International Journal of Innovative Research in Science and Engineering
Volume 08, Issue 11, 2022
www.ijirse.com
ISSN: 2454-9665

A Brief Review on Effects of Climate Change Adaptation and Mitigation Strategies on Biodiversity

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Abstract

Mitigation and adaptation are two main approaches that aimed at reducing the vulnerability to climate change. Mitigation benefits are more global and adaptation benefits are more localized. Mitigation measures focus on greenhouse gas sources and sinks, while adaptation techniques focus on climate sensitive sectors and activities. Mitigation and adaptation measures to combat the adverse impacts of climate change can have both positive and negative consequences on biodiversity, depending on the way in which such strategies are implemented. Biodiversity could be affected by adaptation and mitigation measures in many sectors and the aim of this paper is to identify those climate change adaptation and mitigation measures which are most likely to have significant potential for adverse or beneficial impact on biodiversity, and to identify which habitat types and species groups are most at risk from these measures.

Keywords: *Agriculture, Biodiversity, Climate Change adaptation, climate change mitigation, Energy, Human health*

I. Introduction

The Intergovernmental Panel on Climate Change (IPCC) suggest that warming of the climate system is unequivocal, as is shown by observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, rising global average sea level and changing patterns and frequencies of extreme weather including droughts, heavy precipitation, heat waves and the intensity of tropical cyclones [1]. Observations from all continents and oceans show that many natural ecosystems are responding to regional climate changes, especially increases in temperature [2]. The responses include pole ward and altitudinal range shifts of biota, phenological changes, changes in species' abundance and in community composition [2], as well as changes in form and physiology [3], reproduction [4] and productivity. This shows that some species are already adapting autonomously to current climate change, but it is also projected that the resilience of many species and ecosystems will be exceeded in future. These species may become vulnerable if their adaptive capacity is exceeded. There are two main approaches to addressing the impacts of climate change: mitigation and adaptation. They are both aimed at reducing the vulnerability to climate change and both are viewed as necessary to reduce projected climate change and vulnerability. Mitigation and adaptation are often seen as complementary strategies for dealing with climate change in that both are necessary [5], [6].

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Mitigation: Climate change mitigation seeks a net reduction of greenhouse gas emissions, and also concerns the protection and promotion of carbon sinks, through land use and habitat management. Mitigation involves the encouragement of the use of non-carbon or carbon-neutral energy sources and the improvement of energy efficiency. Mitigation, while often undertaken at the local level has global benefits, with possible ancillary benefits at the local or regional level [7]. A review of the implications for biodiversity of mitigation measures showed that they depended on their context, design and implementation, especially site selection and management practices [8].

Adaptation: Adaptation is vital to avoiding unwanted impacts of climate change, especially in sectors, such as ecosystems which are vulnerable to even moderate levels of warming,[1],[9]. It is also seen as a means maintaining or restoring of ecosystem resilience to single or multiple stresses [10]. The IPCC recognizes two types of adaptation: autonomous (or spontaneous) adaptation and planned (or societal) adaptation.

Mitigation, adaptation and biodiversity: Biodiversity could be affected by adaptation and mitigation measures in many sectors and the aim of this review is to identify those climate change adaptation and mitigation measures which are most likely to have significant potential for adverse or beneficial impact on biodiversity.

This paper will highlight the possible climate change adaptation and mitigation measures and their potential effect on future biodiversity in three different sectors namely, agriculture, energy and human health.

II. Role of mitigation and adaptation in the agricultural sector and its impact on biodiversity

The three main Green House Gas (GHG) constituents from agriculture are [11].

• CO_2, which is released from burnt or decaying plant and soil organic matter.

• CH_4, which comes from the anaerobic decomposition of organic matter (e.g., fermentation digestion in ruminants).

• N_2O, which comes from the transformation of soil and manure nitrogen by microbes.

This section examines the role of mitigation and adaptation in the agricultural sector and its impact on biodiversity. It is divided into livestock and poultry and crop production

A. Livestock and Poultry

Animals in agriculture are the most important sources of CH_4 and N_2O emissions. The rumens of sheep and cattle, flatus from monogastric animals as well as manures are the most important CH_4 sources, whereas N_2O is mostly derived from nitrogen fertilizer, manure applications and urine [12].

