Comparative Risk Assessment to Inform Adaptation Priorities for the Natural Environment: Observations from the First UK Climate Change Risk Assessment

Brown, Iain

Published in:
Climate Services

DOI:
10.3390/cli3040937

Publication date:
2015

Document Version
Publisher's PDF, also known as Version of record

Climate **2015**, *3*, 937-963; doi:10.3390/cli3040937

OPEN ACCESS

climate

ISSN 2225-1154

www.mdpi.com/journal/climate

Article

Comparative Risk Assessment to Inform Adaptation Priorities for the Natural Environment: Observations from the First UK Climate Change Risk Assessment

Iain Brown

James Hutton Institute, Craigiebuckler, Aberdeen AB15 8QH, UK; E-Mail: iain.brown@hutton.ac.uk; Tel.: +44-1224-395-260

Received: 22 July 2015 / Accepted: 02 November 2015 / Published: 17 November 2015

Abstract: Risk assessment can potentially provide an objective framework to synthesise and prioritise climate change risks to inform adaptation policy. However, there are significant challenges in the application of comparative risk assessment procedures to climate change, particularly for the natural environment. These challenges are evaluated with particular reference to the first statutory Climate Change Risk Assessment (CCRA) and evidence review procedures used to guide policy for the UK government. More progress was achieved on risk identification, screening and prioritisation compared to risk quantification. This was due to the inherent complexity and interdependence of ecological risks and their interaction with socio-economic drivers as well as a climate change. Robust strategies to manage risk were identified as those that coordinate organisational resources to enhance ecosystem resilience, and to accommodate inevitable change, rather than to meet specific species or habitats targets. The assessment also highlighted subjective and contextual components of risk appraisal including ethical issues regarding the level of human intervention in the natural environment and the proposed outcomes of any intervention. This suggests that goals for risk assessment need to be more clearly explicated and assumptions on tolerable risk declared as a primer for further dialogue on expectations for managed outcomes. Ecosystem-based adaptation may mean that traditional habitats and species conservation goals and existing regulatory frameworks no longer provide the best guide for long-term risk management thereby challenging the viability of some existing practices.

Keywords: risk assessment; adaptation; climate change; ecosystems; biodiversity

1. Introduction

Responding to climate change has commonly been cited as the archetypal "wicked" or even "super wicked" problem [1]. This attribution emphasizes that the scale of the challenge is framed not only by its diversity and complexity but also that prospective solutions are time-constrained and contain circular assumptions about the discounting of the future based upon present actions. For such a challenge, conventional scientific approaches based upon a reductionist paradigm have been found to be of limited utility to decision makers because they only address a small fraction of the problem rather than issues as a whole [2–4]. Instead, policy makers request a more holistic appraisal of the evidence so that they can make strategic decisions on priorities for action across a wide range of actual or potential consequences [5,6]. Decision-making requirements are therefore characterised by the quality, relevance and timeliness of evidence available, rather than just by its quantity [7,8]. For "wicked" problems, a conventional scientific assumption that the availability of more evidence acts to reduce uncertainty may not actually apply [9].

For climate change adaptation planning, the information gap between scientific outputs and the requirements of decision-makers has been identified as a major barrier [6]. For policy making, requirements are generally expressed as a need for more systematic and synthetic assessment procedures that summarise evidence in the context of both policy priorities and key knowledge gaps [10]. Requirements also highlight that evidence synthesis should be open, transparent and unbiased to avoid any selective filtering that will erode its legitimacy for the decision maker [5], emphasising the importance of translation, mediation and deliberation in the assessment process to ensure it remains both credible and relevant. This has led some commentators to suggest that a new "adaptation science" is required to develop a more solutions-based approach for climate change, thereby using evidence to stimulate innovation in both policy and practice [11].

Risk assessment has been identified as one framework to meet these requirements because it aims to provide a systematic and objective process to evaluate potential sources of harm (hazards) in terms of their societal consequences, including recognition of the key uncertainties [12]. Many decision makers already use risk-based approaches in a wide variety of different contexts, including risk scoring and prioritisation against standardised criteria. Available information typically varies from extremely qualitative to extremely quantitative (including modelling and monitoring data). Hence, generic procedures, such as comparative risk assessment or multi-criteria analysis, that can allow an assessment of trade-offs across disparate information sources, have become increasingly popular [13,14]. Comparative risk assessment, as commonly employed in the health sciences or for environmental protection, provides a systematic review of evidence combining science, policy, and economic analysis as well as stakeholder participation to identify, rank and address topics of greatest risk [15].

The application of risk assessment to climate change can be regarded as a logical extension of such developments [16–18]. National-level assessments to prioritise risks can be structured as key steps in the development of adaptation policy and its mainstreaming with other policy initiatives [19–21]. However, because of the cross-cutting nature of climate change this requires that evidence is analysed and communicated through an evaluation structure that facilitates a common understanding of both the issues and the risk prioritisation process [22–24].

This article addresses the use of scientific information and comparative risk assessment in the context of the first UK Climate Change Risk Assessment (CCRA) [25]. Legislation passed in 2008 requires the

UK Government to undertake an independent CCRA every five years to inform the National Adaptation Programme (NAP) and its devolved equivalents. This statutory obligation is intended to provide a consistent basis for prioritisation of risk-based adaptation actions across all societal sectors and to facilitate comparison against other assumed "non-climate" risks (e.g., national security; disease pandemics) as an extension of standard government guidance for contingency planning [26] (Figure 1). Development and application of a generic risk-based approach is evaluated against the particularly distinctive issues that occur with the natural environment based on its inclusion as one of 11 focal sectors ("Biodiversity and Ecosystem Services") within the CCRA process, covering terrestrial, freshwater and coastal environments (marine issues were assessed separately) [27].

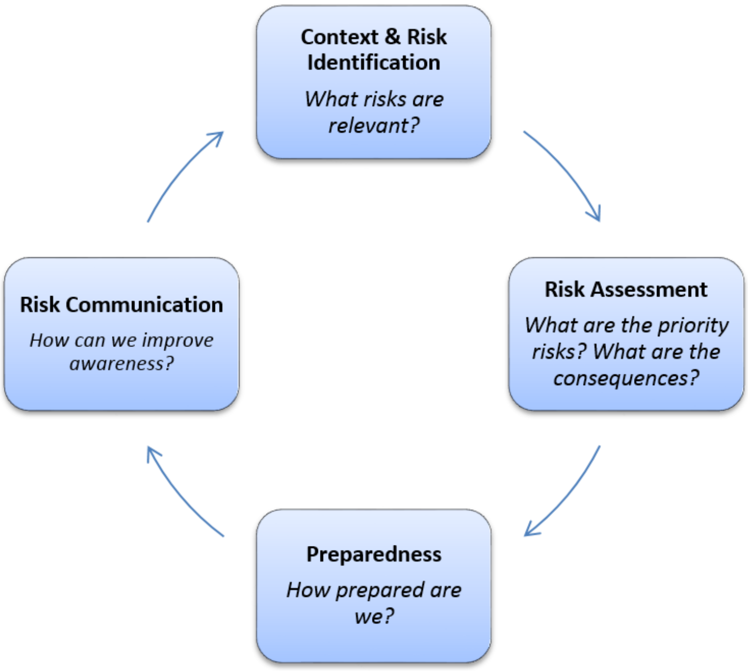

Figure 1. Risk and Preparedness Assessment (RPA) cycle as used in Government contingency planning.

Climate Sensitivity of the Natural Environment

The natural environment is particularly sensitive to changing climatic conditions as evidenced by palaeo-environmental change (e.g., [28]). Species respond to environmental change through their natural adaptive responses either *in situ* (notably "plastic" phenotypic adjustments in behaviour, morphology, physiology, development; or by longer-term evolutionary adjustment in their genotypes) or by movement and dispersal [29]. If these responses are constrained or adaptation cannot keep pace with the rate of change, then a species is at risk of being lost, either locally or regionally (extirpation) or globally (extinction) [30]. Furthermore, if a severe stress is prevalent, then whole communities or other assemblages of species, including distinctive habitat types, may be lost and replaced by other assemblages.

In the present day, the natural environment is exposed to a range of stresses. Most notably, in the UK as with many other countries, land use intensification has led to habitat loss and fragmentation [31] whilst atmospheric pollution has caused habitat change and loss of biodiversity [32]. Extinction rates in the UK across a wide range of taxa are inferred to have increased in the 20th century mainly due to habitat loss and are projected to further increase in the 21st century [33]. Loss of biodiversity and pressures on ecosystem functions (e.g. soil nutrient cycling; water cycling) has also been associated with reductions in wider societal benefits (*i.e.*, “ecosystem services”) that accrue from the natural environment [34].

Climate change may therefore be expected to have important consequences for the natural environment but systematic assessments of adaptation priorities have been limited. Furthermore, ecological assessments of climate change impacts have to-date made limited use of risk assessment methods commonly used by other sectors (e.g., water resource management), although prototype frameworks have been proposed [35], and risk concepts are increasingly applied for invasive species (e.g., [36]).

2. Terminology

Within the multi-disciplinary context of climate change science, the terms risk and vulnerability have often been used either interchangeably or used to refer to different concepts, sometimes acting as a major source of confusion [37]. Here, we follow the Intergovernmental Panel on Climate Change (IPCC) terminology in defining risk as a measure of the potential consequences for issues of human value where the outcome is uncertain [38]. Uncertainty represents a state of incomplete knowledge due to lack of information or disagreement about what is known or even knowable, and may be shown quantitatively (e.g., probability distributions) or qualitatively (e.g., expert opinion) [38].

