ClimeHop: An interactive app for teaching cost-effective biodiversity conservation under climate change – resources for instructors

This document provides additional resources for instructors. It contains a brief guide on how to use the different types of material provided alongside the app, suggestions for questions for class discussions, an extensive reference list that may be used to develop further student activities such as essays or presentations, as well as a brief technical guide. Please see the publication in the Journal of Economic Education (link to be added here) for a brief description of the app and its general purpose.

The app "ClimeHop" has been designed to be used by students individually within a class setting in which the instructor can lead discussions after students complete the different steps of the app. Suggestions regarding possible questions and topics for the discussion sessions can be found below. Depending on the students' background (e.g. economics, ecology or environmental sciences), some questions may be more relevant than others. We also encourage instructors to ask additional questions that are specific to the local conservation situation (including conservation policy instruments). Moreover, species conservation and climate change are topics that are quickly evolving. We would therefore encourage instructors to include current research and policy developments in their class discussions. While no class discussion guide on an evolving topic like climate change and biodiversity loss can ever address all relevant questions, we hope to provide some inspiration of possible aspects to be discussed. We have structured possible discussion questions into three general topics: "biodiversity conservation", "conservation costs and the importance of cost-effectiveness", and "climate change and its impact on cost-effective biodiversity conservation".

In addition to the class discussion guide, we also provide some lecture slides. These slides contain background information on the conservation measures, a hypothetical example with which to explain the concept of cost-effectiveness, the figures from the app, as well as additional results on the effects of climate change that may be discussed. We provide the slides as a ppt file as well as a PDF to enable edits by instructors to adapt the slides to their own needs, and to avoid technical problems regarding specific file formats.

Regarding technicalities of using the app: the app has been tested with students to ensure that the design of the app is intuitive. Nonetheless, we provide an overview of the key options provided in the app below to reduce potential technical problems.

1. Suggestions for discussion questions

We provide discussions questions for three general topics: “biodiversity conservation”, “conservation costs and the importance of cost-effectiveness”, and “climate change and its impact on cost-effective biodiversity conservation”.

Class discussion topic I: biodiversity conservation

1) What are conservation measures? Can you think of other examples than the ones discussed in the app?
   Didactic aim: improve understanding of different types of conservation activities necessary to conserve species, also to help students understand the relevance of results from the app for other conservation settings.
   - We think that regional examples will be particularly valuable. However, some examples of conservation measures include: re-wetting of wetlands, afforestation, species translocation, control of invasive species, etc.
2) Why does a more extensive mowing regime benefit the large marsh grasshopper? Is this also relevant for other species? Can you think of examples? What do you think is the overarching driver of biodiversity loss in agricultural landscapes?
   Didactic aim: deepen the students’ understanding of the conservation problem at hand and further deepen understanding regarding biodiversity conservation in cultural / agricultural landscapes
   - The species is particularly vulnerable when it lives above ground. If mowing machines are used at this time, the grasshopper cannot escape and many will die due to the mechanical mowing process.
   - This is relevant for many other species inhabiting agricultural landscapes such as farmland birds, other insects such as butterflies, but also plants. However, note that mowing at least ones a year is necessary to prevent shrub encroachment and conserve a meadow as a habitat.
   - The key problem for all of these species is an intensive agricultural land use. The frequent use of heavy machinery and intensive agricultural production facilitated by the use of fertilisers and pesticides often means that the agricultural output of cropland and grassland is maximised, but their quality as a habitat for many species declines. For example, if the use of herbicides reduces the variety of wild plant species, a field may also no longer provide habitat for many insects, which in turn are food resources for some bird species. Intensive agricultural land use may therefore have many direct impacts on biodiversity (such as the impact of herbicide usage on wild plants or bird mortality caused by mowing machines) as well as indirect impacts (such as repercussions through the food web). Moreover, structural landscape elements such as hedgerows and individual trees (which provide habitats for many species) have been removed from the landscape to maximize space for production.
   - Many of these species are actually adapted to an extensive agricultural land use, as agriculture has a long tradition in cultural landscapes such as Europe. If there was no agricultural land use, many of these areas would become forests over time, and many species such as farmland birds would no longer find any habitat. An extensive agricultural land use is therefore important for many species inhabiting cultural landscapes with a long tradition of agricultural land use.
   - Note that this is different for many pristine landscapes which were only marginally impacted by human land use for a long time such as Australia and North America. Here, often human land use needs to be minimised for conservation.

