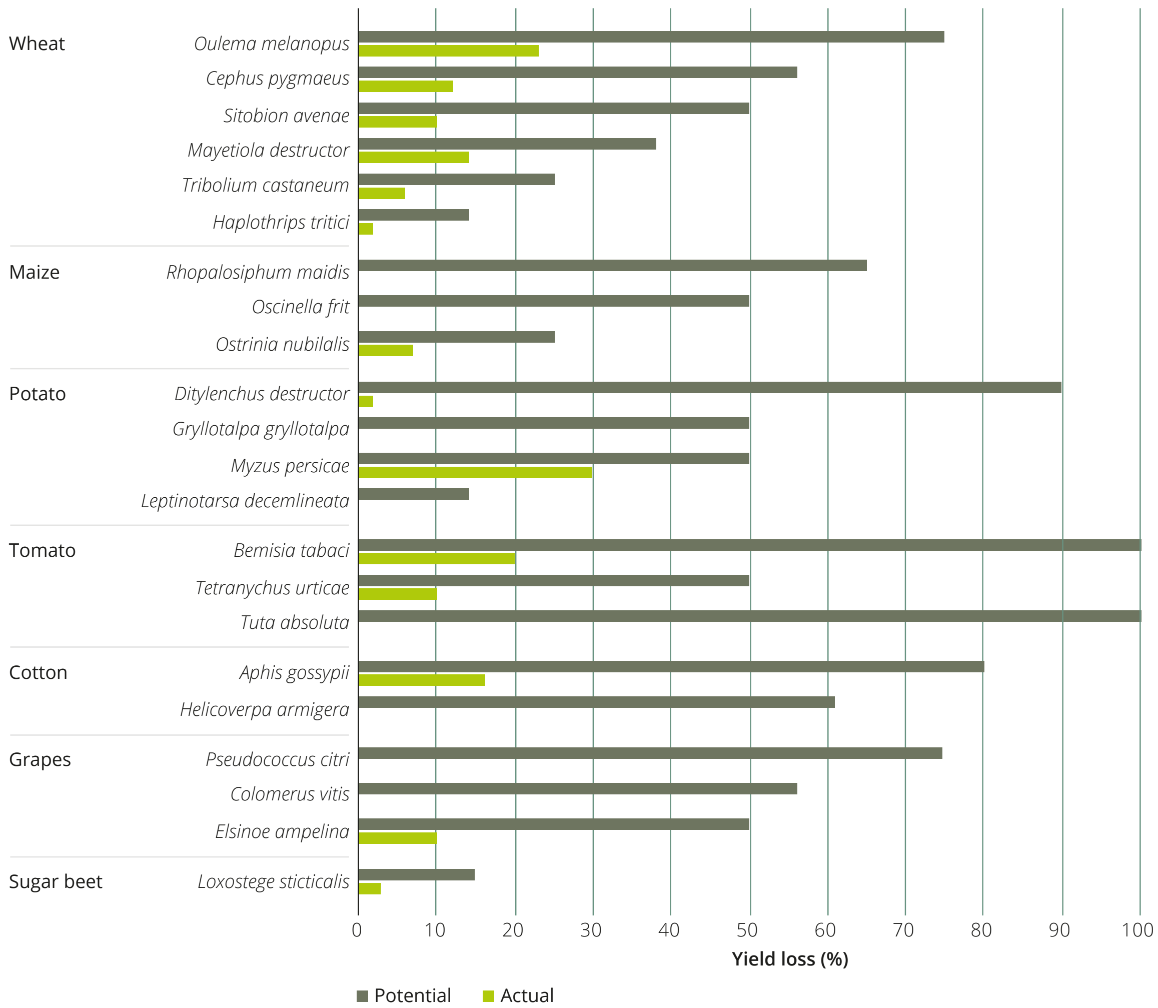
TABLE 5. Twenty pests that cause more than 10 percent (with the potential of more than 50 percent) yield loss to major crops

Crop	Pest
Wheat	*Oulema melanopus* (oat leaf beetle)
	Cephus pygmaeus (European stem sawfly)
	Puccinia graminis (stem rust of cereals)
	Mycosphaerella graminicola (Septoria tritici)
	Blumeria graminis (Powderly mildew of wheat)[®k]
Maize	*Rhopalosiphum maidis* (green corn aphid)
	Ustilago maydis (corn smut) [®a]
Potato	*Myzus persicae* (green peach aphid)*
	Phytophthora infestans (Phytophthora blight)
	Clavibacter michiganensis (Potato ring rot) [®k]
Tomato	*Bemisia tabaci* (tobacco whitefly)*
	Tetranychus urticae (two-spotted spider mite)*
	Fusarium oxysporum (Wilt of tomato)[®k]
Cotton	*Helicoverpa armigera* (cotton bollworm)*
	Aphis gossypii (cotton aphid)*
	Verticillium dahlia (wilt)
Grapes	*Planococcus citri* (citrus mealybug)*
	Plasmopara viticola (grapevine downy mildew)
Sugar beet	Loxostege sticticalis (beet webworm)
	Thanatephorus cucumeris (crown and root rot)[®t]

*Larger number of publications, cause greatest damage in [®k]Kyrgyzstan, [®a]Azerbaijan and [®t]Turkey.

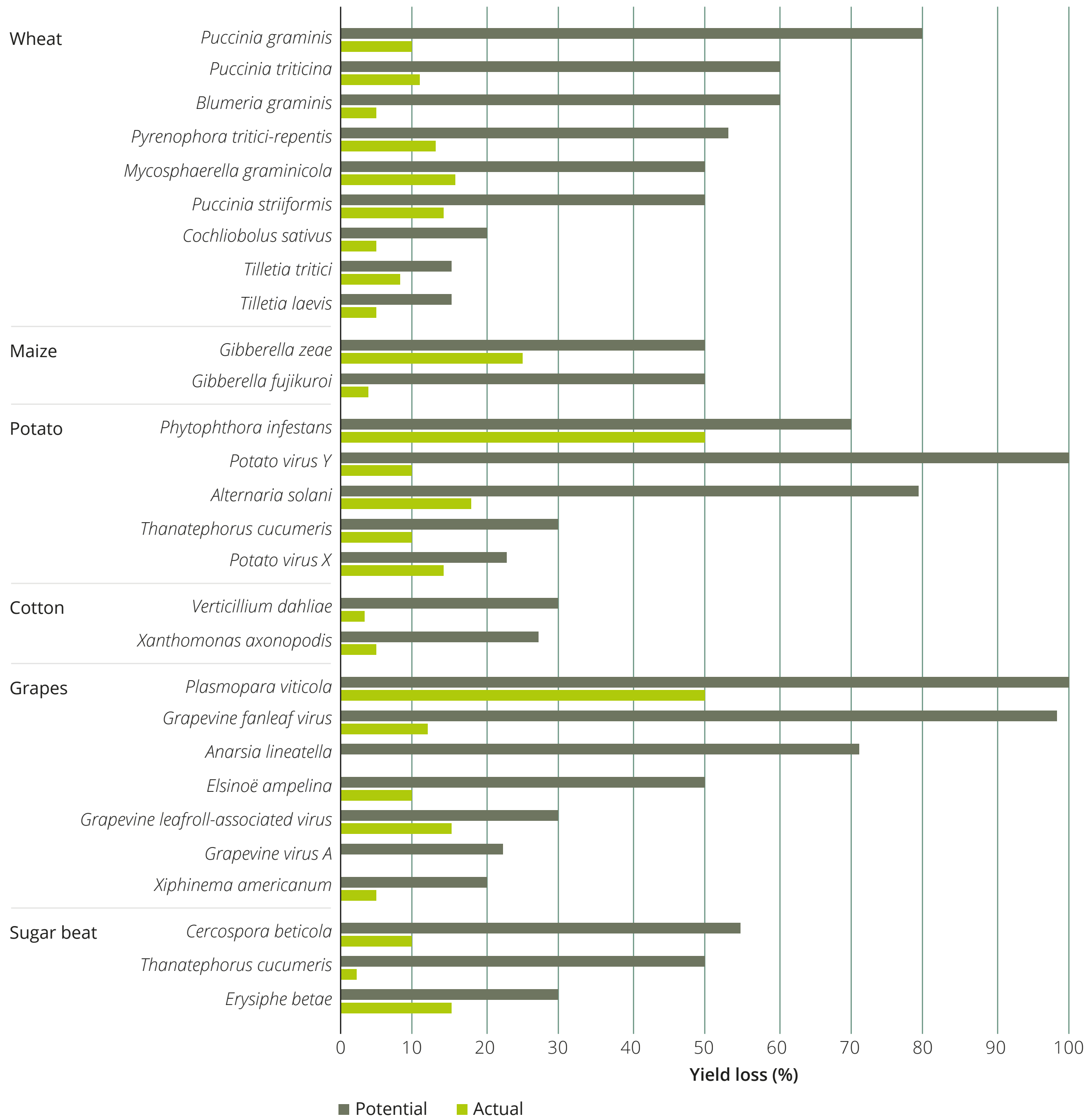
Compendiums (CABI, 2020a, 2020b) and country reports were taken into consideration. In total, 138 pests and 104 diseases were reviewed, out of which 22 pests (Figure 9) that have been recorded to cause great damage were identified. Reports obtained from countries were used to check if the reviewed range captures the damages being recorded in the region. For some pests, their significance to agricultural development is highlighted using the number of publications between 2012–2016 listed in the State of Worlds Plants report by Kew (Willis, 2017).

FIGURE 9. Twenty-two (22) pests that cause the greatest damage for the seven (7) major crops in the region



Source: CABI (2020a, 2020b). CABI's Crop Protection and Invasive Species; Willis (2017). State of Worlds Plants.

FIGURE 10. Twenty-eight (28) diseases-causing pests that cause the greatest damage to major crops in the region, for major plants with their mean and potential damage



Source: CABI (2020a, 2020b). CABI's Crop Protection and Invasive Species; Willis (2017). State of Worlds Plants.

Influence
OF CLIMATIC FACTORS
on current and future distribution
OF MAJOR PLANT PEST

Model and data

The species distribution was modelled based on global presence records and corresponding bioclimatic variables to estimate the potential niches for the occurrence of pests. This was done using Maxent, the most common model in ecological niche modelling (ENM), which estimates the probability of occurrence using presence-only data as a maximum entropy distribution (Phillips *et al.*, 2006).

In order to retain biologically meaningful factors, bioclimatic variables were interpolated for 23 climatic subregions of weather station data with covariates – elevation, cloud cover and distance to coast – thereby adjusting estimates to geoclimatic limits, especially for areas with sparse weather station density and steep environmental gradients such as mountains (Fick & Hijmans, 2017). They capture annual trends (e.g. mean annual temperature, annual precipitation), seasonality (e.g. annual range in temperature and precipitation) and extreme or limiting environmental factors (e.g. temperature of the coldest and warmest month, precipitation of the wet and dry quarters).

The study region falls under six climatologically distinct subregions in Southeastern Europe, the Mediterranean and West-Central Asia, as specified by the Intergovernmental Panel on Climate Change (IPCC) for the sixth assessment report (AR6) (Iturbide *et al.*, 2020; Kim *et al.*, 2020). Climatic models to predict the potential future distributions of the selected pests were chosen under different predicted climatic regimes (GCMs) and socioeconomic scenarios (SSPs). Downscaled monthly future climate data was downloaded from the Coupled

Model Intercomparison Project Phase 6 (CMIP6) for four General Circulation Models (GCMs) and two Shared Socio-economic Pathways (SSPs) for the time period 2040–2060. Here we consider two extreme ends to give a possibility interval: sustainable development (SSP126) and fossil-fuelled development (SSP585). Kim *et al.* (2020), in their evaluation of CMIP6, found that the intermodal spread from 32 CMIP6 models for daily maximum temperatures were narrower than CMIP5, while the daily minimum temperatures were comparable. Even for cooler climates, the bias in surface temperature using the CMIP6 multi-model ensemble (MME) simulation was found to be 0.46°C lower than that of CMIP5 MME (Zhu & Yang, 2020). At the time of analysis, CMIP6 models were yet to be evaluated for use in specific regions, and general model strengths and weaknesses were used to select four GCMs (BCC-CSM2-MR, CNRM-CM6-1, CNRM-ESM2-1, MRI-ESM2-0) that have less bias in predicting the future conditions for the study region.

