JOURNAL OF THE Selva Andina Biosphere
Official Journal of the Selva Andina Research Society.

Review Article

ISSN 2308-3867 (print edition)
JSAB
ISSN 2308-3859 (online edition)

Impact of climate change on production processes, biodiversity and ecosystems. Its relationship with food security

Impacto del cambio climático en los procesos productivos, la biodiversidad y los ecosistemas. Su relación con la seguridad alimentaria

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Keywords:

Biodiversity,
climate change,
ecosystem and plant productivity.

J. Selva Andina Biosph.
2025; 13(1):30-40.

Article ID: 156/JSAB/2024

Article history

Received September 2024.
Returned December 2024.
Accepted February, 2025.
Available online, May, 2025.

Edited by:
Selva Andina Research Society

Palabras clave:

Biodiversidad,
cambio climático,
ecosistemas y productividad vegetal.

Abstract

Climate change, a widespread and increasing global hazard, has a substantial influence on ecosystems and biodiversity. It has a significant impact on plant productivity, mainly through reduced water use efficiency, increased soil salinity, increased heat stress and altered soil health. In addition, by modifying the behaviour, morphology and phenological patterns of species, climate change has a negative impact on biodiversity. This leads to changes in distribution, a decrease in species abundance with an overall loss of biodiversity. Changes in biodiversity caused by climate variations are closely linked to changes in ecosystem services and how this affects human well-being. Both climate change and human activity contribute to the degradation of ecosystem services, which are essential for maintaining the balance of natural systems and fostering socio-economic growth. These ecosystems support livelihoods, sustainability and health, providing vital products and services with high economic and ecological value. Preserving and repairing ecosystems is now more important than ever due to the persistent threat of global climate change, which not only threatens environmental integrity but also poses major challenges to food security.

Resumen

El cambio climático, un peligro global generalizado y creciente, tiene una influencia sustancial en los ecosistemas y la biodiversidad. Su impacto significativo en la productividad vegetal, principalmente a través de la reducción de la eficiencia del uso del agua, el aumento de la salinidad del suelo, incremento del estrés térmico y alteración de la salud del suelo. Además, al modificar el comportamiento, la morfología y los patrones fenológicos de las especies, el cambio climático tiene un impacto negativo en la biodiversidad. Esto conlleva cambios en la distribución, una disminución de la abundancia de especies con la pérdida general de biodiversidad. Los cambios en la biodiversidad provocados por las variaciones climáticas están estrechamente relacionados con los cambios en los servicios ecosistémicos y cómo estos afectan al bienestar humano. Tanto el cambio climático como la actividad humana contribuyen a la degradación de los servicios ecosistémicos, esenciales para preservar el equilibrio de los sistemas naturales y fomentar el crecimiento socioeconómico. Estos ecosistemas sustentan los medios de vida, la sostenibilidad y la salud, ofreciendo productos y servicios vitales con un alto valor económico y ecológico. La preservación y la reparación de los ecosistemas son ahora más importantes que nunca debido a la amenaza persistente del cambio climático global, que no solo pone en peligro la integridad ambiental, sino que también plantea importantes desafíos para la seguridad alimentaria.

Introduction

Global agriculture relies on a relatively small number of crop species, which have been bred to optimize productivity within a relatively narrow range of environmental variations[1]. Moreover, current food security has been achieved through large industrial agriculture, in which large farms often grow the same crops annually, using excessive amounts of pesticides and fertilizers that finally deplete soils, pollute water, cause nutrient loss, decrease biodiversity, and contribute to climate change (CC). On top of the doubt regarding the future environmental impact of agriculture comes the looming threat to yield sustainability caused by CC induced variations in weather patterns[2]. Predictions advise that on a global scale, an increase in land use of ~100 Mha with a tripling of international trade is required by 2050 to meet the future crop needs of 9.8 billion people, without causing any significant change in present cropped land area[3]. Extreme weather events cause massive damage to crop production.

Living and non-living organisms, their ecosystems, and climatic situations can be considered as dependent components of the world, and their balance is essential for the existence of the world[4]. CC is a persistent and growing global threat to biodiversity and ecosystems[5]. CC affects specific species and the way they interact with other organisms and their habitats, which alters the structure and function of ecosystems and the goods and services that natural systems offer to society[5]. As a primary anthropogenic activity, land-use changes could influence the ecosystem process through altering the physical properties of the land surface, such as the albedo, roughness, and evapotranspiration. Human societies could obtain well-being by improving the provision of ecosystem services, regulating the ecosystem services, and the cultural ecosystem services, including food, freshwater provision, carbon sequestration, and landscape aesthetics that are wanted for human life[6].

