Chapter 5

Influence of Climate Change on Weed Vegetation

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Additional information is available at the end of the chapter

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1. Introduction

Climate is the biggest abiotical factor influencing the whole vegetation. At climate changing conditions adaptation ability of vegetation changes to grow in certain territory. Competitive abilities of plants are changing showing through new plant and weed biological qualities.

Global warming and climate change refer to an increase in average global temperatures. Global warming is primarily caused by increases in "greenhouse" gases (GHG). A warming planet thus leads to climate changes which can adversely affect weather in different ways. Some of the prominent indicators for a global warming are: temperature over land, snow cover and glaciers on hills, ocean heat content, sea ice, sea level, sea surface temperature, temperature over ocean, humidity, tropospheric temperature. Global warming in today's scenario is threat to the survival of mankind [55]. Climate change inspired by global warming could lead to change of natural climatic zones, i.e. Tundra would disappear, Taiga would decrease essentially, Mediterranean climate zone would decrease and move to north, deserts and Arid world zones would move 400-800 km north to populous subtropical areas, main agricultural zones would move to north areas with low-fertile and worse soils [56, 57]. Global warming is closely associated as well with a broad spectrum of other climate changes, such as increases in the frequency of intense rainfall, decreases in snow cover and sea ice, more frequent and intense heat waves, rising sea levels, and widespread ocean acidification [55].

"*The damage that climate change is causing and that will get worse if we fail to act goes beyond the hundreds of thousands of lives, homes and businesses lost, ecosystems destroyed, species driven to extinction, infrastructure smashed and people inconvenienced.*" – David Suzuki[1]

1 Suzuki D. BrainyQuote.com, XploreInc, 2014. Available from http://www.brainyquote.com/quotes/quotes/d/davidsuzuk471841.html

Seasons of the years are constantly attended by the increase of marginal air conditions. Many researchers agree that anthropogenic activity is reason for climate change and it induced changes of the nature [1]. Agriculture and forestry take important place in Lithuanian national economy, therefore it is actual to adjust those sectors to climate change for mitigating consequences [2]. The constant competition between agricultural plants and weeds is seen in agro-ecosystems when the yields minimize. Alongside with other factors its progress can be explained by the plant resistance to abiotical factors. Different sensitivity of various varieties and their adaptability to the human activity may govern their relationship in agro-ecosystems. Thus, the adaptability of different abiotical factors for both agricultural plants and weeds should be estimated [3]. Weed spreading regularities are significantly dependent on weed ability to adapt, that is to adapt to changeable factors of environment.

Analogous weed chemical composition to agricultural plants induces competition in agro-phytocenoses for growth factors. Weeds occupied place where agricultural plants could grow [4]. Adaptation possibility of separate plant species is different and can vary their competition as environment conditions change. It can cause serious agricultural problems. Undesirable change of plant species follows when environment conditions vary in ecosystems. Usually weeds signify by higher plasticity [5].

Biological invasions and climate warming are two major threats to the world's biodiversity. To date, their impacts have largely been considered independently, despite indications that climate warming may increase the success of many invasive alien species [50].

The climate system is a complex, interactive system consisting of the atmosphere, land surface, snow and ice, oceans and other bodies of water, and living things. Climate is usually described in terms of the mean and variability of temperature, precipitation and wind over a period of time, ranging from months to millions of years (the classical period is 30 years) [6]. Observations of the climate system are based on direct measurements and remote sensing from satellites and other platforms. Global-scale observations from the instrumental era began in the mid-19th century for temperature and other variables. Paleoclimate reconstructions extended some records back hundreds to millions of years [7].

Changes in the atmospheric abundance of greenhouse gases and aerosols, in solar radiation and in land surface properties alter the energy balance of the climate system [8]. Global GHG emissions due to human activities have grown since pre-industrial times, with an increase of 70% between 1970 and 2004 (Figure 1). Annual CO_2 emissions from fossil fuel combustion and cement production were 8.3 GtC12 yr^{-1} averaged over 2002-2011 and were 9.5 GtC yr^{-1} in 2011, 54% more than the level in 1990. Annual net CO_2 emissions from anthropogenic land use change were 0.9 GtC yr^{-1} on average during 2002 to 2011 [7]. The global atmospheric concentration of carbon dioxide has increased from a pre-industrial value of about 280 ppm to 379 ppm in 2005 (Figure 2). The annual carbon dioxide concentration growth rate was larger during the last 10 years (1995-2005 average: 1.9 ppm per year), than it has been during 1960-2005 (average: 1.4 ppm per year) although there is year-to-year variability in growth rates [8]. In 2011 the concentrations of CO_2 were 391 ppm, and exceeded the pre-industrial levels by about 40% [7].

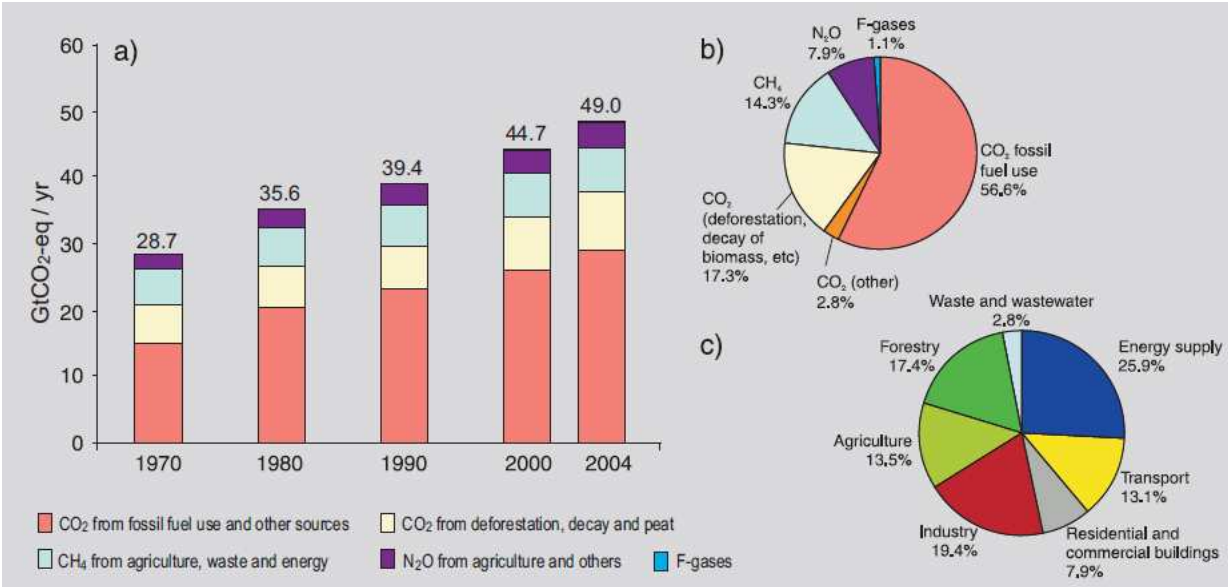

Figure 1. a) Global annual emissions of anthropogenic GHGs from 1970 to 2004. (b) Share of different anthropogenic GHGs in total emissions in 2004 in terms of carbon dioxide equivalents (CO_2-eq). (c) Share of different sectors in total anthropogenic GHG emissions in 2004 in terms of CO_2-eq (Forestry includes deforestation). Source: Climate Change 2007: Synthesis Report [9]

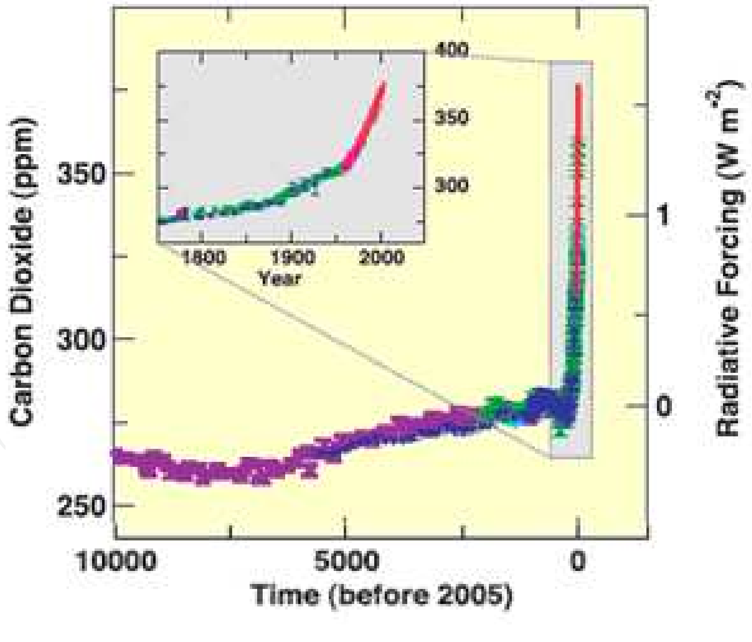

Figure 2. Atmospheric concentrations of carbon dioxide over the last 10,000 years (large panels) and since 1750 (inset panels). Measurements are shown from ice cores (symbols with different colours for different studies) and atmospheric samples (red lines). The corresponding radiative forcings are shown on the right hand axes of the large panels. Source: IPCC, 2007: Summary for Policymakers [8]

The great part of GHG emissions locally, i.e. in Lithuania evaluating separate sectors of economy, is generated from energy supply objects and transport (Figure 3). It is in accordance with other developed industrial countries. As well it is forecasted increase of CO_2 emissions till 2030 in all sectors of economy in Lithuania (Figure 3). Lithuania together with other modern world countries work solving global climate change problems. In Lithuania annual GHG emission terms of carbon dioxide equivalents (CO_2-eq) covered about 4-5 tons per inhabitant and is one of the lowest in European countries where annual GHG of CO_2-eq is about 3-15 tons per inhabitant [10].