Risk may be characterized as combining the magnitude and likelihood of particular outcomes (expressed either qualitatively or quantitatively) and is therefore influenced by both the inherent susceptibility of a system to change and by its level of exposure to external factors that may precipitate that change. Susceptibility to change is a property of both the internal sensitivity of systems (including those elements currently exposed) and their adaptive capacity which may act to reduce susceptibility. Adaptive capacity therefore represents the ability to prepare, respond and recover from risks, and hence to moderate potential damages or take advantage of opportunities [37]. Residual risk is that which remains after taking into account adaptation actions that may either aim to reduce exposure or enhance adaptive capacity [39]. Confusion has occurred in the use of the term “vulnerability” to refer to either inherent susceptibility (independent of exposure) or to evaluate expected outcomes (including both susceptibility and exposure) [37,39,40] therefore use of that term has been avoided.

3. Methodology for the UK CCRA

The generic methodology for the CCRA combined the use of systematic literature review and a risk assessment procedure to communicate scientific evidence to policymakers and other stakeholders [41]. It employed a tiered structure through which an initial broad-based identification, characterisation and screening of risks was followed by a more detailed assessment of those risks identified as higher priority. Emphasis was placed upon evaluating current policies against changing risk factors to identify a notional “adaptation deficit” where policy is insufficient to prevent increased negative impacts: this deficit represents a domain where additional actions would be recommended to maintain risks at an acceptable (“tolerable”) level, contingent on other priorities. The methodology was designed in consultation with a CCRA Advisory Group of policymakers and key stakeholders (including government agencies, other public bodies and industry representatives).

Evidence review, risk scoring and risk prioritization all contain subjective elements as a consequence of the need for rapid assessment of a large amount of evidence, but emphasis was placed upon a transparent and auditable procedure to systematically justify the final priorities. Regarding the use of systematic review, the CCRA adopted an approach of including not only material identified by authors but also by stakeholders and peer reviewers. This was intended to avoid any bias in material selection as critiques of IPCC reporting procedures have previously noted [42,43]. Material was evaluated in terms of its relevance, specificity (particularly geographic scale for key findings) and key assumptions (including use of climate and non-climate data). Evidence for climate change risks was summarized in terms of both its quantity and the degree of consensus between independent sources, as consistent with the use of confidence levels by the IPCC (Figure 2, [44]). To provide a common benchmark for climate change, as evidence sources may have used data from different climate models, reference was made to the 2009 UK Climate Projections (UKCP09) which provided future probabilistic projections for three different emissions scenarios, including a central estimate (50% probability) in addition to low-end and high-end variations (e.g., 10% and 90% probabilities) [45].

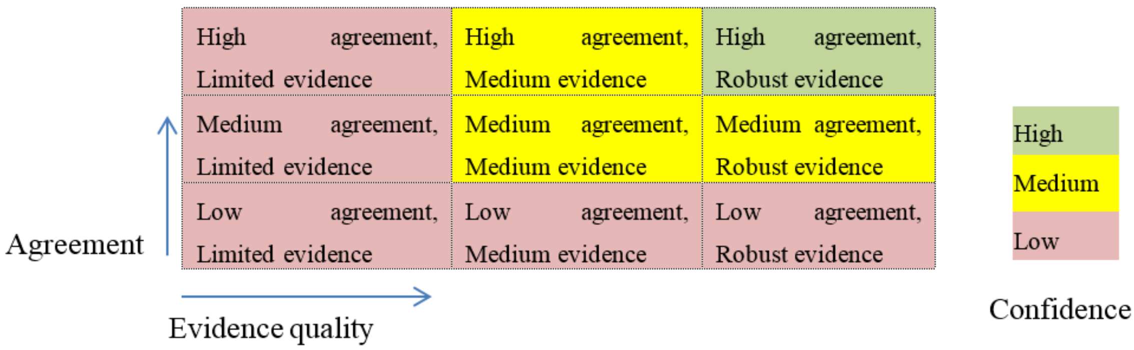

Figure 2. Framework used for uncertainty assessment (adapted from IPCC [44]).

Based upon the review of evidence, prioritisation of risks in the CCRA was guided by a scoring procedure based upon three criteria that were each allocated as negligible, low, medium, or high (scoring as 0, 1, 2 or 3 respectively although in practice, 'negligible' scores were screened out and not included in the formal assessment in order to concentrate on the more important risks) [41]:

(i) the magnitude of the risk (environmental, social and economic consequences), including the potential for irreversible impacts;
(ii) overall likelihood of the risk occurring before the 2080s;
(iii) the urgency with which adaptation decisions need to be made, assessed in terms of whether actions are required to be implemented in the next few years (high score), or in the next 20 years (medium), or in the longer term to the 2080s (low) or beyond (negligible).

The procedure used a standardised approach to reference the magnitude of risks as defined based upon agreement with the CCRA Advisory Group [41] (Table 1).

Table 1. Standard Climate Change Risk Assessment (CCRA) reference schema to define level of consequences across categories.

	Environmental (Area of Priority Habitat Lost in Ha)	Economic (Monetary Costs in £)	Social (Number of People Seriously Affected)
High	>5000	>100 million	10^5–10^6
Medium	500–5000	10–100 million	10^3–10^4
Low	<500	<10 million	10^2–10^3

The following general formula was then used to calculate a final aggregate score:

$$Risk\ Score = 100 * \left\{\frac{Magnitude\colon Environ. + Social + Economic}{9}\right\} * \left\{\frac{Likelihood}{3}\right\} * \left\{\frac{Urgency}{3}\right\} \quad (1)$$

The inclusion of an urgency criterion in the risk scoring is different from conventional risk assessment that uses only a combination of magnitude and likelihood. However, the remit for the CCRA emphasised that it was particularly important to identify priorities in terms of the timescale needed to address risks hence urgency was included despite its dependence on the other two criteria. Urgency was considered particularly relevant for identifying risks which may not necessarily have a high magnitude or likelihood now but will do in the future and have long lead times for adaptation actions to be fully implemented, as for example with planning and development of new infrastructure.

For the natural environment, the "environmental" risk magnitude was defined by the implications for biological diversity across broad habitat groups based upon the potential loss of priority habitats and species defined by the UK Biodiversity Action Plan (BAP) [46]. "Social" and "economic" risk magnitude were combined and both defined by risks to key ecosystem services, representing risks to the wider societal benefits from the natural environment, and including categories represented by provisioning, regulating and cultural ecosystem services (for examples, see [34,47]).

Priority (Tier 2) risks were defined as those with the highest scores above a particular threshold value agreed with the CCRA Advisory Group. The rationale for the more detailed Tier 2 assessment was, where possible, to identify risk metrics that could be used to quantify a future change in risk based upon either analogue data (e.g., past observations), modelling, or expert elicitation. Consequences were defined for three future time periods (2020s, 2050s, 2080s) based upon lower (UKCP09 10% level and low emissions), central (UKCP09 50% level and medium emissions) and upper (UKP09 90% level and high emissions) climate projections.

To provide additional context, risks were also qualitatively assessed against a range of other non-climate (socioeconomic) drivers as follows (including their range):

(i) Population needs/demands (high/low)
(ii) Global stability (high/low)
(iii) Distribution of wealth (even/uneven)
(iv) Consumer driver values and wealth (sustainable/unsustainable)
(v) Level of Government decision making (local/national)
(vi) Land use change/management (high/low Government input).

A final component of the generic CCRA methodology was an overall assessment of adaptive capacity to manage risks within each sector. For the CCRA, adaptive capacity included both elements of structural capacity (based on decision timescales, activity levels, sector complexity) and organisational capacity (including engagement, delivery and leadership processes). To facilitate this assessment, structured interviews were conducted with stakeholders for each sector using a structured approach based upon the PACT multi-level framework which aims to identify the position of organisations on a "ladder" of adaptive capacity, from entry levels ("Awareness" and "Engaging") to more advanced levels of action ("Pioneering" and "Leading") [48]. For the biodiversity and ecosystems sector, this included 26 individual interviews covering policymakers, nature conservation agencies, academics, and non-governmental organisations, at both national and local scale.

4. Results of the Risk Assessment

4.1. Risk Identification and Characterisation

For the natural environment, eight main groups of risks were identified by systematic review and then evaluated (Table 2) as described in more detail below. Available evidence highlighted that knowledge of climate change responses for individual species is generally better than for species interactions, and is typically informed by particular taxa that have good monitoring data, notably birds and butterflies. Current knowledge of climate change is therefore generally poorer at higher levels of ecological organisation, as represented by habitats and ecosystems. A recurrent issue was found to be that, in the absence of longer-term monitoring data, confidence in attributing trends from observational data to climate change is often confounded by shorter-term climate variability. In the UK, this confounding effect is particularly manifest through the climate-related phenomena of the North Atlantic Oscillation which fluctuates between milder wetter and cooler drier multi-year phases, with a tendency for the milder wetter phase to dominate over recent decades [49]. Furthermore, the presence of localised influences on environmental responses, such as land use change, mean that spatially-comprehensive datasets are required to robustly distinguish climate from other factors, and again these are typically only available for some species.

At species level, good evidence of the impacts of current climate change is provided by phenological recording, notably of earlier spring events [50], and by northerly movements in species' range distributions across several taxa [51,52]. Evidence for range shifts is usually stronger for expansion at the leading-edge (cold) margin compared to contraction at the trailing-edge (warm) margin, which may be related to time lags, biotic interactions or simply that colonisation by new species is easier to recognise compared to confirmed extirpation or extinction [53]. The key issue for risk assessment is that comparison of observed range shifts with those predicted from climate change implies that species are "lagging" behind the rate of climate warming as a consequence of either natural constraints on dispersal or by habitat fragmentation and degradation due to human land use [54,55]. Multiple sources of evidence therefore support a general finding that many species are unable to track the changing "climate space" previously associated with their distribution either due to natural constraints or lack of available habitat due to land use change. This means that there is an increased risk of species loss (extirpation or extinction) and an overall reduction in biodiversity.

Table 2. Climate risks evaluated for the natural environment.