For all pests, 45 candidate models with parameters reflecting all combinations of three distinct subsets of the 19 bioclimatic variables, five feature classes and three regularization multiplier settings were evaluated using the KUENM package in the R programming language (Cobos *et al.*, 2019). Presence data was downloaded from the GBIF database (GBIF, 2020) and adjusted for sampling bias using the kernel density distribution for all presence records of their taxonomic family.

Current and future climatic habitat suitability for major crop pests

The climate-induced presence or absence of pests in the region is projected for the period 2040–2060. The bioclimatic suitability was used to model with the maximum entropy distribution. Currently, the presence of pests is estimated to be higher in the Caucasus than in Central Asia. Predictions show that Central Asia would have optimal bioclimatic conditions and is projected to experience higher pest occurrence in the future. Based on the analysis of past and current climatic conditions, the Caucasus region has the most suitable conditions for the occurrence of pests *Clavibacter michiganensis*, *Helicoverpa armigera*, *Plasmopara viticola* and *Ustilago maydis*.

The best-fitting models predict more favourable conditions for the occurrence of major pests in Central Asia than in other regions, with much less suitable conditions projected for the Southeastern Europe region. Comparing Central Asia and Southeastern Europe, we see that the predicted occurrence from past and current bioclimatic conditions is much lower for Central Asia than for Southeastern Europe, but this is projected to flip over the 20-year period.

Figure 11 shows suitability maps for the 20 major pests affecting wheat, cotton, maize, potatoes, tomatoes, grapes and sugar beets. The wheat pest *Oulema melanopus* is projected to be of a lesser concern in all regions, while Cephus pygmeus is projected to be of a lesser concern in the western regions but of a greater concern in Central Asia. *Blumeria graminis* is projected to be of a great concern for all regions, especially in Central Asia and some parts of other regions, where the probability of occurrence shifts from almost zero to as high as one. This is indicative of more conducive bioclimatic conditions for *Blumeria graminis* in the medium term of 2040–2060. The wheat pest *Puccinia graminis* is projected to be of major concern in the southern parts of Southeastern Europe, the Caucasus and Central Asia. Although the current distribution range is more in the northwestern areas of Southeastern Europe and Central Asia, the distribution shifts south and east over the 2040–2060 projected period. The distribution of *Mycosphaerella graminicola* shows its dominance in the Caucasus, Southeastern Europe and parts of the eastern Central Asia, but its future distribution range is projected to shift to central and western Central Asia.

The distribution range of the cotton pest *Aphis gossypii* is spread across all regions, but under climate change it will shift mostly to Southeastern Europe, the Caucasus and the northeastern and western subregions of Central Asia. The central and western subregions of Central Asia are projected to have moderately declining conditions. For the cotton pest *Helicoverpa armigera*, conditions are predicted to become less favourable, except in Turkmenistan. *Verticillium dahliae* is predicted to be of a major concern in northern Turkey and Bosnia and Herzegovina. Its future distribution range shows a shift to central Turkey, North Macedonia, Azerbaijan and the greater part of Central Asia. A huge change is projected in the central to southwestern part of Central Asia, affecting Kazakhstan, Uzbekistan and Turkmenistan.

For maize, the pest *Rhopalociphum maidis* is predicted to have moderate suitable conditions for the habitat in the regions, which is likely to decrease in the future. *Ustilago maydis* is predicted to be of greater concern in northern Turkey, Serbia and Bosnia and Herzegovina and the northwestern part of Kazakhstan, and it is projected to continue to be a potential threat in the hinterland of Turkey, the southern Caucasus and the north and southeastern subregions of Central Asia.

For the potato pest *Myzus persicae*, a huge shift is predicted from the western regions of Southeastern Europe and the Caucasus, where the occurrence is projected to decline, to Central Asia, in particular the central parts of Kazakhstan. For the potato disease-causing pest *Phytophthora infestans*, the optimal climatic distribution range is predicted to be the northern subregions of Southeastern Europe, but future predictions show limiting conditions over the 2040–2060 simulated period. While the current distribution range of the potato pest *Clavibacter michiganensis* is the northern parts of the regions, a southward shift is projected to cause significant threats to future potato growing in Turkmenistan, Uzbekistan and southern Turkey, which are currently predicted to have low *C. michiganensis* prevalence.

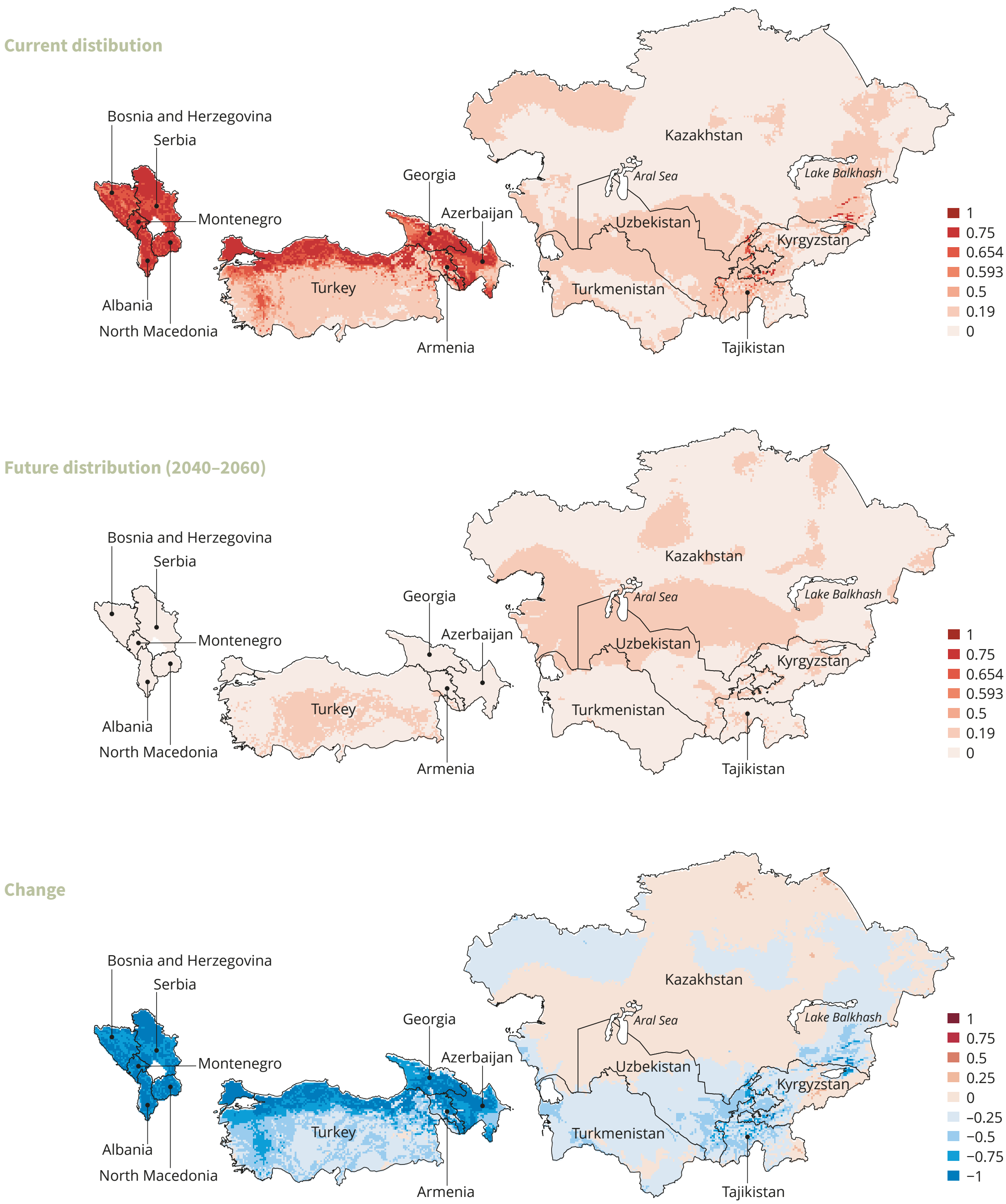
Across the study region, the major tomato pests are predicted (modelled using past and current climatic conditions) and projected (future projections/predictions based on climate change models) to have low to moderate bioclimatic habitat suitability. *Bemisia tabaci* is predicted to have low prevalence, but climate change projections will moderately shift the probabilities of occurrence in Turkey and Uzbekistan. *Tetranychus urticae* is projected to be of a lesser concern in the future, but the current predictions show areas with suitable climatic conditions in Albania, the western part of Turkey, Serbia and Georgia. The tomato pest *Fusarium oxysporum* is predicted to have low possibilities of occurrence in Turkey and Albania, with future shift to southeastern Turkmenistan and Uzbekistan.

Climate change is projected to have lesser impact on major grape pests *Planococcus citri* and *Plasmopara viticola*. Planococcus citri is of a lesser concern, as its bioclimatic suitability range is predicted and projected to be much lower under future climate change. For *Plasmopara viticola*, which is predicted to be prevalent mainly in Southeastern Europe and the Caucasus, future occurrence is projected to drop.

The sugar beet pest *Loxostege sticticalis* is predicted to occur in Central Asia and Southeastern Europe, but its suitability range in the region is projected to significantly decline over the 2040–2060 predicted period. However, the sugar beet pest *Thanatephorus cucumeri*s is projected to increase its distribution, especially in Central Asia's central and western subregions. In Southeastern Europe, a southward shift is projected.

FIGURE 11. Bioclimatic suitability for occurrence of 20 major crop pests, the predicted future distribution and corresponding climate induced change

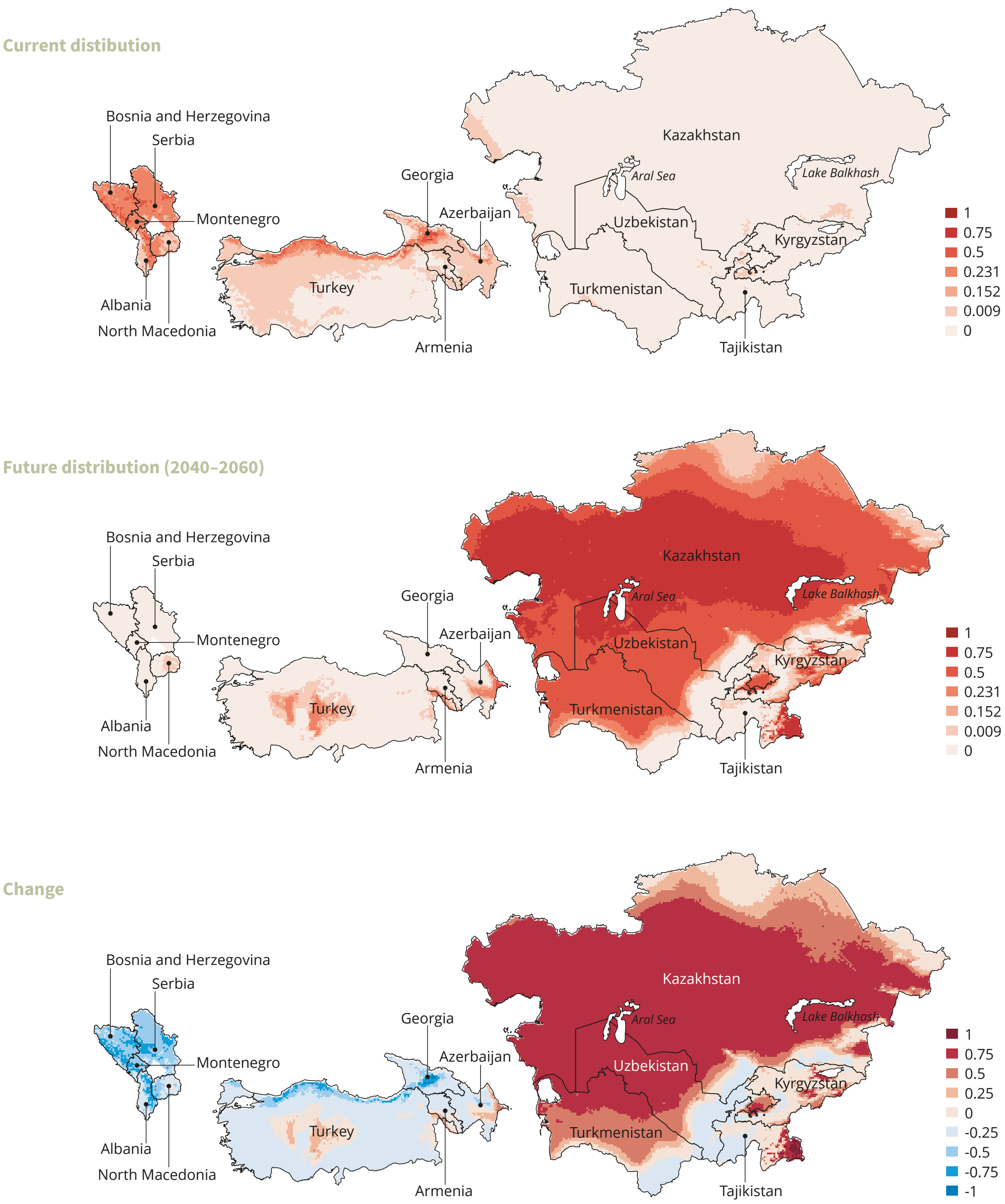
Wheat pests / *Oulema melanopus*



NB: The thresholds used on the legend are from Maxent plus the 0.5 and 0.75 suitability probability.