Impact of CC on biodiversity, the organisms cope with changes in their environment by altering their behavior or morphology. Behavioral replies to CC can result from variations in temperature and manifest before changes at the population and species level, such as distribution changes or population declines[7]. Differential alterations in phenology among interacting organisms could drive population declines through reduced reproductive success and/or increased predation or competition[8,9]. CC is driving large-scale shifts in species distribution, abundance, and reorganization of terrestrial and aquatic ecosystems[10]. Geographic range shifts are widespread across taxa and ecosystems. Therefore, the objective of this paper was to review the impact of CC on plant productivity, biodiversity, and ecosystem service.

Development

Impact of climate change on plant productivity

Water use scarcity and drought. Water deficits pose a serious threat to crop productivity and food security in many parts of the world due to poor or erratic rainfall and depletion of groundwater reserves[11]. Improvements in crop productivity under conditions of limited water availability are vital to meet global food demand[12]. CC is predicted to increase the frequency of droughts and floods, both of which will be problematic for food production[13]. Water scarcity and drought are one of the enormous effects on plant growth and plant productivity.

Salinity stress. It is an important yield-limiting factor that poses a significant threat to agriculture worldwide. Salinity is considered one of the leading limiting factors responsible for the growth and production decline of crops throughout the world, principally in arid and semiarid regions[14]. Furthermore, it is stron-

gly evident that higher concentrations of salt ions in soil negatively affect plant growth and productivity, the uptake of other necessary ions which plants require for several metabolic and enzymatic activities[15].

High temperature stress. CC-led rises in local and global temperatures pose a significant threat to plant growth and crop production[16]. Heat stress can damage all stages of plant growth from germination to reproduction, limiting the productivity of major staple food crops[11]. The plant reproductive organs and processes leading to seed set are very vulnerable to increasing temperatures. The current information and understanding of the molecular mechanisms that contribute to this temperature sensitivity are ably discussed, which summarizes their regulation of male and female reproductive organ development and fertilization, together with heat-induced abnormalities at flowering[17].

Impact of CC on biodiversity

Behavior and morphology change. One way that organisms cope with changes in their environment is by changing their behavior or morphology. Behavioral responses to climate alteration can result from changes in temperature and manifest before changes at the population and species level, such as distribution changes or population decrease[7]. Behavioral responses include seeking shade or refuge, altering feeding times, changing site use, and shifting circadian or circannual rhythms[7,18]. Morphological changes commonly entail changes in body size, for example, increasing summer temperatures have been associated with reduced body size and increased wing length in North American migratory birds[19]. The relative impact of CC versus other stressors fluctuates depending on the species or ecosystem. Diverse biological communities and functioning ecosystems are critical to maintaining the ecosystem services that support human well-being[5].

Phenological change. Phenology, or the seasonal timing of biological events, is a critical part of ecological relationships[20] and a primary indicator of species responses to CC[21]. Although changes in phenology are well familiar, trends are far from homogenous[22], a result of high variability in climate drivers and phenological responses across habitat kinds[23-25]. Phenological shifts in marine and aquatic habitats are less well known in comparison to terrestrial systems, largely due to the difficulty detecting and tracking aquatic organisms[21]. Nonetheless, there have been perfect directional shifts in the timing of seasonal aquatic and marine abiotic drivers, including earlier transitions from winter to spring temperatures[26] and previous ice melting and runoff increase[21,27]. Marine phytoplankton can respond rapidly to such abiotic changes, resulting in a change of timing of phytoplankton blooms[28], which in turn can make a mismatch with secondary consumers and alter the food web structure[27,29]. Differential shifts in phenology among interrelating organisms could drive population declines through reduced reproductive success and/ or increased predation or competition[8,9].

Geographic range shifts. CC is driving widespread shifts in species distribution, abundance, and the reform of terrestrial and aquatic ecosystems[10]. Geographic range shifts are broad across taxa and ecosystems. Northern Hemisphere birds, for example, are decreasing in abundance along species' southern and minor elevation range edges[30,31]. Marine organisms have also demonstrated range shifts, in some cases at more quickly rates than in terrestrial systems and in pace with climate velocities. Arctic marine environments are experiencing fluctuations in sea ice cover, increasing temperatures, and ocean acidification, resulting in range shifts for marine fish, arthropods, and marine mammals[32].