Type of Change	Specific Risks	Quality of Evidence *	Score **
RANGE SHIFTS	Species unable to track changing climate space	Robust	**72 (0.72, 1, 1)**
	Species unable to find suitable microclimate	Medium	22 (0.5, 0.66, 66)
SEASONAL SHIFTS	Disruption to annual migration patterns	Medium	**51(0.77, 1, 0.66)**
SPECIES INTERACTIONS	Generalists favoured over specialists	Medium	**41 (0.62, 1, 0.66)**
	Asynchrony—breeding cycle & food supply	Limited	34 (0.51, 1, 0.66)
	Competition between C3 and C4plants	Limited	7 (0.33, 0.66, 0.33)
	Changing growth/survival rates	Limited	37 (0.56, 1, 0.66)
	Changing interactions between trophic levels	Limited	16 (0.72, 0.66, 0.33)
	Changes in community genetic diversity	Limited	12 (0.56, 0.66, 0.33)
ECOSYSTEM FUNCTIONING	Reduced primary productivity	Limited	22 (0.66, 1, 0.33)
	Loss of soil organic carbon	Limited	**59 (0.89, 1, 0.66)**
	Faster decomposition and nutrient cycling	Limited	22 (0.66, 1, 0.33)
PHYSICAL PROCESSES	Loss of habitats to coastal evolution	Robust	**83 (0.83, 1, 1)**
	Loss of habitats to fluvial floodplain evolution	Medium	13 (0.61, 0.66, 0.33)
	Disruption of water thermal regime & stratification	Medium	**44 (0.66, 0.66, 1)**
	Loss of snow cover	Robust	18 (0.56, 1, 0.33)
	High flow impacts on aquatic ecosystems	Medium	24 (0.56, 0.66, 0.66)
	Low flow impacts on aquatic ecosystems	Medium	**61 (0.61, 1, 1)**
	Saline intrusion	Medium	7 (0.33, 0.66, 0.33)
	Increased soil moisture deficits and drying	Medium	**88 (0.88, 1, 1)**
	Increased soil erosion	Medium	24 (0.56, 0.66, 0.66)
	Increased waterlogging	Medium	40 (0.61, 1, 0.66)
PESTS & DISEASE	Increased risk from existing pests and diseases	Medium	**77 (0.77, 1, 1)**
	Risks from novel pathogens	Limited	8 (0.77, 0.33, 0.33)
EXTREME EVENTS	Tree loss during windstorms	Limited	5 (0.44, 0.33, 0.33)
	Major coastal flood/reconfiguration	Medium	**58 (0.88, 0.66, 1)**
	Major fluvial flood	Medium	33 (0.5, 1, 0.66)
	Major drought events	Limited	**72 (0.72, 1, 1)**
	Large-scale wildfire	Medium	**44 (0.66, 1, 0.66)**
INDIRECT RISKS	Agricultural expansion/intensification	Medium	**55 (0.83, 1, 0.66)**
	Agricultural abandonment	Limited	24 (0.56, 0.66, 0.66)
	Water quality/pollution risk	Medium	**83 (0.83, 1, 1)**
	Atmospheric deposition of pollutants	Limited	24 (0.56, 0.66, 0.66)
	Climate change mitigation measures	Limited	**66 (0.66, 1, 1)**
	Reduced environmental flows due to increased societal water demand	Medium	**83 (0.83, 1, 1)**

***** Qualitative assessment of evidence quality based on availability of multiple peer-reviewed sources (Figure 2).
****** Total Score in % as 100 × (magnitude, likelihood, urgency) from Equation (1). **Bold indicates priority risks**.

Patterns of annual migration also show evidence of change, including variations between short-distance and long-distance migrants [56,57] which has important consequences for several species identified within the UK BAP. At smaller scales, there is some evidence of species movements to find more suitable microclimate: for example, studies of the silver spotted skipper butterfly (*Hesperia comma*) suggest a shift in habitat preference towards cooler, taller grasslands [58]. However, relatively little evidence has been presented for changes in evolutionary genetic responses at present, possibly due to the longer time periods required [59].

Greater uncertainty currently exists for risks that may be associated with changing species interactions. Asynchronous variations in phenological responses between inter-related species across trophic levels have been postulated to be leading to a mismatch in timing of key events, as for example with breeding cycles of predators and the availability of food from prey species [60,61], but conclusive cause-effect demonstration of this risk remains to be fully established. Ecological theory would suggest as habitats become modified then those species that are more generalist in their habitat preferences would benefit at the expense of those that are specialists, and there is some evidence of this from analysis of changes in woodland flora [62] which also has consequent implications for loss of biodiversity. Regarding future changes, although several studies have developed model-based projections to identify species at risk using bioclimatic envelopes, very few of these studies have dealt explicitly with dynamic interactions among species, such as migration, dispersal and competition [63] which currently limits their utility in a wider risk assessment.

Climate change variables are associated with key ecosystem functions, such as primary productivity and the cycling of water, nutrients and organic matter. For example, the summer 2003 drought in Europe was reported to have reduced net primary productivity in many ecosystems [64]. However, the inherent complexity of ecosystems, operating across multiple scales in time and space, with non-linear effects and time lags, mean that information is often extrapolated from controlled experiments which have shown sensitivity of carbon dynamics in soils and waters with resultant implications for atmospheric carbon emissions [65]. Measured declines in soil organic carbon in England and Wales have been recorded across multiple land use categories and therefore attributed to climate change [66], but more recent assessment of these data suggest that only on organic soils under semi-natural habitats is climate change acting as a significant influence otherwise other factors appear to be dominant in explaining such declines (e.g., changes in livestock numbers) [67]. A key source of uncertainty for risk assessment at ecosystem level is how climate variables will interact with changing atmospheric carbon dioxide levels in influencing responses in both plant physiology and soil fauna, together with their symbiotic interactions [68]. However, the projected shift towards warmer drier summers for the UK [45] has important implications for soil moisture levels and the habitats they support, particularly on soils where structure or textural properties imply susceptibility to drought risk. Similarly, soils may be adversely affected through changes in erosion patterns related to heavy rainfall events although current evidence suggests land management to be the primary driver of soil erosion in the UK [69].

In rivers and lakes, changes in water flows and water levels, together with changing thermal regime and water quality can have important consequences for aquatic species and habitats. Long-term trends are however particularly difficult to detect in most regions because of large interannual and interdecadal variability that is also apparently strongly associated with phases of the NAO [70]. By contrast, there is stronger evidence for the influence of climate change in coastal environments due to the steady rise in relative sea levels and the consequent loss of intertidal habitats, often exacerbated by man-made coastal defences that restrict the opportunity for intertidal habitat to move inland with the changing tidal limits [71].

The potential increased risk from pest species (*i.e.*, those with a high nuisance value) has been identified as highest for invasive non-native species (INNS) that, once established, disperse rapidly due to a lack of natural competitors, causing loss of native biodiversity and ecosystem disruption, often with severe economic consequences [72]. Introduction of INNS to-date has been predominantly by human agency (deliberate or accidental) with climate as a background factor particularly through the increased frequency of milder winters which encourages increased survival rates, persistence and dispersion. With a greater magnitude of future climate change, including warmer winters, the climate-related risk component for INNS was identified by the CCRA as very likely to increase [27]. Similarly, increased risk of emerging infectious diseases from pathogenic micro-organisms was highlighted in the CCRA due to enhanced survival rates in warmer conditions but lack of data on new pathogens means that assessing this risk remains speculative, especially due to interactions with non-climate drivers [73].

A separate category of climate change risks (Table 2) was identified for high-magnitude low-frequency extreme events that have the potential to cause major changes in ecosystems beyond those that occur due to more gradual incremental changes. In terms of consequences for the natural environment from extreme events, additional risks were particularly highlighted by the potential increased damages from coastal flooding, drought and wildfire. For example, although human agency is currently the main risk factor for large-scale wildfires in the UK, a projected increased frequency of warmer drier summers implies a likely increased risk in sensitive areas (e.g., forest, heathland or grassland areas) based upon previous large-scale wildfire outbreaks during similar conditions (e.g., [74]).

Biodiversity and ecosystems will also be indirectly influenced by climate change responses initiated by other actors in the land use sector. This indirect risk is particularly exemplified by the status of agricultural land in the UK as the current climate provides significant constraints on land use in many marginal areas, most notably in the uplands. A shift in climate towards warmer drier summers has therefore been inferred to bring more opportunities to expand or intensify agricultural activities rather than causing land abandonment, with implications for biodiversity in those areas [75,76]. Climate change (including elevated CO_2 levels) will also indirectly interact with existing pressures such as through water-borne and atmospheric pollutants. Many semi-natural habitats are naturally nutrient poor and support slower-growing assemblages of plants that are adapted to these conditions, but evidence already exists that enhanced atmospheric nitrogen deposition (from anthropogenic sources) is allowing faster growing species to outcompete slower-growing species that would normally occur on these sites [32,77]. The CCRA also identified that climate change mitigation measures (e.g., renewable energy schemes) may potentially have a significant impact on the resilience of the natural environment (positive or negative), although currently evidence for this is rather limited due to most of the schemes being relatively recent developments.

4.2. Evaluation and Screening for Priority Risks

Based upon the CCRA risk scoring procedure, 14 priority risks for the natural environment were identified (Table 2) using a nominal threshold value (40) agreed across all sectors as representing an acceptable cut-off when used to identify policy priorities, despite its arbitrary value. The scoring identified those risks with the highest potential consequences in terms of magnitude and likelihood, together with the assumed urgency for action due to these consequences being realised in the short or medium term rather than long-term. Due to limitations on data availability for water-related risks, the prioritisation combined extreme event and indirect risks (*i.e.*, drought and water demand) with the specific risks for water quantity, quality and thermal regime to provide a more holistic assessment of these risks.