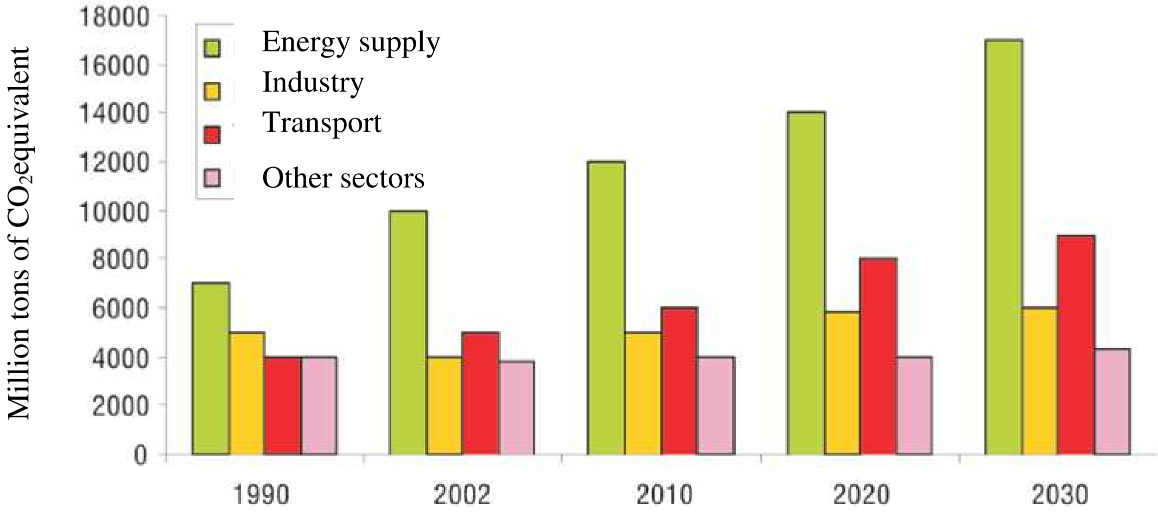

Figure 3. Present and forecasted share of anthropogenic GHGs in total emission in terms of carbon dioxide equivalent (CO_2-eq) in Lithuania. Source: Ministry of Environment of the Republic of Lithuania [10]

Global warming is the increase of the average temperature of the Earth's near-surface air and the oceans since the mid-twentieth century and its projected continuation. Global mean surface temperature anomaly relative to 1961–1990 is presented in figure 4. Each of the last three decades has been successively warmer at the Earth’s surface than any preceding decade since 1850 [7]. The warmest eleven years from twelve records in the world since 1850 were stated in the period of 1995-2006 [8].

In Lithuania there was registered unique climate expression – even seven warm winters successively in the period of 1988/1989 – 1994/1995. Such long period of anomalously warm winters in the Baltic region were not registered during last 200 years [13]. Climate changes in Lithuania manifest through increasing air temperatures and precipitation during winter and slightly increase of air temperatures and decrease of precipitation during summer time [14].

Dynamics of average air temperature in Lithuania during 1961–2006 is presented in figure 5. The results from three locations, i.e. Klaipėda, Kaunas and Vilnius, showed increasing calculated trend-lines (dotted lines) and actual air temperature variation (solid lines).

Lithuanian average year air temperature in 1991–2006 increased by 0.7-1.0 °C relatively to 1961-1990 (Figure 6). That shows fast local climate warming in Lithuania. Climate warming

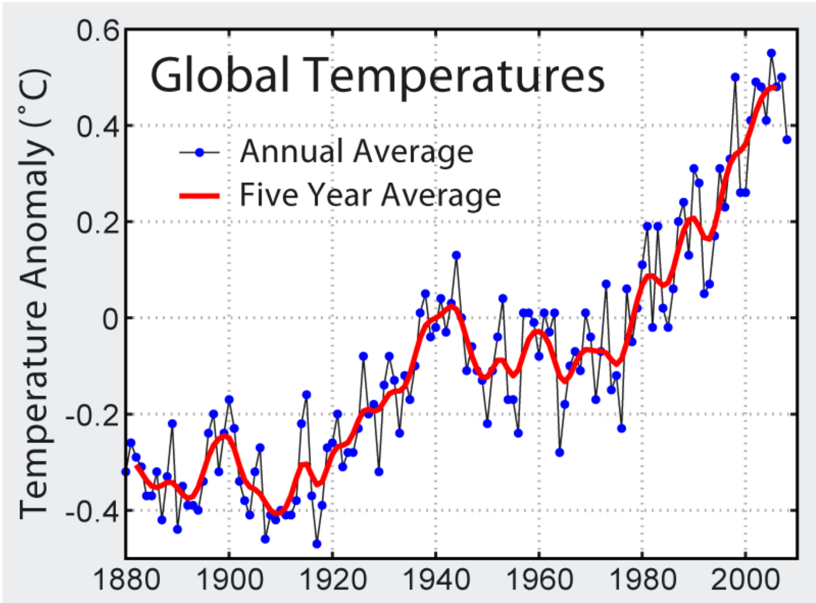

Figure 4. Global mean surface temperature anomaly relative to 1961–1990. Source: Climate Change 2007: The Physical Science Basis [8, 11, 12]

tendencies are the most expressed in North and West Lithuania. Therefore, the last 16 year (1991-2006) average air temperature in Lithuania overcame the limit of 6°C.

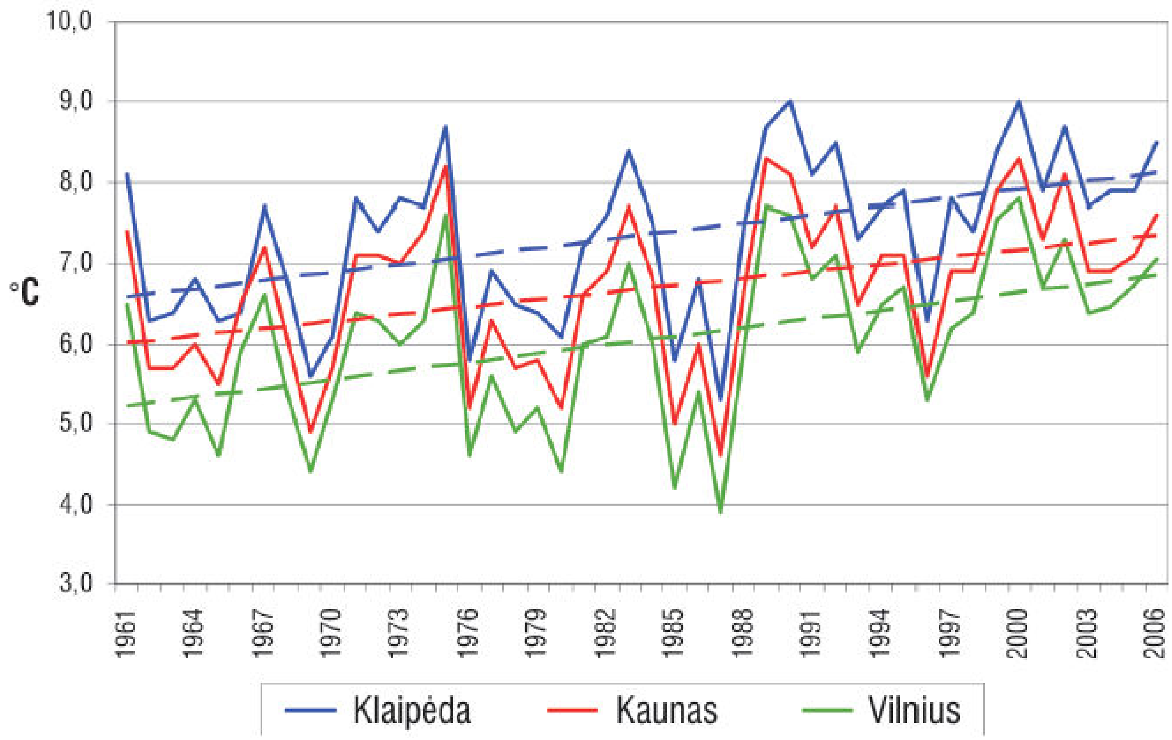

Figure 5. Average year air temperature (°C) change dynamics linear trends (dotted lines) in Lithuania during 1961–2006. Source: Lithuanian Hydrometeorological Service under the Ministry of Environment [10]