Biodiversity loss. Globally, biodiversity is being lost and increasingly threatened through a range of an-

thropogenic actions[33,34]. The Convention on Biological Diversity defines biodiversity loss as the long-term or permanent qualitative or quantitative reduction in components of biodiversity and their potential to provide goods and services, to be measured and managed at global, regional, and national levels. The most important drivers behind the current loss of biodiversity are habitat modification, overexploitation, CC, invasive alien species, and chains of extinction, known collectively as the evil five-biodiversity threats. Even if it is difficult to disentangle the effects of CC from other anthropogenic stressors for a range of species, consequently, forecasts may provide insights into the multiple components of CC and their relative distribution fears to global biodiversity[35]. The current threat from habitat destruction, land use change or fragmentation, and gradual population growth interacts with CC in a nonlinear way so that the negative impacts are higher than expected on biodiversity[34].

Impact of CC on ecosystems. The impact of CC on ecosystem-level changes in response to CC are due to direct impacts from CC drivers and interacting effects of species- and population-level responses. It focuses on several key ecosystem-level characteristics and properties affected by CC: primary production; species interactions and emergent properties, including biological invasions; and the impact of extreme events on ecosystem resilience[36]. Due to prolonged droughts and flash floods brought about by extreme rainfall events, with the changes of monsoon pattern, sea level rise, and increasing temperatures, affect ecosystem services[37].

Primary productivity. Almost all life on Earth depends on primary producers, photosynthetic organisms that are the foundation of most food webs and are responsible for producing Earth's oxygen and regulating important components of carbon cycling and sequestration. CC has had erratic effects on primary production across spatial and temporal scales[38]. Globally, terrestrial primary production increased during the late 20th and early 21st centuries due to the fertilizing effect of increasing atmospheric CO_2, nutrient additions from human activities, longer developing seasonal time, and forest regrowth[39]. Warming and increased atmospheric CO_2 may also affect belowground biogeochemical processes, such as carbon and nitrogen cycling, which can affect terrestrial production[40]. However, even in energy-limited forests, drought and extreme temperatures could limit of increase in growth[41].

In marine and aquatic systems, phytoplankton are accountable for nearly all primary production and generate almost half of the total global primary production. Phytoplankton growth rates affect CO_2 uptake from seawater and organic carbon export to the deep ocean, and also impact fisheries productivity. In contrast, gradually reduced ice cover at higher latitudes raises sunlight availability to the ocean surface, increasing phytoplankton growing seasons and annual primary production[28]. Understanding how these changes affect the food web is crucial for maintaining sustainable fisheries.

Species interactions, emergent properties, and biological invasions. Variability in species' exposure and responses to CC are primary driver of changed species interactions. Emergent properties of ecosystems, including community features such as food-web structure and function that are mediated by species interaction, are altering as species shift their distributions and phenologies in response to climate impacts[42]. Many non-native invasive species are opportunistic generalists that can take advantage of changing situations, colonize disturbed areas, and out-compete species, thereby changing community composition, dominance, production, and increasing extinction danger in some cases[43].

Moreover, many non-native invasive plants species respond more positively than native plants to concentration CO_2, nitrogen deposition, and temperature,

likely increasing their competitiveness under extremely CC[6]. Stronger competitive capabilities will likely lead to higher non-native invasive plant abundance and declines of native species abundances and community diversity[44]. Penetration of non-native species into natural communities has already negatively impacted biodiversity[44].

Extreme events and ecosystem resilience. CC has changed the duration, magnitude, and frequency of extreme events, including droughts, forest fires, and heatwaves[45]. Many of these actions have significant impacts on ecosystems and interact with other climate-driven alterations, reducing ecological resilience.

More extreme droughts and wildfires, driven by rising temperatures and altered precipitation patterns, affect ecosystem structure and function, particularly in forested ecosystems[46]. Drought weakens tree defenses, increasing susceptibility to other disturbances, including insects, pathogens, invasive species[47], while drought impacts have direct long-term consequences, drought-facilitated disturbances can result in more instant changes to forest ecosystem structure and function[48]. Increased storm intensity can affect ecosystems and human communities through extreme flooding, erosive waves, and higher storm surges, making recovery from extreme events more challenging. Rising ocean temperatures have also led to periods of extraordinarily warm conditions across the globe, known as marine heatwaves[49]. Increasing ocean temperatures are driving widespread coral bleaching, contributing to coral cover loss, impacting fish communities, and increasing exposure of nearby shores to waves.