FIGURE 11. *(cont.)*

Wheat pests *(cont.)* / *Cephus pygmaeus*



NB: The thresholds used on the legend are from Maxent plus the 0.5 and 0.75 suitability probability.

FIGURE 11. *(cont.)*

Wheat pests *(cont.)* / *Blumeria graminis*

Current distibution

Future distribution (2040–2060)

Change

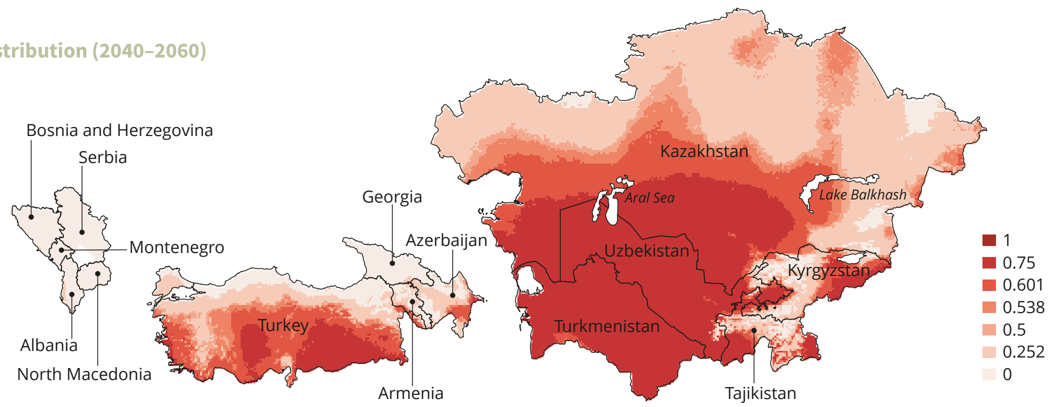
NB: The thresholds used on the legend are from Maxent plus the 0.5 and 0.75 suitability probability.

FIGURE 11. *(cont.)*

Wheat pests *(cont.)* / *Puccinia graminis*

Current distibution

Future distribution (2040–2060)



Change

NB: The thresholds used on the legend are from Maxent plus the 0.5 and 0.75 suitability probability.

FIGURE 11. *(cont.)*

Wheat pests *(cont.)* / *Mycosphaere gramicola*

Current distibution

Future distribution (2040–2060)

Change

NB: The thresholds used on the legend are from Maxent plus the 0.5 and 0.75 suitability probability.

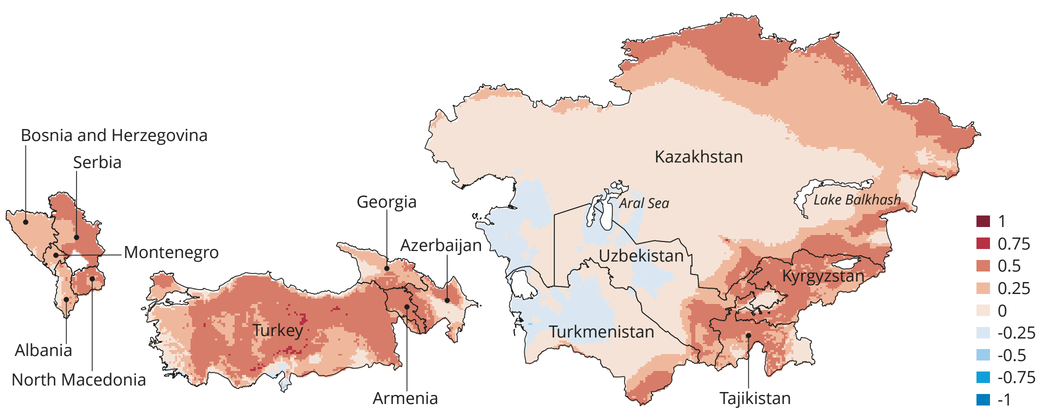
FIGURE 11. *(cont.)*

Cotton pests / *Aphis gossypii*

Current distibution

Future distribution (2040–2060)

Change



NB: The thresholds used on the legend are from Maxent plus the 0.5 and 0.75 suitability probability.

FIGURE 11. *(cont.)*

Cotton pests *(cont.)* / *Helicoverpa armigera*

Current distibution

Future distribution (2040–2060)

Change

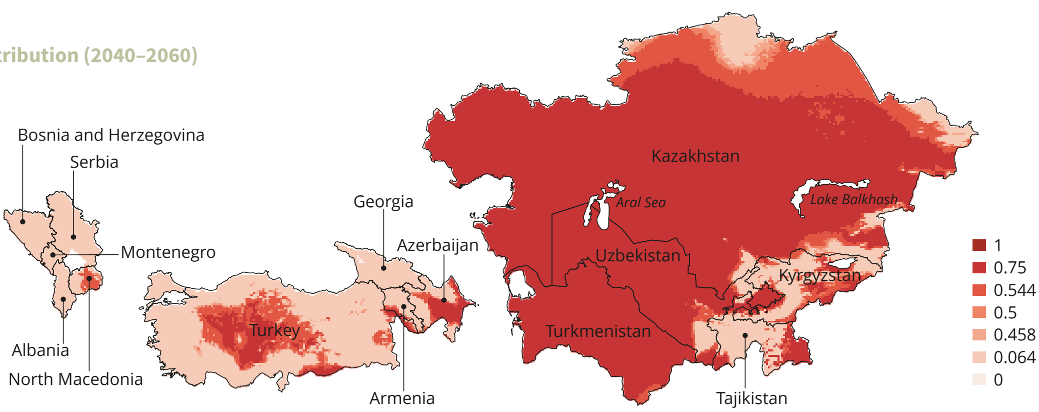
NB: The thresholds used on the legend are from Maxent plus the 0.5 and 0.75 suitability probability.

FIGURE 11. *(cont.)*

Cotton pests *(cont.)* / *Verticillium dahliae*

Current distibution

Future distribution (2040–2060)

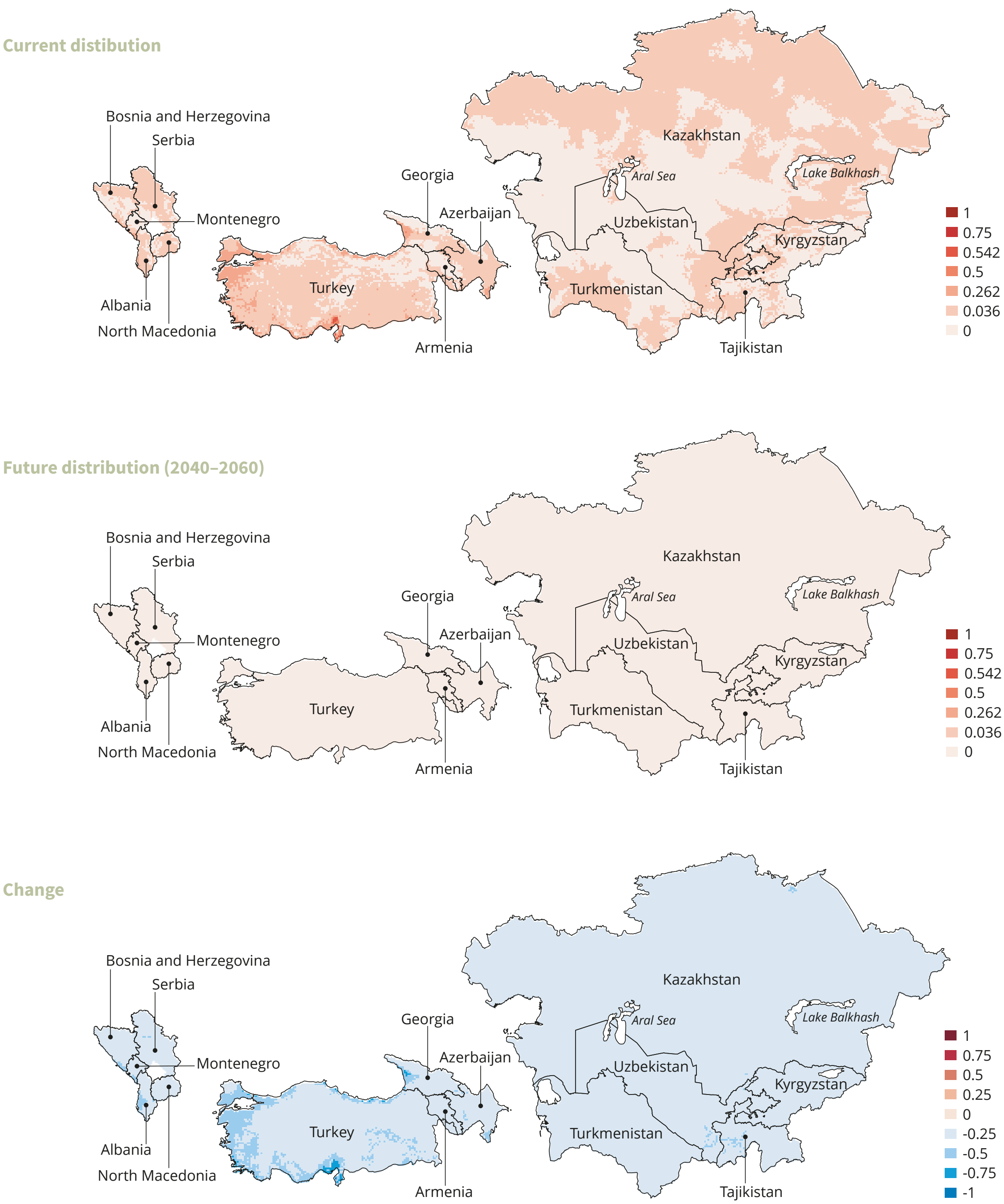


Change

NB: The thresholds used on the legend are from Maxent plus the 0.5 and 0.75 suitability probability.