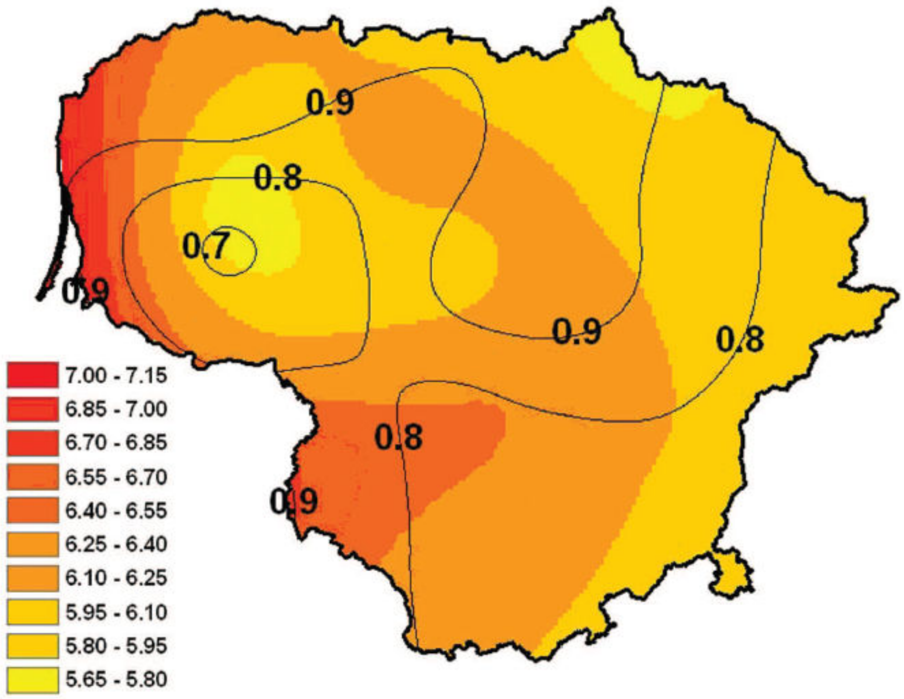

Figure 6. Lithuanian average year air temperature (°C) in 1961–1990. The air temperature differences between 1961-1990 and 1991-2006 are shown by isolines. Source: Lithuanian Hydrometeorological Service under the Ministry of Environment [10]

During the second half of the 20th century and early part of the 21st century, global average surface temperature increased and sea level rose. Over the same period, the amount of snow cover in the Northern Hemisphere decreased (Figure 7). If radiative forcing was to be stabilised in 2100 at A1B levels, thermal expansion alone would lead to 0.3 to 0.8 m of sea level rise by 2300 (relatively to 1980–1999) [8].

The best estimates and likely ranges for global average surface air warming for six SRES emissions marker scenarios are shown in figure 8. Including uncertainties in the future greenhouse gas concentrations and climate sensitivity, the IPCC, scientific intergovernmental body set up by the World Meteorological Organization (WMO) and by the United Nations Environment Programme (UNEP), anticipates a warming of 1.1°C to 6.4°C by the end of the 21st century, relatively to 1980–1999 [8].

The globally averaged combined land and ocean surface temperature data show a warming of 0.85°C, over the period of 1880 to 2012. The total increase between the average of the 1850–1900 and the 2003–2012 periods is 0.78°C. For the longest period when calculation of regional trends is sufficiently complete (1901 to 2012), almost the entire globe has experienced surface warming [7]. If radiative forcing was to be stabilised in 2100 at B1or A1B levels (Figure 8), a further increase in global average temperature of about 0.5°C would be still expected, mostly by 2200. Thermal expansion would continue for many centuries, due to the time required to transport heat into the deep ocean [8].

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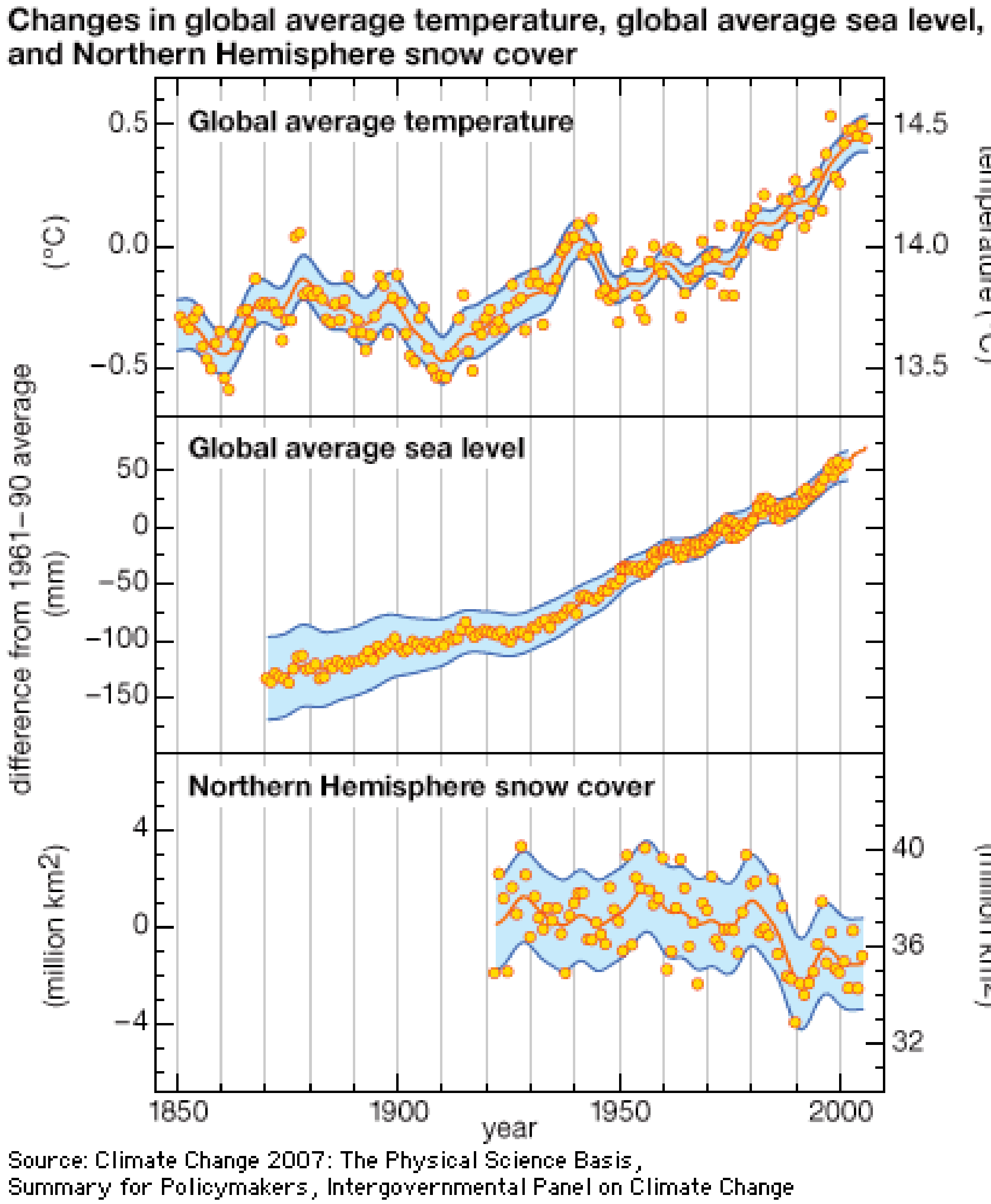

Figure 7. Changes in global average temperature, global average sea level and Northern Hemisphere snow cover. Source: Climate Change 2007: The Physical Science Basis, Summary for Policymakers, IPCC [8]

Over the last two decades, the Greenland and Antarctic ice sheets have been losing mass, glaciers have continued to shrink almost worldwide, and Arctic sea ice and Northern Hemisphere spring snow cover have continued to decrease in extent [7]. Analogous to global tendencies, due to warming climate, day number with snow cover became more unstable and is being decreasing in Lithuania. Day number with snow cover during 1991-2006 relatively to 1961-1990 averagely decreased by 4-10 days (Figure 9). However, during winter emerging maximal snow cover thick increased by 0.8-2.0 cm. It is connected with last year's increase of cold season precipitation amount and more often heavy snowing [10].