Ecosystem services. Diverse biological communities and functioning ecosystems are critical to maintaining ecosystem services that support human well-being[5]. Therefore, CC impacts on species, populations, and ecosystems affect the accessibility and delivery of ecosystem services, including changes to provisioning, regulating, supporting, and cultural services.

Provisioning services. Climate-induced changes in provisioning services, the material goods that people obtain from ecosystems and biodiversity, can have deep effects on human economies and well-being. Surface water scarcities are likely in dry years in some locations[6]. Increasing stream temperatures also affect water quality[50]. These fluctuations will stress water supplies, potentially increasing water treatment costs. Alterations in water supply, along with other climate change impacts, can change agricultural production. Droughts and other extreme events can minimize crop yield and quality[51], with production declines projected for several important crop species as temperatures increase[52]. In freshwater systems, increasing stream temperatures will negatively affect some harvested species. Water, food, wood, and other goods are some of the material benefits people get from ecosystems called provisioning services.

Regulating services. Biodiversity and ecosystems provide important regulation services, such as sequestering carbon, moderating the effects of extreme events, maintaining soil and air quality, and controlling disease spread[36]. Coastal wetlands are highly productive ecosystems that store carbon[53,54]. CC is affecting the ability of ecosystems to provide this service as species range abundances and habitat conditions shift. For example, Aedes mosquitoes, which transmit diseases such as dengue, are expanding their geographic distribution, increasing disease risk[55]. Maintaining the quality of air and soil, providing flood and disease control, or pollinating crops are some of the regulating services delivered by ecosystems. They are often unseen and therefore mostly taken for granted. When they are injured, the resulting losses can be substantial and difficult to restore.

Supporting services. The combination of higher nutrient loading and increasing temperatures is increasing the frequency, duration, and extent of cyanobacteria responsible for damaging algal blooms, which can negatively impact human and animal health. Providing living spaces for plants or animals and sustaining a diversity of plants and animals, are supporting services and the basis of all ecosystems and their services. Ecosystems provide living spaces for plants and animals; they also support a diversity of complex processes that support the other ecosystem services. Some habitats have an exceptionally high number of species, which results them further genetic variation than others. These are known as biodiversity hotspots.

Cultural services. Are the non-material benefits that people obtain from biodiversity and ecosystems, such as cultural identity, recreation, and mental and physical health. Despite their importance to human wellbeing, cultural services have been under deliberated compared to other ecosystem services[56]. There is growing evidence that human health benefits from exposure to natural ecosystems[57], conversely, climate-driven extremes such as increased temperatures and storms can decline mental and physical human health[58]. The non-material benefits people gain from ecosystems are called cultural services. They include aesthetic inspiration, cultural identity, sense of home, and spiritual experience related to the entire natural environment. Typically, opportunities for tourism and recreation are also included within the group. Cultural services are intensely interconnected with each other and often connected to provisioning and regulating services.

Conclusion

This review was more focused on the effect of CC on plant productivity, biodiversity, and the ecosystem. CC is a pervasive and growing risk to biodiversity, ecosystems, and ecosystem services. CC was shocking the world by hampering agriculture and its products. Poisonous gases and Industrialization cause global warming, which ultimately disturbs the world's environment. CC has destructive effects on plant growth and yield. Abiotic stresses are the major type of stresses that cause plant growth decline. CC has an extremely significant effect on individuals, populations, and species through changes in behavior and morphology, phenology, and range shifts, and at the ecosystem level through changes in species interactions, primary production and emergent properties, and extreme events. Ecosystems and biodiversity underpin important services to people, thus, these changes impact provisioning, regulating, supporting, and cultural services, with implications for human wellbeing. The effects of CC on biodiversity were made up continuously, often predicting fast-paced extinction of species, loss of natural habitats, and moves in the distribution and abundance of species. Pressures on biodiversity can push ecosystems beyond what might be termed a safe functioning space. From there: i) Conduct extensive field studies and long-term monitoring to assess the impacts of CC on various plant species, particularly those critical to ecosystem functions and services. ii) Prioritize the conservation of biodiversity hotspots, which are more vulnerable to CC due to their rich but often delicate ecosystems. iii) Encourage the adoption of agroforestry and other sustainable agricultural practices that enhance plant productivity while maintaining biodiversity and ecosystem services. iv) Advocate for the integration of CC adaptation and mitigation strategies into national and regional environmental policies. v) Increase public awareness of the impacts of CC on plant productivity, biodiversity, and ecosystems through education and outreach programs.