The original proposal to quantify priority risks using suitable metrics was found to be impractical for the range of risks identified. Data were usually available only for local case studies and for most risks there remains a lack of spatially comprehensive baseline data on which to base a quantitative assessment when expressed in terms of national area of habitat affected and the implications for ecosystem services. Therefore, to provide a UK-level profile of the most likely changes in risk (Table 3), "expert opinion" was adopted based upon a consensus of CCRA contributors, reviewers, and the Advisory Group using the same categories of consequences (economic, social, environmental) as Tier 1. Only two risks ("*Species unable to track changing climate space*" and "*Coastal evolution*") were assessed with high confidence based upon this consensus approach; this high confidence was based upon robust baseline evidence for species movements across several taxa (e.g., [50]) and regarding coastal change (e.g., [78]). No consensus could be established for evidence for one of the risks ("*Climate change mitigation measures*") because of the limited and conflicting reporting at present. Although the consequences for all risks were generally identified as increasing into the future as climate changes increases in magnitude (assuming no further adaptation), variations in risk profile between climate projections (lower/central/upper) also implied that the rate of climate change is critical in determining the level of risk. At higher rates of climate change, there is therefore a higher "adaptation deficit" in terms of undesirable consequences based upon a continuation of current policies and plans.

The relative influence of climate against socio-economic drivers is summarised in Table 4. Land use change, population change, attitudes to sustainable consumption, and governance, were identified as the most important factors that interact with climate change across all of the prioritised risks. In addition, for those risks with a strong international dimension (e.g., species migration routes; invasive non-native species) then changes in global security are also identified as an important factor. As Table 4 assumes a comparison against the UKCP09 central estimate for future climate change, a lower or higher rate of climate change will modify the relative influence of climate against socio-economic factors, and their interactions.

Adaptation strategies currently being developed to manage these risks are summarised in Table 5. However, to-date these strategies have generally been implemented only at local scales rather than as co-ordinated initiatives. Implementation has also tended to be opportunistic rather than spatially targeted at the most suitable locations (*cf.* [79,80]). Interviews with sector stakeholders conducted during the CCRA identified a general high level of awareness of climate change risks and a strong commitment to tackle climate change. However, complex governance structures were identified as a major constraint acting against coordinated implementation of adaptation strategies. This complexity is particularly apparent in the need for "joined-up" responses across multiple organisations, each of which has differing responsibilities and priorities. In addition, multiple levels of decision-making exist, including international obligations, national policy, regional planning structures and local site management. The current legislative and regulatory framework has therefore been considered as inflexible and limited in terms of its ability to adequately accommodate change [47,79]. Where cross-agency or cross-sectoral protocols have been established, the complexity of arrangements can mean a reluctance to revisit them, or a reluctance to change habitual procedures that are based upon traditional conservation objectives from the historic past or at particular locations.

Table 3. Changing risk profile for priority risks with future time periods and different climate projections.

Risk	Confidence *	Risk Class **								
		2020s ***			2050s			2080s		
		Lower	Central	Upper	Lower	Central	Upper	Lower	Central	Upper
Species unable to track changing climate space	H	**2**	**2**	**3**	**2**	**3**	**3**	**2**	**3**	**3**
Disruption to migration patterns	M	**1**	**2**	**2**	**2**	**2**	**3**	**2**	**3**	**3**
Increased soil moisture deficits and drying	M	**1**	**2**	**2**	**1**	**2**	**3**	**2**	**3**	**3**
Large-scale wildfire	M	**1**	**1**	**2**	**1**	**2**	**3**	**2**	**2**	**3**
Disruption to water thermal regime/stratification	M	**1**	**2**	**2**	**2**	**2**	**3**	**2**	**3**	**3**
Low flow risks	M	**1**	**2**	**2**	**2**	**2**	**3**	**2**	**3**	**3**
Risks from water quality and pollution	M	**1**	**2**	**2**	**1**	**2**	**3**	**1**	**2**	**3**
Loss of habitats to coastal evolution	H	**1**	**2**	**2**	**1**	**2**	**3**	**2**	**3**	**3**
Major coastal flood/reconfiguration	L	**1**	**2**	**3**	**2**	**2**	**3**	**2**	**3**	**3**
Generalists favoured over specialists	L	**1**	**2**	**2**	**2**	**2**	**3**	**2**	**3**	**3**
Loss of soil organic carbon	L	**1**	**2**	**2**	**1**	**2**	**3**	**1**	**3**	**3**
Increased risk from invasive species, pests & diseases	L	**1**	**2**	**2**	**2**	**2**	**3**	**2**	**3**	**3**
Risks from climate mitigation measures	L	**?**	**?**	**?**	**?**	**?**	**?**	**?**	**?**	**?**

***** Based upon the schema in Figure 2: H-High; M-Medium; L-Low. ****** Risk class based upon the most likely consequences for the period/projection and the highest consequences per category as defined by Table 1. 3 = Low; 2 = Medium; 1 = Low. ******* Range of projections based upon UKCP09: lower = low emissions 10% level; central = med emissions 50% level; upper = high emissions 90% level.

Table 4. Relative importance of socio-economic drivers as compared to climate change (central UKCP09 projection).

Risk	Population Needs/Demands	Global Stability	Wealth Distribution	Consumer Values	Gov. Decision Making	Land Use Change/Management
Increased soil moisture deficits and drying	✓				✓	✓
Loss of habitats to coastal evolution (including extreme events & reconfiguration)	✓		✓	✓	✓	✓
Risks from invasives, pests and diseases	✓✓	✓		✓✓	✓	✓
Species unable to track changing climate space	✓			✓	✓	✓ or ✓✓
Indirect risks from climate mitigation schemes	✓	✓	✓	✓	✓✓	✓✓
Loss of soil organic carbon	✓			✓	✓	✓ or ✓✓
Disruption tospecies migration	✓	✓		✓	✓	✓
Disruption to water thermal regime/stratification	✓			✓	✓	✓
Generalists benefiting at the expense of specialists	✓				✓	✓ or ✓✓
Large-scale wildfire risk	✓		✓	✓	✓	✓✓
Risks from water quality & pollution	✓			✓	✓	✓✓
Low flow risks including droughts and indirect effects	✓		✓	✓	✓	✓ or ✓✓

NB Relative importance compared to climate change may be dependent on rate and magnitude of change. ✓ Relevant, ✓✓ Relevant and a stronger driver of change than climate.

Table 5. Summary of general adaptation strategies for biodiversity and ecosystems.

Strategy	Rationale	Implementation Level
Habitat networks	Improve connectivity and reduce habitat fragmentation	Early stages; most advanced for woodland habitats
Buffer zones	To establish sympathetic land uses around isolated habitats (e.g., wetland or ancient woodland)	Early stages; some schemes piloted by NGO conservation bodies
Landscape/habitat diversification	To enhance the variety of ecological niches that species can exploit to adapt to changing conditions	Early stages
Climate refugia	Protection of biodiversity hotspots and centres of endemism	Suitable locations postulated, but not formally recognised at present
"Rewilding" schemes	Restoration of the natural landscape through minimal intervention	Several schemes underway
Managed retreat of coastal zone	Either by active intervention (e.g., breaching of sea-walls) or by minimal management to allow inland migration of coastal habitats in response to sea-level rise.	Several schemes underway; all small scale
Ecological restoration	Habitat recreation such as in riparian "corridors", intertidal zone, grasslands, woodlands and bog. Biodiversity linked to wider societal benefits e.g., flood/erosion control, C storage, water quality, landscape amenity, recreation.	A traditional nature conservation strategy implemented at local level
Greenspace and Bluespace planning	Particularly in urban or regeneration areas to develop larger-scale spatial planning of water features and habitats	Actively incorporated into some planning strategies at local/region level
Translocation	Deliberate species movement to more suitable locations for those species with restricted habitats or low dispersal ability	Several trial schemes underway for species identified as high vulnerability (e.g., relict arctic fish); also transplanting of seed

5. Discussion

The use of comparative risk assessment by the UK CCRA served to identify a series of priority risks which formed the statutory basis for government action [26]. It also had an educational role to improve awareness of the issues, including limitations of current responses and associated knowledge gaps. Primary risks for the natural environment were highlighted as habitat-related restrictions on species dispersal or *in situ* adaptation, together with more specific issues in which direct climate change is expected to particularly affect sensitive ecosystems, notably freshwaters, wetlands, coastal habitats and some upland habitats. These direct risks are likely to be accompanied by indirect risks from wildfire, pests and diseases, land use change (especially agricultural land use), and pollution. Such indirect effects, particularly land use change, demonstrate the complex linkages between climate change risks and socioeconomic factors. For several risks, significant uncertainty exists even for the current level of climate sensitivity due to the confounding factors. This means that attempts to predict future changes in risk are fundamentally limited due to high uncertainty in both drivers and outcomes. Managing climate change risks through coordinated adaptation strategies rather than piecemeal interventions is in its early stages but further compounded by complex decision-making responsibilities.

Despite the clarity of its key findings, critique of the CCRA can draw attention to the procedures used for risk identification, scoring and prioritisation. A particular challenge for the natural environment was finding the appropriate level of generalization for risks, especially considering that many risks are systemically inter-dependent. More specific risks could have been identified for particular species and habitats although this would have required a more intensive evaluation procedure and inevitably the need for a longer stakeholder dialogue. Similarly, the scoring procedure and chosen threshold value to identify priority risks may be criticised for being subjective rather than following a more objective process as implied by conventional risk assessment. For the natural environment, the utility of area of habitat lost or damaged as a common metric can be queried on the grounds that some habitats are richer or rarer than others, although the use of priority habitats defined according to the UK BAP provided a direct relevance to current policy. Ultimately, the emergence of novel ecosystems composed of species assemblage that have no present-day analogue also challenges a conventional conservation approach [81].