Animal breeding and husbandry

- **Breed choice**

Mitigation measure: There are many different breeds of cattle, pigs, and sheep

Adaptation measure: Choice of breeds that are more adaptable or tolerant of climatic extremes [13], [14]

Impact on biodiversity: No effect.

- **Twinning**

Mitigation measure: Increase productivity by ensuring that twins are produced instead of a single offspring.

Adaptation measure: Not applicable.

Impact on biodiversity: Negative – possible effects of increased grazing intensity in species-rich grasslands.

- **Animal housing and in-barn manure management**

New low-emission livestock and poultry housing systems

Mitigation measure: Reduces all GHG and NH_3 emissions compared to normal housing systems.

Adaptation measure: climate control in a better way to reduce heat stress [13], [15], [16].

Impact on biodiversity: Possible negative effect if replaces old, traditional buildings that are home to bats or nesting birds (e.g., barn owl) [17], [18] .Bats like to roost in roof voids, cervices, cracks, hollows and cavities that are likely not to exist in new buildings.

- **Grassland and grazing management**

Adaptation of fertilization on demand

Mitigation measure: Nutrient addition to grassland is synchronized with demand; this reduces GHG emissions by improving productivity.

Adaptation measure: Not applicable.

Impact on biodiversity: Positive – excessive use of fertilizers is curbed, which will reduce the likelihood of the environmental damage to nutrient sensitive ecosystems like species-rich grassland, woodland and water courses [19],[20]

- **Consideration of pasture age and composition**

Mitigation measure: Re-improvement of pasture increases productivity by sowing improved varieties.

Adaptation measure: Not applicable

Impact on biodiversity: Negative – the improvement of unimproved grassland has been a major source of biodiversity loss in European grasslands. Replacing species-rich grassland with a sward of one or two varieties not only reduces plant diversity but insect, mammal and bird diversity as well [19], [21].. Furthermore, replacing species-rich semi-natural grasslands by sown species-poor mixtures is also likely to impact the diversity and density of bio control agents, with flow-on effects to crop production and thus future pesticide use.

- **Control groundwater level fluctuations**

Mitigation measure: Fluctuating groundwater can result in increased N_2O emissions due to air in soil with high N_2O concentrations being driven out with rising water levels. Periodic drying and wetting of soils also promote production and emission of N_2O. It involves irrigation and drainage control.

Adaptation measure: Adding drainage system to increase accessibility to grazing pastures after wetter winters. Irrigation maintains grass yield in drought summers.

Impact on biodiversity: Probably negative – improved drainage will increase nitrate leaching which could result in eutrophication and biodiversity loss in water courses [22], [23] . Control of groundwater level fluctuations may decrease plant diversity in grasslands where fluctuating water levels combine with microtopography to provide a diversity of microhabitats, i.e. spatial heterogeneity that promotes species coexistence. Also excessive water extraction from ponds or rivers may result in loss of biodiversity[24].

- **Planting fast-growing trees to provide shade**

Mitigation & Adaptation measure: Heat stress reduces productivity (including milk yield), increases stress, discomfort and even mortality in livestock [13],[16] .Planting fast growing tree species (e.g., Populus spp) provides shade, which livestock readily use [25].

Impact on biodiversity: Positive or negative - the addition of trees may be beneficial to biodiversity by providing insect and bird habitats; on the other hand, if trees are planted in species-rich unimproved grassland they may reduce biodiversity by shading out the ground flora [26], [27]. Genetically diverse poplar stands will offer positive flow-on effects for soil microorganisms, insects etc.

B. Crop production

Crop systems allow farmers to mitigate GHGs in three main ways reducing emissions, enhancing removals and avoiding emissions.

- **Continuous plant cover (catch crops and intercrops)**

Mitigation measure: Catch crops are usually sown after the harvest of one crop and before the sowing of the next. They offer forage or green manure (providing fertility for the soil thereby reducing nitrogen applications for the next crop) potential and are usually based on quick growing plants that will establish before winter. Catch crops can also be planted amongst the crop as in intercropping systems. Their mitigation benefits include reducing N_2O emissions or leachate, improving N-use efficiency and carbon sequestration in the soil.