3) In the app, we only look at the large marsh grasshopper. Does it make sense to only look at a single species? Why? Why not?
Didactic aim: encourage critical thinking regarding the relevance of results for species conservation in general and the development of (broad) policy recommendations
    - The large marsh grasshopper is an indicator species (remember: this means that it provides an indication of the quality of grasslands and wet meadows in Central Europe). This means that if we manage to conserve this species, other species will benefit as they inhabit the same type of habitat.
    - Generally, considering more species would be very valuable. If we only consider a single species (even if it is an indicator species), we may lose species with similar but not identical habitat requirements as we did not consider all aspects that are relevant for these species.
        - For example: here, we will look at grassland areas that are suitable for the large marsh grasshopper under climate change. However, a different species that may prefer the same habitat type may have additional requirements – for example, a specific plant to feed on. If we do not consider this additional requirement, the species may be lost.
    - However, considering all aspects that may be relevant for many different species in an integrated ecological-economic analysis quickly becomes very complicated. Focusing on an indicator species may therefore be a necessary simplification. However, when making policy decisions, these simplifications need to be kept in mind.

Class discussion topic II: conservation costs and the importance of cost-effectiveness

1) Why should we care about the costs of conservation? Shouldn't we conserve species at all costs?
Didactical aim: deepen the students' understanding regarding the influence of conservation costs on the final conservation outcome that may be obtained
    - Typically, only a certain amount of financial or other resources is available for conservation purposes (one may think as an example of a conservation fund which has a limited amount of money).
    - These resources have to be spent in a way that the conservation outcome is maximised. This implies that we need to consider conservation costs.
2) What are possible conservation costs in the case study?
Didactical aim: improve students' understanding regarding the different dimensions that need to be considered when assessing conservation costs
    - Opportunity costs of land use: what profit (revenue minus costs) do we lose by changing the agricultural land use to conserve the species?
    - This means we need to consider differences in agricultural yield between conservation and the previous intensive agricultural land use.
    - Depending on the conservation measure, we may also need more or less machinery. For example, if we mow fewer times, we will need the mowing machines fewer times. This reduces costs of machinery use (petrol, maintenance costs, etc.).
    - We may also have different labour costs. Again, if we mow fewer times, we will have lower labour costs.
    - Finally, one should consider transaction costs. Transaction costs are the costs of any (economic) exchange, such as the time and effort of making a decision and planning. In the case of conservation, transaction costs include costs of getting information on

which conservation measure is the most suitable and choosing conservation sites. Transaction costs are not included in the app as this would be too complicated. However, they need to be considered when making recommendations about conservation policy instruments as transaction costs may differ between policy instruments.

3) Why do conservation costs differ spatially? Can you think of examples of particularly costly and low-cost areas?
   Didactical aim: improve the students' understanding regarding the spatial variation of opportunity costs
   - Opportunity costs of conservation depend on what could be done with the land if it was not used for conservation. In the case study, this is agricultural production. The agricultural yield depends on, for example, soil quality which may differ spatially.
   - Other examples (to be adapted to local conditions):
     - Low-cost sites: mountains, dry areas, flooded areas.
     - High-cost sites: particularly fertile land, land for residential or industrial development.
4) Why do different mowing regimes have different costs?
   Didactical aim: improve students' understanding of how the costs of different land uses differ
   - This depends on the number of mowing events: on fertile land and with a favourable climate, farmers typically mow up to 4 times; the fewer times farmers are allowed to harvest the grass, the higher the loss in fodder.
   - It also depends on the timing of harvest: for example, a very late harvest has low quality (think of what grassland looks like in late summer) – this harvest is less valuable as fodder than if you harvest in late spring.
5) How could we get farmers to implement conservation measures?
   Didactical aim: encourage students to start thinking about how to incentivise farmers to implement conservation measures
   - Farmers need to earn money from farming – generally, we cannot rely on farmers implementing costly conservation measures if this means they would make a loss.
   - However, if we pay farmers for implementing conservation measures, they would no longer make losses.
   - This is the idea of agri-environment schemes: here, farmers are remunerated for voluntarily implementing conservation measures.