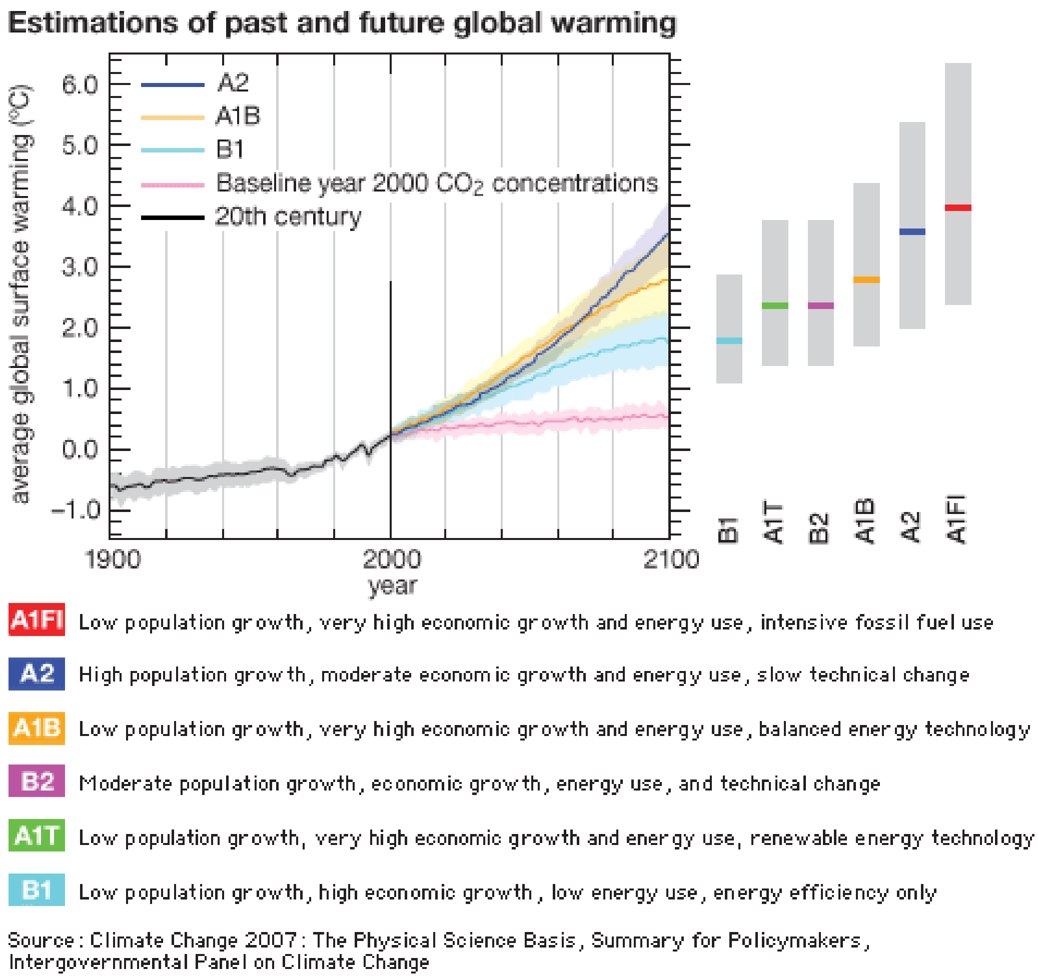

Figure 8. Global warming: estimations of past and future global warming. Source: Climate Change 2007: The Physical Science Basis, Summary for Policymakers, IPCC [8]

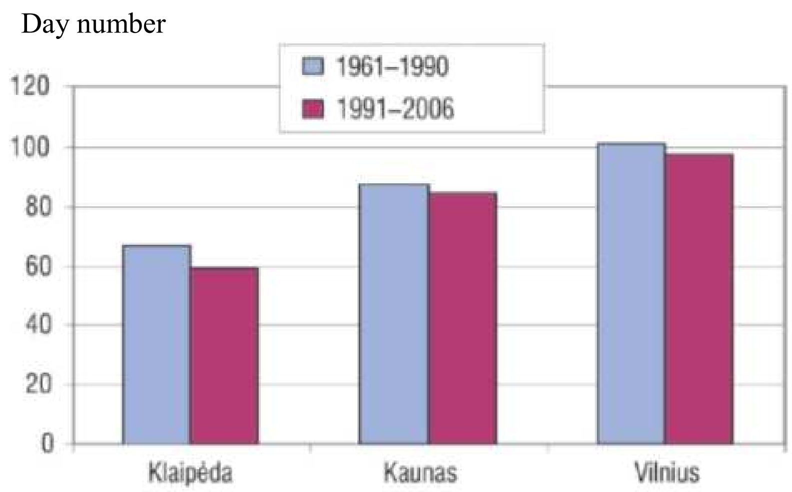

Figure 9. Average number of days with snow cover in Klaipėda, Kaunas and Vilnius, Lithuania during 1961-1990 and 1991-2006. Source: Lithuanian Hydrometeorological Service under the Ministry of Environment [10]

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Projected global average surface warming for 2020-2029 and the end of the 21st century (2090–2099) relatively to 1980–1999 are shown in figure 10. Projected warming in the 21st century shows scenario independent geographical patterns similar to those observed over the past several decades. Warming is expected to be the greatest over land and at the highest northern latitudes, and the least over the Southern Ocean and parts of the North Atlantic Ocean (Figure 10) [8].

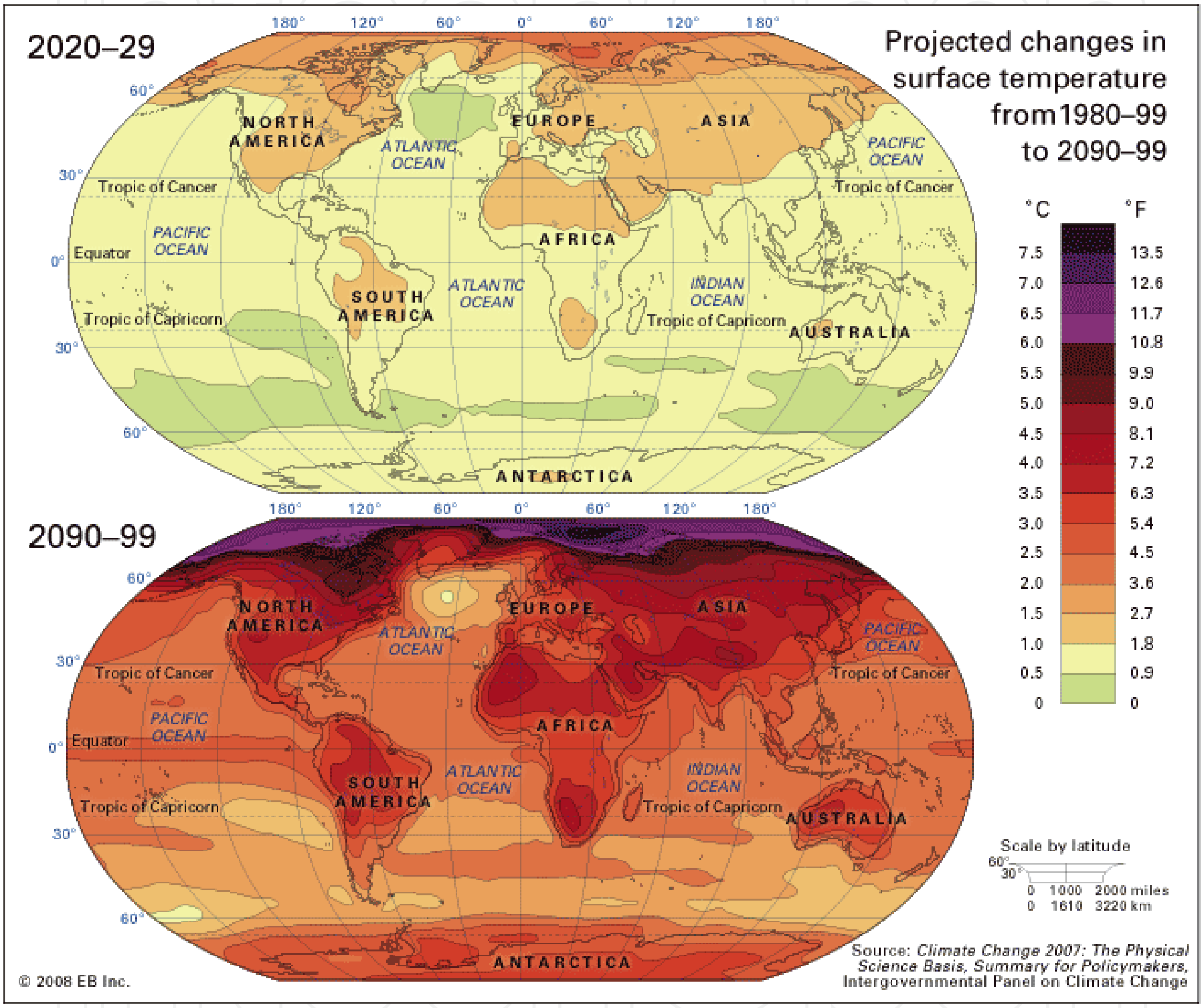


Figure 10. Projected changes in mean surface temperature by the late 21st century according to the A1B climate change scenario. All values for the period 2020-2029 and 2090–2099 are shown relatively to the mean temperature values for the period of 1980–1999. Source: Climate Change 2007: The Physical Science Basis, Summary for Policymakers, IPCC [8]