FIGURE 11. *(cont.)*

Maize pests / *Rhopalosiphum maidis*



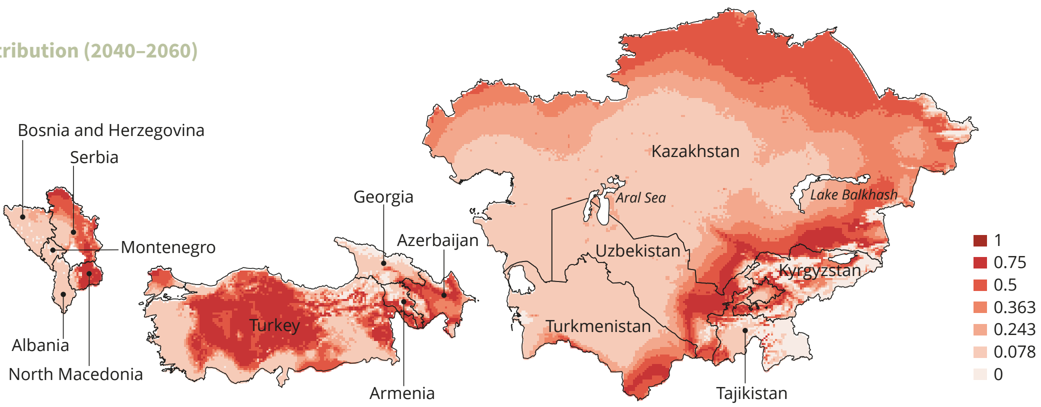
NB: The thresholds used on the legend are from Maxent plus the 0.5 and 0.75 suitability probability.

FIGURE 11. *(cont.)*

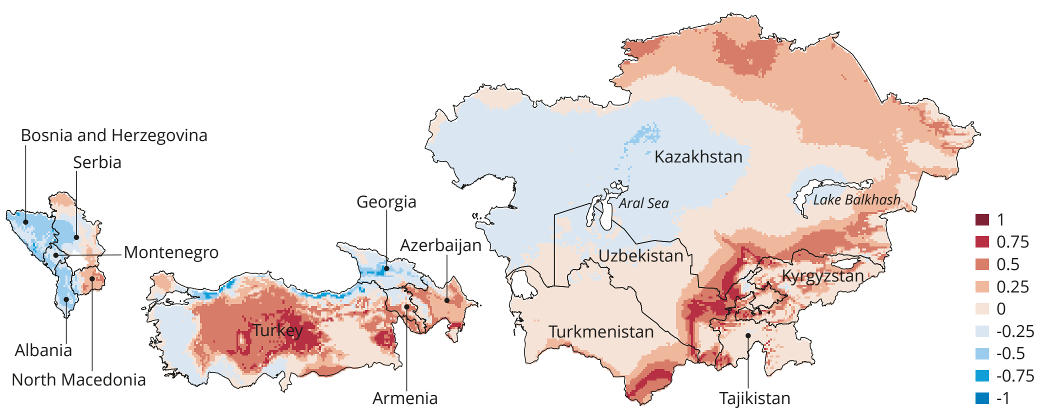
Maize pests *(cont.)* / *Ustilago maydis*

Current distibution

Future distribution (2040–2060)



Change

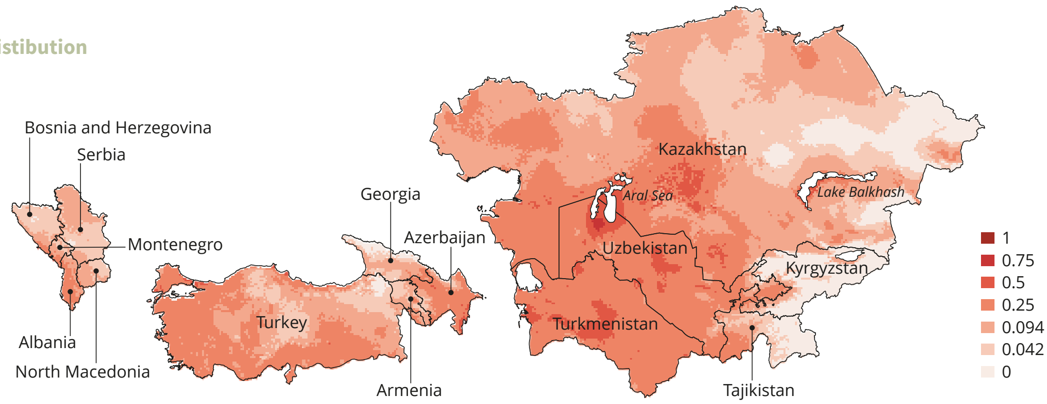


NB: The thresholds used on the legend are from Maxent plus the 0.5 and 0.75 suitability probability.

FIGURE 11. *(cont.)*

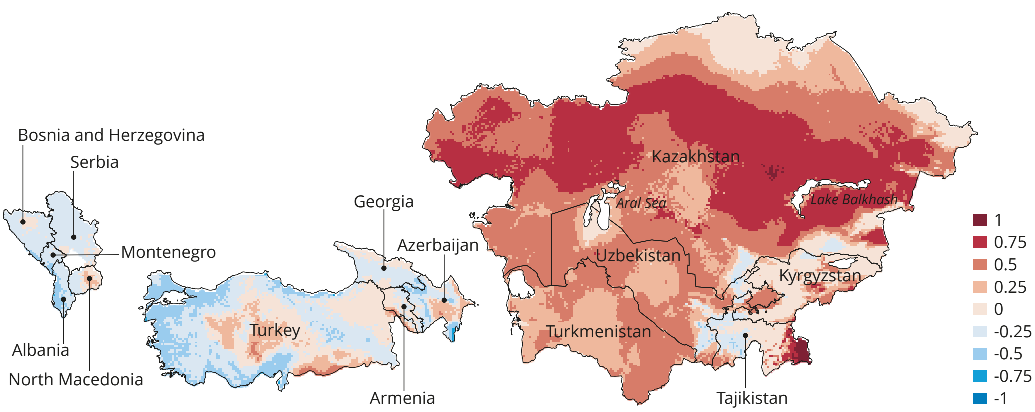
Potato pests / *Myzus persicae*

Current distibution



Future distribution (2040–2060)

Change



NB: The thresholds used on the legend are from Maxent plus the 0.5 and 0.75 suitability probability.

FIGURE 11. *(cont.)*

Potato pests *(cont.)* / *Phytophthora infestans*

Current distibution

Future distribution (2040–2060)

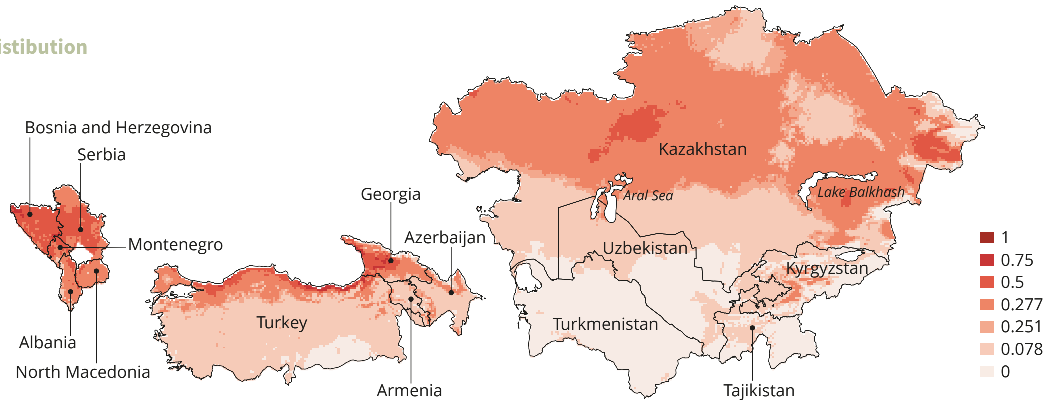
Change

NB: The thresholds used on the legend are from Maxent plus the 0.5 and 0.75 suitability probability.

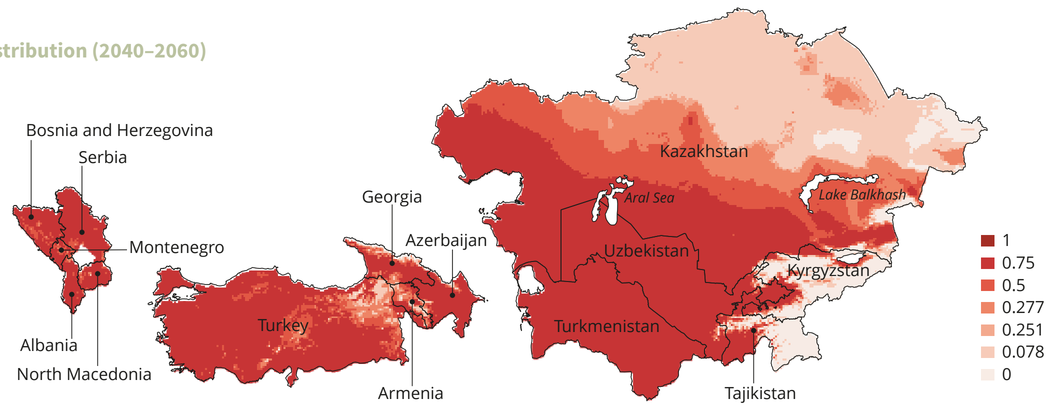
FIGURE 11. *(cont.)*

Potato pests *(cont.)* / *Clavibacter michiganensis*

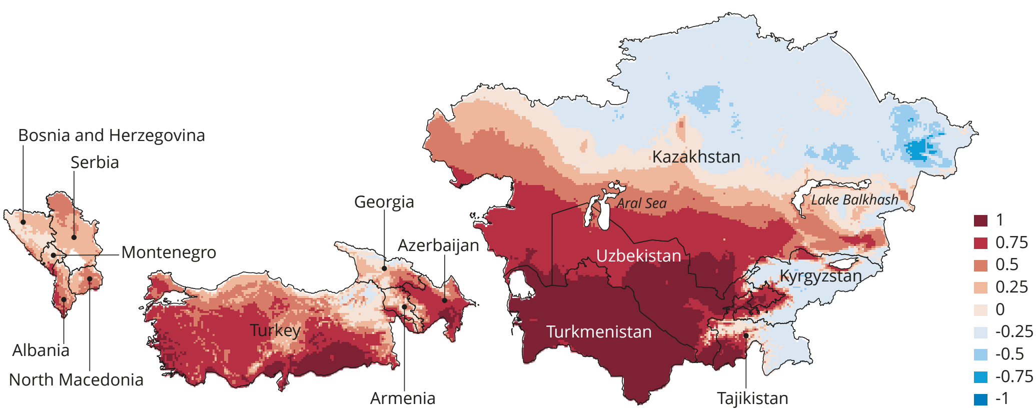
Current distibution



Future distribution (2040–2060)



Change



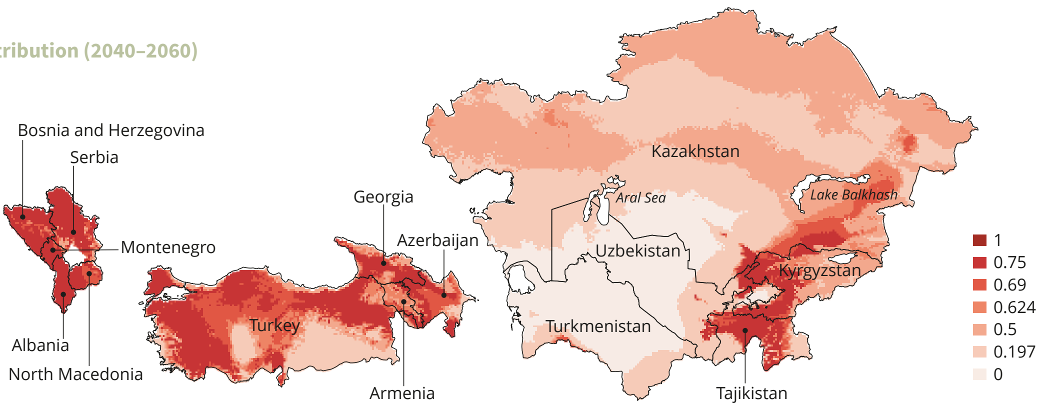
NB: The thresholds used on the legend are from Maxent plus the 0.5 and 0.75 suitability probability.