Conversely, the procedure adopted by the CCRA may be considered to represent a pragmatic compromise between extraneous detail and the need to follow a reasonably comprehensive evaluation procedure to elucidate priorities. Feedback from the Advisory Group and other stakeholders was in general agreement that the most appropriate priority risks were identified, despite the limitations of the assessment procedure, suggesting that the risk screening process was relatively successful. In particular, those risks for which further adaptation actions should be developed in the current policy cycle (rather than future cycles) were considered to be adequately included although this resulted in exclusion of some risks for which there is currently very little evidence. A more serious deficiency was that quantification of priority risks was limited by data availability and suitable metrics. Hence the tiered risk assessment could not proceed much further than qualitative assessment guided by expert opinion and peer review. Nevertheless, as has been particularly highlighted when evaluating changes in ecosystem services [47], such qualitative procedures are often necessary in delivering a broad-based and timely summary of evidence for informing policy responses without being biased towards evidence from a particular study or location with good data. Qualitative assessment also provides the scope for targeted refinement of the evidence base with strategic emphasis on key knowledge gaps in further cycles of the CCRA and policy development. This may be further enabled by improvement of the systematic evidence review process [43], for example by using pedigree analysis, NUSAP method or PRISMA method [8,82].

The first UK CCRA therefore may be considered to have succeeded in its goal to identify and prioritise risks but was less successful in quantifying the magnitude of the risk and the necessary level of adaptation action to address the "adaptation deficit". However, although not its original intention, the CCRA has also served to encourage important insights into assumed goals for risk management and adaptation responses, with important implications for the natural environment. It is therefore argued that the most important contribution of the first UK CCRA was through the interactive science-policy process it stimulated on priority risks rather than its end-product in terms of discrete targeting of adaptation actions. In this context, as recently advocated for health issues (*cf.* [83]), risk assessment for climate change may be more appropriately referenced against a post-normal scientific framework that includes contextual and subjective factors rather than original aspirations for a purely objective procedure that provides definitive but abstract "answers" on proscribed actions to address risk. The format of the question for risk assessment is therefore equally important.

During the risk prioritisation process, a constructive dialogue developed amongst stakeholders regarding the evaluation of risks and the current level of adaptation, which highlighted not only information gaps but also queried why further information may actually be needed as a precursor for actions in the first instance. For the natural environment, this was accompanied by a shared realisation that a purely top-down information-driven approach to risk assessment (*i.e.*, "science-first" rather than "policy first" [84]) would, at least for the foreseeable future, be dominated by uncertainty stemming both from the complexity of the issues and the wide range of potential future climate projections. This consequently encouraged a greater recognition of the benefits that could be gained from the more "controllable" aspects of risk management, notably through measures that enhanced adaptive capacity and ecosystem resilience: these would help manage risks regardless of the future pathway. Furthermore, there was acknowledgement that an ecosystem-based approach would potentially allow a more systemic approach to manage multiple climate risks rather than addressing each risk in isolation.

The concept of adaptive capacity can therefore be recognized as a particularly important property for ecosystem-based adaptation. Adaptive capacity within the CCRA was generically defined as the factors that enable human systems to successfully adjust to climate change. However, from a natural environment perspective it was strongly advocated that this was an incomplete perspective because the term "adaptive capacity" also defines the ecological factors that enable an ecosystem to adjust to changes in its external environment [85]. Ecological adaptive capacity is therefore defined by the diversity within species (phenological and genetic), together with the diversity across species through their symbiotic and competitive associations, which ultimately sustain the structure, organization, and functioning of an ecosystem in combination with abiotic processes. At species level, key traits can be recognized that facilitate adaptation: degree of specialized habitat or inter-species requirements, genetic variability, reproduction rate, dispersal ability, physiological tolerance, morphology, behavior, and ability to change traits (phenotypic plasticity). Such adaptive capacity can be facilitated both by landscape diversity with a varied mix of habitats and by diversity in response options which allows for outcome uncertainty due to the complex interactions occurring in socio-ecological systems [47,86].

Ecosystems have intrinsic self-organising properties to adjust to change, providing an inherent resilience to maintain structure and function. During past climate changes, species have often persisted within refugia that have been able to resist or buffer against change, maintaining viable relict populations that resisted extinction [63]. This natural adaptive capacity has often now been reduced due to stresses such as land use change and pollution. In landscapes with small fragmented habitats (often defined by protected areas), opportunities for *in situ* adaptation are limited and ultimately genetic variation is constrained by restricted meta-population sizes [87], whilst the lack of landscape connectivity with other suitable habitat can restrict dispersal. This means that many species are susceptible to changing climatic conditions, and the risks to biodiversity are therefore defined by the level at which the exposure (rate and magnitude) of climate change exacerbates this intrinsic susceptibility.

In the UK, nearly all habitats have had some form of human modification and some are reliant on human intervention to maintain current distributions. The CCRA procedure highlighted that a proscriptive prediction-based approach to biodiversity conservation, such as through targets for particular habitats or species, is highly likely to be unviable because of the pervasive uncertainties. A more fundamental challenge is that the definition of priority habitats based upon a known distinctive assemblage of species is likely to be confounded as phylogenetic relationships are modified (as evidenced by palaeo-environmental data) and with the emerging prospect also of novel assemblages and ecosystems. Hence, enhancing flexibility and resilience through natural adaptive capacity rather than proscribed outcomes is increasingly recognised as a more viable strategy for risk management, which will be further facilitated when human adaptive capacity (organisational and structural) is aligned with natural adaptive capacity. This goal is recognised in the principles of adaptive management but in practical terms there is a pressing need to know the most effective approaches to implement these principles in different circumstances [88,89]. Hence, strategies to build resilience can be characterised as relatively safe "no-regret" approaches to tackle climate change, notably the reduction of existing pressures such as pollution, overgrazing, invasive species, and loss of organic matter from soils. Beyond resilience-based approaches, strategies that aim to accommodate change and then promote a transformation towards new conservation objectives may be necessary but are likely to involve a higher degree of risk because the outcomes are difficult to influence with any certainty [90]. The current ecological network of protected sites provides a firm basis on which to build these actions, but in the UK at present this network needs to be complemented by wider landscape measures to improve cohesion, quality and quantity of habitat because protected sites are too spatially constrained to provide climate change resilience [31,91]. This would suggest that a strategy completely based on a precautionary approach may be as unviable as prediction-based optimization approaches, and the focus instead should be on identifying measures that are proactive but robust in the context of a range of possible future pathways [92].

Two further issues have specific relevance for managing climate change risks in the natural environment. Firstly, legislative barriers need to be challenged to ensure that adaptation is kept as a "live" ongoing issue and that it is not constrained by static planning frameworks [93]. Secondly, many fundamental decisions on risk management are contingent on public attitudes to biodiversity and the natural environment, therefore having a very important ethical and philosophical dimension [94]. Most practitioners would acknowledge that maintaining current ecosystem composition and species is unrealistic, not least because there are limited resources for conservation. However, this means that decisions involve difficult choices on the relative viability of different species and habitats. For example, the dynamics of sea level rise in the coastal zone mean that conservation of marine habitats (e.g., saltmarsh) may require that they occupy locations that currently contain freshwater or terrestrial habitats. The existence of many inter-related factors means that ecosystem-based management cannot provide an exact science in terms of expected outcomes, and this has been exemplified by current coastal "managed realignment" schemes that have often provided surprises through resulting changes in habitats and species [95].

Basic questions therefore remain to be resolved regarding the ultimate objective of risk management, notably how much humans should intervene to accommodate change or to conserve the status quo [96]. In many cases, to accommodate change may require some form of deliberate disturbance to overcome the "natural inertia" of dominant species [97]. For example, this may include the translocation of seeds to enhance diversity and increase turnover of genetic material. Intervention-based schemes can therefore have significantly different aspirations for their outcomes compared to other schemes that have adopted the philosophy that "nature knows best" (e.g., re-wilding schemes). In addition to the limits for adaptation defined by the natural environment, outcomes are also defined by society contingent on ethics, knowledge, attitudes to risk, and culture [98]. These mutable limits are underpinned by diverse values and they are particularly expressed through the values people attach to places and landscapes, including synergies between natural and cultural assets. The challenges for adaptation policy are particularly exemplified by the dilemma in distinguishing so-called "native" and "non-native" species [99], and the eventual need to shift from a conventional conservation paradigm that protects existing "priority" species to one that also accommodates the objective of maintaining healthy functioning ecosystems, probably by containing a mix of new and existing species [90].

The CCRA therefore helped show that informed dialogue regarding "acceptable" levels of risk is still at an early stage and yet this is a key influence on adaptation planning. Research has previously shown that limits for tolerable risk are usually value-laden or normative [100] and attitudes to the natural environment are usually further complicated because consequences for people are experienced indirectly rather than directly. It was convenient for the CCRA to assume an objective to conserve the same mix of species, habitats, and level of ecosystem services as at present, even though most contributors and participants regarded this as unrealistic. Further dialogue is therefore clearly required on the societal and policy goals for risk assessment.

Several key topics requiring further research were identified during the CCRA process (Table 6, [101]). The basic knowledge gap in understanding change is in the dynamics of ecosystem interactions, particularly the role of natural adaptive responses, and hence the limits to and thresholds for maintaining adaptive capacity. More systematic collection, analysis and communication of change data (spatial and temporal), including attribution against different drivers of change, would provide a significantly improved evidence base of "what works, where and when" [102]. In modelling future risks, bioclimate envelopes need to be integrated with other sources of information to better account for the range of expected biotic and abiotic interactions, for example with species traits or niche models [103–105]. Further work is also required on valuation of biodiversity and ecosystem services so that costs and benefits can be better compared with other sectors. Current estimates are often highly contentious, not least because of the importance of non-use (existence) values for biodiversity, including shared and cultural values, and because conventional economic approaches do not make an explicit recognition of the importance of ecosystem resilience in buffering undesirable change [106].

Table 6. Key research issues identified for biodiversity and ecosystem adaptation.