Class discussion topic III: climate change and its impact on cost-effective biodiversity conservation

1) Why is climate change such a big problem for biodiversity? Can you think of examples which illustrate the impact of climate change on species?
   Didactic aim: improve general understanding of why biodiversity is threatened by climate change
   - Species need specific biotic and abiotic conditions in their habitat.
   - Changes in climatic conditions such as temperatures, precipitations, and soil humidity as well as extreme events such as droughts and heat waves may mean that current habitat sites are no longer suitable.
   - We encourage instructors to search for regional and current examples in which climate change impacts biodiversity.

2) Do you think climate change also changes the costs and ecological effectiveness of these measures?
   Didactic aim: encourage students to think about the mechanisms behind different conservation measures, in particular how climate change may influence costs and effectiveness
   - This may be discussed based on the examples for conservation measures students came up with in question 1 of discussion topic 1. However, some examples include:
     - re-wetting of wetlands: this may become more necessary from an ecological perspective, but climate change may also cause increasing droughts which may lead to higher input prices (water), which may increase conservation costs.
     - afforestation: if profits of monoculture forests decrease under climate change (e.g. due to higher risks from disease and forest fire), the relative costs of mixed forests for conservation decrease.
     - species translocation and the control of invasive species may also become more important from an ecological perspective due to the impacts of climate change.

2. Further references

Publications that the results presented in ClimeHop are based on

Gerling C, Drechsler M, Leins J, Keuler K, Radtke K, Schulz B, Sturm A, Wätzold F. 2022. Combining ecological-economic modelling and climate science for the cost-effective spatio-temporal allocation of conservation measures in the face of climate change. *Q Open, 2*(1):qoac004.

This paper describes the basic modelling approach used to examine the impact of climate change on the LMG and conservation costs.

Drechsler M, Gerling C, Leins J, Keuler K, Sturm A, Wätzold F. 2021. A quantitative approach for the design of robust and cost-effective conservation policies under uncertain climate change: the case of grasshopper conservation in Schleswig-Holstein, *Journal of Environmental Management, 296*.

This paper focuses on issues of climate change uncertainty and the robustness of different conservation strategies, and shows results for different climate scenarios.

Biodiversity conservation: conservation measures and policy instruments

Henle K, Alard D, Clitherow J, Cobb P, Firbank L, Kull T, McCracken D, Moritz RFA, Niemelä J, Rebane M, Wascher D, Watt A, Young J. 2008. Identifying and managing the conflicts between agriculture and biodiversity conservation in Europe–A review. *Agriculture, Ecosystems & Environment, 124*(1-2):60-71.

This paper discusses the key reasons of conflicts between agriculture and biodiversity conservation: agricultural intensification, land abandonment and changing scales of agricultural operations.

Johst K, Drechsler M, Mewes M, Sturm A, Wätzold F. 2015. A novel modeling approach to evaluate the ecological effects of timing and location of grassland conservation measures. *Biological Conservation, 182*:44-52.

This paper focuses on the impacts of extensive land use on meadows on biodiversity (birds, butterflies, grassland types), highlighting particularly the role of spatial heterogeneity and the importance of the timing of mowing.

Landis DA. 2017. Designing agricultural landscapes for biodiversity-based ecosystem services. *Basic and Applied Ecology, 18*.

This paper focuses on how to "design" agricultural landscapes for biodiversity with a specific focus on agricultural intensification and landscape simplification as key problems.

Hanley N, Banerjee S, Lennox GD, Armsworth PR. 2012. How should we incentivize private landowners to 'produce' more biodiversity? *Oxford Review of Economic Policy, 28*(1):93-113.

This paper focuses on how to provide landowners with incentives for biodiversity conservation by outlining the key problems and reviewing different policy instruments.

Lewis DJ, Plantinga AJ, Nelson E, Polasky S. 2011. The efficiency of voluntary incentive policies for preventing biodiversity loss. *Resource and Energy Economics, 33*(1):192-211.

This paper focuses on different designs of incentive-based instruments for terrestrial vertebrates in the Willamette Basin, USA and considers spatial heterogeneity of the value of land for biodiversity and agriculture.