2. Material and methods

Lithuanian territory situated between 53°54′N and 56°27′N latitude, 20°56′E and 26°51′E longitude [53] occupies intermediate geographical position between west European oceanic climate and Eurasian continental climate. Cold air masses transfered from Arctic induce decrease of air temperatures which is reason of spring and early autumn frosts and of hard frost in winter time. Warm air masses from tropics are seldom which form thaws during winter and clear hot days during summer. Climate of the Lithuanian territory forms in different radiation and circulation conditions. Differences in these conditions hardly cross the boundaries of microclimatic differences; therefore, Lithuania belongs to western region of the Atlantic Ocean continental climatic area [45, 52] with average annual precipitation of 675 mm (572-907 mm) and temperature of 6-7°C [53, 54].

Phytotron vegetative pot experiments. The plastic pots (capacity of 5 L) substrata of turf (pH 6.0-6.5) were used. Till the emergence of white goosefoot *Chenopodium album* L. and one week after, pots were kept in a greenhouse, and then moved to the phytotron for 2 weeks. The emerged weeds were thinned out to 25 seedlings per pot. Results were evaluated after 21 days from weed emergence. Length of sprouts was measured (mm) and weed biomass (g per pot) was established oven-dried at 65°C.

Investigated weed genus white goosefoot *Chenopodium album* L. is widely spread in Europe, Asia and belongs to cosmopolitan group of plants. *C. album* is spread in agricultural lands and set–aside all over the world [15, 16]. White goosefoot *C. album* is annual hardly exterminated weed because one plant can give about 100,000 or till 200,000 seeds that germinate not all at once [15, 17].

2.1. Complex effect of CO_2 and temperature

The experimental factor was the environment of contrasting carbon dioxide (CO_2) concentrations and temperature level combinations.

Four levels of CO_2 concentration:

- 350 ppm (control treatment)
- 700 ppm
- 1500 ppm
- 3000 ppm

Two levels of temperature regimes:

- 21°C/17°C (control treatment)
- 25°C/21°C

CO_2 concentration, temperature regimes and their combinations were tested in the Phytotron vegetative pot experiments.

Concentration of CO_2 was regulated using CO_2 cylinder-reservoir controlled by CO_2 measurer "CO_2RT-5" (produced by Regin, Sweden). Photoperiod 16/8 h was achieved using high-pressure sodium (HPS) lamps SON-T Agro (Philips). The level of background radiation (PAR) made 170 micro-mol m^{-2} s^{-1}. PAR was measured with RF-100 Radiometer-Photometer with G.PAR-100 detector cell (produced by Sonopan, Poland).

2.2. Effect of UV-B radiation

Six levels of UV–B radiation (wavelength 290-320 nm) were tested:

- 0 kJ m^{-2} d^{-1}(control treatment)
- 1 kJ m^{-2} d^{-1}
- 3 kJ m^{-2} d^{-1}
- 5 kJ m^{-2} d^{-1}
- 7 kJ m^{-2} d^{-1}
- 9 kJ $m^{-2}$$d^{-1}$

To generate the chosen UV–B radiation Medical lamps "Philips TL 40W/12 RS" UV–B were used.

2.3. Effect of ozone

Four levels of ozone concentrations were tested:

- 0 μg m^{-3} (control treatment)
- 120μg m^{-3}
- 240 μg m^{-3}
- 360 μg m^{-3}

The selected ozone concentration was reached using the ozone generator OSR-8 (Ozone Solutions, Inc.) 5 days per week, 7 hours per day. Ozone concentration was measured by the mobile ozone measuring equipment OMC-1108 (Ozone Solutions, Inc.).

2.4. Complex effect of UV-B radiation and ozone

Combination influence of two levels of ozone concentrations 120 μg m^{-3} and 360 μg m^{-3} with two levels of UV–B radiation: 3 kJ $m^{-2}$$d^{-1}$and 9 kJ m^{-2} $d^{-1}$was tested.

Experimental schema of UV–B radiation and ozone combinations is as follows:

- CT – control treatment, the plants were not exposed to either ozone or UV-B.
- O_3+O_3 – plants exposed to 120 μg m^{-3} ozone concentration and later to the supplemental 360 μg m^{-3} ozone concentration.
- O_3+UVB – plants exposed to 120 μg m^{-3} ozone concentration, and later to the supplemental 9 kJ m^{-2} d^{-1} UV-B radiation.
- UVB+UVB – plants exposed to 3 kJ m^{-2} d^{-1} UV-B radiation and later to the supplemental 9 kJ m^{-2} d^{-1} UV-B radiation.
- UVB+O_3 – plants exposed to 3 kJ m^{-2} d^{-1} UV-B radiation, and later to the supplemental 360 μg m^{-3} ozone concentration.

- CT+O_3 – plants exposed to 360 μg m^{-3} ozone concentration.
- CT+UVB-plants exposed to 9 kJ m^{-2} d^{-1} UV-B radiation.

2.5. Complex effect of ozone and temperature

Experimental photoperiod is 14/10 h. Ozone impact duration is 12 days.

Three levels of ozone concentrations:

- 20 μg m^{-3} (control treatment)
- 40 μg m^{-3}
- 80 μg m^{-3}

Two levels of temperature regimes:

- 21ºC/14ºC (control treatment)
- 25ºC/16ºC

2.6. Complex effect of UV-B radiation and temperature

Experimental photoperiod is 14/10 h. Impact duration is 8 days.

Three levels of UV–B radiation:

- 0 kJ m^{-2} d^{-1} (control treatment)
- 2 kJ m^{-2} d^{-1}
- 4 kJ m^{-2} d^{-1}

Two levels of temperature regimes:

- 21ºC/14ºC (control treatment)
- 25ºC/16ºC

The experiments were conducted in three replications [18].

Data analysis. The collected data of the experiments were analysed by means of ANOVA. The treatment effects were tested for significance using the *Sigma Stat* software package [19] and the *Selekcija* software package [20].

3. Auto-ecological adaptability of weeds

Weeds are plants growing in undesirable places (i.e. crops and etc.) by human and competing with cultural plants for the growth factors and elements. Cultural plants can be counted as weeds if they are growing in crops of other cultural plants, for example, rye in wheat and etc. *Autoecology* is the branch of ecology which deals with individual species and their reactions to environmental factors. *Adaptivity* is the ability to react to change; adaptability allows the plant (weed) to function despite changes in the environment.

3.1. Complex effect of CO_2 and temperature

During the past decades the climate change and environment pollution became the important factors influencing the plant growth, development and productivity. The anthropogenic activity constantly changes the abiotical factors that surround us. The increasing air temperature, carbon dioxide, ozone, UV-B radiation and etc. are the factors constantly felt by the plants and their ability to adapt to the changing situation secures their productivity and agro-ecosystem stability [3].

Continued emissions of greenhouse gases will cause further warming and changes in all components of the climate system [7]. Limiting climate change will require substantial and sustained reductions of greenhouse gas emissions. Climate-carbon cycle coupling is expected to add carbon dioxide to the atmosphere as the climate system warms, but the magnitude of this feedback is uncertain. Based on current understanding of climate-carbon cycle feedback, model studies suggest that to stabilise at 450 ppm carbon dioxide could require that cumulative emissions over the 21st century would be reduced from the average of approximately 670 GtC (2460 $GtCO_2$) to approximately 490 GtC (1800 $GtCO_2$). Similarly, to stabilise at 1000 ppm, this feedback could require that cumulative emissions would be reduced from the model average of approximately 1415 GtC (5190 $GtCO_2$) to approximately 1100 GtC (4030 $GtCO_2$) [6, 8]. Depending on the scenario, about 15 to 40% of emitted CO_2 will remain in the atmosphere longer than 1,000 years [7]. This could result in the global climate change. Plants react to the increased concentration of CO_2, therefore this can trigger the processes of plant biomass accumulation [21].