FIGURE 11. *(cont.)*

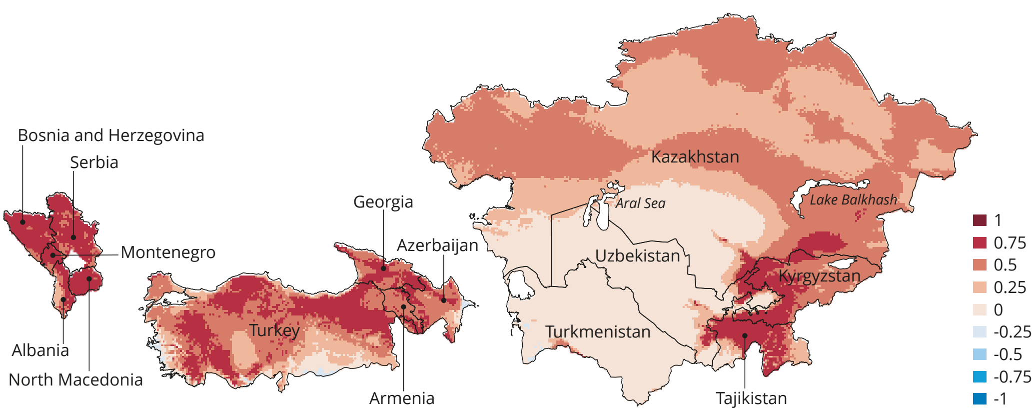
Tomato pests / *Bemisia tabaci*

Current distibution

Future distribution (2040–2060)



Change



NB: The thresholds used on the legend are from Maxent plus the 0.5 and 0.75 suitability probability.

FIGURE 11. *(cont.)*

Tomato pests *(cont.)* / *Tetranychus urticae*

Current distibution

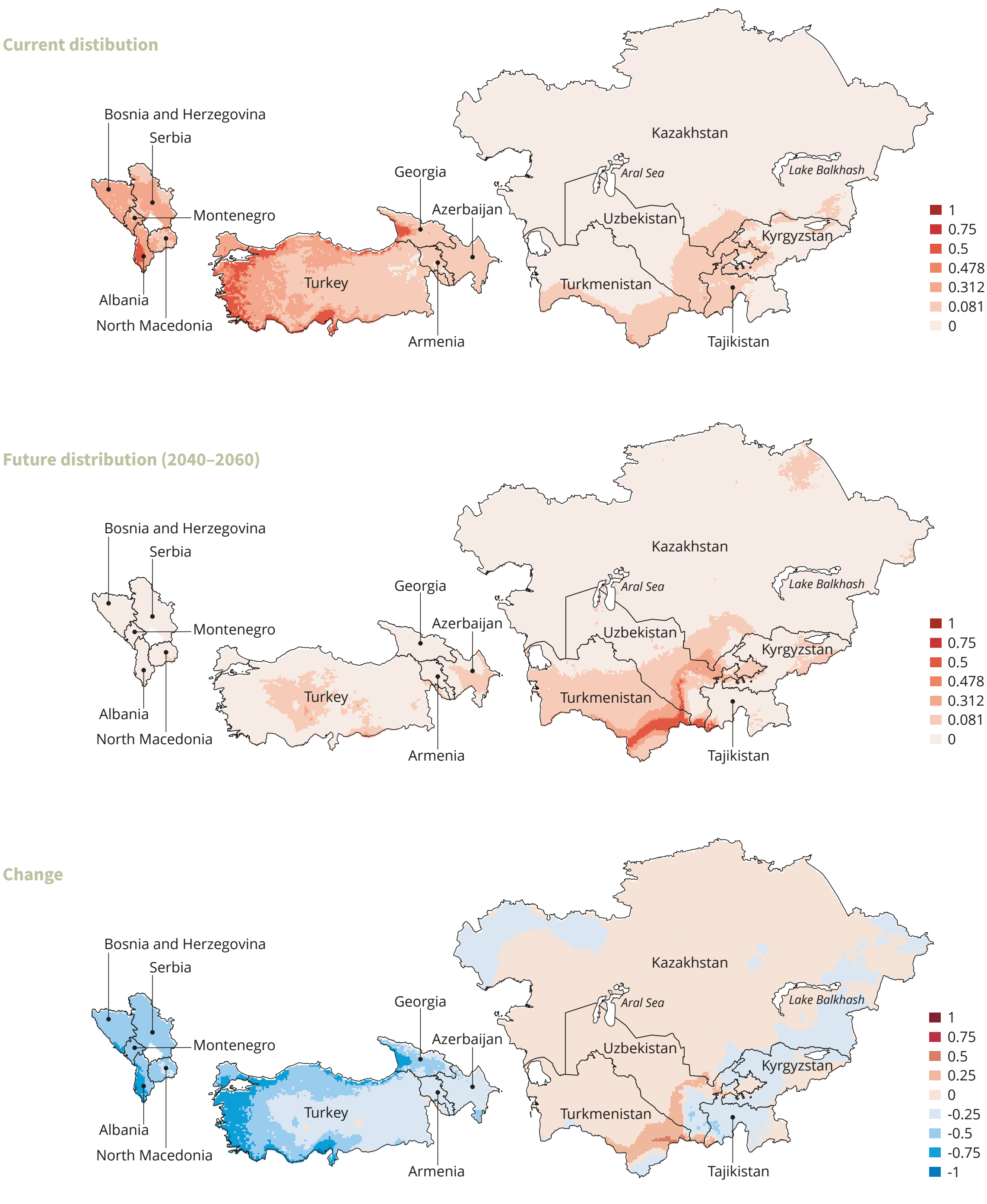
Future distribution (2040–2060)

Change

NB: The thresholds used on the legend are from Maxent plus the 0.5 and 0.75 suitability probability.

FIGURE 11. *(cont.)*

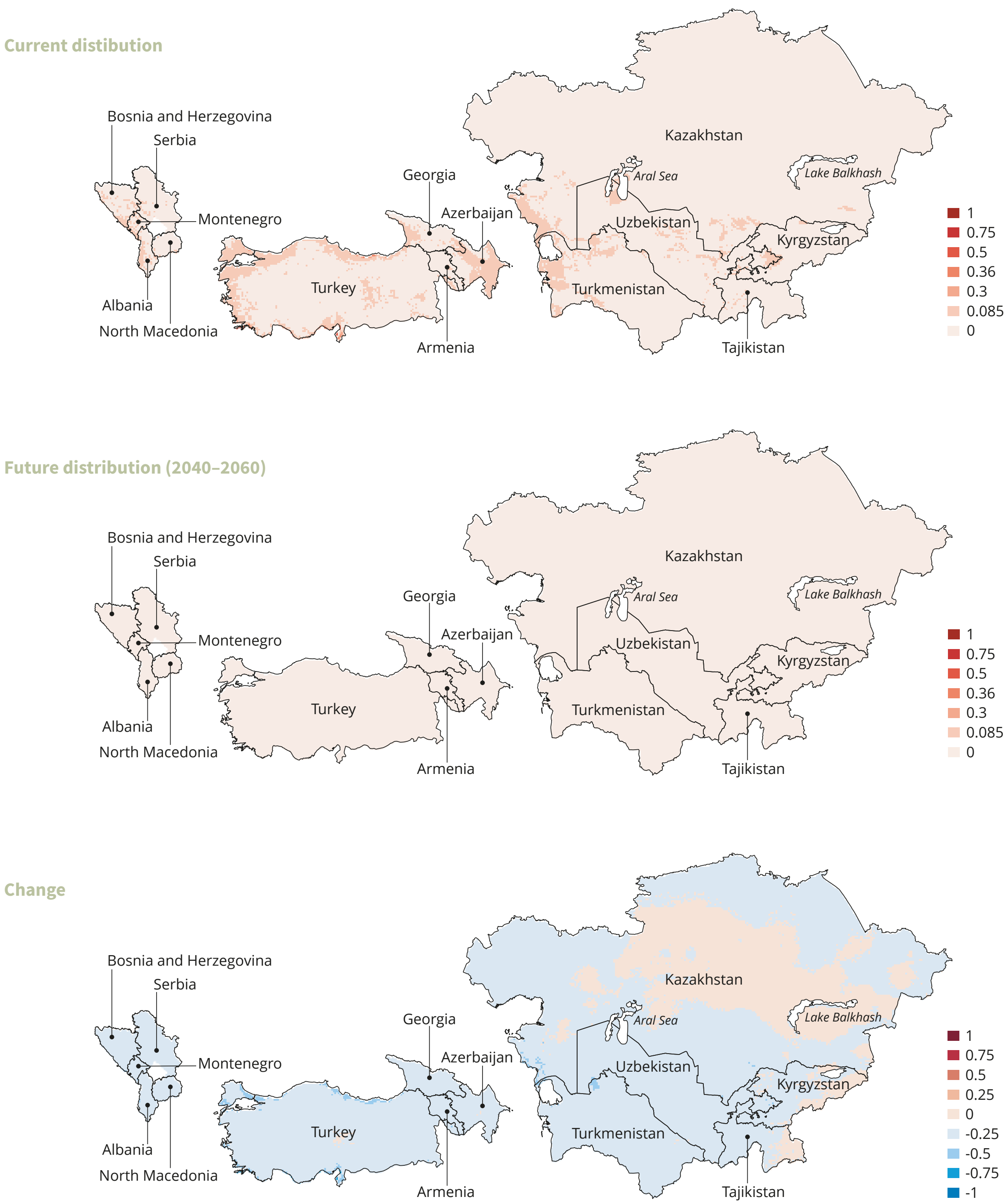
Tomato pests *(cont.)* / *Fusarium oxysporum*



NB: The thresholds used on the legend are from Maxent plus the 0.5 and 0.75 suitability probability.

FIGURE 11. *(cont.)*

Grape pests / *Planococcus citri*

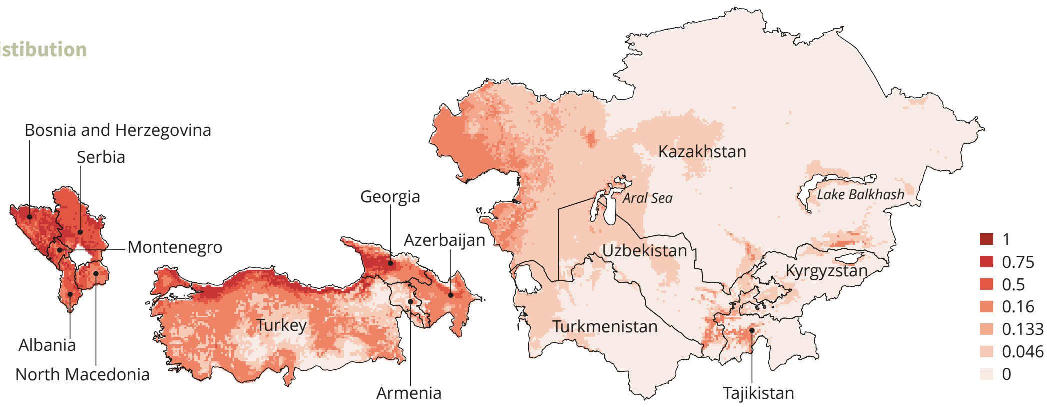


NB: The thresholds used on the legend are from Maxent plus the 0.5 and 0.75 suitability probability.

FIGURE 11. *(cont.)*

Grape pests *(cont.)* / *Plasmopara viticola*

Current distibution



Future distribution (2040–2060)

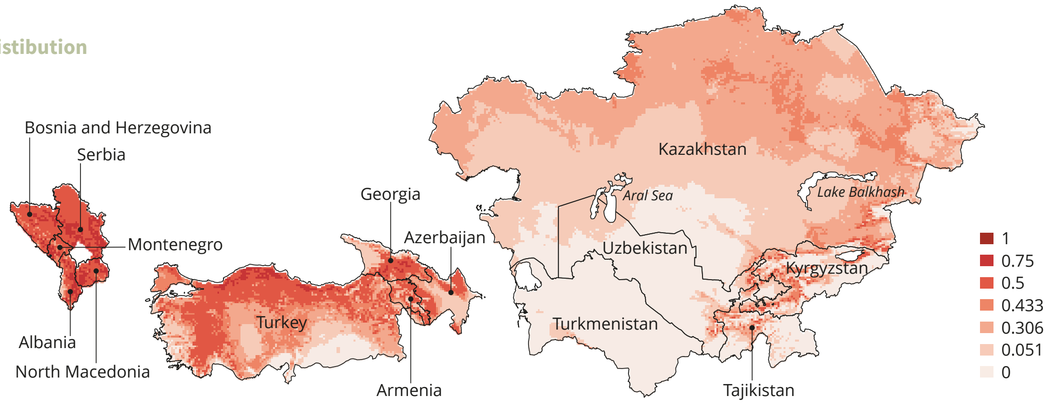
Change

NB: The thresholds used on the legend are from Maxent plus the 0.5 and 0.75 suitability probability.