Issue	Research Requirement
Species distributions and interactions	Improved modelling beyond current bioclimate envelope models which can have significant limitations for some species.
Atmospheric pollution	Understanding interactions with climate change regarding critical loads
Freshwater ecosystems	Upscaling from site to region/national level. Interactions between water temperature, water quality and water quantity
Soils	Better understanding of the dynamics of soil biodiversity, organic matter and nutrient cycling as key components of ecosystem functioning
CO_2 interactions	Better understanding of how CO_2 enrichment interacts with climate variables in ecosystem responses
Natural adaptive capacity	Improved understanding of phenotype plasticity and genetic adaptability across species (e.g., Donnelly *et al.*, 2012). This has particular relevance to the viability of translocation schemes
Biophysical processes	Integration of ecological, geomorphological and hydrological processes and their impacts on habitats
Migration routes	Risk assessment of pathways and key stopover sites
Protected area networks	Risk assessment of networks to identify critical links and to identify strategic enhancements
Landscape-scale initiatives	Tools to evaluate habitat connectivity and landscape permeability, across multiple time periods, including land use change scenarios
In situ adaptation options	Analysis of scope for increasing the resilience of species within their existing range, including increased habitat heterogeneity, refugia, and use of aspect (notably cooler north-facing slopes)
Risk metrics and threshold analysis	Identification of key thresholds for irreversible species population declines (e.g., [101])
Economic valuation	Improved techniques to value the full range of benefits from biodiversity and ecosystems (including cultural interactions), and to incorporate resilience
Adaptation/mitigation	Opportunities to build synergies between climate change mitigation and adaptation strategies

6. Conclusions

Comparative risk assessment provides a promising tool to address and prioritise the large suite of potential risks that could occur from climate change. In the UK, the CCRA provided the first comprehensive assessment of priority risks but also identified important opportunities to learn about further requirements that are needed to make progress on adaptation policy. A distinguishing feature was the complexity of risks, often involving interactions that produce both direct and indirect impacts, and that require integrated responses. For the natural environment, these indirect risks were particularly evident in terms of interactions with use of land and water. Important socioeconomic interactions were also highlighted for invasive non-native species and wildfire. Risk complexity in addition to the uncertainty regarding future projections of climate change means that there are inherent limitations in projecting risks into the future. Hence, the CCRA made more progress with broad-based risk screening as part of a prioritisation procedure rather than through risk quantification to establish changes in magnitude and likelihood of consequences. Stakeholders are increasingly acknowledging these uncertainties and some are now changing tactics to develop risk management strategies that incorporate uncertainty rather than adopt a "wait and see" approach for adaptation that assumes uncertainties will soon be resolved. The benefits from the CCRA were therefore more typically expressed through an interactive process of stakeholder-informed risk awareness, assessment and appraisal, rather than a quantified end product. This need for an ongoing dialogue on knowledge exchange for climate change risk assessment concurs with previous findings on the IPCC reporting process [107], identifying a need for reflexive and iterative procedures. For example, a key emerging requirement was the need to be more explicit about the goals for risk assessment, including levels of tolerable risk, particularly as it seems unviable to maintain the status quo in terms of the current mix of species and habitats. Climate change risks therefore contain subjective and contextual components which need to be transparently declared and which act against a purely objective approach, as has been similarly found with the necessary inclusion of expert judgement to define key parameters in climate change modelling [108]. These are issues that will need to be addressed in future versions of the CCRA through its five-year implementation cycle.

The CCRA process particularly highlighted the added benefits of integrated responses to climate change through "ecosystem-based adaptation" that can also enhance natural resilience to buffer undesirable and uncertain change. This included fundamental recognition of ecological adaptation as a natural process that often provides an under-recognised complement for human adaptation processes, but also that in socio-ecological systems people have a key role in facilitating ecological adaptation. Actions to counter current sensitivities by enhancing natural adaptive capacity and resilience therefore provide "no-regrets" measures that will reduce risks regardless of uncertainties in the rate of climate change and level of exposure [109]. The key response that will enhance this capacity is to reduce existing pressures, thereby significantly reducing the likelihood of crossing key thresholds that would lead to irreversible and severely damaging consequences [110].

Acknowledgments

The CCRA Advisory Group are thanked for providing very useful and informative comments on the use of evidence to inform policy requirements.

Conflicts of Interest

The author declares no conflict of interest.

References

1. Levin, K.; Cashore, B.; Bernstein, S.; Auld, G. Overcoming the tragedy of super wicked problems: Constraining our future selves to ameliorate global climate change. *Policy Sci.* **2012**, *45*, 123–152.
2. Hulme, M. Reducing the future to climate: A story of climate determinism and reductionism. *Osiris* **2011**, *26*, 245–266.
3. Dilling, L.; Lemos, M.C. Creating usable science: Opportunities and constraints for climate knowledge use and their implications for science policy. *Glob. Environ. Chang.* **2011**, *21*, 680–689.
4. Lindzen, R.S. Climate physics, feedbacks, and reductionism (and when does reductionism go too far?) *Eur. Phys. J. Plus* **2012**, *127*, doi:10.1140/epjp/i2012-12052-8.

5. Lemos, M.C.; Kirchhoff, C.J.; Ramprasad, V. Narrowing the climate information usability gap. *Nat. Clim. Chang*. **2012**, *2*, 789–794.
6. Kiem, A.S.; Austin, E.K. Disconnect between science and end-users as a barrier to climate change adaptation. *Clim. Res.* **2013**, *58*, 29–41.
7. Sarewitz, D.; Pielke, R.A., Jr. The neglected heart of science policy: Reconciling supply of and demand for science. *Environ. Sci. Policy* **2007**, *10*, 5–16.
8. Van der Sluijs, J.P.; Petersen, A.C.; Janssen, P.H.M. Exploring the quality of evidence for complex and contested policy decisions. *Environ. Res. Lett.* **2008**, *3*, doi:10.1088/1748-9326/3/2/024008.
9. Ungar, S. Knowledge, ignorance and the popular culture: Climate change *versus* the ozone hole. *Public Underst. Sci.* **2000**, *9*, 297–312.
10. Meinke, H.; Nelson, R.; Kokic, P.; Stone, R.; Selvaraju, R.; Baethgen, W. Actionable climate knowledge: From analysis to synthesis. *Clim. Res.* **2006**, *33*, 101–110.
11. Swart, R.; Biesbroek, R.; Capela Lourenço, T. Science of adaptation to climate change and science for adaptation. *Front. Environ. Sci*. **2014**, *2*, doi:10.3389/fenvs.2014.00029.
12. Morgan, M.G.; Henrion, M. *Uncertainty: A Guide to Dealing with Uncertainty in Risk and Policy Analysis*; Cambridge University Press: Cambridge, UK, 1992.
13. Linkov, I.; Satterstrom, F.K.; Kiker, G.; Batchelor, C.; Bridges, T.; Ferguson, E. From comparative risk assessment to multi-criteria decision analysis and adaptive management: Recent developments and applications. *Environ. Int.* **2006**, *32*, 1072–1093.
14. Assmuth, T.; Hildén, M. The significance of information frameworks in integrated risk assessment and management. *Environ. Sci. Policy* **2008**, *11*, 71–86.
15. Pullin, A.S.; Knight, T.M.; Watkinson, A.R. Linking reductionist science and holistic policy using systematic reviews: Unpacking environmental policy questions to construct an evidence-based framework. *J. Appl. Ecol.* **2009**, *46*, 970–975.
16. Willows, R.; Connell, R. *Climate Adaptation: Risk, Uncertainty and Decision Making*; UK Climate Impacts Programme: Oxford, UK, 2003.
17. Carter, T.R.; Jones, R.N.; Lu, X.; Bhadwal, S.; Conde, C.; Mearns, L.O.; O'Neill, B.C.; Rounsevell, M.; Zurek, M.B. New assessment methods and the characterisation of future conditions. In *Climate Change 2007: Impacts, Adaptation and Vulnerability*; Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J., Hanson, C.E., Eds.; Cambridge University Press: Cambridge, UK, 2007; pp. 133–171.
18. Jones, R.N.; Preston, B.L. Adaptation and risk management. *WIREs Clim. Chang.* **2011**, *2*, doi:10.1002/wcc.97.
19. Zebisch, M.; Grothmann, T.; Schröter, D.; Hasse, C.; Fritsch, U.; Cramer, W. *Klimawandel in Deutschland. Vulnerabilität und Anpassunsstrategien klimasensitiver Systeme*; German Federal Environment Agency: Dessau, Germany, 2005.
20. Balas, M.; Essl, F.; Federer, A.; Formayer, H.; Prutsch, A.; Uhl, M. *Klimaänderungsszenarian und Vulnerabilität*; Federal Environment Agency: Vienna, Austria, 2010.
21. Holthausen, N.; Perch-Nielsen, S.; Locher, P.; de Haan van der Weg, P.; Pütz, M.; Bründl, M. *Pilotprojekt Analyse Klimabedingter Risiken und Chancen in der Schweiz, Schlussbericht*; Bundesanstalt für Umwelt: Bern, Switzerland, 2011.