Funding source

For this publish there is no any kinds of financial support.

Conflicts of interest

The author declares no conflict of interest in publishing the paper.

Acknowledgements

First, I would like to thank almighty of god for allowing us to complete this Article review in peace patience and with great honor. Secondly, we would like to acknowledge Ethiopian forestry development Jimma center for adjusting suitable condition for internet service to conduct this article research. Ethical considerations I hereby declare that the research article entitled.

Ethical considerations

I hereby declare that the review entitled “Review on the impact of climate change on plant productivity, Biodiversity and Ecosystem “is our original work and has not been published any elsewhere and all sources of material used for this review have been correctly approved.

Research limitations

This research had access to primary sources, so there were no limitations in the review.

Consent for publication

The author, after reviewing the document, approves it for publication.

Use of Artificial Intelligence

I assume that the entire document was drafted based on ethical and professional criteria, and that AI was not used in the drafting of the text.

Cited Literature

1. Kukal MS, Irmak S. Climate-Driven crop yield and yield variability and climate change impacts on the U.S. great plains agricultural production. Sci Rep 2018;8(1):3450. DOI: https://doi.org/10.1038/s41598-018-21848-2
2. Porfirio LL, Newth D, Finnigan JJ, Cai, Y. Economic shifts in agricultural production and trade due to climate change. Palgrave Commun 2018;4:111. DOI: https://doi.org/10.1057/s41599-018-0164-y
3. Pastor AV, Palazzo A, Havlik P, Biemans H, Wada Y, Obersteiner M, et al. The global nexus of food-trade-water sustaining environmental flows by 2050. Nat Sustain 2019;2:499-507. DOI: https://doi.org/10.1038/s41893-019-0287-1
4. Khaine I, Woo SY. An overview of interrelationship between climate change and forests. Forest Sci Technol 2014;11(1):11-8. DOI: https://doi.org/10.1080/21580103.2014.932718
5. Ichii K, Molnár Z, Obura D, Purvis A, Willis K. Status and trends - nature. In: Brondízio ES, Settele J, Diaz S, Ngo HT, editors. Global Assessment Report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. Bonn: IPBES secretariat; 2019. p. 206-70. DOI: https://doi.org/10.5281/zenodo.3832005
6. Liu Y, Oduor AMO, Zhang Z, Manea A, Tooth IM, Leishman MR, et al. Do invasive alien plants benefit more from global environmental change than native plants. Glob Chang Biol 2017;23(8):3363-70. DOI: https://doi.org/10.1111/gcb.13579