FIGURE 11. *(cont.)*

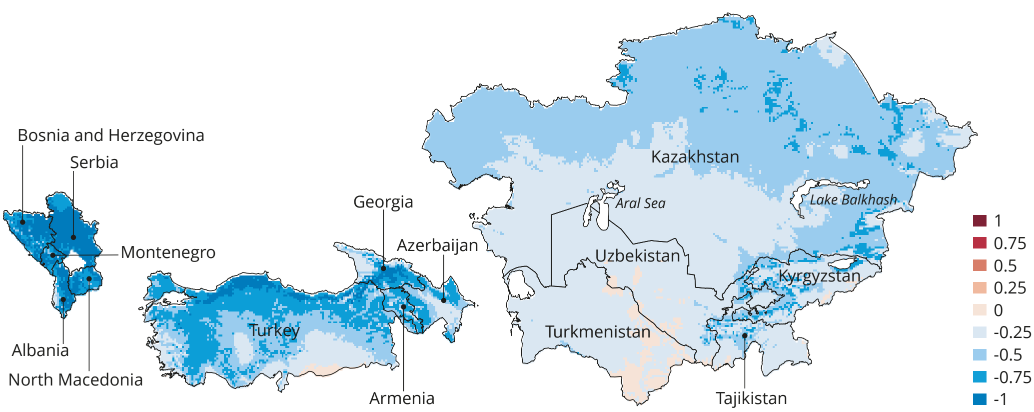
Sugar beet pests / *Loxostege sticticalis*

Current distibution



Future distribution (2040–2060)

Change



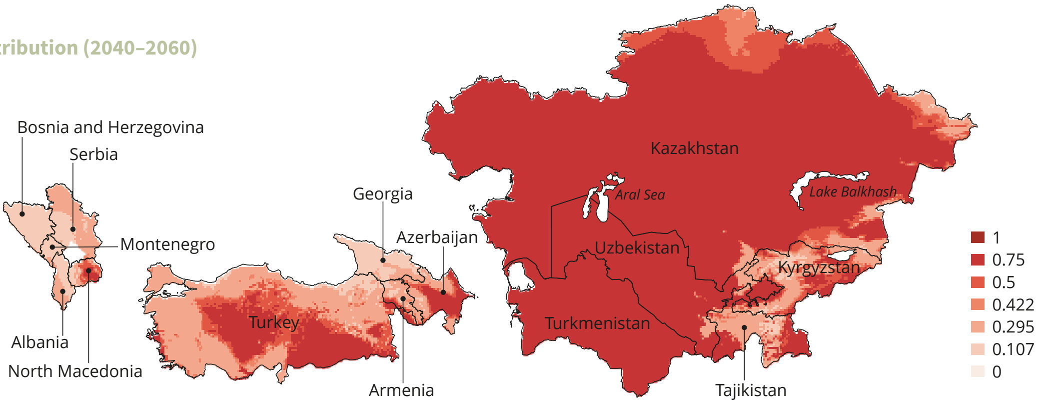
NB: The thresholds used on the legend are from Maxent plus the 0.5 and 0.75 suitability probability.

FIGURE 11. *(cont.)*

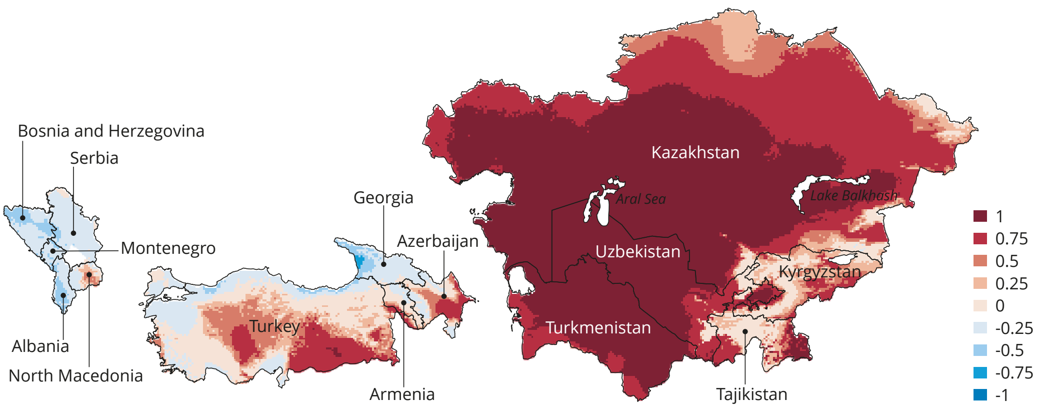
Sugar beet pests *(cont.)* / *Thanatephorus cucume*

Current distibution

Future distribution (2040–2060)



Change



NB: The thresholds used on the legend are from Maxent plus the 0.5 and 0.75 suitability probability.

Source: UN (2020) modified by Authors modelled climate change induced pest distributions.

Note: The pest distributions were modelled using 19 climatic variables for the years 1970 to 2000 (WorldClim.org by Fick and Hijimans, 2017) and pest occurrence data from Global Biodiversity Information Facility (gbif.org, 2020) and then projected for the years 2040—2060 using four General Circulation Models (GCMs) and two Shared Socioeconomic Pathways (SSPs). The country boundaries are from UN (2020).

CURRENT AND FUTURE DISTRIBUTIONS OF PESTS IN CENTRAL ASIA

The results of the analysis of the bioclimatic suitability for the presence of major pests in Central Asia show that conditions are favourable:

- for *Helicoverpa armigera*, *Puccinia graminis* and *Oulema melanopus* in all five Central Asia countries;
- for *Myzus persicae* in all Central Asia countries except Kyrgyzstan;
- for *Loxostege sticticalis* in Kazakhstan and Kyrgyzstan;
- for *Tetranychus urticae* in Turkmenistan and Uzbekistan; and
- for *Ustilago maydis* and *Clavibacter michiganensis* in Kazakhstan.

Climate change is projected to create favourable conditions for the occurrence of *Clavibacter michiganensis*, *Thanatephorus cucumeris*, *Blumeria graminis* and *Cephus pygmeus*. Subtle reduction in climate suitability is projected in Kyrgyzstan and Tajikistan for Helicoverpa armigera; in Kazakhstan, Kyrgyzstan and Tajikistan for *Loxostege sticticalis*; and in Turkmenistan and Uzbekistan for *Tetranychus urtica*e and *Oulema melanopus*.

CURRENT AND FUTURE DISTRIBUTIONS OF PESTS IN THE CAUCASUS REGION

In the Caucasus (Figure 13), the bioclimatic suitability for pests is highly organism- and pathogen-specific. It is projected that climate change would induce increased incidences of the cotton pest Aphis gossypii, the maize pest Ustilago maydis in Armenia and Azerbaijan (with reduced suitability in Georgia), the potato pest Clavibacter michiganensis, the tomato pest Bemisia tabaci, and the wheat pest Blumeria graminis. Significantly reduced suitability is projected for a number of pests in the Georgian region. In all three countries, reduced bioclimatic suitability is projected for the cotton pest Helicoverpa armigera, the sugar beet pest Loxostege sticticalis and the wheat pest Oulema melanopus. In Azerbaijan and Georgia, suitability is furthermore predicted to decrease for the grape pest Plasmopara viticola and the tomato pest Tetranychus urticae. Additionally, reduced suitability throughout Georgia is predicted for the cotton pest Verticillium dahliae, the potato pest Phytophthora infestans and the wheat pest Puccinia graminis. The suitability for Clavibacter michiganensis is projected to increase mainly in Armenia and Azerbaijan and to decrease in Georgia.

CURRENT AND FUTURE DISTRIBUTIONS OF PESTS IN SOUTHEASTERN EUROPE COUNTRIES

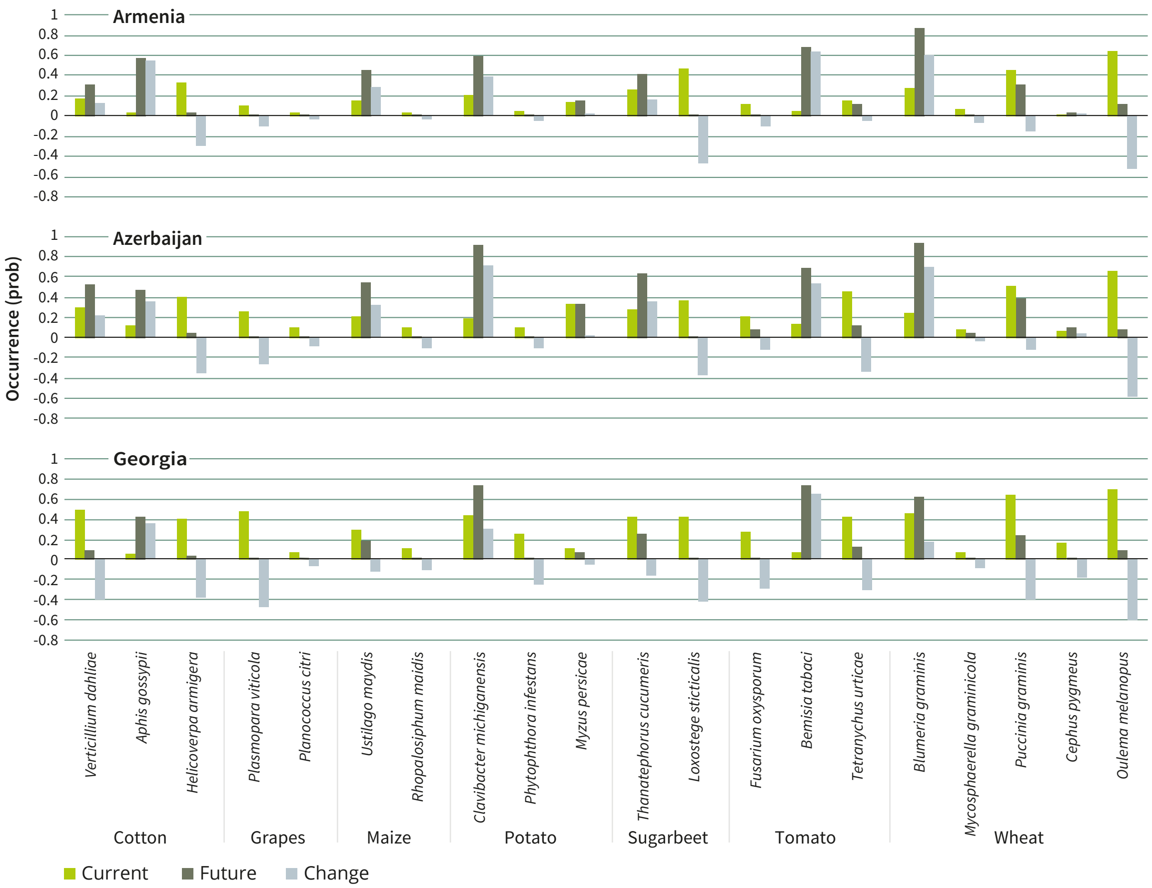
Figure 14 shows that in Southeastern Europe there are more downward-facing bars for change than upward-facing ones. This indicates that, in general, the habitat suitability for pests in the Southeastern Europe region is projected to decline. However, across the region, climate change increases bioclimatic suitability for the cotton pest Aphis gossypii, the potato pest Clavibacter michiganensis, and the tomato pest Bemisia tabaci. Suitability is projected to decrease for the cotton pests Clavibacter michiganensis (though not as much in North Macedonia) and Helicoverpa armigera, the grape pest Plasmopara viticola, the potato pest Phytophthora infestans, the sugar beet pest Loxostege sticticalis, the tomato pests Fusarium oxysporum and Tetranychus urticae, and the wheat pests Puccinia graminis, Cephus pygmeus and Oulema melanopus. Noteworthy, the habitat suitability in the Southeastern Europe region for Oulema melanopus, Plasmopara viticola and Loxostege sticticalis is predicted to be higher, but in the future, it is projected to drop, indicating a much lesser probability of their occurrence. Although habitat suitability for the maize pest Ustilago maydis and the sugar beet pest Thanatephorus cucumeris is projected to decrease in Albania and in Bosnia and Herzegovina, it is expected to increase in Turkey and North Macedonia.

