Institution: University of York		
Unit of Assessment: 5 - Biological Sciences		
Title of case study: Resilient strategies for conservation under climate change		
Period when the underpinning research was undertaken: 2001-2020		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
Chris D Thomas	Professor & Director of Leverhulme Centre for Anthropocene Biodiversity	2004-present
Jane K Hill	Professor of Ecology	2001-present
Colin Beale	Reader in Ecology	2012-present
Period when the claimed impact occurred: 1 August 2013-31 December 2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact (indicative maximum 100 words)

York research underpins the Intergovernmental Panel on Climate Change's (IPCC) scientific consensus that climate change has already caused widespread changes to the distributions of species, and is a major cause of species endangerment. Our research highlighting the risks to biodiversity has provided strong motivation for the development of climate change mitigation throughout the world, as exemplified by the Paris Accord. York approaches to developing adaptive conservation strategies to accommodate increasingly dynamic biological systems has given rise to a paradigm shift that has permeated government (e.g. the UK Nature Recovery Network) and non-governmental conservation policies (e.g. IUCN international guidelines and UK wildlife NGO landscape conservation strategies).

2. Underpinning research (indicative maximum 500 words)

Professors Chris Thomas FRS and Jane Hill, and Dr Colin Beale, have transformed understanding of the sensitivity of species to climate change, and the consequent risk of extinction. They have led the development of conservation strategies which are more resilient in accommodating dynamic change.

Extinction risk from climate change. Thomas *et al.'s* (**3.1**) model projections were the first to estimate how many species are at risk of extinction from anthropogenic climate change at a global scale, thus establishing a new focus for thousands of subsequent studies (over 7,500 citations). In a series of subsequent papers published between 2006 and 2013, York researchers then demonstrated local extinctions in both temperate and tropical regions in response to temperature and precipitation changes.

Species distributions are dynamic in response to climate change. Thomas, Hill and York students (**3.2**) demonstrated that terrestrial species have colonised higher elevations two times and higher latitudes three times faster than previously reported. They were the first researchers to show that species' have moved further in regions experiencing greater warming, cementing the link (attribution) between climate change and range shifts. In addition, they published the taxonomically broadest studies demonstrating climate-related range shifts, and provided the first evidence for tropical invertebrates.

Assessing risks and opportunities. Thomas, Hill & Beale subsequently co-developed a practical risk assessment framework with conservationists, the first to incorporate conservation opportunities associated with climate change, in addition to assessing risks (**3.3**). This framework proved to be the most effective method at predicting changes to the status of species through time.

Assisted colonisation as an approach to climate change conservation. Thomas and colleagues developed the first decision framework to identify different potential conservation intervention measures for species responding to climate change (**3.4**), identifying when human-assisted translocation (assisted colonisation) may be required to save species from extinction. Hill and Thomas then successfully completed the first assisted colonisation experiment as proof-of-principle.

Connectivity conservation to facilitate species movement. Thomas and Hill played a pivotal role in establishing the science of metapopulation ecology, specifically developing understanding of the colonisation dynamics of species responding to climate change in fragmented landscapes. They and NGO collaborators were first to demonstrate the need for habitat connectivity to facilitate climate-driven range expansions: they showed that habitat generalists but not specialists were expanding polewards (**3.5**) and provided strong theoretical and empirical evidence that rates of polewards range expansion are linked to habitat connections. They were also first to show that many expanding species disproportionately colonise nature reserves, underpinning conservation strategies (**3.6**).

Taken together, this research identifies the dynamics of species' distributions, the risk of extinction from climate change, and develops and validates approaches for the conservation of biodiversity experiencing rapid environmental change.

3. References to the research (indicative maximum of six references)

Thomas, Hill & Beale published >200 articles in the field described, of which the following are examples (York staff in **bold**; York PDRA underlined; Thomas/Hill PhD student italic):

3.1. Extinction threat. Thomas C.D. *et al.* (2004) Extinction risk from climate change. *Nature* 430: doi.org/10.1038/nature02719 & doi.org/10.1038/nature02121. Refereed journal article & correspondence. Google Scholar citations >7,500

3.2. Dynamic range shifts. *Chen I-C.*, **Hill J.K.**, Ohlemüller R., Roy D.B. & **Thomas C.D.** (2011) Rapid range shifts of species associated with high levels of climate warming. *Science* 333, 1024-1026. doi:10.1126/science.1206432 Refereed journal article. GS citations >3,400

3.3. Risks and opportunities. Thomas C.D., **Hill J.K.,** Anderson B.J., **Beale C.M.** & 7 others (2011) A framework for assessing threats and benefits to species responding to climate change. *Methods in Ecology and Evolution* 2, 125-142. DOI: doi.org/10.1111/j.2041-210X.2010.00065.x Refereed journal article. GS=125 citations