7. Beever EA, Hall LE, Varner J, Loosen AE, Dunham JB, Gahl MK, et al. Behavioral flexibility as a mechanism for coping with climate change. Front Ecol Environ 2017;15(6):299-308. DOI: https://doi.org/10.1002/fee.1502
8. Wann GT, Aldridge CL, Seglund AE, Oyler-McCance SJ, Kondratieff BC, Braun CE. Mismatches between breeding phenology and resource abundance of resident alpine ptarmigan negatively affect chick survival. Ecol Evol 2019;9(12):7200-12. DOI: https://doi.org/10.1002/ece3.5290
9. Zimova M, Mills LS, Nowak JJ. High fitness costs of climate change-induced camouflage mismatch. Ecol Lett 2016;19(3):299-307. DOI: https://doi.org/10.1111/ele.12568
10. Lenoir J, Svenning JC. Climate-related range shifts-a global multidimensional synthesis and new research directions. Ecography 2015;38(1):15-28. DOI: https://doi.org/10.1111/ecog.00967
11. Hussain HA, Men S, Hussain S, Chen Y, Ali S, Zhang S, et al. Interactive effects of drought and heat stresses on morpho-physiological attributes, yield, nutrient uptake and oxidative status in maize hybrids. Sci Rep 2019;9(1):3890. DOI: https://doi.org/10.1038/s41598-019-40362-7
12. Balyan S, Kumar M, Mutum RD, Raghuvanshi U, Agarwal P, Mathur S, et al. Identification of miRNA-mediated drought responsive multi-tiered regulatory network in drought tolerant rice, Nagina 22. Sci Rep 2017;7(1):15446. DOI: https://doi.org/10.1038/s41598-017-15450-1
13. Mar S, Nomura H, Takahashi Y, Ogata K, Yabe M. Impact of erratic rainfall from climate change on pulse production efficiency in lower Myanmar. Sustainability 2018;10:402. DOI: https://doi.org/10.3390/su10020402
14. Kaashyap M, Ford R, Kudapa H, Jain M, Edwards D, Varshney R, et al. Differential Regulation of genes involved in root morphogenesis and cell wall modification is associated with salinity tolerance in chickpea. Sci Rep 2018;8(1):4855. DOI: https://doi.org/10.1038/s41598-018-23116-9
15. Hanin M, Ebel C, Ngom M, Laplaze L, Masmoudi K. New insights on plant salt tolerance mechanisms and their potential use for breeding. Front Plant Sci 2016;7:1787. DOI: https://doi.org/10.3389/fpls.2016.01787
16. Priya M, Sharma L, Kaur R, Bindumadhava H, Nair RM, Siddique KHM, et al. GABA (γ-aminobutyric acid), as a thermo-protectant, to improve the reproductive function of heat-stressed mungbean plants. Scientific reports 2019;9:7788. DOI: https://doi.org/10.1038/s41598-019-44163-w
17. Lohani N, Singh MB, Bhalla PL. High temperature susceptibility of sexual reproduction in crop plants. J Exp Bot 2020;71(2):555-68. DOI: https://doi.org/10.1093/jxb/erz426
18. McCann EL, Johnson NS, Pangle KL. Corresponding long-term shifts in stream temperature and invasive fish migration. Can J Fish Aquat Sci 2018;75(5):772-8. DOI: https://doi.org/10.1139/cjfas-2017-0195
19. Weeks BC, Willard DE, Zimova M, Ellis AA, Witynski ML, Hennen M, et al. Shared morphological consequences of global warming in North American migratory birds. Ecol Lett 2020;23(2):316-25. DOI: https://doi.org/10.1111/ele.13434
20. Rudolf VH. The role of seasonal timing and phenological shifts for species coexistence. Ecol Lett 2019;22(8):1324-38. DOI: https://doi.org/10.1111/ele.13277
21. Staudinger MD, Mills KE, Stamieszkin K, Record NR, Hudak CA, Allyn A, et al. It's about time: a synthesis of changing phenology in the gulf of maine ecosystem. Fish Oceanogr 2019;28(5):532-66. DOI: https://doi.org/10.1111/fog.12429
22. Cohen JM, Lajeunesse MJ, Rohr JR. A global synthesis of animal phenological responses to climate change. Nature Clim Change 2018;8(3):224-8. DOI: https://doi.org/10.1038/s41558-018-0067-3