FIGURE 12. Climate change-induced distribution of major crop pests in Central Asia

Source: Authors modelled climate change induced pest distributions.

Note: The pest distributions were modelled using 19 climatic variables for the years 1970 to 2000 (WorldClim.org by Fick and Hijimans, 2017) and pest occurrence data from Global Biodiversity Information Facility (gbif.org, 2020) and then potential change projected for the years 2040—2060 using four General Circulation Models (GCMs) and two Shared Socioeconomic Pathways (SSPs).

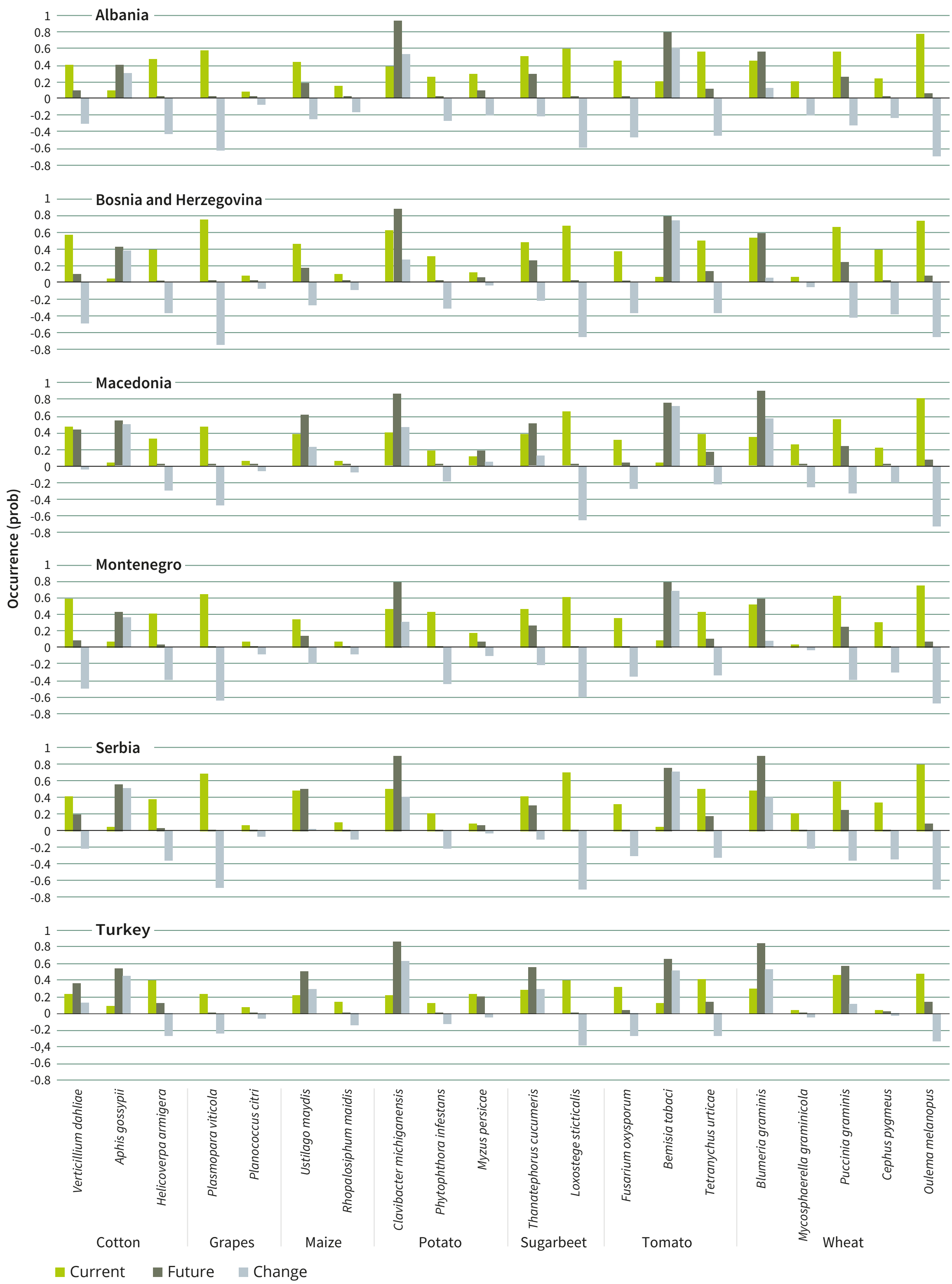
FIGURE 13. Climate change-induced distribution of major crop pests in the Caucasus



Source: Authors modelled climate change induced pest distributions.

Note: The pest distributions were modelled using 19 climatic variables for the years 1970 to 2000 (WorldClim.org by Fick and Hijimans, 2017) and pest occurrence data from Global Biodiversity Information Facility (gbif.org, 2020) and then potential change projected for the years 2040—2060 using four General Circulation Models (GCMs) and two Shared Socioeconomic Pathways (SSPs).

FIGURE 14. Climate change-induced distribution of major crop pests in Southeastern Europe



Source: Authors modelled climate change induced pest distributions.

Note: The pest distributions were modelled using 19 climatic variables for the years 1970 to 2000 (WorldClim.org by Fick and Hijimans, 2017) and pest occurrence data from Global Biodiversity Information Facility (gbif.org, 2020) and then potential change projected for the years 2040—2060 using four General Circulation Models (GCMs) and two Shared Socioeconomic Pathways (SSPs).

Recommendations

ON THE NEED

for monitoring

FOR INDIVIDUAL PATHOGENS

IN SPECIFIC SUBREGIONS

A

griculture continues to play a significant role in the economy and livelihoods in the three subregions: Central Asia, the Caucasus and Southeastern Europe. The agricultural production of USD 100 billion recorded by FAO is short of the potential production if adjusted for pests, which cause crop losses of 8 percent to 30 percent. The region is at crossroads, with climate change projected to create warmer and more humid conditions conducive for pest infestation, exacerbating economic losses by another 10–25 percent, shifting losses from 8–30 percent to 18–55 percent. To a significant extent, these negative effects would be a consequence of induced pest prevalence and potential mass reproduction, which would erode the gains of favourable conditions for crop production. It is therefore imperative for the governments in the region to devise mechanisms for anticipating, monitoring and controlling pests.

Using past and current pest occurrence and bioclimatic data plus the future predicted bioclimate scenarios, this work has revealed that (except for the wheat pest *Blumeria graminis*, which would spread to all parts) the projected hotspots are crop, species and subregion specific. Hence, crop-, pathogen- and region-specific strategies need to be devised.

In Central Asia, projections are for the wheat pest *Cephus pygmaeus* to spread to central Kazakhstan and Uzbekistan, for the wheat pest *Blumeria graminis* to spread widely, and for the pest Puccinia graminis to have wider occurrence in Turkey, Uzbekistan, south Kazakhstan and southeastern Kyrgyzstan. The cotton pest *Verticillium dahliae* and the potato pests Myzus persicae and *Clavibacter michiganensis* are projected to cover the whole area of Turkey, Uzbekistan and Kazakhstan. The sugar beet pest *Thanatephorus cucumeris* is projected to spread across all of Central Asia.

In the Caucasus (Azerbaijan and Armenia) and Southeastern Europe (central Turkey, Serbia and North Macedonia), climate change is projected to enhance bioclimatic suitability for the wheat pest *Blumeria gramini*s, the cotton pest *Aphis gossypi*i and the maize pest *Ustilago maydis*. Meanwhile, climate change is projected to enhance bioclimatic suitability for the tomato pest *Bemisia tabaci*, the potato pest *Clavibacter michiganensis* and the sugar beet pest *Thanatephorus cucumeri*s (in central-southeastern Turkey and eastern North Macedonia).

Climate change is projected to reduce the bioclimatic range for the wheat pest *Oulema melanopus* in Southeastern Europe (except southern Turkey) and in the Caucasus. Similarly, declining climate suitability is projected for the wheat pest *Puccinia graminis* in Southeastern Europe (except southern Turkey) and across Georgia and Armenia. Bioclimatic suitability also is expected to decline for the cotton pest *Helicoverpa armigera* in all subregions of the Caucasus and Southeastern Europe, as well as in Kyrgyzstan and Tajikistan. The climatic suitability for the tomato pest *Tetranychus urticae* is projected to be reduced in Southeastern Europe, the Caucasus, west Turkmenistan, Uzbekistan and Kazakhstan.

REFERENCES

Ahouissoussi, N., Neumann, J. E., & Srivastava, J. P. 2014. *Building resilience to climate change in South Caucasus agriculture (English)* (No. 87601; Directions in Development Agriculture and Rural Development, p. 167). The World Bank. http://documents1.worldbank.org/curated/en/193691468012673593/pdf/Building-resilience-to-climate-change-in-South-Caucasus-agriculture.pdf

Balliu, A., & Çota, E. 2007. BIOLOGICAL CONTROL OF MAIN GREENHOUSE PESTS IN ALBANIA. *Acta Horticulturae*, *729*, 489–492. https://doi.org/10.17660/ActaHortic.2007.729.83

Berger, H. K. 2001. The western corn rootworm (Diabrotica virgifera virgifera): A new maize pest threatening Europe. *EPPO Bulletin*, *31*(3), 411–414. https://doi.org/10.1111/j.1365-2338.2001.tb01021.x

Borgemeister, C. 2020. *The boom and burst of desert locust in northeast Africa* (CRC-TRR 228) [Audio]. https://www.crc228.de/2020/04/20/podcast-the-boom-and-burst-of-desert-locust-in-northeast-africa/

Brust, G. E., & Gotoh, T. 2018. Chapter 5—Mites: Biology, Ecology, and Management. In *Sustainable Management of Arthropod Pests of Tomato* (pp. 111–130). Elsevier. https://doi.org/10.1016/B978-0-12-802441-6.00005-X

CABI. 2020a. *Crop Protection Compendium*. www.cabi.org/cpc

CABI. 2020b. *Invasive Species Compendium*. www.cabi.org/ivc

Callaway, E. 2013. Pathogen genome tracks Irish potato famine back to its roots. *Nature*, nature.2013.13021. https://doi.org/10.1038/nature.2013.13021

Camprag, D., Sekuliã, R., & Kereši, T. 2006. Forecasting of major sugar beet pest occurrence in Serbia during the period. *Proc. Nat. Sci, Matica Srpska Novi Sad.*, 187–194.

CNRM & CERFACS. 2019. *Models and Contribution to CMIP6*. Centre National de Recherches Météorologiques. http://www.umr-cnrm.fr/cmip6/spip.php?rubrique8

Cobos, M. E., Peterson, A. T., Barve, N., & Osorio-Olvera, L. 2019. kuenm: An R package for detailed development of ecological niche models using Maxent. *PeerJ*. https://doi.org/10.7717/peerj.6281

Daku, L. 2002. *Assessing farm-level and aggregate economic impacts of olive integrated pest management programs in Albania: An ex-ante analysis.* [Doctor of Philosophy]. Virginia Polytechnic Institute and State University.