Carbon dioxide as the carbon source used to synthesize the plant biomass is a very important abiotical factor in agriculture. Estimating the influence of CO_2 concentration for the growth of white goosefoot *Chenopodium album* L., the control treatment was compared with 350 ppm CO_2. Gradually CO_2 concentration was increased up to 700 ppm and 1500 ppm and it maximized the growth of white goosefoot and its biomass accumulation on the regular basis. When CO_2 concentration was increased up to 3000 ppm, the growth of *C. album* was reduced but still remained greater than CO_2 concentration in the control treatment (Figure 11). This means, that *C. album* can successfully adapt to the twice as great CO_2 concentrations, but it reaches the limit of the maximum growth. Other researchers [51] estimated also more intensive growth of other crop weed – *Parthenium hysterophorus* L. (whitetop weed) under a climate change scenario involving an elevated atmospheric CO_2 (550 μmol mol^{-1}) concentration. *P. hysterophorus* plants grew significantly taller (52%) and produced more biomass (55%) than under the ambient atmospheric CO_2 concentration (380 μmol mol^{-1}) [51].

The increasing concentration of atmospheric CO_2 is observed to increase plant photosynthesis and plant growth, which drives an increase of carbon storage in terrestrial ecosystems. However, plant growth is constrained by the availability of anthropogenic reactive nitrogen (Nr) in soils. This means that in some nitrogen-poor ecosystems, insufficient Nr availability will limit carbon sinks, while the deposition of Nr may instead alleviate this limitation and enable larger carbon sinks [22].

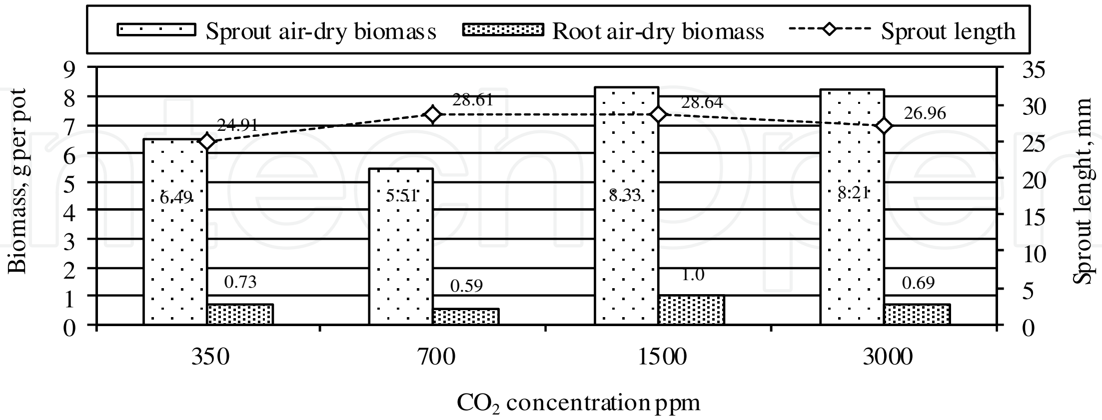
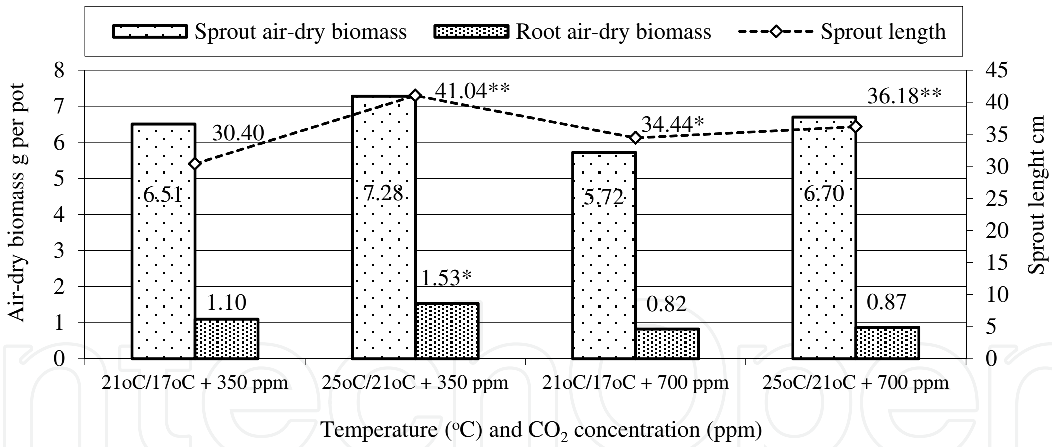


Figure 11. *Chenopodium album* L. white goosefoot accumulated biomass from a pot (g) and seedlings length (mm) under different CO_2 concentrations [23]

In addition to land use and climate-induced vegetation changes, CO_2 affects vegetation forcing indirectly, reducing transpiration from plants as stomata open less with increasing CO_2, resulting in localized atmospheric drying and warming [22, 24].



Note. * – significant differences in comparison with control treatment (21°C/17°C+350 ppm) at $P < 0.05$ and **-at $P < 0.01$.

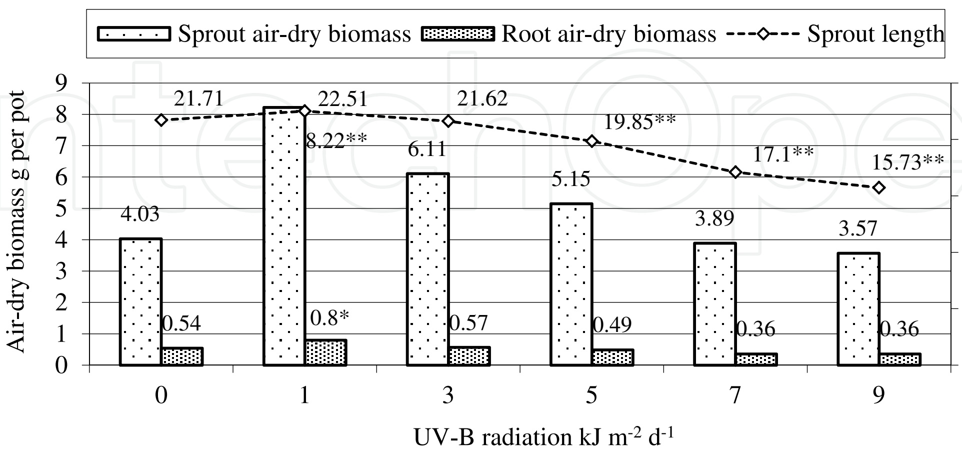
Figure 12. *Chenopodium album* L. white goosefoot accumulated biomass from a pot (g) and seedlings length (mm) under different combinations of temperature regimes and CO_2 concentrations [23]

Continuing experiment under controlled phytotron conditions, complex impact of actual and forecasted CO_2 and temperature to the growth of white goosefoot *C. album* were tested (Figure 12). Increase of temperature to forecasted 25°C/21°C initiates growth of white goosefoot more quickly and accumulates its biomass more intensively. But the increase of CO_2 concentration up to 700 ppm at this forecasted temperature starts to inhibit the growth of white goosefoot and its roots (Figure 12). It was established that the most favourable conditions for *C. album* early growth were at higher temperature regime 25°C/21°C with both CO_2 concentrations. However, for the root growth initiation, especially, optimal conditions were with lower – 350 ppm – CO_2 concentration (Figure 12). Higher CO_2 concentration 700 ppm with actual lower temperature regime 21°C/17°C showed the negative influence on early growth of *C. album*.

3.2. Effect of UV-B radiation

The shorter are waves of the radiation, the greater is the effect of the ultraviolet radiation on living organisms [25, 26]. Molecule alternations and damages inevitably alter other processes: activity of genes, metabolism, intensity of photosynthesis which, consequently, influence the growth of the plant [27]. The reduction of the photosynthesis intensity due to the impact of UV-B radiation is related to slight conductance of stomata and the quantity of photosynthetic pigments [28]. Height and biomass of the majority of plant species have a tendency to reduce due to the UV-B radiation [28-30].

Experimental data showed that low UV-B radiation of 0, 1 and 3 kJ m^{-2} d^{-1} had a positive effect on early growth of *Chenopodium album* white goosefoot (Figure 13). *C. album* can accumulate up to 30% of biomass in excess in the background of 1 kJ m^{-2} d^{-1} UV-B radiation with reference to the control treatment. Increasing the intensity of UV-B radiation, the length of the *Chenopodium album* L. over-ground part was systemically decreasing. Consequently, as UV-B radiation constantly increased up to 9 kJ m^{-2} d^{-1}, the length of *C. album* over-ground part starting from 3 kJ m^{-2} d^{-1} gradually decreased by 28%. The over-ground part biomass of the *C. album* was decreasing respectively when increasing the UV-B radiation. The least over-ground part and root biomass of *C. album* were accumulated at the 9 kJ $m^{-2}d^{-1}$ UV-B radiation. Gradually increasing UV-B radiation till 9 kJ $m^{-2}d^{-1}$ *C. album* biomass decreased till 2 times compared it to the control treatment 0 kJ m^{-2} d^{-1} (Figure 13).