23. Chmura HE, Kharouba HM, Ashander J, Ehlman SM, Rivest EB, Yang LH. The mechanisms of phenology: the patterns and processes of phenological shifts. Ecol Monogr 2019;89(1):e01337. DOI: https://doi.org/10.1002/ecm.1337
24. Fu YH, Zhao H, Piao S, Peaucelle M, Peng S, Zhou G, et al. Declining global warming effects on the phenology of spring leaf unfolding. Nature 2015;526(7571):104-7. DOI: https://doi.org/10.1038/nature15402
25. Pearson KD. Spring-and fall-flowering species show diverging phenological responses to climate in the Southeast USA. Int J Biometeorol 2019; 63(4):481-92. DOI: https://doi.org/10.1007/s00484-019-01679-0
26. Thomas AC, Pershing AJ, Friedland KD, Nye JA, Mills KE, Alexander MA, et al. Seasonal trends and phenology shifts in sea surface temperature on the North American northeastern continental shelf. Elem Sci Anth 2017;5:48. DOI: https://doi.org/10.1525/elementa.240
27. Post E. Implications of earlier sea ice melt for phenological cascades in arctic marine food webs. Food Webs 2017;13:60-6. DOI: https://doi.org/10.1016/j.fooweb.2016.11.002
28. Wasmund N, Nausch G, Gerth M, Busch S, Burmeister C, Hansen R, et al. Extension of the growing season of phytoplankton in the western Baltic Sea in response to climate change. Mar Ecol Prog Ser 2019;622:1-16. DOI: https://doi.org/10.3354/meps12994
29. Sundby S, Drinkwater KF, Kjesbu OS. The North Atlantic spring-bloom system-where the changing climate meets the winter dark. Front Mar Sci 2016; 3:28. DOI: https://doi.org/10.3389/fmars.2016.00028
30. Ralston J, DeLuca WV, Feldman RE, King DI. Population trends influence species ability to track climate change. Glob Chang Biol 2017;23(4): 1390-9. DOI: https://doi.org/10.1111/gcb.13478
31. Tayleur C, Caplat P, Massimino D, Johnston A, Jonzén N, Smith HG, et al. Swedish birds are tracking temperature but not rainfall: evidence from a decade of abundance changes. Glob Ecol Biogeogr 2015;24(7):859-72. DOI: https://doi.org/10.1111/geb.12308
32. Mecklenburg CW, Mecklenburg TA, Sheiko BA, Steinke D. Pacific arctic marine fishes [Internet]. Akureyri: Conservation of Arctic Flora and Fauna; 2016 [cited May 12, 2024]. 406 p. Retrieved from: https://oaarchive.arctic-council.org/items/326ba9f5-4770-4e52-aaee-baa28f0830a3/full
33. Fardila D, Kelly LT, Moore JL, McCarthy MA. A systematic review reveals changes in where and how we have studied habitat loss and fragmentation over 20 years. Biol Conserv 2017;212(Pt A): 130-8. DOI: https://doi.org/10.1016/j.biocon.2017.04.031
34. Barlow J, França F, Gardner TA, Hicks CC, Lennox GD, Berenguer E, et al. The future of hyperdiverse tropical ecosystems. Nature 2018;559 (7715):517-26. DOI: https://doi.org/10.1038/s41586-018-0301-1
35. Trull N, Böhm M, Carr J. Patterns and biases of climate change threats in the IUCN Red List. Conserv Biol 2018;32(1):135-47. DOI: https://doi.org/10.1111/cobi.13022
36. Weiskopf SR, Rubenstein MA, Crozier LG, Gaichas S, Griffis R, Halofsky JE, et al. Climate change effects on biodiversity, ecosystems, ecosystem services, and natural resource management in the United States. Sci Total Environ 2020; 733:137782. DOI: https://doi.org/10.1016/j.scitotenv.2020.137782
37. Jayathunga RDS, Gunarathne K. Role of INDCs in the 'blue green era'of Sri Lanka. In: Sumathipala WL, Senaratne A, Gamage G, Jayathunga RDS, Dulani T, editors. Neela Haritha, the Climate Change magazine of Sri Lanka [Internet].

Sampathpaya: Ministry of Mahaweli Development & Environment; 2015. p.17-20. Retrieved from: http://envmin.nsf.gov.lk/handle/1/813

38. Lipton D, Rubenstein MA, Weiskopf SR, Carter SL, Peterson J, Crozier L, et al. Ecosystems, ecosystem services, and biodiversity. In: U.S. Global Change Research Program, editors. Fourth National Climate Assessment. Washington: U.S. Global Change Research Program; 2018. p. 268-321. DOI: https://doi.org/10.7930/NCA4.2018.CH7
39. Campbell EY, Dunham JB, Reeves GH, Wondzell SM. Phenology of hatching, emergence, and end-of-season body size in young-of-year coho salmon in thermally contrasting streams draining the Copper River Delta, Alaska. Can J Fish Aquat Sci 2018;76(2):185-91. DOI: https://doi.org/10.1139/cjfas-2018-0003
40. Melillo JM, Frey SD, DeAngelis KM, Werner WJ, Bernard MJ, Bowles FP, et al. Long-term pattern and magnitude of soil carbon feedback to the climate system in a warming world. Science 2017; 358(6359):101-5. DOI: https://doi.org/10.1126/science.aan2874
41. Anderegg WRL, Trugman AT, Badgley G, Anderson CM, Bartuska A, Ciais P, et al. Climate-driven risks to the climate mitigation potential of forests. Science 2020;368(6497):eaaz7005. DOI: https://doi.org/10.1126/science.aaz7005
42. Breeggemann JJ, Kaemingk MA, DeBates TJ, Paukert CP, Krause JR, Letvin AP, et al. Potential direct and indirect effects of climate change on a shallow natural lake fish assemblage. Ecol Freshw Fish 2016;25(3):487-99. DOI: https://doi.org/10.1111/eff.12248
43. Schmitt JD, Peoples BK, Castello L, Orth DJ. Feeding ecology of generalist consumers: a case study of invasive blue catfish *Ictalurus furcatus* in Chesapeake Bay, Virginia, USA. Environ Biol Fish 219;102(3):443-65. DOI: https://doi.org/10.1007/s10641-018-0783-6
44. Bradley BA, Laginhas BB, Whitlock R, Allen JM, Bates AE, Bernatchez G, et al. Disentangling the abundance-impact relationship for invasive species. Proc Natl Acad Sci USA 2019;116(20):9919-24. DOI: https://doi.org/10.1073/pnas.1818081116
45. Jay A, Reidmiller DR, Avery CW, Barrie D, DeAngelo BJ, Dave A, et al. Overview. In: U.S. Global Change Research Program, editors. Fourth National Climate Assessment. Washington: U.S. Global Change Research Program; 2018. p. 33-71. DOI: https://doi.org/10.7930/NCA4.2018.CH1
46. Clark JS, Iverson L, Woodall CW, Allen CD, Bell DM, Bragg DC, et al. The impacts of increasing drought on forest dynamics, structure, and biodiversity in the United States. Glob Chang Biol 2016;22(7):2329-52. DOI: https://doi.org/10.1111/gcb.13160
47. Trottier N, Groeneveld E, Lavoie C. Giant hogweed at its northern distribution limit in North America: Experiments for a better understanding of its dispersal dynamics along rivers. River Res Appl 2017;33(7):1098-106. DOI: https://doi.org/10.1002/rra.3149
48. Loehman RA, Keane RE, Holsinger LM, Wu Z. Interactions of landscape disturbances and climate change dictate ecological pattern and process: spatial modeling of wildfire, insect, and disease dynamics under future climates. Landscape Ecol 2017;32(7):1447-59. DOI: https://doi.org/10.1007/s10980-016-0414-6
49. Hobday AJ, Alexander LV, Perkins SE, Smale DA, Straub SC, Oliver EC, et al. A hierarchical approach to defining marine heatwaves. Prog Oceanogr 2016;141:227-38. DOI: https://doi.org/10.1016/j.pocean.2015.12.014
50. Warziniack TW, Elmer MJ, Miller CJ, Dante-Wood SK, Woodall CW, Nichols MC, et al. Effects of climate change on ecosystem services. In: Halofsky JE, Peterson DL, Ho JJ, Little NJ, Joyce