Nelson E, Polasky S, Lewis DJ, Plantinga AJ, Lonsdorf E, White D, Bael D, Lawler JJ. 2008. Efficiency of incentives to jointly increase carbon sequestration and species conservation on a landscape. *PNAS, 105*(28):9471-9476.

This paper focuses on policy instruments for species conservation and carbon sequestration in the Willamette Basin, USA.

Wätzold F, Drechsler M, Johst K, Mewes M, Sturm A. 2016. A Novel, Spatiotemporally Explicit Ecological-economic Modeling Procedure for the Design of Cost-effective Agri-environment Schemes to Conserve Biodiversity. *American Journal of Agricultural Economics, 98*(2):489–512.

This paper focuses on the cost-effective design of an agri-environment scheme for birds, butterflies and grassland types in Saxony, Germany, considering spatial heterogeneity in conservation costs and impacts and the impact of different land use timings.

Costs and cost-effective biodiversity conservation

Naidoo, R., Balmford, A., Ferraro, P. J., Polasky, S., Ricketts, T. H., & Rouget, M. (2006). Integrating economic costs into conservation planning. Trends in ecology & evolution, 21(12), 681-687.

The paper introduces to the concept of costs in biodiversity conservation in general and conservation planning in particular.

Armsworth, P. R. (2014). Inclusion of costs in conservation planning depends on limited datasets and hopeful assumptions. Annals of the New York Academy of Sciences, 1322(1), 61-76.

The paper is more advanced in terms of how to consider costs in in biodiversity conservation and conservation planning.

Mettepenningen, Evy, Ann Verspecht, and Guido Van Huylenbroeck. "Measuring private transaction costs of European agri-environmental schemes." Journal of Environmental Planning and Management 52.5 (2009): 649-667.

The paper provides an introduction to transaction costs in the context of agri-environment schemes for biodiversity conservation.

Ando, A., Camm, J., Polasky, S., & Solow, A. (1998). Species distributions, land values, and efficient conservation. Science, 279(5359), 2126-2128.

This paper was among the first to integrate costs in conservation planning and demonstrates well the superiority of the cost-effectiveness approach over purely ecological criteria.

Wätzold, F., & Schwerdtner, K. (2005). Why be wasteful when preserving a valuable resource? A review article on the cost-effectiveness of European biodiversity conservation policy. Biological conservation, 123(3), 327-338.

This paper introduces the idea of cost-effectiveness in different policy settings applying considering different types of costs.

Cost-effective conservation under climate change

Alagador D, Cerdeira JO, Araújo MB. 2014. Shifting protected areas: scheduling spatial priorities under climate change. *Journal of Applied Ecology, 51*(3):703-713.

This paper examines optimal conservation sites for different species on the Iberian Pensinsula over time given that climate change causes species' range shifts.

Ando AW, Mallory ML. 2012. Optimal portfolio design to reduce climate-related conservation uncertainty in the Prairie Pothole Region. *Proceedings of the National Academy of Sciences of the United States of America, 109*(17):6484-6489.

This paper introduces "modern portfolio theory" as a method of selecting conservation sites under uncertain climate change, considering wetland conservation in the Prairie Pothole Region as a case study.

Gerling C, Drechsler M, Keuler K, Sturm A, Wätzold F. 2023 Time to consider the timing of conservation measures: designing cost-effective agri-environment schemes under climate change. *Agricultural and Resource Economics Review, 52*(2):231-249.

This paper examines how cost-effective agri-environment schemes for bird conservation need to change under climate change.

Huber R, Snell R, Monin F, Brunner SH, Schmatz D, Finger R. 2017. Interaction effects of targeted agri-environmental payments on non-marketed goods and services under climate change in a mountain region. *Land Use Policy, 66*: 49-60.

This paper focuses on cost-effective agri-environment schemes for different non-market goods/ services in the Visp area, Switzerland and explicitly considers the challenge of climate change.

Lewis DJ, Polasky S. 2018. An auction mechanism for the optimal provision of ecosystem services under climate change. *Journal of Environmental Economics and Management, 92*:20-34.

This paper focuses on changes in conservation outcomes due to climate change and proposes an auction mechanism for the provision of ecosystem services under these dynamic conditions.