3.4. Assisted colonisation. Hoegh-Guldberg, O., **Thomas C.D.** & 5 others (2006) Assisted colonization and rapid climate change. *Science* 321, 345-346. doi:10.1126/science.1157897 Refereed journal policy forum. GS >850 citations

3.5. Connectivity conservation (a). Warren M.S., **Hill J.K.**, **Thomas, C.D.** & 14 others (2001) Rapid responses of British butterflies to opposing forces of climate and habitat change. *Nature* 414, 65-69. DOI: doi.org/10.1038/35102054. Refereed journal article. GS=1300 citations

3.6. Connectivity conservation (b). Thomas C.D., Gillingham P.K., Anderson B.J., Hodgson J.A., **Hill J.K.** & 17 others (2012) Protected areas facilitate species' range expansions. *Proceedings of the National Academy of Sciences* 109, 14063-14068. doi.org/10.1073/pnas.1210251109. Refereed journal article. GS=159 citations.

Indicators of quality: All 6 are peer refereed; **3.1**, **3.2**, **3.4** & **3.5** are in the top general science journals (*Science* and *Nature*), of which **3.1** was the third most highly-cited out of 120,000 climate change papers analysed by the NGO Carbon Brief in 2015. **3.6** is also in a top general science journal, and **3.3** is in the top ecological methods journal. References **3.2** (EU), **3.3**, **3.5** & **3.6** (all NERC) arose from peer-reviewed grants.

4. Details of the impact (indicative maximum 750 words)

The consensus view that humanity should minimise anthropogenic climate change (climate 'mitigation') and adjust to the consequences of inevitable climate change (climate 'adaptation') stems from the observed and projected impacts of climate change on people and on the natural world, the latter with a strong focus on biodiversity. University of York research underpins the expert and societal consensus relating to biodiversity, impacting decision-making at all levels. York work identified that climate change increases extinction risks (hence the need for climate mitigation) and underpins the development of conservation strategies to facilitate species survival (climate change adaptation strategies).

Scientific consensus. York research underpinned the scientific consensus of the **Intergovernmental Panel on Climate Change (IPCC)** that biodiversity is responding to, and is at risk from, anthropogenic climate change**.** Contributions include:

1) Multiple contributions. 22 separate Thomas, Hill and/or Beale publications are cited in the IPCC AR5 (2014) report on climate change Impacts, Adaptation, and Vulnerability (**5.1a**).
2) Extinction risk. AR5 concludes that: "*There is a consensus that climate change over the coming century will increase the risk of extinction for many species*" (IPCC AR5 WG2 Part A p295; **5.1a**), drawing on earlier IPCC AR4 reports that focus on the global conclusion first established by Thomas *et al.* in **3.1**. This conclusion was prominently highlighted in the AR4 reports' Summary for Policymakers, that 20 to 30% of plant and animal species are likely to be at increasingly high risk of extinction as global mean temperatures exceed a warming of 2 to 3°C above pre-industrial levels, as cited in AR4, which references Thomas *et al.* (**3.1**).
3) Species are changing their geographic distributions in response to climate change. AR5 relies heavily on Thomas/Hill research for this conclusion. IPCC AR5 states (WG2 Part A p294; **5.1a**): "*A recent synthesis of range shifts indicates that terrestrial animal species have moved at rates that correspond better with changes in temperature when climate is measured only in the regions where the range shifts were observed (Chen* et al., *2011)* (**3.2**), *providing greater confidence in attribution of the range shifts to climate change. Average range shifts across taxa and regions in this study were approximately 17 km poleward and 11 m up in altitude per decade*".
4) Key conclusions. York research is a major contributor to the consensus in the IPCC AR5 Synthesis Report (p6; **5.1b**) and WG2 Summary for Policymakers (p4; **5.1b**): "*Many ... species have shifted their geographic ranges ... in response to ongoing climate change (high confidence)*". The co-ordinating lead author of the IPCC Ecosystems Chapter states: "*The IPCC's AR5 high-confidence judgement that terrestrial species are moving their geographic distributions polewards in response to climate change stems from research carried out at York. In particular, Chen et al. (2011)* (**3.2**) *represented the most important evidence to link rates of polewards and upslope range shifts to levels of warming in different regions*" **(5.1c)**.