LA, editors. Climate change vulnerability and adaptation in the Intermountain Region: Part 1. Washington: US Department of Agriculture. p. 376-403. DOI: https://doi.org/10.2737/RMRS-GTR-375PART2

51. Gowda P, Steiner JL, Olson C, Boggess M, Farrigan T, Grusak MA. Agriculture and rural communities. In: U.S. Global Change Research Program, editors. Fourth National Climate Assessment. Washington: U.S. Global Change Research Program;2018. p. 391-433. DOI: http://doi.org/10.7930/NCA4.2018.CH10
52. Zhao C, Liu B, Piao S, Wang X, Lobell DB, Huang Y, et al. Temperature increase reduces global yields of major crops in four independent estimates. Proc Natl Acad Sci USA 2017;114(35): 9326-31. DOI: https://doi.org/10.1073/pnas.1701762114
53. Davis JL, Currin CA, O'Brien C, Raffenburg C, Davis A. Living shorelines: coastal resilience with a blue carbon benefit. PLoS One 2015;10(11): e0142595. DOI: https://doi.org/10.1371/journal.pone.0142595
54. Howard J, Sutton-Grier A, Herr D, Kleypas J, Landis E, Mcleod E, et al. Clarifying the role of coastal and marine systems in climate mitigation. Front Ecol Environ 2017;15(1):42-50. DOI: https://doi.org/10.1002/fee.1451
55. Ebi KL, Nealon J. Dengue in a changing climate. Environ Res 2016;151:115-23. DOI: https://doi.org/10.1016/j.envres.2016.07.026
56. Runting RK, Bryan BA, Dee LE, Maseyk FJ, Mandle L, Hamel P, et al. Incorporating climate change into ecosystem service assessments and decisions: a review. Glob Chang Biol 2017;23(1): 28-41. DOI: https://doi.org/10.1111/gcb.13457
57. Sandifer PA, Sutton-Grier AE, Ward BP. Exploring connections among nature, biodiversity, ecosystem services, and human health and well-being: Opportunities to enhance health and biodiversity conservation. Ecosyst Serv 2015;12:1-15. DOI: https://doi.org/10.1016/j.ecoser.2014.12.007
58. Obradovich N, Migliorini R, Paulus MP, Rahwan I. Empirical evidence of mental health risks posed by climate change. Proc Natl Acad Sci USA 2018; 115(43):10953-8. DOI: https://doi.org/10.1073/pnas.1801528115