Adaptation measure: Catch crops may offer adaptation benefits too: in winter floods they offer soil stabilization and prevent erosion; potential reduction in increased pest populations (e.g., root nematodes in potatoes: [28] through the use of allelopathic species that give off toxic chemicals (e.g., Tagetes spp.[29],[30]; potential as a mulch to reduce water loss and provide an emergency forage crop in drought conditions [31].

Impact on biodiversity: Positive and negative – catch crops reduce nitrate leaching (Kirchmann et al., 2002), which can cause eutrophication in watercourses[23],[20]. They can also provide cover for many farmland bird and insect species [33] and reduce soil erosion which would have positive effects on local biodiversity[34] (DEFRA, 2005a). However, if catch crops replace over-winter stubbles there could be a resulting loss of invertebrate and bird species [35],[36],[37],[38]

- **Conversion of arable land to grasslands**

Mitigation measure: Increase carbon sequestration through conversion to permanent plant cover.

Adaptation measure: If climate has become too extreme for crop production.

Impact on biodiversity: Positive and negative – conversion to 'species-rich' grassland will have benefits for invertebrate and bird populations [33]; introduction of grassland buffer strips also reduces risk of nutrient leaching and runoff into watercourses[22],[23] . However at the same time, conversion of some arable lands may reduce biodiversity if they have been managed in a 'biodiversity-friendly' way, e.g., organic rotation with spring crops and other agri-environmental scheme prescriptions [39],[33],[40].

- **Planting fast-growing trees to provide shade**

Mitigation & Adaptation measure: Heat stress reduces productivity (including milk yield), increases stress, discomfort and even mortality in livestock [13], [16]. Planting fast growing tree species (e.g., Populus spp) provides shade, which livestock readily use [25].

Impact on biodiversity: Positive or negative - the addition of trees may be beneficial to biodiversity by providing insect and bird habitats; on the other hand, if trees are planted in species-rich unimproved grassland they may reduce biodiversity by shading out the ground flora [26], [27]. Genetically diverse poplar stands will offer positive flow-on effects for soil microorganisms, insects etc.

- **Use of genetically modified crops**:

Many of the techniques listed below are still in development but offer great potential for climate change adaptation and mitigation. The threat to biodiversity of these techniques is highly controversial and requires further risk assessment.Some of the examples are:

Herbicide resistant crops, Virus resistant crops, Pest resistant crops, Fungal resistant crops, Drought resistant crops, Flood resistant crops and Salt tolerant crops.

Impact of GM crops on biodiversity:

Possibly positive and/or negative –research on the effects of GM crops is still in the early stages and as yet there are no really conclusive outcomes. Some possible negative outcomes are:

i) A change in the invasibility of the crop through greater competitive ability [41], [42]; this could have repercussions for neighbouring natural habitats with some native species being replaced by the invasive crop.

ii) Gene flow from crop species populations to populations of wild relatives [43],[41],[44]; this could result in losses of genetic diversity, reduced genetic fitness or increased genetic fitness (becoming invasive).

iii) Development of herbicide resistant weeds[41], [45], which could result in the use of more aggressive and harmful herbicides to control them.

iv) Changes in soil ecology [46] that may include effects on bacterial diversity, number and activity, fungal counts, effects on numbers of protozoa, nematodes and collembolan, diversity of nematodes, and woodlice mortality (the long-term effects are still uncertain and much research needs to be done).

- Indirect effects on wildlife – complete weed control in herbicide resistant crops has been shown to reduce weed diversity and consequently invertebrate and bird diversity [47], [48]

- **Change in herbicide and pesticide usage**

Mitigation measure: Climate change may result in a greater or lesser abundance and diversity of weed, pathogen and pest species[49]. New species may start to appear [28], [50] and farmers may have to use more pesticides to maintain crop yield and productivity. Some pest numbers may decrease though (e.g., aphids in southern England: [51].