Note. Significant differences from control treatment (0 kJ m^{-2} d^{-1}) at * $P < 0.05$ and **-at $P < 0.01$

Figure 13. The above-ground and root biomass from a pot (g) and seedling length (mm) of *Chenopodium album* L. white goosefoot under different UV–B radiation (kJ m^{-2} d^{-1}) levels [31]

3.3. Effect of ozone

When the ozone layer in the stratosphere becomes thinner, the ozone concentration at the soil surface increases. Ozone concentration at the soil surface is also insecure to the plant development [3]. The ozone gas acts as strong oxidator in the plant cells and destabilizes the vital functions [32]. Short impact of ozone may cause various injuries to leaves, moreover, under the long-term continuous influence plants become less, the crop decreases, leaves are injured [33, 34]. Ozone adds to quicker senescence of plant leaves and their early fall. These processes are determined by the increase of free radicals in the plant cells [35, 36].

Evaluating the effect of ozone concentration on *C. album* white goosefoot growth, it has been established that the increasing ozone concentration had no statistically reliable impact on *C. album* growth, however, the tendency of over-ground part length ($p=0.074$) and air-dry biomass ($p=0.958$) decreasing was observed (Figure 14). The sprout height decreased by 15.4%, 16.8% and 2.0% in ozone concentration of 120 μg m^{-3}, 240 μg m^{-3} and 360 μg m^{-3} accordingly, compared it with the control treatment. *C. album* white goosefoot have lost 20.3%, 5.2% and 21.1% their sprout air-dry biomass at ozone concentration of 120 μg m^{-3}, 240 μg m^{-3} and 360 μg m^{-3} in respond to control treatment of 0 μg m^{-3} of ozone, respectively.

Plants are known to suffer damage due to exposure to levels of ozone (O_3) above about 40 ppb [22, 37]. It is established that surface ozone detrimentally affects plant productivity [38]. Tropospheric ozone can also affect the natural uptake of CO_2 by decreasing plant productivity [22].

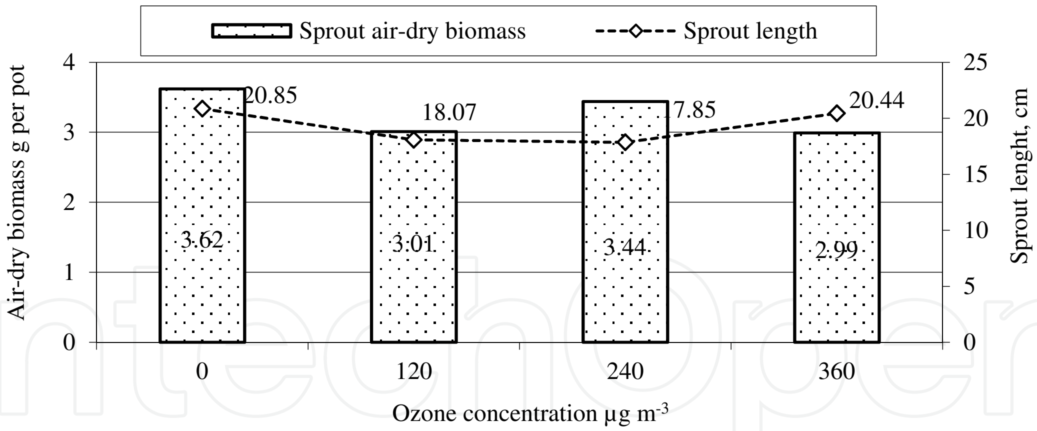


Figure 14. The *Chenopodium album* L. white goosefoot air-dry biomass and length of the over-ground part under the influence of ozone [31]

3.4. Complex effect of UV-B radiation and ozone

Ozone layer absorbs the greatest part of UV rays radiated by the Sun and other space bodies and protects plants and live organisms from their negative impact. Ozone depletion would increase the amount of ultraviolet light reaching the surface damaging terrestrial and marine ecosystems [22]. Since the beginning of the eight decade of the XX century the rapid breaking of the ozone layer in the stratosphere has been noticed as well as the increase of the intensity of UV radiation.

Ozone O_3 formed in the troposphere as a result of NO_x and volatile organic compound emissions reduces plant productivity, and therefore reduces CO_2 uptake from the atmosphere [22]. The depletion of the ozone layer is induced by the pollutants containing chlorine and bromine ions released into the environment [39]. The thickness of the ozone layer has the greatest impact on the flow of the UV-B radiation [25, 26].

During the complex research (Table 1) the negative impact of ozone and UV-B radiation on white goosefoot *C. album* growth increased in comparison to the impact of ozone (Figure 14) and UV-B (Figure 13) when effecting separately. *C. album* is unable to adapt to the increasing UV-B radiation and the intensifying complex impact of ozone and UV-B.

Treatment	Over-ground plant part				Root	
	After the first action	After the second action				
	Sprout length, mm	Sprout length, mm	Green biomass, g pot^{-1}	Air-dry biomass, g pot^{-1}	Green biomass, g pot^{-1}	Air-dry biomass, g pot^{-1}
#CT	44.17	48.38	54.04	12.37	10.19	1.77
O_3+O_3	50.33*	54.74 **	38.27*	11.50	10.60	1.90
O_3+UVB	51.00*	51.90*	46.69	10.82	12.73	1.98
UVB+UVB	47.53	47.98	45.83	12.10	9.60	1.75
UVB+O_3	51.13*	52.20*	35.58*	10.26	11.43	1.81
CT+O_3	49.63*	56.12**	37.84*	10.01	10.34	1.90
CT+UVB	51.83**	53.72*	50.11	12.92	14.86	2.07
P	0.017	0.001	0.024	0.398	0.071	0.820

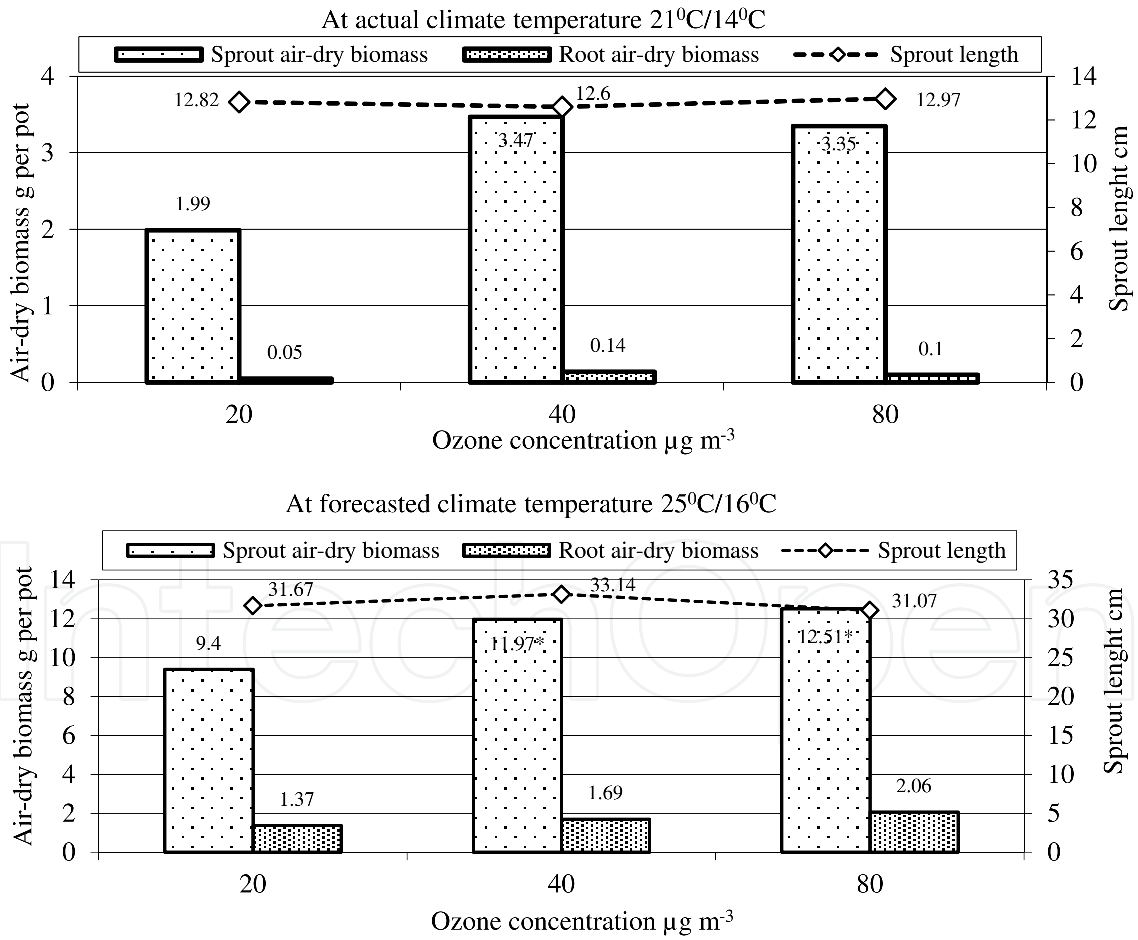
Note. #CT – control treatment; significant differences from control treatment (#CT) at * $P < 0.05$ and **-at $P < 0.01$