UN and NGO consensus leading to climate mitigation policies. These York-influenced IPCC reports represent the single most important body of scientific evidence feeding into global, regional and national climate change consensus and policy development. They have led to the widespread societal and organisational acceptance that both human welfare and biodiversity are at risk, and hence that climate mitigation is required. For example:
1) Intergovernmental bodies. The Convention on Biological Diversity (CBD International Treaty) referred to IPCC AR5 (and earlier AR4) reports in preparing evidence (**5.2**, which includes **3.1-3.5**) for the Paris UN Framework Convention on Climate Change UNFCCC COP21 meetings in Dec. 2015. The CBD (2015) drew attention to the need for climate mitigation citing the threat of extinction from climate change, shifts in the distributions of species, and elevational and latitudinal shifts in ecosystems - the IPCC evidence is strongly based on York research (see above).
2) NGO opinion and representations. NGOs produced reports to influence the Paris COP21 meetings including WWF and the influential UK NGO RSPB report on the impacts of climate change on wildlife and conservation options (RSPB 2015; **5.3a**). RSPB's Head of People Conservation Science states: "*The RSPB report cited 21 York Biology papers, more than any other University globally, two of which were picked out as major case studies*" **(5.3b)**.
3) The Paris Accord (UNFCCC COP21). The York-influenced IPCC AR4 and AR5 reports, CBD reports, UN (e.g. UNEP) and NGO reports, which represent 'institutional consensus opinion', provided the core component of the factual information relating to climate change concerns for life on Earth, feeding into the Paris meetings. The coordinating lead author of the IPCC Ecosystems Chapter states: "*the AR4 and AR5 reports provided the primary evidence base used to underpin policy development in the run up to the Paris Accord, and that concern for biodiversity (which links back to York research) was a major part of the motivation*" (**5.1c**). Ultimately, this motivation resulted in agreement to limit global warming to 2°C, ideally 1.5°C. This process has driven emissions targets for every nation (INDCs, Intended Nationally Determined Contributions) and a reduction in expected climate change, relative to business as usual. The Paris Accord, signed in December 2015, reduces climate change risk to biodiversity, given that the extinction risk to species scales with the level of warming/emissions (**3.1**).

Adaptation strategies for biodiversity conservation. Traditional conservation thinking in the late 20th century was predominantly framed as the encroachment of human influences into an otherwise relatively stable nature. York research showed that species' populations and distributions are highly dynamic in response to climatic and other environmental changes, and that conservation requires new and adapted approaches to accommodate the dynamism of species. Impacts include:

1) Risk and opportunity assessment for species. The Thomas *et al.* (**3.3**) methods for assessing threats and opportunities for climate-affected species has been taken up widely, for example by: the RSPB to assess risks and opportunities for all UK bird species (**5.3b**), Defra/Natural England for over 3000 UK species (Pearce-Higgins J. *et al.* 2017, Biol Conserv 213, 124-134, with co-authors Beale & Thomas) and the International Union for the Conservation of Nature (IUCN). According to the award-winning IUCN Climate Change Specialist Group Chair (**5.4**): "(**3.3**) *informed the IUCN Species Survival Commission Guidelines for Assessing Species' Vulnerability to Climate Change, a practitioner focussed document translating research into on-the-ground conservation guidance."* Thomas was author of a major case study in that report. Furthermore, York's research and decision framework (**3.4**) for assisted colonisation led to important changes in IUCN's Guidelines for Reintroductions and Other Conservation Translocations: "*York's work ... influenced the revision of the … guidelines [which] break from all historic guidance ... on species releases outside historical ranges in the context of climate change*" (**5.4**).

2) Landscape-scale conservation policy and implementation. York researchers stimulated landscape-scale 'connectivity' conservation policies to address the interacting challenges of habitat fragmentation and climate change. Government agency Natural England (Thomas was a working group member) developed a 2015 climate change 'Report Card' (**5.5a**) which highlighted geographic range shifts of species, drawing largely on Thomas and Hill research (including **3.2**; full page illustration on p7 of the report). The evidence cited in the Report Card to validate the need for connectivity is Thomas *et al.*'s (**3.6**) analysis of species colonising protected area networks. IPCC cites the same work in support of the value of protected area networks (**5.1a**, p324). Report **5.5a** then influenced the UK Climate Change Risk Assessment 2017 (**5.5b**), which cited 11 Thomas, Beale & Hill publications). Thus, York-based understanding of climate-driven geographic range shifts has been crucial to conservation policy development.