Adaptation measure: As above

Impact on biodiversity: Positive or negative – Increased use of herbicides and pesticides will reduce weed diversity and abundance which will also affect water quality, invertebrate numbers etc. Conversely, reductions in chemical inputs will be beneficial for biodiversity [19], [52]. Impacts are likely to be regional.

III. Role of mitigation and adaptation in the energy supply sectors and its impact on biodiversity

- **Nuclear power**

Nuclear power is one the most vulnerable energy sectors in terms of adaptation to climate change

Effects on biodiversity

The impact of nuclear power production on nearby and distant ecosystems is considerable. Environmental effects can be categorized from the mining of uranium to waste disposal of spent fuel. There have been a number of studies focusing on the environmental impacts from the mining and milling of uranium [53],[54]. Water discharge from power plants can affect species through temperature differences and increased turbidity (cloudiness)[55],[56]. The final aspect to consider is the treatment of radioactive nuclear waste[57],[58]. Due to the extremely long half-life of radioactive materials the design and implementation of containment strategies is very important.

- **Solar energy**

Solar energy is the main source of practically all our energy [59]. The potential for solar power is immense and could potentially meet global demands quite easily with correct siting and efficient distribution[60],[61] . The direct use of solar energy can be summarized in two main forms - solar thermal energy and electricity generation [61], [62]

Effects on biodiversity

The environmental effects resulting from the manufacture and operation of solar technologies are, in comparison to other energy sources, are quite minimal[62], [8], [63] . The disposal of (toxic) materials at the end of the life-cycle can pose problems[63] .

- **Wind power**

Rigorous conservation movements over development of wind farms have opposed many wind energy projects. There have been long-standing concerns over the impacts on wildlife, particularly birds [64], [65].

Effects on biodiversity

i)Habitat loss[64],[66] and fragmentation: Disturbance effects have been shown to range from 75 m to 800 m from turbines for some birds

ii) Bird and bat collision, [64], [66], [65]

iii) Barrier to bird migration[66],[65]

- **Hydropower**

Hydropower has been harnessed throughout the world and is the largest current renewable energy sector [61]. Tidal power come from two forms: tidal stream which uses the kinetic energy of water moving through turbines; and, barrages which uses the difference in height between low and high tides (potential energy). Tidal stream power is generally more environmentally benign than barrage systems.

Effects on biodiversity

i) Changes in flow [67]
ii) Fish mortality from turbines [67]
iii) Changes to intertidal areas [67]
iv) Changes in fish migratory patterns [67]
v) Turbidity and sediment movement [67]
vi) Salinity [68]

IV. Role of mitigation and adaptation in the Human health sector and its impact on biodiversity

Emerging evidence suggests that climate change will have diverse implications for human health. The increasing incidence of extreme weather events such as heat waves, floods and storms may affect human health and well being directly. In addition, climate change may result in a series of indirect effects, for example changes in the distribution and seasonality of vector-born, water-born, and other infectious diseases, as well as allergenic pollen species [69], [70]. In the face of multiple pressures caused by climatic alterations several adaptation measures have been considered to reduce the negative effects on human health. These measures include investments into public education programs, the establishment of early warning systems, vaccination programs and schemes for vector and pathogen control[70], [71]. Measures to prevent heat related diseases and vector-born diseases are currently in the focus of the scientific literature. Therefore, the present review concentrates on adaptation strategies related to these two topics and their likely impacts on biodiversity.

The majority of health measures refer to adaptation, whereas mitigation is rarely involved.

i) Heat waves

- **Education programs**

Mitigation measure: Not applicable.

Adaptation measure: Reduce individual vulnerability to heat through altered behaviour.

Impact on biodiversity: No effect.

- **Early warning systems**

Mitigation measure: Not applicable.

Adaptation measure: Reduces the incidence of heat stroke and heat mortality.

Impact on biodiversity: No effect.

- **Improvement of emergency plans**

Mitigation measure: Not applicable**.**

Adaptation measure: Enhances the ability of medical emergency services and other health infrastructure to respond to particular natural hazards.

Impact on biodiversity: No effect.

- **Passive cooling of buildings through improved isolation and building design Mitigation measure:** Decreases energy use for active cooling and thereby green house gas (GHG) emissions.