Table 1. *Chenopodium album* L. white goosefoot biomass and length of the over-ground part after the exposure to both ozone and UV-B radiation [31]

3.5. Complex effect of ozone and temperature

Continuing research of ozone concentration, impact on white goosefoot *Chenopodium album* growth, complex effect of ozone concentration 20, 40 and 80μg m^{-3} and of actual and forecasted climate temperature regimes were evaluated (Figure 15). Increase of the ozone concentration from 20 μg m^{-3}, increased accumulation of *C. album* sprout air-dry biomass by 74% at 40 μg m^{-3} and by 68% at 80 μg m^{-3} and root air-dry biomass by 280% at 40 μg m^{-3} and by 200% at 80 μg m^{-3} in the actual climate temperature conditions 21°C/14°C. At forecasted climate higher temperature (25°C/16°C), the rising ozone concentration from 20 to 40 and 80μg m^{-3} increased the accumulation of *C. album* sprout air-dry biomass by 27-33% and root air-dry biomass by 23-50%, accordingly. Investigated ozone concentration and temperature regimes complex had no significant effect on *C. album* plant height (Figure 15). It was established that *C. album* is adapted to the actual and forecasted climate temperature and ozone concentration variations till 80 μg m^{-3} of ozone in the environment. Increasing ozone concentration further till 120, 240 and 360 μg m^{-3}, there was observed negative effect on *C. album* growth and abilities to adapt to higher ozone concentration were not determined (Figure 14).

The sprout root ratio of air-dry biomass changing concentration of ozone at different levels of temperatures showed, that *C. album* root growth was 3.5-5.8 times more intensive at forecasted than at actual climate temperature regimes (Lithuanian conditions). At actual climate temperature under ozone concentration of 20, 40 and 80 μg m^{-3} white goosefoot *C. album* sprout root ratio of air-dry biomass covered 39.8, 24.8 and 33.5 and at forecasted climate temperature covered 6.9, 7.1 and 6.1, accordingly.



Note. * – significant differences from the control treatment (20 μg m^{-3}) at $P < 0.05$.

Figure 15. The influence of ozone on *Chenopodium album* L. white goosefoot growth at actual and forecasted climate temperature [40]

3.6. Complex effect of UV-B radiation and temperature

At changing climate conditions competitive abilities of plants are changing showing through new weed biological qualities. Increase of weed ability of over-wintering for weed species that during winter time traditionally were frosting at conventionally colder climate conditions [41, 42]. It was established that during winter time in winter wheat crop annual weeds, even some summer annual ones, had increased adaptivity of successful surviving winter frosts and accumulated higher one plant average mass by 5-6% during winter time; especially when the weather is favourable for prolonged development of weeds even at low density of perennial weeds in the crop [42-44]. Even short-time brief changes of meteorological conditions in crop during vegetation are inducing mechanism of plant/weed adaptivity. Namely, weed seed rain in the crop regularly intensified with increase of temperature and sunlight duration and vice versa [45, 46]. Under heavily polluted or dark cloudy skies, plant productivity may decline as the diffuse effect is insufficient to offset decreased surface irradiance [47]. Plants need a certain amount of UV-B radiation. They stimulate biochemical processes and inhibit to fast plant growing and slow accumulation of air-dry biomass [48]. Due to UV-B radiation height and air-dry biomass of many plant genus decrease [28, 29]. The intensity of UV-B radiation is determined by the seasson, day and night period and meteorological conditions. According to the data of Kaunas meteorological station and Palanga avia-meteorological station, the average UV-B radiation doses during clear summer days reach 2.1–2.5 kJ m^{-2} d^{-1} [49].

UV-B radiation	Over-ground part			Root		Over-ground part and root ratio	
	Height cm	Green mass g	Air-dry mass g	Green mass g	Air-dry mass g	Green mass	Air-dry mass
Actual climate temperature 21°C/14°C							
0 kJ m^{-2} d^{-1}	7.10	28.27	1.89	2.35	0.25	12.0	7.6
2 kJ m^{-2} d^{-1}	5.53**	11.63**	1.01*	1.12*	0.13*	10.4	7.8
4 kJ m^{-2} d^{-1}	6.31**	5.02**	0.53**	0.88*	0.09*	5.7	5.9
P	0.001	0.001	0.002	0.040	0.013	–	–
Forecasted climate temperature 25°C/16°C							
0 kJ m^{-2} d^{-1}	21.36	68.89	6.05	2.92	0.54	23.6	11.2
2 kJ m^{-2} d^{-1}	14.47**	34.73**	3.22**	1.89	0.28**	18.4	11.5
4 kJ m^{-2} d^{-1}	12.22**	15.38**	1.63**	0.94*	0.16**	16.4	10.2
P	0.001	0.001	0.001	0.017	0.002	–	–

Note. * – significant differences from the control treatment (0 kJ m^{-2} d^{-1}) at $P < 0.05$ and ** – at $P < 0.01$.

Table 2. The influence of UV-B radiation on white goosefoot *C. album* growth at actual and forecasted climate temperature [40]

The next experiment increasing UV-B radiation intensity till 4 kJ m^{-2} d^{-1} showed significant negative influence on white goosefoot *C. album* development already at UV-B radiation 2 kJ m^{-2} d^{-1} at both-actual 21°C/14°C and forecasting 25°C/16°C climate temperature regimes (Table 2).The over-ground green biomass of *C. album* effected by UV-B radiation of 4 kJ m^{-2} d^{-1}decreased 5.6 and 4.5 times at actual and forecasted climate temperature respectively compared it with the control treatment (UV-B radiation 0 kJ m^{-2} d^{-1}), while root green biomass decreased 2.7 and 3.1 times, accordingly. *C. album* over-ground part and root air-dry biomass accumulation decreased nearly twice (1.9 times) already at UV-B radiation 2 kJ m^{-2} d^{-1} at both temperature regimes and declined till 3.6-3.7 and 2.8-3.4 times at UV-B radiation 4 kJ m^{-2} d^{-1}, accordingly. Increasing intensity of UV-B radiation, *C. album* height growth inhibited significantly as well. The highest evaluated UV-B radiation in the experiment decreased plant height by 11% at actual climate temperature and by 43% at forecasted warmer climate temperature. Received data of experiment confirmed that *C. album* is sensitive to UV-B radiation in actual colder and forecasted warmer temperature regimes. *C. album* plant over-ground part and root green and air-dry biomass ratio with increase of UV-B radiation regularly decreased. It could be result of plant protection mechanism activation intensifying transpiration process.

4. Conclusions

1. Plant ability to survive under unfavourable conditions depends upon the intensity and character of the unfavourable factors. Abiotical factors of low intensity influencing plants induce weed growth, however, weed growth is regularly smothered as their intensity increases.

2. Increase of CO_2 concentration positively affected the early growth of white goosefoot *Chenopodium album* L. and reached the optimum at 1500 ppm. Higher temperature regime 25°C/21°C compared with 21°C/17°C compounded more favourable conditions for *C. album* early growth at both – 350 ppm and 700 ppm – CO_2 concentrations. White goosefoot successfully adapts even to several times increased concentration of CO_2.

3. Minor UV-B radiation concentrations 1-3 kJ m^{-2} d^{-1} induced *C. album* growth; however, the increasing UV-B radiation (5-9 kJ m^{-2} d^{-1}) reliably decreased both the length of the over-ground part and the biomass of white goosefoot.

4. Increasing ozone concentration to 120, 240 and 360 μg m^{-3} had a tendency to suppress *C. album* growth by 2-14% of its sprout length and by 5-17% of its accumulated air-dry biomass. However, complex investigation of ozone and temperature showed that *C. album* is adapted to actual and forecasted climate temperature and ozone concentration variations till 80 μg m^{-3} of the environment.

5. Complex investigation of UV-B radiation and temperature showed significantly negative influence on *C. album* growth and biomass accumulation already at UV-B radiation 2 kJ m^{-2} d^{-1} of both actual 21°C/14°C and forecast 25°C/16°C climate temperature regimes.

6. Joint action of ozone and UV-B radiation on *C. album* growth increased negative effect relatively to separate impact of ozone and UV-B. White goosefoot in early growth stage is unable to adapt to increasing UV-B radiation (>3 kJ m^{-2} d^{-1}) and the intensifying complex impact of ozone and UV-B.

7. The experimental results suggest that in long-term (more than 30 years) time period weeds are well adapted to changing climate conditions and will become more competitive in temperate climate zone. For successful weed control in the crop of agricultural plants present weed control methods and strategy should be reviewed and improved adapting them to threats of global warming and climate change.

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