Delić, D., Radulović, M., Vakić, M., A.Sunulahpašić, Villamor, D. E. V., & Tzanetakis, I. E. 2020. Raspberry leaf blotch emaravirus in Bosnia and Herzegovina: Population structure and systemic movement. *Molecular Biology Reports*, *47*(6), 4891–4896. https://doi.org/10.1007/s11033-020-05560-x

Deutsch, C. A., Tewksbury, J. J., Tigchelaar, M., Battisti, D. S., Merrill, S. C., Huey, R. B., & Naylor, R. L. 2018. Increase in crop losses to insect pests in a warming climate. *Science*, *361*(6405), 916–919. https://doi.org/10.1126/science.aat3466

Dixon, J., Gulliver, A., & Gibbon, D. 2001. *Farming systems and poverty: Improving farmers' livelihoods in a changing world*. FAO & World Bank. http://www.fao.org/3/a-ac349e.pdf

FAO. 2020a. *Pesticides Use* (FAOSTAT) [Dataset]. Food and Agriculture Organization of the United Nations. http://www.fao.org/faostat/en/#data/QV

FAO. 2020b. *Production: Value of Agricultural production* (FAOSTAT) [Dataset]. Food and Agriculture Organization of the United Nations. http://www.fao.org/faostat/en/#data/QV

FAO. 2020c. *Protecting plants, protecting life: International year of plant health (IYPH)*. http://www.fao.org/plant-health-2020

Fick, S. E., & Hijmans, R. J. 2017. WorldClim 2: New 1-km spatial resolution climate surfaces for global land areas. *International Journal of Climatology*, *37*(12), 4302–4315. https://doi.org/10.1002/joc.5086

GBIF. 2020. Free and Open Access to Biological Data. https://www.gbif.org/. *Occurrences*. https://www.gbif.org/occurrence/search

Gixhari, B., Hekuran, V., Hajredin, T., & Adriatik, C. 2017. GEOGRAPHIC DISTRIBUTION ASSESSMENT OF THE MAIN WHEAT LEAF DISEASES IN ALBANIA. *International Conference of Ecosystems (ICE2017)*.

Hajima, T., Watanabe, M., Yamamoto, A., Tatebe, H., Noguchi, M. A., Abe, M., Ohgaito, R., Ito, A., Yamazaki, D., Okajima, H., Ito, A., Takata, K., Ogochi, K., Watanabe, S., & Kawamiya, M. 2020. Development of the MIROC-ES2L Earth system model and the evaluation of biogeochemical processes and feedbacks. *Geoscientific Model Development*, *13*(5), 2197–2244. https://doi.org/10.5194/gmd-13-2197-2020

Harris, I., Jones, P. D., Osborn, T. J., & Lister, D. H. 2014. Updated high-resolution grids of monthly climatic observations—The CRU TS3.10 Dataset. *International Journal of Climatology*, *34*, 623–642. https://doi.org/10.1002/joc.3711

Held, I. M., Guo, H., Adcroft, A., Dunne, J. P., Horowitz, L. W., Krasting, J., Shevliakova, E., Winton, M., Zhao, M., Bushuk, M., Wittenberg, A. T., Wyman, B., Xiang, B., Zhang, R., Anderson, W., Balaji, V., Donner, L., Dunne, K., Durachta, J., … Zadeh, N. 2019. Structure and Performance of GFDL's CM4.0 Climate Model. *Journal of Advances in Modeling Earth Systems*, *11*(11), 3691–3727. https://doi.org/10.1029/2019MS001829

Iturbide, M., Gutiérrez, J. M., Alves, L. M., Bedia, J., Cimadevilla, E., Cofiño, A. S., Cerezo-Mota, R., Di Luca, A., Faria, S. H., Gorodetskaya, I., Hauser, M., Herrera, S., Hewitt, H. T., Hennessy, K. J., Jones, R. G., Krakovska, S., Manzanas, R., Marínez-Castro, D., Narisma, G. T., … Vera, C. S. 2020. *An update of IPCC climate reference regions for subcontinental analysis of climate model data: Definition and aggregated datasets* [Preprint]. Data, Algorithms, and Models. https://doi.org/10.5194/essd-2019-258

Karacic, A., & Filipovic, A. 2015. *Survey for the four major viruses in potato 'poluranka' local cultivar in Herzegovina*. 159–162.

Kim, Y.-H., Min, S.-K., Zhang, X., Sillmann, J., & Sandstad, M. 2020. Evaluation of the CMIP6 multi-model ensemble for climate extreme indices. *Weather and Climate Extremes*, *29*, 100269. https://doi.org/10.1016/j.wace.2020.100269

Kolomiets, S. 1999. Populations of Septoria spp. Affecting winter wheat in the forest-steppe zone of the Ukraine. In *Septoria and Stagonospora diseases of cereals: A compilation of global research* (pp. 32–33). CIMMYT.

Kovačević, M., Đurić, Z., Jović, J., Perković, G., Lolić, B., Hrnčić, S., Toševski, I., & Delić, D. 2014. First Report of Stolbur Phytoplasma Associated with Maize Redness Disease of Maize in Bosnia and Herzegovina. *Plant Disease*, *98*(3), 418–418. https://doi.org/10.1094/PDIS-04-13-0371-PDN

Muntyan, E. M., Batco, M. G., Todiras, N. A., & Yazlovetsky, I. G. 2018. The Detection of Echinothrips americanus Morgan (Thysanoptera: Thripidae) in the Republic of Moldova. *Russian Journal of Biological Invasions*, *9*(2), 143–146. https://doi.org/10.1134/S2075111718020078

Natalia, M.-M., Ion, T., Anna, M., & Elena I-S. 2019. *A review of the major pest insects of tomato crops in the Republic of Moldova*. *1*, 1–12.

Oerke, E. C. 2006. Crop losses to pests. *The Journal of Agricultural Science*, *144*(1), 31–43. https://doi.org/10.1017/S0021859605005708

Perić, P., Marčić, D., Prijović, M., Ogurlić, I., & Andrić, G. 2009. EFFECTIVENESS OF BIORATIONAL PESTICIDES FOR CONTROLLING SOME VEGETABLE PESTS IN SERBIA. *Acta Horticulturae*, *830*, 531–538. https://doi.org/10.17660/ActaHortic.2009.830.76

Phillips, S. J., Anderson, R. P., & Schapire, R. E. 2006. Maximum entropy modeling of species geographic distributions. *Ecological Modelling*, *190*(3–4), 231–259. https://doi.org/10.1016/j.ecolmodel.2005.03.026

Prijović, M., Škaljac, M., Drobnjaković, T., Žanić, K., Perić, P., Marčić, D., & Puizina, J. 2014. Genetic variation of the greenhouse whitefly, *Trialeurodes vaporariorum* (Hemiptera: Aleyrodidae), among populations from Serbia and neighbouring countries, as inferred from *COI* sequence variability. *Bulletin of Entomological Research*, *104*(3), 357–366. https://doi.org/10.1017/S0007485314000169

Radonjić, S., & Hrnčić, S. 2017. *A review of new alien arthropod pests and their impact on agriculture crops in montenegro*. 203–210.

Radosavljevic, A., & Anderson, R. P. 2014. Making better Maxent models of species distributions: Complexity, overfitting and evaluation. *Journal of Biogeography*, *41*(4), 629–643. https://doi.org/10.1111/jbi.12227

Rashidvash, V. 2015. The Caucasus, Its Peoples, and Its History. *International Research Journal of Interdisciplinary & Multidisciplinary*, *1*, 30–36.

Richter, I., & Tokinaga, H. 2020. An overview of the performance of CMIP6 models in the tropical Atlantic: Mean state, variability, and remote impacts. *Climate Dynamics*, *55*(9–10), 2579–2601. https://doi.org/10.1007/s00382-020-05409-w

Simova, D., Skuhravá, M., & Skuhravý, V. 2000. GALL MIDGES (DIPTERA: CECIDOMYIIDAE) OF SERBIA. *Acta Entomologica Serbica*, *5*(1/2), 47.

Sivcev, I., Stankovic, S., Kostic, M., Lakic, N., & Popovic, Z. 2009. Population density of *Diabrotica virgifera virgifera* LeConte beetles in Serbian first year and continuous maize fields. *Journal of Applied Entomology*, *133*(6), 430–437. https://doi.org/10.1111/j.1439-0418.2009.01402.x

SORS. 2018. *Statistical Yearbook of the Republic of Serbia, 2018*. Statistical Office of the Republic of Serbia. https://www.stat.gov.rs/en-us/publikacije/publication/?p=11525

Stankovic, S., Zabel, A., Kostic, M., Manojlovic, B., & Rajkovic, S. 2004. Colorado potato beetle [Leptinotarsa decemlineata (Say)] resistance to organophosphates and carbamates in Serbia. *Journal of Pest Science*, *77*(1), 11–15. https://doi.org/10.1007/s10340-003-0020-7

Sugonyaev, E. 2009. IPM Programs in Commonwealth of Independent States and Russia. In R. Peshin & A. Dhawan (Eds.), *Integrated Pest Management: Dissemination and Impact* (pp. 455–479). Springer Netherlands.

Swart, N. C., Cole, J. N. S., Kharin, V. V., Lazare, M., Scinocca, J. F., Gillett, N. P., Anstey, J., Arora, V., Christian, J. R., Hanna, S., Jiao, Y., Lee, W. G., Majaess, F., Saenko, O. A., Seiler, C., Seinen, C., Shao, A., Solheim, L., von Salzen, K., … Winter, B. 2019. *The Canadian Earth System Model version 5 (CanESM5.0.3)* [Preprint]. Climate and Earth System Modeling. https://doi.org/10.5194/gmd-2019-177

Timus, A., & Croitora, N. 2006. The Phytosanitary form and fighting measure Against disease and pest of Sugar Beet from Republic of Moldova. *International Symposium on Sugar Beet*, 227–238.

UNFCCC. 2013. *Second national communication of Bosnia and Herzegovina under the United Nations Framework Convention on Climate Change*. Council of ministers of Bosnia and Herzegovina.

UN. 2020. *Map of the World* [online]. [Cited 1 January 2021]. un.org/geospatial/file/3420/download?token=bZe9T8I9?

Voldoire, A., Saint-Martin, D., Sénési, S., Decharme, B., Alias, A., Chevallier, M., Colin, J., Guérémy, J. -F., Michou, M., Moine, M. -P., Nabat, P., Roehrig, R., Salas y Mélia, D., Séférian, R., Valcke, S., Beau, I., Belamari, S., Berthet, S., Cassou, C., … Waldman, R. 2019. Evaluation of CMIP6 DECK Experiments With CNRM-CM611. *Journal of Advances in Modeling Earth Systems*, *11*(7), 2177–2213. https://doi.org/10.1029/2019MS001683

Willis, K. J. 2017. *State of the World's Plants* [Report]. Royal Botanic Gardens.

Wu, T., Lu, Y., Fang, Y., Xin, X., Li, L., Li, W., Jie, W., Zhang, J., Liu, Y., Zhang, L., Zhang, F., Zhang, Y., Wu, F., Li, J., Chu, M., Wang, Z., Shi, X., Liu, X., Wei, M., … Liu, X. 2019. The Beijing Climate Center Climate System Model (BCC-CSM): The main progress from CMIP5 to CMIP6. *Geoscientific Model Development*, *12*(4), 1573–1600. https://doi.org/10.5194/gmd-12-1573-2019

Xin, X. 2019. Performance of BCC-CSM2-MR in simulating summer climate changes in East Asia. *Geophysical Research Abstracts*, *21*.

Yukimoto, S., Kawai, H., Koshiro, T., Oshima, N., Yoshida, K., Urakawa, S., Tsujino, H., Deushi, M., Tanaka, T., Hosaka, M., Yabu, S., Yoshimura, H., Shindo, E., Mizuta, R., Obata, A., Adachi, Y., & Ishii, M. 2019. The Meteorological Research Institute Earth System Model Version 2.0, MRI-ESM2.0: Description and Basic Evaluation of the Physical Component. *Journal of the Meteorological Society of Japan. Ser. II*, *97*(5), 931–965. https://doi.org/10.2151/jmsj.2019-051

Zhu, Y.-Y., & Yang, S. 2020. Evaluation of CMIP6 for historical temperature and precipitation over the Tibetan Plateau and its comparison with CMIP5. *Advances in Climate Change Research*, S1674927820300617. https://doi.org/10.1016/j.accre.2020.08.001

Zurovec, O., Vedeld, P., & Sitaula, B. 2015. Agricultural Sector of Bosnia and Herzegovina and Climate Change–Challenges and Opportunities. *Agriculture*, *5*(2), 245–266. https://doi.org/10.3390/agriculture5020245

ISBN 978-92-5-134776-8

9 789251 347768

CB5954EN/1/11.21