UK Government policy. UK government conservation policy throughout the 2014-2020 period has been underpinned by the 'Lawton Report' (*Making Space for Nature*), whose lead author states (**5.6a**) "*York research was critical to* [my] *2010 government- commissioned review for Defra…* [which] *has more citations to Thomas and Hill than to any other ecologists upon whose work we draw*". York research enabled the Lawton Report to identify the benefits of "*bigger, better, joined up*" conservation ('joined up' is a policy-friendly articulation of 'connectivity'). This mantra now permeates all aspects of UK governmental and NGO conservation policy. The Lawton Report, and a Defra White Paper that resulted from it, has since been translated into Defra's 25-year plan, published in 2018 (**5.6b**). The 25-year plan states (p7) that "*We will ensure broader landscapes are transformed by connecting habitats into larger corridors for wildlife, as recommended by Sir John Lawton*", specifically by developing a Nature Recovery Network (NRN). Defra's subsequent rationale for the NRN reads: "*The NRN will be a national network of wildlife-rich places. Our aim is to expand, improve and connect these places across our towns, cities and countryside*" (Defra 2020, **5.6c**). This is a simple re-wording of the "*bigger, better, joined up*" Lawton conclusion that was based on York research. On 28 Sept 2020, PM Boris Johnson quantified this as a commitment by the UK government to protect 30% of the UK's land by 2030. The NRN Delivery Partnership for England was launched on 5th Nov 2020, with speeches by Defra ministers Rebecca Pow (repeating the '*joined up*' conclusion) and Lord Goldsmith, supported by government, local government, NGOs, landowners, and the farming and food industry. The 2019-2021 Environment Bill encapsulating this is passing through parliament (as at December 2020). Thus, climate change research at York underpins current and future landscape policy strategies.

UK conservation NGOs also developed landscape-scale programmes to meet challenges identified by York research. Butterfly Conservation's Landscape Target Areas cover >5 million ha (in 2020) and were directly inspired by Thomas and Hill's underpinning research, according to Butterfly Conservation's Director of Science (**5.7**): "*Professor Thomas and Hill*['s].. *research*

has been a strong driving force in the development of Butterfly Conservation's influential '*landscape scale approach' to the conservation of threatened species.*" The RSPB invited Thomas to provide scientific underpinning for its Futurescapes programme launch to encourage landscape-scale conservation, standing at over 2 million ha in 2020. Likewise, the Wildlife Trusts (46 UK County Wildlife Trusts) have developed over 100 Living Landscapes, justified by the Trusts in 2018 (**5.8**) as "*bigger, better managed, and more joined up*" (from Lawton) and citing 10 Thomas & Hill articles directly. These cover over 1.5 million ha (6% of UK land surface), explicitly in response to the problem of habitat isolation in fragmented UK landscapes. Invertebrate conservation NGO Buglife has developed its 'B-lines' climate change strategy to connect landscapes; to create and restore 150,000 ha of flower-rich habitat across Britain (winning the 2016 European Landowners Association's Bee Award). Buglife's CEO states that York's research underpinned "*the principles behind B-Lines – an approach whereby we use data on remaining flower rich habitats to map a set of lines of least resistance to reconnect them* [such that]*… wildflower habitat restoration can be targeted to maximise the ability of species to disperse in response to climate change. The scheme now has the active support of all four UK governments*." (**5.9**)

In summary the evidential basis for recent biological responses, future impacts, and the framing of the need for climate mitigation and biodiversity-related adaptation and conservation strategies are deeply influenced by York research.

5. Sources to corroborate the impact (indicative maximum of 10 references)

5.1. Intergovernmental Panel on Climate Change Reports and Evidence: (a) AR5 Climate Change 2014: Impacts, Adaptation, and Vulnerability; https://www.ipcc.ch/site/assets/uploads/2018/02/WGIIAR5-PartA_FINAL.pdf. (b) AR5 Climate Change 2014 Synthesis Report; https://www.ipcc.ch/site/assets/uploads/2018/02/SYR_AR5_FINAL_full.pdf (c) Letter from co-ordinating lead author of the IPCC Ecosystems Chapter.
5.2. Convention on Biological Diversity (2015) Preliminary report on the contribution of Aichi Biodiversity Targets to land-based climate mitigation.
5.3. Royal Society for the Protection of Birds Evidence: (a) RSPB 2015: The Nature of Climate Change; (b) Letter from RSPB Head of People Conservation Science
5.4. Letter from IUCN Climate Change Specialist Group Chair
5.5. UK climate and conservation policy: (a) Natural England (2015) Biodiversity Climate Change Impacts Report Card; (b) UK Climate Change Risk Assessment Evidence Report (2016/17): Chapter 3, Natural Environment and Natural Assets.
5.6. Defra Reports and UK government legislation: (a) Letter from lead author of Defra report, Making Space for Nature; (b) Defra (2018) A Green Future: Our 25 Year Plan to Improve the Environment (c) Defra Policy Paper: Nature Recovery Network
5.7. Letter from Director of Science of NGO Butterfly Conservation
5.8. Wildlife Trusts Development of Living Landscapes
5.9. Letter from CEO of Buglife