Adaptation measure: Reduces the incidence of heat stroke and heat mortality.

Impact on biodiversity: Birds, mammals and invertebrates living in urban habitats may lose their breeding sites if these measures are not conducted appropriately.

ii) Vector born diseases

- **Education programs**

Mitigation measure: Not applicable.

Adaptation measure: Reduces individual vulnerability. For example, altered human behaviour may lead to reduced exposure to vectors and therefore, may decrease transmission rates [72]

Impact on biodiversity: No effect.

- **Use of insect repellents**

Mitigation measure: Not applicable.

Adaptation measure: Wearing insect repellents on clothes and skin may reduce exposure to vector species [72].

Impact on biodiversity: No effect.

- **Early warning systems**

Mitigation measure: Not applicable.

Adaptation measure: Early warning systems may improve individual adaptation measures to encounter insect outbreaks.

Impact on biodiversity: No effect.

- **Vaccination programs**

Mitigation measure: Not applicable.

Adaptation measure: Vaccination may provide resistance of a human population against pathogens.

Impact on biodiversity: No direct effect. Biodiversity may benefit from vaccination if vector control by pesticides can be reduced.

- **Draining wetlands**

Mitigation measure: Not applicable.

Adaptation measure: Draining wetlands destroys the breeding habitat of mosquito species.

Impact on biodiversity: Drainage has been shown to reduce biodiversity of wetlands [73], [74]. As wetlands usually inhabit a large number of species [75], a significant loss of biodiversity may result if wetlands are drained for mosquito control. Mediterranean wetlands may be particularly endangered as mosquito born diseases may spread into these regions first.

- **Mosquito control by introducing fish**

Mitigation measure: Not applicable.

Adaptation measure: *Gambusia affinis* mosquito fish and other fish species act as biological control agent against mosquito larvae [76].

Impact on biodiversity: Introduced non-native species may compete with native species for resources, thereby altering community structures, food webs and affecting ecosystem functions [77]. Predation by *Gambusia affinis* which was introduced for mosquito control has been shown to adversely affect amphibian populations [78], arthropod populations[79] and to contribute to the extinction of populations [80].

- **Mosquito control using Bacillus thuringiensis var. israelensis toxine (Bti)**

Mitigation measure: Not applicable.

Adaptation measure: If digested Bti prevents the growth of mosquito larvae, thereby reducing mosquito populations.

Impact on biodiversity: Although considered as environmentally safe [81] repeated Bti applications have been shown to affect aquatic non-target organisms [83]. Adverse effects on food webs in wetland habitats may result [82].

The use of chemical and biological control agents for mosquito control is expected to affect arthropod biodiversity in particular and is considered to have a generally negative effect because non-target organisms are affected as well. For example, there may also be direct and indirect effects on higher trophic levels such as birds and fishes. The magnitude of damage to non-target organisms generally depends on the degree of selectivity of the agent and its mode of application. Generally, microbial control agents such as *Bacillus thuringensis israelensis* or *Bacillus spaericus* affect non-target organisms to a lesser extent than chemical compounds as organophosphates, pyrethroids or DDT.

The climate change related measures in the health sector are primarily concerned with adaptation and the impact does depend on the manner of implementation. This is particularly true of the various options for the control of disease vectors, where there is a high potential and risk for negative impacts on biodiversity. Care, therefore, should be taken in the selection and implementation of methods and further research carried out into less harmful means of control.

V. Conclusion

This review has shown possible interactions between sectoral mitigation and adaptation measures and between these and biodiversity. Those which are particularly negative or positive have been identified and their likelihood of implementation assessed. Thus the opportunities for and risks to biodiversity can be recognized and appropriate strategies can be undertaken which, ideally, achieve the win-win-win situation. An integrated approach is required in this regard, in order to achieve maximum benefit for all concerned. A generic framework for identifying the inter-relationships between mitigation and adaptation measures, both within and between sectors need to be developed based on the win-win-win trilogy. There are uncertainties and gaps in our knowledge, but there is a need to promote win-win-win situations and avoid or minimize those which pose high risks for biodiversity in order to maximize the efficiency and effectiveness of the mitigation and adaptation measures being taken to address climate change.

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