22. De Bruin, K.; Delink, R.B.; Ruijs, A.; Bolwidt, L.; van Buuren, A.; Graveland, J.; de Groot, R.S.; Kuikman, P.J.; Reinhard, S.; Roetter, R.P.; *et al*. Adapting to climate change in the Netherlands: An inventory of climate adaptation options and ranking of alternatives. *Clim. Chang.* **2009**, *95*, 23–45.
23. Biesbroek, G.; Swart, R.; Carter, T.; Cowan, C.; Henrichs, T.; Mela, H.; Morecroft, M.; Rey, D. *Europe Adapts to Climate Change: Comparing National Adaptation Strategies*; Partnership for European Environmental Research (PEER): Helsinki, Finland, 2009.
24. De Bremond, A.; Engle, N.L. Adaptation policies to increase terrestrial ecosystem resilience: Potential utility of a multicriteria approach. *Mitig. Adapt. Strateg. Glob. Chang.* **2014**, *19*, 331–354.
25. Defra. *UK Climate Change Risk Assessment: Government Report*; Defra: London, UK, 2012.
26. UK Cabinet Office Strategy Unit. *Risk: Improving Government's Capability to Handle Risk and Uncertainty*; Cabinet Office Strategy Unit: London, UK, 2002.
27. Brown, I.; Ridder, B.; Alumbaugh, P.; Barnett, C.; Brooks, A.; Duffy, L.; Webbon, C.; Nash, E.; Townend, I.; Black, H.; *et al. Biodiversity and Ecosystem Services: UK CCRA Sector Report*; Defra: London, UK, 2012.
28. Willis, K.J.; Bailey, R.M.; Bhagwat, S.A.; Birks, H.J.B. Biodiversity baselines, thresholds and resilience: Testing predictions and assumptions using palaeoecological data. *Trends Ecol. Evol.* **2010**, *25*, 583–591.
29. Bellard, C.; Bertelsmeier, C.; Leadley, P.; Thuiller, W.; Courchamp, F. Impacts of climate change on the future of biodiversity. *Ecol. Lett.* **2012**, *15*, 365–377.
30. Visser, M.E. Keeping up with a warming world; assessing the rate of adaptation to climate change. *Proc. Biol. Sci.* **2008**, *275*, 649–659.
31. Lawton, J.H.; Brotherton, P.N.M.; Brown, V.K.; Elphick, C.; Fitter, A.H.; Forshaw, J.; Haddow, R.W.; Hilborne, S.; Leafe, R.N.; Mace, G.M.; *et al. Making Space for Nature: A Review of England's Wildlife Sites and Ecological Network*; Defra: London, UK, 2010.
32. Britton, A.; Beale, C.M.; Towers, W.; Lewison, R. Biodiversity gains and losses: Evidence for homogenisation of Scottish alpine vegetation. *Biol. Conserv.* **2009**, *142*, 1728–1739.
33. Hambler, C.; Henderson, P.A.; Speight, M.R. Extinction rates, extinction-prone habitats, and indicator groups in Britain and at larger scales. *Biol. Conserv.* **2011**, *144*, 713–721.
34. UK NEA. *The UK National Ecosystem Assessment: Synthesis of the Key Findings*; UNEP-WCMC: Cambridge, UK, 2011.
35. Thomas, C.D.; Hill, J.K.; Anderson, B.J.; Bailey, S.; Beale, C.M.; Bradbury, R.B.; Bulman, C.R.; Crick, H.Q.; Eigenbrod, F.; Griffiths, H.M.; *et al*. A framework for assessing threats and benefits to species responding to climate change. *Methods Ecol. Evol*. **2010**, *2*, 125–142.
36. Essl, F.; Nehring, S.; Klingenstein, F.; Milasowszky, N.; Nowack, C.; Rabitsch, W. Review of risk assessment systems of IAS in Europe and introducing the German-Austrian Black List Information System (GABLIS). *J. Nat. Conserv.* **2011**, *19*, 339–350.
37. Gallopin, G. Linkages between vulnerability, resilience and adaptive capacity. *Glob. Environ. Chang.* **2006**, *16*, 293–303.
38. Intergovernmental Panel on Climate Change (IPCC) Working Group 2. Glossary. Available online: https://ipcc-wg2.gov/AR5/images/uploads/WGIIAR5-Glossary_FGD.pdf (accessed on 12 October 15).

39. Intergovernmental Panel on Climate Change (IPCC). *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*: *A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change*; Cambridge University Press: Cambridge, UK, 2012.
40. Costa, L; Kropp, J.P. Linking operations and definitions of vulnerability: Lessons from case studies in climate-change and risk-hazard context. *Sustain. Sci.* **2013**, *8*, 1–9.
41. Wallingford, H.R. *The UK Climate Change Risk Assessment 2012: Evidence Report*; Defra: London, UK, 2012.
42. Petticrew, M.; McCartney, G. Using systematic reviews to separate scientific from policy debate relevant to climate change. *Am. J. Prev. Med.* **2011**, *40*, 576–578.
43. Berrang-Ford, L.; Pearce, T.; Ford, J.D. Systematic review approaches for climate change adaptation research. *Reg. Environ. Chang.* **2015**, *15*, 755–769.
44. Mastrandrea, M.D.; Field, C.B.; Stocker, T.F.; Edenhofer, O.; Ebi, K.L.; Frame, D.J.; Held, H.; Kriegler, E.; Mach, K.J.; Matschoss, P.R.; *et al. Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties*; Intergovernmental Panel on Climate Change (IPCC): Geneva, Switzerland, 2010.
45. Met Office. *UK Climate Change Projections 2009 (UKCP09)*; UK Met Office: Exeter, UK, 2009.
46. UK Biodiversity Action Plan. Available online: http://jncc.defra.gov.uk/page-5705 (accessed on 15 May 2015).
47. Brown, I.; Berry, P.; Everard, M.; Firbank, L.; Harrison, P.; Lundy, L.; Quine, C.; Rowan, J.; Wade, R.; Watts, K. Identifying robust response options to manage environmental change using an Ecosystem Approach: A stress-testing case study for the UK. *Environ. Sci. Policy* **2015**, *52*, 74–88.
48. Alexander Ballard Ltd. The PACT Framework. Available online: https://www.weadapt.org/knowledge-base/climate.../module-pact (accessed on 12 October 15).
49. Straile, D.; Stenseth, N.S. The North Atlantic Oscillation and ecology: Links between historical time-series, and lessons regarding future climate warming. *Clim. Res*. **2007**, *34*, 259–262.
50. Menzel, A.; Sparks, T.H.; Estrella, N.; Koch, E.; Aasa, A.; Ahas, R.; Alm-Kübler, K.; Bissolli, P.; Braslavská, O.; Briede, A.; *et al.* European phenological response to climate change matches the warming pattern. *Glob. Chang. Biol.* **2006**, *12*, 1969–1976.
51. Hickling, R.; Roy, D.B.; Hill, J.K.; Fox, R.; Thomas, C. The distribution of a wide range of taxonomic groups are expanding polewards. *Glob. Chang. Biol.* **2006**, *12*, 450–455.
52. Chen, I.-C.; Hill, J.K..; Ohlemüller, R.; Roy, D.B.; Thomas, C.D. Rapid range shifts of species associated with high levels of climate warming. *Science* **2011**, *333*, 1024–1026.
53. Thomas, C.D.; Franco, A.; Hill, J.K. Range retractions and extinction in the face of climate warming. *Trends Ecol. Evol*. **2006**, *21*, 415–416.
54. Menéndez, R.; González Megías, A.; Hill, J.K.; Braschler, B.; Willis, S.G.; Collingham, Y.; Fox, R.; Roy, D.B., Thomas, C.D. Species richness changes lag behind climate change. *Proc. Biol. Sci.* **2006**, *273*, 1465–1470.
55. Devictor, V.; van Swaay, C.; Brereton, T.; Brotons, L.; Chamberlain, D.; Heliölä, J.; Herrando, S.; Julliard, R.; Kuussaari, M.; Lindström, Å.; *et al.* Differences in the climatic debts of birds and butterflies at a continental scale. *Nat. Clim. Chang.* **2012**, *2*, 121–124.

56. Thomas, C.D.; Robinson, R.A.; Crick, H.Q.P.; Learmonth, J.A.; Maclean, I.M.D.; Bairlein, F.; Forchhammer, M.C.; Francis, C.M.; Gill, J.A.; Godley, B.J.; *et al.* Travelling through a warming world—Climate change and migratory species. *Endanger. Species Res*. **2009**, *7*, 87–99.
57. Visser, M.E.; Perdeck, A.C.; van Balen, J.H.; Both, C. Climate change leads to decreasing bird migration distances. *Glob. Chang. Biol*. **2009**, *15*, 1859–1865.
58. Davies, Z.G.; Wilson, R.J.; Coles, S.; Thomas, C.D. Changing habitat associations of a thermally constrained species, the silver spotted skipper butterfly, in response to climate warming. *J. Anim. Ecol.* **2006**, *75*, 247–256.
59. Donnelly, A.; Caffarra, A.; Kelleher, C.T.; O'Neill, B.F.; Diskin, E.; Pletsers, A.; Proctor, H.; Stirnemann, R.; O'Halloran, J.; Peñuelas, J.; *et al*. Surviving in a warmer world: Environmental and genetic responses. *Clim. Res.* **2012**, *53*, 245–262.
60. Visser, M.E.; Holleman, L.J.M.; Gienapp, P. Shifts in caterpillar biomass phenology due to climate change and its impact on the breeding biology of an insectivorous bird. *Oecologia* **2006**, *147*, 164–172.
61. Thackeray, S.J.; Sparks, T.H.; Frederiksen, M.; Burthe, S.; Bacon, P.J.; Bell, J.R.; Botham, M.S.; Brereton, T.M.; Bright, P.W.; Carvalho, L.; *et al*. Trophic level asynchrony in rates of phenological change for marine, freshwater and terrestrial environments. *Glob. Chang. Biol.* **2010**, *16*, 3304–3013.
62. Kirby, K.J.; Smart, S.M.; Black, H.I.J.; Bunce, R.G.; Corney, P.M.; Smithers, R.J. *Long Term Ecological Change in British Woodlands (1971–2001)*; English Nature: Peterborough, UK, 2005.
63. Thuiller, A.C.; Araújo. M.B.; Berry, P.M. Predicting global change impacts on plant species' distributions: Future challenges. *Perspect. Plant Ecol. Evol. Syst.* **2008**, *9*, 137–152.
64. Ciais, P.; Reichstein, M.; Viovy, N.; Granier, A.; Ogée, J.; Allard, V.; Aubinet, M.; Buchmann, N.; Bernhofer, C.; Carrara, A.; *et al.* Europe-wide reduction in primary productivity caused by heat and drought in 2003. *Nature* **2005**, *437*, 529–533.
65. Sowerby, A.; Emmett, B.A.; Tietema, A. Contrasting effects of repeated summer drought on soil carbon efflux in hydric and mesic heathland soils. *Glob. Chang. Biol*. **2008**, *14*, 2388–2404.
66. Bellamy, P.H.; Loveland, P.J.; Bradley, R.I.; Lark, R.M.; Kirk, D. Carbon losses from all soils across England and Wales. *Nature* **2005**, *437*, 245–248.
67. Barraclough, D.; Smith, P.; Worrall, F.; Black, H.I.J.; Bhogal, A. Is there an impact of climate change on soil carbon contents in England and Wales? *Eur. J. Soil Sci.* **2015**, *66*, 451–462.
68. Schils, R.; Kuikman, P.; Liski, J.; van Oijen, M.; Smith, P.; Webb, J.; Hiederer, R. *Review of Existing Information on the Interrelations between Soil and Climate Change (ClimSoil): Final Report*; European Commission: Brussels, Belgium, 2008.
69. Boardman, J. Soil erosion in Britain: Updating the record. *Agriculture* **2013**, *3*, 418–442.
70. Watts, G.; Battarbee, R.W.; Bloomfield, J.P.; Crossman, J.; Daccache, A.; Durance, I.; Elliott, J.A.; Garner, G.; Hannaford, J.; Hannah, D.M.; *et al.*. Climate change and water in the UK—Past changes and future prospects. *Prog. Phys. Geogr.* **2015**, *39*, 6–28.
71. Doody, J.P. 'Coastal squeeze'—An historical perspective. *J. Coast. Conserv.* **2004**, *10*, 129–138.
72. Hulme, P.E. Biological invasions in Europe: Drivers, pressures, states, impacts and responses. In *Biodiversity under Threat*; Hester, R., Harrison, R.M., Eds.; Issues in Environmental Science and Technology, No. 25; Royal Society of Chemistry: Cambridge, UK, 2007; pp. 56–80.
73. Akin, S.-M.; Martens, P. A Survey of Dutch Expert Opinion on Climatic Drivers of Infectious Disease Risk in Western Europe. *Climate* **2014**, *2*, 310–328.

74. Albertson, K.; Aylen, J.; Cavan, G.; McMorrow, J. Climate change and the future occurrence of moorland wildfires in the Peak District of the UK. *Clim. Res.* **2010**, *45*, 105–118.
75. Brown, I.; Towers, W.; Rivington, M.; Black, H. Influence of climate change on agricultural land-use potential: Adapting and updating the land capability system for Scotland. *Clim. Res.* **2008**, *37*, 43–57.
76. Brown, I.; Poggio, L.; Gimona, A.; Castellazzi, M. Climate change, drought risk and land capability for agriculture: Implications for land use in Scotland. *Reg. Environ. Chang.* **2011**, *11*, 503–518.
77. De Vries, W.; Wamelink, G.W.; van Dobben, H.; Kros, J.; Reinds, G.J.; Mol-Dijkstra, J.P.; Smart, S.M.; Evans, C.D.; Rowe, E.C.; Belyazid, S.; *et al.* Use of dynamic soil-vegetation models to assess impacts of nitrogen deposition on plant species composition: An overview. *Ecol. Appl.* **2010**, *20*, 60–79.
78. Nicholls, R.J.; Townend, I.H.; Bradbury, A.P.; Ramsbottom, D.; Day, S.A. Planning for long-term coastal change: Experiences from England and Wales. *Ocean Eng.* **2013**, *71*, 3–16.
79. Burch, S.; Berry, P.; Sanders, M. Embedding climate change adaptation in biodiversity conservation: A case study of England. *Environ. Sci. Policy* **2014**, *37*, 79–90.
80. Van Teeffelen, A.; Meller, L.; van Minnen, J.; Vermaat, J.; Cabeza, M. How climate proof is the European Union's biodiversity policy? *Reg. Environ. Chang.* **2015**, *15*, 997–1010.
81. Truitt, A.M.; Granek, E.F.; Duveneck, M.J.; Goldsmith, K.A.; Jordan, M.P.; Yazzie, K.C. What is novel about novel ecosystems: Managing change in an ever-changing world. *Environ. Manag.* **2015**, *55*, 1217–1226.
82. Martinez, G.S.;Williams, E.; Yu, S.S. The economics of health damage and adaptation to climate change in Europe: A review of the conventional and grey literature. *Climate* **2015**, *3*, 522–541.
83. Grinnell, F. Rethinking our approach to risk. *Nature* **2015**, *522*, 257.
84. Dessai, S.; Hulme, M. Assessing the robustness of adaptation decisions to climate change uncertainties: A case-study on water resources management in the East of England. *Glob. Environ. Chang.* **2007**, *17*, 59–72.
85. Lindner, M.; Maroschek, M.; Netherer, S.; Kremer, A.; Barbati, A.; Garcia-Gonzalo, J.; Seidl, R.; Delzon, S.; Corona, P.; Kolström, M.; *et al.* Climate change impacts, adaptive capacity, and vulnerability of European forest ecosystems. *Forest Ecol. Manag.* **2010**, *259*, 698–709.
86. Elmqvist, T.; Folke, C.; Nyström, M.; Peterson, G.; Bengtsson, J.; Walker, B.; Norberg, J. Response diversity, ecosystem change, and resilience. *Front. Ecol. Environ.* **2003**, *1*, 488–494.
87. Hill, J.K.; Thomas, C.D.; Fox, R.; Telfer, M.G.; Willis, S.G.; Asher, J.; Huntley, B. Responses of butterflies to twentieth century climate warming: Implications for future ranges. *Proc. Biol. Sci.* **2002**, *269*, 2163–2171.
88. Heller, N.E.; Zavaleta, E.S. Biodiversity management in the face of climate change: A review of 22 years of recommendations. *Biol. Conserv.* **2009**, *142*, 14–32.
89. Keith, D.A.; Martin, T.G.; Mcdonald-Madden, E.; Walters, C. Uncertainty and adaptive management for biodiversity conservation. *Biol. Conserv.* **2011**, *144*, 1175–1178.
90. Morecroft, M.D.; Crick, H.Q.P.; Duffield, S.J.; Macgregor, N.A. Resilience to climate change: Translating principles into practice. *J. Appl. Ecol.* **2012**, *49*, 547–551.

91. Hodgson, J.A.; Thomas, C.D.; Wintle, B.A.; Moilanen, A. Climate change, connectivity and conservation decision making: Back to basics. *J. Appl. Ecol.* **2009**, *46*, 964–969.
92. Lempert, R.J.; Collins, M.T. Managing the risk of uncertain threshold responses: Comparison of robust, optimum, and precautionary approaches. *Risk Anal.* **2007**, *27*, 1009–1026.
93. Cliquet, A.; Backes, C.; Harris, J.; Howsam, P. Adaptation to climate change: Legal challenges for protected areas. *Utrecht Law Rev.* **2009**, *5*, 158–175.
94. Grasso, M.; Markowitz, E.M. The moral complexity of climate change and the need for a multidisciplinary perspective on climate ethics. *Clim. Chang.* **2015**, *130*, 327–334.
95. Pethick, J. Estuarine and tidal wetland restoration in the United Kingdom: Policy and practice. *Restor. Ecol.* **2002**, *10*, 431–437.
96. Minteer, B.A.; Collins, J.P. Move it or lose it? The ecological ethics of relocating species under climate change. *Ecol. Appl.* **2010**, *20*, 1801–1804.
97. Theurillat, J.-P.; Guisan, A. Potential impact of climate change on vegetation in the European Alps: A review. *Clim. Chang.* **2001**, *50*, 77–109.
98. Adger, WN.; Dessai, S.; Goulden, M.; Hulme, M.; Lorenzoni, I.; Nelson, D.R.; Naess, L.O.; Wolf, J.; Wreford, A. Are there social limits to adaptation to climate change? *Clim. Chang.* **2009**, *93*, 335–354.
99. Thomas, C.D. Anthropocene Park? No alternative. *Trends Ecol. Evol.* **2011**, *2*, 497–498.
100. Slovic, P. *The Perception of Risk*; Earthscan: London, UK, 2008.
101. Drake, J.M.; Griffin, B.D. Early warning signals of extinction in deteriorating environments. *Nature* **2010**, *467*,456–459.
102. Sutherland, W.J. Predicting the ecological consequences of environmental change: A review of the methods. *J. Appl. Ecol.* **2006**, *43*, 599–616.
103. Wiens, J.A.; Stralberg, D.; Jongsomjit, D.; Howell, C.A.; Snyder, M.A. Niches, models, and climate change: Assessing the assumptions and uncertainties. *Proc. Natl. Acad. Sci. USA* **2009**, *106*, 19729–19736.
104. Dawson, T.P.; Jackson, S.T.; House, J.I.; Prentice, I.C.; Mace, G.M. Beyond predictions: Biodiversity conservation in a changing climate. *Science* **2011**, *332*, 53–58.
105. Pacifi, M.; Foden, W.B.; Visconti, P.; Watson,J.; Butchart, S.; Kovacs, K.; Scheffers, B.; Hole, D.; Martin, T.; Akçakaya, H.; *et al.* Assessing species vulnerability to climate change. *Nat. Clim. Chang.* **2015**, *5*, 215–225.
106. The Economics of Ecosystems & Biodiversity (TEEB). *The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundations*; Earthscan: London, UK, 2010
107. Van der Sluijs, J.P. Uncertainty and dissent in climate risk assessment: A post-normal perspective. *Nat. Cult.* **2012**, *7*, 174–195.
108. Sexton, D.M.H.; Murphy, J.M. Multivariate prediction using imperfect climate models part II: Robustness of methodological choices and consequences for climate sensitivity. *Clim. Dyn.* **2012**, *38*, 2543–2558.
109. Hallegatte, S. Strategies to adapt to an uncertain climate change. *Glob. Environ. Chang.* **2009**, *19*, 240–247.

110. Driscoll, D.; Felton, A.; Gibbons, P.; Felton, A.M.; Munro, N.T.; Lindenmayer, D.B. Priorities in policy and management when existing biodiversity stressors interact with climate-change. *Clim. Chang.* **2012**, *111*, 533–557.