Santangeli A, Lehikoinen A, Bock A, Peltonen-Sainio P, Jauhiainen L, Girardello M, Valkama J. 2018. Stronger response of farmland birds than farmers to climate change leads to the emergence of an ecological trap. *Biological Conservation, 217*:166-172.

This paper addresses the impacts of climate change on the timing of the life cycle of farmland birds and of agricultural land use.

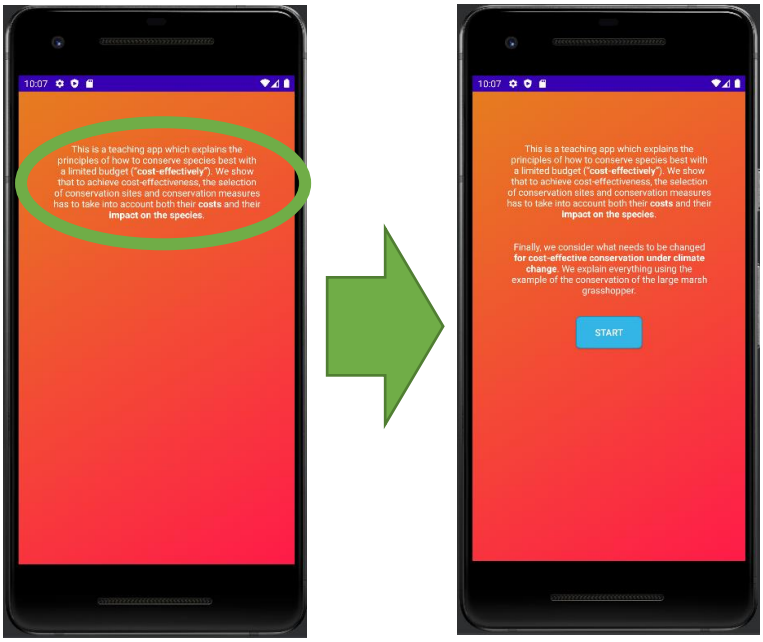
Zwiener VP, Padial AA, Marques MCM, Faleiro FV, Loyola R, Peterson AT. 2017. Planning for conservation and restoration under climate and land use change in the Brazilian Atlantic Forest. *Diversity and Distributions, 23*(8):955-966.

This paper examines priority sites for the conservation of woody plants in the Atlantic Forest Biodiversity Hotspot in Brazil under different climate change scenarios.

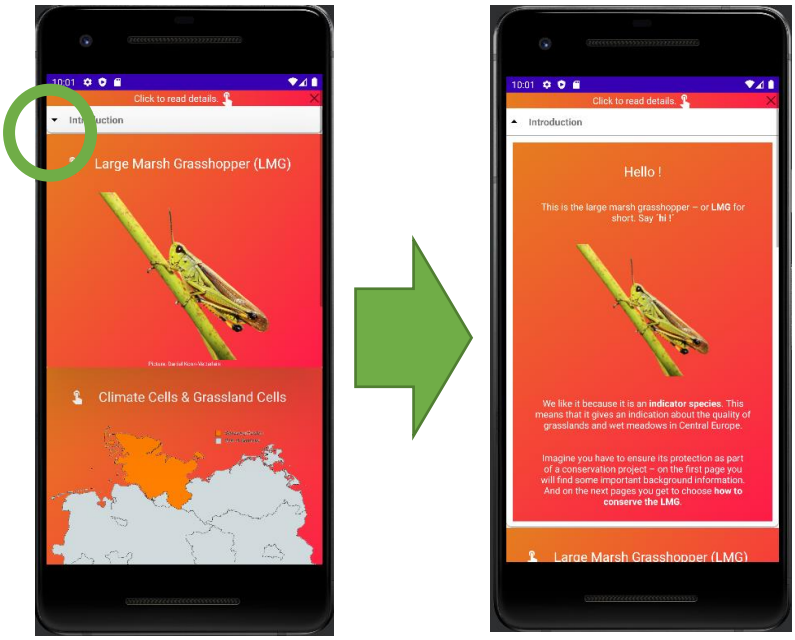
3. Technical guide to the app

Regarding technicalities of using the app: the app has been tested with students to ensure that the design of the app is intuitive. Nonetheless, we provide an overview of the key options provided in the app here to reduce potential technical problems:

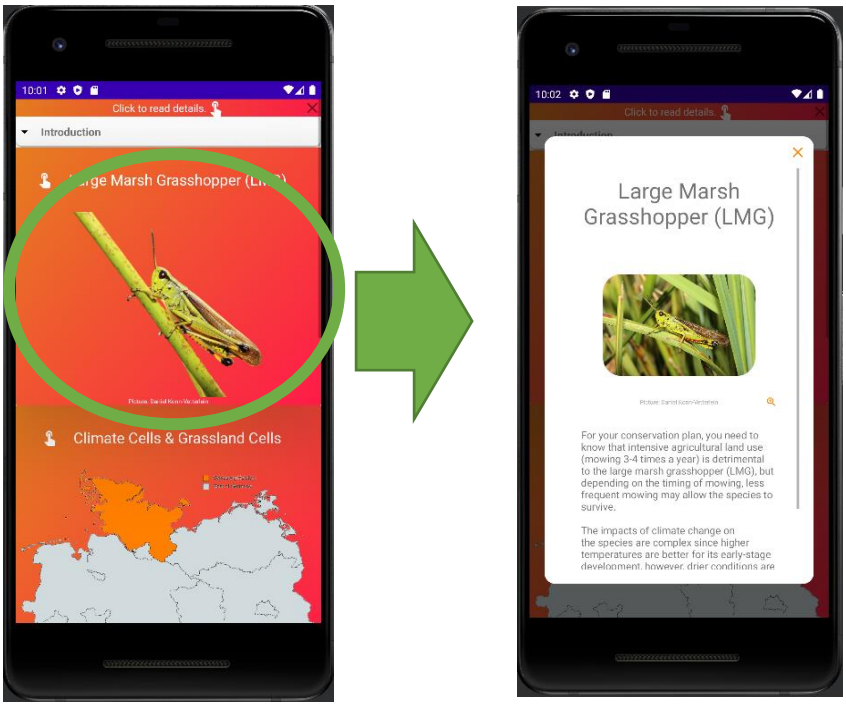
For animated text, you may click anywhere on the text to jump the animation and see the entire text instantly:



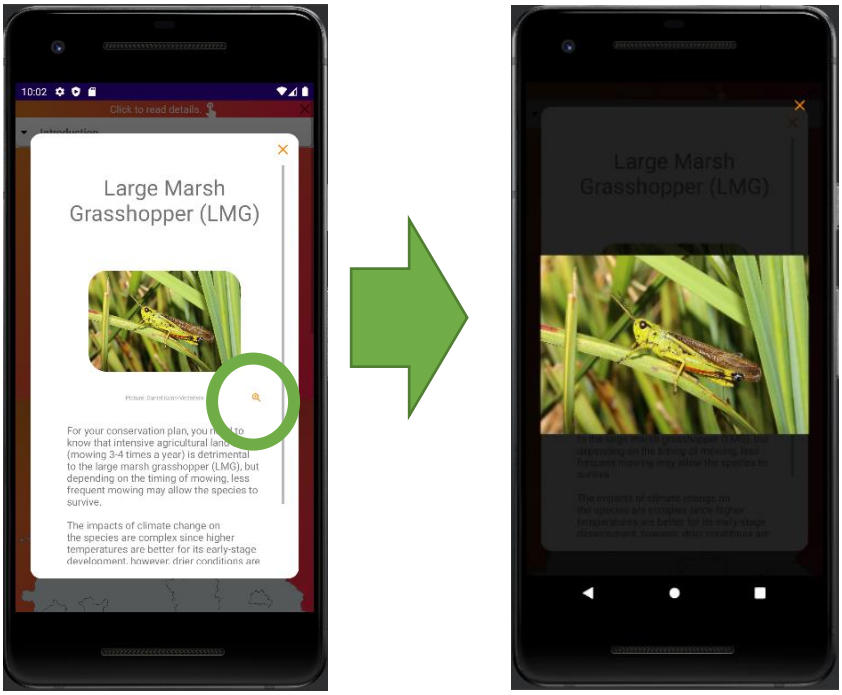
Click on the arrow to see additional explanations:



Click anywhere on the images to see additional information in the pop-up boxes:



Click on the magnifying glass symbol to open the images/ tables/ figures in full screen mode:



Click on the information button to open a pop-up window with additional information: