

Identifying and Analysing Adaptation Turning Points in the Hindu Kush Himalayan Region



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About HI-AWARE Working Papers

This series is based on the work of the Himalayan Adaptation, Water and Resilience (HI-AWARE) consortium under the Collaborative Adaptation Research Initiative in Africa and Asia (CARIAA) with financial support from the UK Government's Department for International Development and the International Development Research Centre, Ottawa, Canada. CARIAA aims to build the resilience of vulnerable populations and their livelihoods in three climate change hot spots in Africa and Asia. The programme supports collaborative research to inform adaptation policy and practice.

HI-AWARE aims to enhance the adaptive capacities and climate resilience of the poor and vulnerable women, men, and children living in the mountains and flood plains of the Indus, Ganges, and Brahmaputra river basins. It seeks to do this through the development of robust evidence to inform people-centred and gender-inclusive climate change adaptation policies and practices for improving livelihoods.

The HI-AWARE consortium is led by the International Centre for Integrated Mountain Development (ICIMOD). The other consortium members are the Bangladesh Centre for Advanced Studies (BCAS), The Energy and Resources Institute (TERI), the Climate Change, Alternative Energy, and Water Resources Institute of the Pakistan Agricultural Research Council (CAEWRI-PARC) and Wageningen Environmental Research (Alterra). For more details see www.hi-aware.org.

Titles in this series are intended to share initial findings and lessons from research studies commissioned by HI-AWARE. Papers are intended to foster exchange and dialogue within science and policy circles concerned with climate change adaptation in vulnerability hotspots. As an interim output of the HI-AWARE consortium, they have only undergone an internal review process.

Feedback is welcomed as a means to strengthen these works: some may later be revised for peer-reviewed publication.

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Identifying and Analysing Adaptation Turning Points in the Hindu Kush Himalayan Region

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Acronyms and Abbreviations

ATP	Adaptation Turning Point
HI-AWARE	Himalayan Adaptation, Water and Resilience Research
ICPR	International Commission for the Protection of the Rhine
IPCC	Intergovernmental Panel on Climate Change
RH	Relative Humidity
RCP	Representative Concentration Pathways
NGO	Non-governmental Organisation
UNFCCC	United Nations Framework Convention on Climate Change

Summary

This framework document aims to introduce a proactive approach to assess adaptation needs and encourage timely adaptation. The idea behind this approach is that if an assessment shows that specific policies and practices of stakeholders are at risk of failure due to climate change, corrections are encouraged and losses or damages can be prevented. The approach focuses on identifying whether and when the performance of policies, management, and social-cultural practices drops below a decisive level due to climate change, and adaptation is required.

We call the moment at which a decisive change in performance is reached an 'adaptation turning point'. The assessment of turning points shows there is an imperative to act, and it aims to help proactively and timely plan alternative strategies. In cases with a development or implementation deficit and where the performance of the existing policies and practices is already unsatisfactory, the turning point lies in the past. If, in these cases, changes can be attributed to climate change, the assessment of turning points helps identify the adaptation gap.

With respect to new practices, the assessment of turning points shows when these practices become viable in order to facilitate a smooth transition to alternative systems and practices. For development policies, an adaptation turning point assessment asks whether development goals are achievable under climate change and can be sustained.

By introducing this approach in the Hindu Kush Himalayan region we want to ascertain whether the assessment is a meaningful addition to adaptation approaches by allowing, in particular, for a substantial dialogue between stakeholders and scientists about the amount of change that is acceptable, when conditions could be reached that are unacceptable or more favourable, how likely these conditions are, and what adaptation to consider. The approach is not to be understood in isolation, but connects to other work in the HI-AWARE project, in particular the development of adaptation pathways and the assessment of critical moments.

With this document we aim to deliver a framework for identifying adaptation turning points. The document offers a broad scoping of the approach, next to the identification of its potential application in HI-AWARE. This also marks the start of the dialogue in the HI-AWARE project on the applicability and value of the concept in the Hindu Kush Himalayan region. The assessment of adaptation turning points will be a contribution to other research in HI-AWARE, such as adaptation pathways development.



1. Introduction

Climate change will have wide-ranging effects on the environment, and on social-economic and related sectors, including water resources, agriculture and food security, human health, and biodiversity (UNFCCC, 2007). With climate change affecting livelihoods, the need for adaptation has become increasingly recognised. Gaining new knowledge on the complexities, timing, and possible adaptation measures for climate impacts is crucial for current and future adaptation. This has been the inspiration for HI-AVARE to introduce several assessment approaches to be piloted and refined with partners in the Hindu Kush Himalayan region (see also Section 2.3):

- Community-based climate vulnerability and capacity assessments
- Critical moments
- Adaptation turning points (this document)
- Adaptation pathways

These approaches are closely connected and together span the adaptation cycle from assessing adaptation needs to developing adaptive responses. Box 1 gives an example of the type of headline statement, which could result from the combined assessment in HI-AVARE.

Box 1: Headline findings food security Indus Basin (see Section 3.1 for details)

After 2050 climate change is projected to put wheat-based food security in the Indus basin at risk, since climate change suppresses wheat yields in large parts of Punjab. Without measures, by 2100 most of Pakistan is expected to be affected, as well as parts of India.

Already little rain after sowing and early rains during harvesting challenge the winter wheat production. Results for the Soan River Basin show, for example, how April has become a critical month over the last ten years. In April many crops germinate and are particularly sensitive to water stress. Here, supplement irrigation would be particularly effective.

Looking towards the future we find that precipitation trends are not so clear; instead the real concern stems from high temperatures in winter, hindering vernalisation. South Punjab will be hit first and by 2050 years with reduced yields due to high temperatures are projected to become frequent. By the end of the century also North Punjab is expected to suffer. So, relying on production in the Northern, higher areas can help, but will also run into climate limitations.

Importantly, in a high climate change scenario (RCP 8.5) also wheat production in India is gravely affected, with temperatures above the lethal limit for wheat.

This gives us 30-50 years to rethink food safety in this region. Alternative technologies can emerge over time that sustain wheat production in the area. Supporting alternative crops will need to be given precedence over compensating losses in existing crops.

What you may have noted from the headline statement is that it pays special attention to when specific climate impacts of concern occur and what are timely responses. In doing so it offers an additional perspective to asking who and what is exposed or impacted by climate change, and where vulnerable people and their livelihoods are located (questions emphasised in vulnerability analysis and impact assessment). This, in short, is the contribution, which we aim to make with the assessment approaches piloted in HI-AWARE.

This framework document will focus on what we will call 'adaptation turning points' (ATP). An assessment of 'adaptation turning points' aims to contribute to adaptation by:

1. Identifying and communicating stakeholder relevant implications of climate change to raise awareness.
2. Giving guidance to adaptation planning, in particular to the identification of adaptation needs, the manifestation these adaptation needs through time and the timeliness of responses.

The assessment can be used in combination with other approaches to cover the full adaptation cycle and successfully realise adaptation. In this framework document we present the background and practical steps for assessing adaptation turning points. We also offer examples of existing studies and cases relevant for HI-AWARE.

The framework document first introduces the background and definitions for assessing turning points (Section 2). Section 3 introduces methodological steps and offers case study examples of turning points. In Section 4 elements of the methodology for HI-AWARE are introduced. Section 5 discusses the broader implications of the approach, its possible limitations, and challenges to be considered in HI-AWARE.

2. Background, Definitions, and Framing

2.1. Background and Rationale

The relationship between climate change and development is twofold. On the one hand, climate change affects development efforts. On the other hand, development critically shapes climate change vulnerability and adaptive capacity. Enhancing resilience to respond to effects of climate change includes adopting good development practices that are consistent with building sustainable livelihoods, and, in some cases, challenging current models of development. Integrating overall climate change policy and development can be all the more relevant if cross-linkages between poverty, the use of natural capital, and environmental degradation are recognised (IPCC, 2014).

Climate change adaptation planning historically started with the generation and interpretation of climate projections, and an analysis of their impacts and the resulting vulnerabilities to be reduced (Dessai and Hulme, 2004, Dessai et al., 2009). Although the amount of information available on climate impacts and vulnerability has increased over the years, challenges have emerged for the uptake and practical use of this information. Recent studies observe that in order to satisfy policy makers, adaptation assessments are inverted to start from the interest and action potential of a decision-maker, which are then studied in the context of changes in the climate (Cash et al. 2006; Pyke et al., 2007; Reeder and Ranger, 2011; Downing, 2012; Hanger et al., 2013, Werners et al., 2013). This is also called the “policy first” approach (Ranger et al., 2013) and is at the base of robust decision making (Hallegatte et al. 2012; Lempert et al., 2013).

Adding to this, the incorporation of climate concerns in prevalent development interventions is the best option, since development is what most countries care about (IPCC, 2014). This makes sense, because actors are looking for ways to connect climate change to their pre-existing political interests or policy competencies (Huiteima et al., 2013). Starting from the interest and competencies of stakeholders may ensure the much-needed willingness of stakeholders to take action on adaptation.

This is an assumption we want to test with the approach presented in this framework paper. We are encouraged by consultative processes in the HI-AWARE study in India, which have highlighted political will and governance to be key parameters of successful implementation of any initiative that benefits societies at large.

In this framework document we build on the idea that political will to act on climate change can result from showing whether current development practices and policies can cope with climate change and increased climate variability. We presume that adaptation becomes relevant (only) if the amount of change is unacceptable to those who can do something directly or indirectly in a given context, or when interests can be realised more effectively by alternative practices. For example, if water scarcity aggravates to levels where political interests are at stake, the administration would experience an imperative to act. In such a situation, it is not only important to know the extent of the impact, but also when and how likely this situation occurs, to provide the requisite time for adapting.

2.2. Definition and Illustration

This framework document proposes an approach to be further tested in HI-AWARE to communicate the need for adaptation and encourage proactive adaptation. The idea behind this approach is that if assessment shows that policies and programmes can no longer deliver effectively due to climate change, timely correction can be made so that losses or damages may be prevented or averted.

We propose to use 'adaptation turning point' for the specific situation in which a decisive threshold in the performance of policies and practices is reached due to climate change. This includes the situation in which new practices have become more attractive than current.

The assessment of turning points will depend on the case and its specific context. Although the methodology will differ per case, two central elements of the assessment are:

1. Discuss what defines unacceptable change: what (performance) targets and thresholds exist for different stakeholders? Who defines these thresholds? At what scale? What particular actions, sectors, programmes or schemes are at stake?
2. Assess when thresholds are reached (including capturing scenario uncertainty in a time range).

We will discuss these elements here, before attempting a further break down into practical assessment steps in the next chapters. The assessment of adaptation turning points (ATP) starts from identifying the performance thresholds that specific groups of actors do not want to transgress. This sets it apart from many other risk and impact assessments. The threshold of concern will have to be determined for each specific context. To be able to define what is 'acceptable' and 'not acceptable', consultative processes need to be followed to understand properly where the limits stand for what, to whom, and when. The method could be applied across various scales including national, sub-national and local scales depending on the objective. Examples of policies and practices of concern include:¹

- Policy objectives (e.g. development objectives, sustainable development goals, flood risk, food security, water security, number of people with access to safe drinking water, disaster risk reduction);
- Project, programme and investment objectives (e.g. irrigation security / reservoir level, power generation, revenues from land conversion and management, performance sewerage / drainage system);
- Social, cultural, religious objectives (e.g. gender roles, religious laws, risk tolerance such as the situation in which people decide to leave their house because of high indoor temperature or heavy precipitation / (flash) floods); and
- Economic and institutional objectives (e.g. yield of alternative crop compared to current crop, household income).

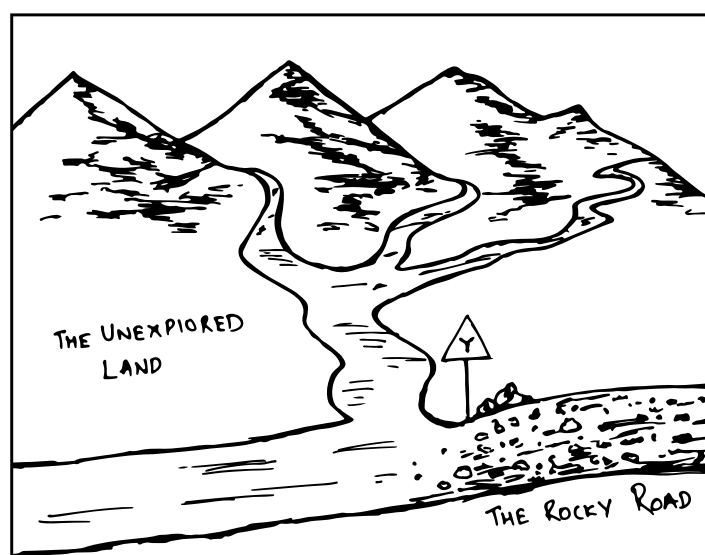
Assessing adaptation needs in terms of (un)desirable change and stakeholder preferences has the important consequence that it invites to elicit and discuss the direction of change and the thresholds that different actors do not want to transgress. Ultimately, this question is a normative one – what change is considered and how much change and risk are actors willing or forced to accept? Importantly, it is also giving rise to debates how risks are perceived, whose preferences are considered, and who determines what is acceptable, and when adjustments or alternatives are to be taken.

We acknowledge that Kwadijk et al. (2010) introduced the concept of 'adaptation tipping points' in a policy study of long-term water safety in the Netherlands, a term which has since gained popularity. Adaptation tipping points are defined similarly to how we define adaptation turning points as points where the magnitude of change due to climate change is such that the current management strategy will no longer be able to meet its objectives. To avoid confusion with the term 'tipping point' that people tend to associate with a major change or collapse in biophysical systems (Folke, 2006), we propose to use 'adaptation turning point' in this HI-AWARE framework document. Another reason to use the term turning points is our focus on the normative nature of the thresholds of concern. Especially in a context where there is already an implementation deficit, it may be questioned whether such thresholds give rise to system features that justify the use of the term tipping point (multiple stable states, non-linear change, feedbacks as driving mechanism, limited reversibility (Milkoreit et al., 2018)). Annex A offers additional background on definitions of tipping points, turning points and thresholds used in literature.

¹An assessment of turning points will have to determine its focus based on actor interests and competencies.

Figure 2.1 and Figure 2.2 depict important aspects of an adaptation turning point and its assessment. Figure 2.1 illustrates that an adaptation turning point does not mean that catastrophic consequences are inevitable and largely irreversible (what one may call a tipping point). Instead, it implies progressive failure of current management practices (the 'rocky road'), such that actors may wish to turn to alternatives (the 'unexplored land'). Even though for actors to adapt and take the 'benign' fork off the rocky road may be no simple task (Abel et al., 2011; Geels, 2011; Renaud et al., 2013). It also acknowledges that alternatives may emerge or evolve over time. Each alternative in turn will have its own lifetime in meeting its objectives under climate change.

Figure 2.1: Illustration of a turning point. The current direction is becoming unattractive in time (the 'rocky road') and a turn to alternative routes is up for consideration (the 'unexplored land') (Werners et al., 2015)



After a decisive threshold has been found, the timing of the adaptation turning point needs to be assessed. This determines the time available to plan and implement adaptation strategies. Figure 2.2 illustrates a turning points assessment. Firstly, it offers examples of thresholds, which may exist for river discharge, such as:

- Discharge threshold between states in transboundary water agreement;
- Environmental flow (discharge reserved for ecosystems by agreement); and
- Discharge at which a water saving programme enters into force (e.g. changing reservoir management or limiting abstraction by certain water users) in order to limit salt intrusion in the delta.

Secondly, Figure 2.2 shows when these thresholds are likely to be reached, by combining the thresholds with a graph of changes in river discharge over time. The figure uses the highly stylised example of discharge under two climate change scenarios to illustrate that future changes in discharge are uncertain. The Figure also shows how scenario uncertainty is translated into a time range in which an adaptation turning point is likely to occur for a given threshold. Finally the figure shows how the turning point can be postponed by implementing timely adaptation; in this case a measure that increased the discharge, which was implemented in 2018.

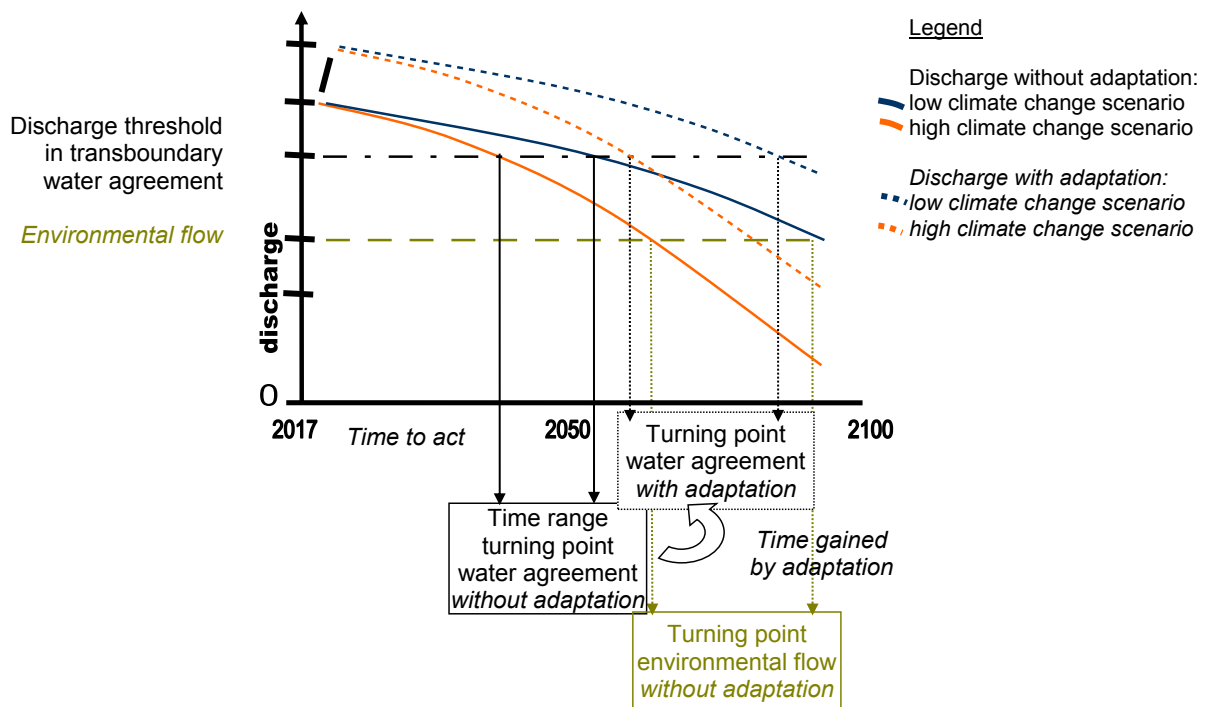
Expressing uncertainty as a time range (when will a critical performance threshold be reached) is a crucial aspect of the assessment. It differs from assessments where uncertainty is expressed the range of values in a certain projection year. The assessment also delimits the time to adapt. Importantly, due to uncertainties, the turning point typically is not a particular point in time, but rather a time range.

A threshold likely to arrive in bio-physical terms may be either advanced or delayed, based on other social-economic and techno-political considerations. Note that if Figure 2.2 were elaborated in a real example, it would be critical to understand what discharge indicator is used in the policies and, accordingly, would have to be plotted and assessed in the figure. For example, the total annual run-off or low flow (dry season discharge) may be more appropriate than average annual discharge.

In cases of an implementation gap or deficit, and if the performance of existing policies and practices is already unsatisfactory, the turning point lies in the past and the assessment will help identify the adaptation gap.

With respect to new practices, the assessment of turning points shows when these practices become viable in order to facilitate a smooth transition to alternative livelihood systems and practices.

Figure 2.2: Threshold (here: average crop yield target) is translated into a time range in which it is likely to be reached. The figure uses hypothetical crop yields



2.3. Link to Other Assessments and Concepts in HI-AWARE

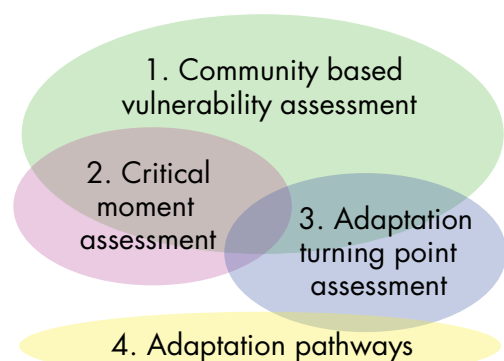
To further adaptation planning HI-AWARE has tested and refined four related approaches with partners in the Hindu Kush Himalayan region:

- Community-based climate vulnerability and capacity assessments (HI-AWARE Research Component 2);
- Critical moments (HI-AWARE Research Component 4, (HI-AWARE Working Paper 10);
- Adaptation turning points (HI-AWARE Research Component 4) (this document); and
- Adaptation pathways (HI-AWARE Research Component 5, HI-AWARE Working Paper).

This section aims to delineate and define the relationship between these concepts. Figure 2.3 illustrates the relations and workflow between the concepts vulnerability, critical moments, adaptation turning points, and adaptation pathways. An important task for HI-AWARE is to define adaptation turning points and pathways in such a way as to minimise overlap and confusion and maximise the added value of distinguishing the different concepts.

‘Critical climate stress moments’ are defined as those moments, when households, communities, and the livelihood systems they depend on are especially vulnerable to climate and weather-related risks and hazards (Groot et al., 2017). Importantly, the identification of critical moments may help identify the critical climate conditions and the thresholds that society wishes not to transgress.

Figure 2.3: The relations and workflow between the concepts vulnerability, critical moments, adaptation turning points, and adaptation pathways in the HI-AWARE approach



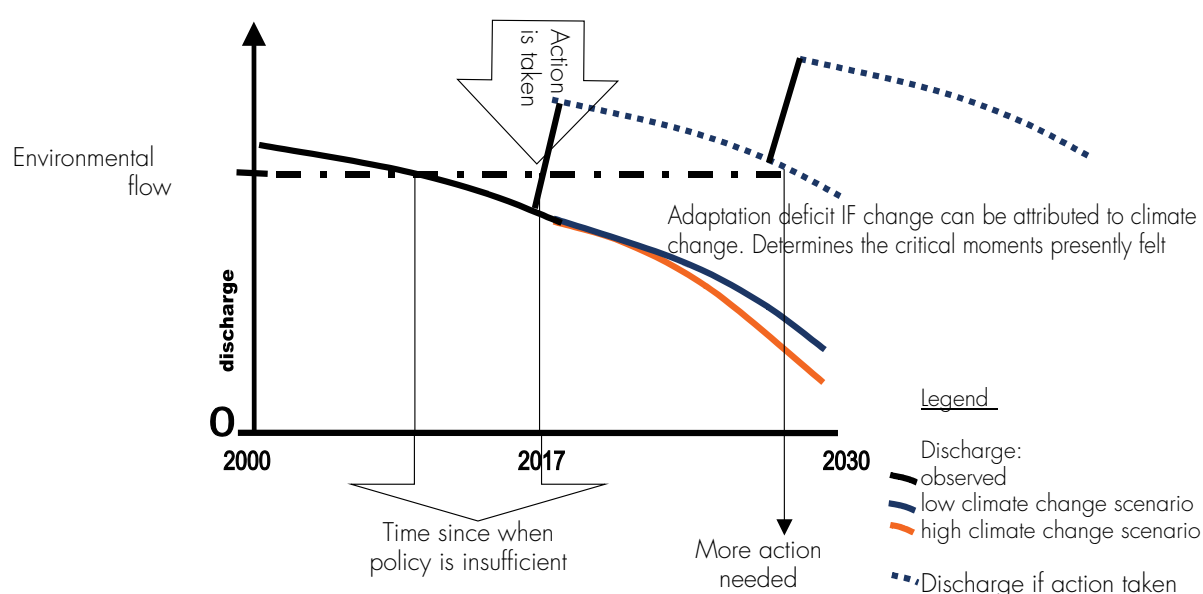
An important question will be whether the conditions, which result in a critical moment, occur more frequently under future climate change and give rise to turning points. This is a connection between a critical moment assessment and turning points that can be explored in HI-AWARE cases to see the added value of the combined approach. These assessments are more separated when the focus of an adaptation turning point assessment is on regional (development) policies.

The main difference between critical moments and adaptation turning points is that critical moments are recurring and map vulnerabilities as they are currently perceived by actors and communities, whereas adaptation turning points are non-recurring and aim to map decisive impact thresholds that are yet to occur. Critical moments refer to a period of time within a year during which actors and communities are most vulnerable. As such, critical moments are recurring, yet how affected people are will differ between years. Adaptation turning points, on the other hand, start from the goals and aspirations of actors and asks when these will be decisively affected by climate change. Adaptation turning points refer to a unique non-recurring period of time, corresponding to a predefined impact threshold for which action is an imperative. The climate conditions under which a turning point occurs may not have been experienced yet and unknown to actors.

When key vulnerabilities and turning points have been identified, the next step is to look at adaptation measures; that is, now to identify measures to eliminate or postpone adaptation turning points. These measures may be combined into adaptation pathways to reduce critical vulnerabilities and eliminate or postpone turning points over time.

To fully understand and implement adaptation turning points (and critical moments), adaptation deficits need to be understood too. An adaptation deficit is a failure to adapt to existing climate risks (Levina and Tirpak, 2006). In Figure 2.4 we can see for example, that when a threshold is reached in 2017 with temperature rising by 1°C and critical moments are occurring more frequently with climate stress, the adaptation deficit is increasing along with climate change, unless action is taken. On a timeline, various interventions could be made in terms of governance, policies, information and technologies as well as short, medium, and long-term planning. However, if these actions are not undertaken, the adaptation deficit is likely to increase. The aim of recognising an adaptation turning points is to be proactive before that turning point is reached.

Figure 2.4: Illustration of thresholds, adaptation deficit, and turning points



2.4. Opportunities and Challenges for the Assessment

A key motivation for elaborating the approach is that turning points are policy-oriented, and can focus the assessment of climate scenarios to determine when action needs to be taken. A turning point assessment can consider a range of objectives, which encourages discussion on acceptable change and critical values now and in the future. In case of formal policy objectives, the assessment of adaptation turning points may be relatively uncontested, and may converge on a moment in time at which existing policies and management practices may fail due to climate change. This provides an opportunity to scale the various activities and indicate changes in the policies and measures over time. It also allows planning adaptation better, keeping in mind the risks as well as timeliness of investments to be made. In particular, it helps define so-called adaptation pathways (an approach to be elaborated in HI-AWARE Research Component 5). Examples can be found in the Delta Programme (Delta Commissioner, 2010) and the Thames Estuary 2100 Project (Reeder and Ranger, 2011). This said, focussing on societal preferences, values, and interests (e.g. Adger et al., 2009, Asselt and Renn, 2011), the assessment of turning points will be more diffuse and is likely not to set a well-defined moment in time.

Another challenge relates to a potential focus on existing objectives rather than new challenges. In addition, simplicity is lost when thresholds are less-well defined, when turning points have multiple drivers, and when there is a multiplicity of viewpoints about risk perception and goals to be sustained.

At this point we would emphasise not all climate related concerns would lend themselves to be pinpointed as turning points. Nevertheless, early assessments suggest that the discussion itself is useful about at what level impacts become salient and decisive for stakeholders, and what evidence we have of the occurrence of turning points in climate scenarios. Indeed, making evident existing uncertainties and ambiguities may be an asset already, for it may signal a possible lack of commitment encountered when trying to plan adaptation.

3. Case Examples of Turning Point Assessments

To contribute to our understanding of turning points, this section gives references to case examples from literature, the methods used, and concrete examples of turning point assessments. Table 3.1 offers an overview of case studies from literature. Within each assessment the choice of tools and methods is found to differ, depending on the case. Although the methodologies differ per case, three common steps are discerned in each of the case-example assessments. These are:

1. Discuss what defines unacceptable change: what (performance) targets and thresholds exist for different actors? Who defines these thresholds? Who(m) are these thresholds for? At what scale to define thresholds? Is it for a particular action, sector, programme or scheme?
2. Identify under what climatic conditions thresholds are reached. What climate conditions are critical for reaching objectives in a particular spatial and institutional context?
3. Assess when thresholds are reached (including capturing scenario for uncertainty in a time range).

These three steps will be illustrated in the following cases, describing: 1) the thresholds of interest, 2) the climate conditions under which thresholds are reached, and 3) the adaptation turning points and lessons from the case. This section offers two early HI-AWARE cases for illustration. The cases given here are limited in scope and could be further elaborated, including a broader assessment of thresholds and climatic conditions of concern. For other examples of turning points, which could be explored in the context of HI-AWARE, please see Table 4.1 in the next Chapter.

Table 3.1: Case examples of turning point assessments existing in literature

Case example	References
Flood risk in the Thames estuary	(Lavery and Donovan, 2005, Stafford Smith et al., 2011)
Hydrological and technical thresholds for long-term water management in the Netherlands	(Kwadijk et al., 2010; Reeder and Ranger, 2011; Lempert, 2013)
Salmon restoration programme, Rhine River	Section 3.3 + (Bölscher et al. 2013)
Inland waterway transport	(Riquelme-Solar et al. 2015)
Wine production in Tuscany, Italy	(Werners et al. 2015)

3.1. Example 1: Food Security and Wheat Production in the Indus Basin²

3.1.1 Social political thresholds of interest

We start with a broader exploration of management and policy issues around food security. Then we select issues for further study. The selection is limited to illustrate the assessment of turning points. It does not cover all aspects of food security (food availability, access, and utilisation). The policy review focuses on Pakistan national policy.

² This chapter is based on: Strating, T. (2017), Climate Change in the Hindu Kush Himalayan region. Adaptation Turning Points for water and food related policy objectives and management strategies, M.Sc. Thesis, Water Systems and Global Change Group, Wageningen University & Research, the Netherlands

One of the main objectives in the National Climate Change Policy (2012) of the Government of Pakistan is 'to ensure water security, food security and energy security of the country in the face of the challenges posed by climate change' (Government of Pakistan, 2012). The Ministry of National Food Security and Research states in their draft National Food Security Policy (2017) that poverty, food security, and food safety remain major issues and to achieve food security is an essential part of their programme (Government of Pakistan, 2017). Also in the Pakistan Vision 2025 food security is an important issue and they envision a Pakistan where 'all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life' (Government of Pakistan, 2013). The objectives in the Pakistan Vision 2025 to achieve food security are:

1. Protect the most food insecure segments of the population.
2. Create a modern, efficient, and diversified agricultural sector that supplies adequate food for the population and quality products for export.
3. Optimise production and supply mix in line with current and projected needs.
4. Ensure provision of stable and affordable access to adequate nutritious and safe food.
5. Sustainable use of the resource base in line with regional and global standards.

In these policies food security is not further operationalised in specific yield targets or thresholds. In more general terms, the draft National Food Security Policy aims to achieve agriculture growth at the rate of 4% per annum. Projections of population size for Pakistan range from 218-250 million in 2025 to 265-359 million in 2050. As a result of growing population, more food has to be produced to maintain, or improve, the level of food security in the country (Kirby et al., 2017).

Looking at crop production more specifically, Pakistan has increased its production of cereals and pulses by a factor of 3.5 since the 1960s. However, pulses, and edible oil are still imported to meet domestic demands. In terms of rice production Pakistan is self-sufficient and is also exporting (Ahmad and Farooq, 2015). The staple food crop is wheat, which is grown in many different regions of the country despite the diversity in climate in the country (Sultana et al., 2009). The production of wheat in the province of Punjab contributes to about 80% of the total wheat production (Tariq et al., 2014). The production of wheat accounts for 13% of the total value in agricultural production, and in 2008-2009 wheat accounted for an increase in the GDP by almost 3% (Ashfaq et al., 2011).

In the following assessment we focus on wheat production as a key crop for food security. As the objective of the policies is to ensure food security in the face of climate change and a growing population, we assume that the threshold for wheat production is any crop loss due to climate change. In the remaining section we explore the climate conditions critical at which crop loss occurs, when these conditions occur, and which of these conditions will be limiting first.

3.1.2. Climatic conditions for reaching thresholds

The cropping calendar for Pakistan shows that (winter) wheat is being planted from October till halfway December (<http://www.fao.org/gIEWS/countrybrief/country.jsp?code=PAK>). After the growing period, which is from January till March, the crop is harvested from April till early June. Temperature is an important factor in the different growth stages of wheat. Wheat requires a minimum temperature of 5-10 °C to develop past the dormancy stage as also a long cold season for plant development before flowering (Tariq et al., 2014; Thapa-Parajuli and Devkota, 2016).

If high temperatures occur during the winter season (rabi season), it could result in a reduction of growth and yield due to shortening of the growing season and therefore the interception of solar radiation (Arshad et al., 2016). During November, the month in which wheat is sown, the crop needs a relatively high temperature. There are upper limits beyond which temperature also negatively affects wheat production (especially during November and January).

Table 3.2 and Table 3.3 give an overview of the critical climate parameters that have been identified in literature for the production of wheat.

Table 3.2: Critical temperatures (°C) for wheat (Porter and Gawith, 1999; Luo, 2011)

Temperatures	Phenophases					
	Lethal limits	Sowing	Vernalisation	Terminal spikelet	Anthesis	Grain filling
$T_{l_{min}}$	-17.2 (1.2)					
$T_{l_{max}}$	47.5 (0.5)					
T_{base}		3.5 (1.1)	-1.3 (1.5)	1.5 (1.5)	9.5 (0.1)	9.2 (1.5)
T_{opt}		22.0 (1.6)	4.9 (1.1)	10.6 (1.3)	21.0 (1.7)	20.7 (1.4)
T_{max}		32.7 (0.9)	15.7 (2.6)	>20.0	31.0	35.4 (2.0)

Legend: lethal limits of wheat crop ($T_{l_{min}}/T_{l_{max}}$) and cardinal temperatures ($T_{base}/T_{opt}/T_{max}$) for different growth stages

Table 3.3: Thresholds for wheat. From: ¹ (Hussain and Mudasser, 2007), ² (Arshad et al., 2016), ³ (Ahlawat and Kaur, 2015), ⁴ (Prasad and Djanaguiraman, 2014). The conditions for high temperature (HT) stress are 36/26 (°C) day/night, 14 h photoperiod and 85% RH.

Growth stage	Unit	Value	
Growing season length ¹	Days	157 (optimum)	This is the average optimum amount of days for the growing season of wheat.
Photosynthesis ²	[°C]	30.0	Higher temperatures are damaging to leaf photosynthesis and can accelerate senescence, which reduces grain filling.
Yield ^{3,4}	[°C]	20-25 (optimum)	For a good yield, this is the range for the optimum temperature.
Anthesis ¹	[°C]	32.0	Higher temperatures prior or during anthesis cause reduced seed size, pollen sterility, and stigma desiccation.
Grain filling ⁴	[°C]	36.0 day/26.0 night	An increase in the duration of high temperature decreases floret fertility and individual grain weight.

Literature did not give any thresholds with respect to rainfall. This is in contrast to the assessment of critical moments that was done with stakeholders in HI-AWARE study areas (Groot et al., 2017). From an assessment in the Soan River Basin (Gang village, Rawalpindi district) we derived the following thresholds for wheat production:

- Loss of yield and harvest with rains in February - March (> 20 mm rain/day)
- Yield loss when there are no 'good rain' in October: 2-3 hours rain, minimum of 15-20 mm rain

3.1.3 Adaptation turning points and lessons

From the above identification of climatic conditions, thresholds were selected for the assessment of turning points. We use 1) T_{max} during the different growth stages, 2) Lethal limits (tipping point for wheat yield), 3) Precipitation thresholds.

Since Punjab is the major province where wheat is grown, the analysis focuses on this Province. Since it is a large area and has quite some regional differences, it was divided into a Northern and a Southern part for the assessment.

The climate scenarios generated by HI-AWARE were used for the assessment (period 2010-2100) (Lutz et al., 2016). This selection was made, since they offer high-quality downscaled data, to substantiate the value of assessment of turning points for scenario development, and to maintain consistency in HI-AWARE.

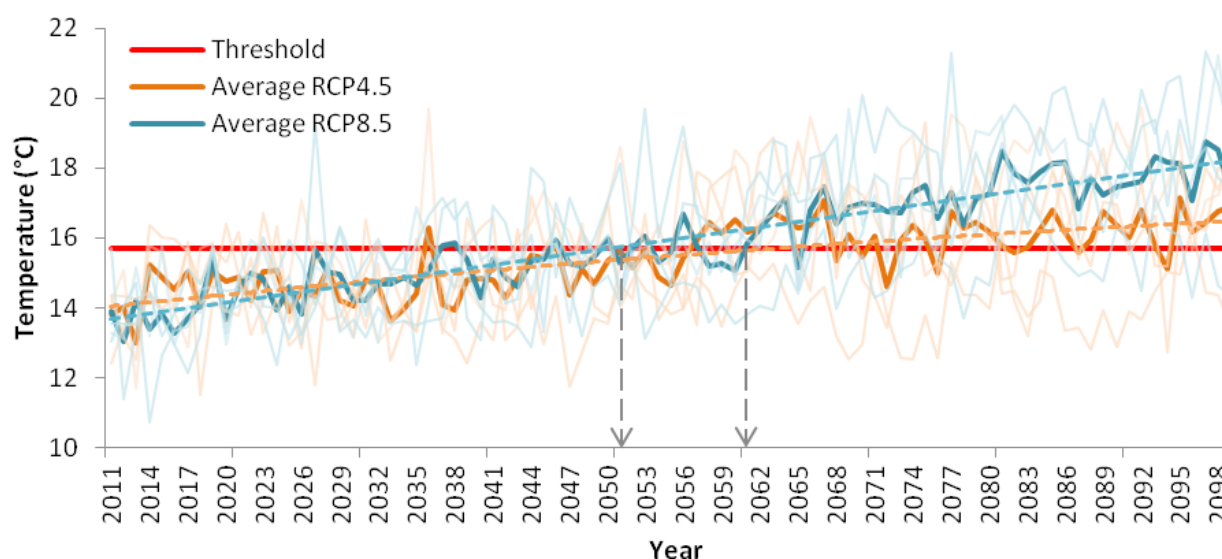
Table 3.4 summarises the thresholds, which were used in the analysis and when these thresholds would be exceeded during the different growth stages according to the HI-AWARE climate scenarios.

Table 3.4: Thresholds used and ATP assessment for wheat production in Punjab

Threshold ATP\Growth stage	Sowing	Vernalisation	Terminal spikelet	Anthesis	Grain filling
Temperature threshold T_{max}	> 32.7	> 15.7	>20.0	> 31.0	> 35.4
Period [Days of year]	273 – 349	1 – 31	32 – 75	76 – 106	107 – 137
Threshold exceeded N Punjab	NN	few events	NN - few events	NN	NN
Threshold exceeded S Punjab	NN	2050-2060	2 050-2070	End century	>2090
Lethal limit	47.5				
Threshold exceeded N Punjab	Few exceedances by the end of the century				
Threshold exceeded S Punjab	Regular exceedance after 2050, however very dependent on model and scenario used in the analysis				
Threshold exceeded HKH region	North and Central India are expected to have similar temperature extremes as projected for Southern Punjab				
Precipitation threshold	# days rain (>20 mm)		# days heavy rains (> 20 mm)		
Period	October		February – March		
Threshold exceeded	Events occur, no trend in the number of events. High variability between years. The variability in the number of events per year increases especially in North Punjab				

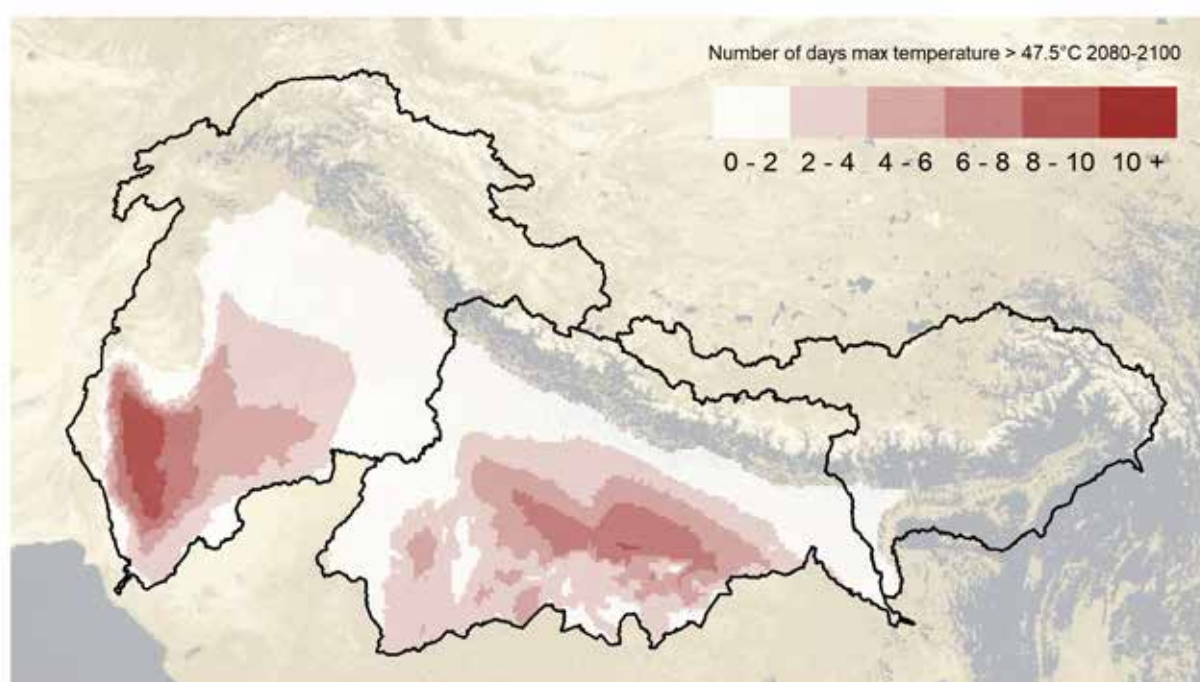
The analysis suggests that wheat production in North Punjab is only towards the end of the century projected to be limited by exceedances of cardinal temperatures and temperature extremes. Variability in yield may increase due to low rains after sowing and heavy rains during harvesting. The situation in South Punjab looks different. Here the vernalisation and terminal spikelet stages seem to be the most critical. By mid-century the average temperature is expected to have exceeded the threshold. The threshold for vernalisation is the first to be exceeded (see Figure 3.1). This does not mean that yields become zero, but adverse effects do occur above these temperature thresholds and yields are affected, the extent to which will also depend on the variety (cf. Morgan et al., 2008).

Figure 3.1: Average temperature in South Punjab during vernalisation stage of wheat for different climate models (individual models: thin line, averages: thick line) and climate scenarios (red: RCP 4.5 and blue: RCP 8.5).



Looking at the lethal temperature threshold (the tipping point for wheat production), the results are inconclusive with large differences between climate models and scenarios. In case of climate scenario RCP 4.5 few exceedances occur in the course of the century. With the RCP 8.5 scenario it seems likely that near the end of the century the lethal temperature threshold is exceeded multiple times, annually. This would mean that the wheat plant will be damaged beyond recovery and will not produce. Not only South Punjab is affected by this increase in extreme daily temperatures, North and Central India are projected to experience this temperature stress towards 2100 (see Figure 3.2).

Figure 3.2: Average number of days with temperature above lethal limit threshold 2080-2100 (three model average, climate scenario RCP 8.5).



Summarising, food security in the Indus Basin has not been approximated in terms of a specific yield target. Therefore it is difficult to assess turning points with respect to government food security policy targets. We focussed on wheat production as a key staple and government concern. The question is whether a wheat-based food security policy is sustainable under climate change.

Our analysis of turning points so far shows that after 2050 climate change is projected to put wheat-based food security in the Indus basin at risk, since climate change suppresses wheat yields in large parts of Punjab. Without measures, by 2100 most of Pakistan is found to be affected, as well as parts of India.

Already, few rains after sowing and early rains during harvesting challenge winter wheat production. Looking towards the future we find that precipitation trends are not so clear; instead, the real concern stems from high temperatures in winter, hindering vernalisation.

South Punjab will be hit first and by 2050, years with reduced yields become frequent. By the end of the century also North Punjab can be expected to suffer; cf. Hussain and Mudasser's (2007) comparative analysis of wheat production in the Swat district (960 metres above sea level) and the Chitral district (on average 1,500 metres above sea level). Thus, relying on production in northern higher areas may help, but the current varieties may also run into climate limitations. This gives us 30-50 years to rethink wheat-based food security. Supporting alternative varieties and crops will become essential rather than compensating for losses in existing crops.

Note: the assessment of turning points may also be used to assess where changes in climate offer opportunities for the cultivation of new crops. A crop farmers in Pakistan are interested in, is olive, and several farmers are already making the shift towards cultivating olives. The conditions for olives were found to be good on the short to medium term, with new areas becoming suitable. However, the results are inconclusive regarding the suitability of olives towards the end of the century. Also, social and cultural concerns, competing claims over water, as well as governance issues, such as financial incentives, would have to be considered. These factors codetermine when recurring yield reductions would make wheat production unsustainable for farmers and alternatives are adopted.

3.2. Example 2: Assessment of Turning Points for Heat Stress

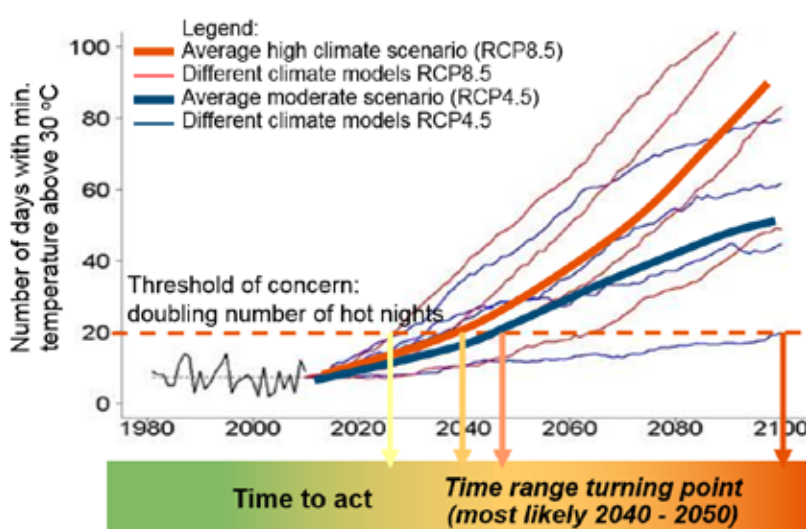
The following short example is building on the work in RC2 and RC3 on heat stress.

Threshold: heat stress. We are interested in the health implications of heat stress.

Climate conditions: We mark a doubling of the number of hot nights as the threshold of interest (that is, nights in which the temperature stays higher than 30 degrees Centigrade).

Figure 3.3 assesses the number of hot nights projected by different climate models and scenarios. It shows that all projections suggest an upward trend, yet there is great uncertainty in the projections. The turning point is increasingly likely after 2030. In each of the projections the turning point is reached before the end of the century.

Figure 3.3: Example of turning point assessment for heat stress in Faisalabad, Pakistan



3.3. Example 3: Turning Points for Salmon Restoration Programmes, River Rhine

3.3.1. Social-political thresholds of interest

This case study investigated whether climate change could render untenable the policy to reintroduce salmon in the River Rhine (Bölscher et al., 2013). So, the case offers an adaptation turning point assessment for nature conservation policies.

Atlantic salmon was a common anadromous fish species in the Rhine that went extinct in the 1950s. Reintroduction started when the Rhine state governments accepted the Rhine Action Plan in 1987 (ICPR, 2009). Not only the Rhine national governments, but also regional authorities and NGOs are involved in the implementation. Bringing back the salmon is, therefore, not only an abstract water policy objective, but also an stimulation for many small-scale public and private initiatives along the Rhine streams and rivers (Buijse et al., 2002).

In 2001 the Rhine ministers adopted the 'Rhine 2020 – Programme on the sustainable development of the Rhine' (ICPR, 2001), which resulted in an action plan 'Rhine Salmon 2020' (ICPR, 2004). The main objective is the re-establishment of a self-sustaining, wild, Atlantic salmon population in the Rhine by 2020. As such it contributes to policy efforts to enable fish migration in the Rhine river basin and improve habitat conditions. In total, investments of €528 million for the adaptation of infrastructure (weirs, dams) and habitat restoration are planned until 2015. These programmes do not consider climate change. Actors are concerned about potential implications that climate change may have for policy success.

3.3.2. Climatic conditions for reaching thresholds

The most direct link between climate change and the success of the reintroduction programme is through the water temperature, which affects the propagation and spawning migration of the salmon (Bölscher et al., 2013). In theory, water discharge also influences migration, but in larger rivers, like the Rhine, it is not physically limiting (Todd et al., 2010).

Literature reports diverse thermal boundary conditions for the Atlantic salmon (for an overview see Table 2 in Bölscher et al., (2013)). Two boundary conditions have been identified from literature and expert interviews as particularly relevant to threatening salmon reintroduction: 1) Short but regularly occurring periods of heat with potentially lethal temperatures between 25 °C and 33 °C and 2) Long periods of mean water temperatures higher than 23 °C. In the latter case the time window for salmon to migrate from the sea into the Rhine may become too small.

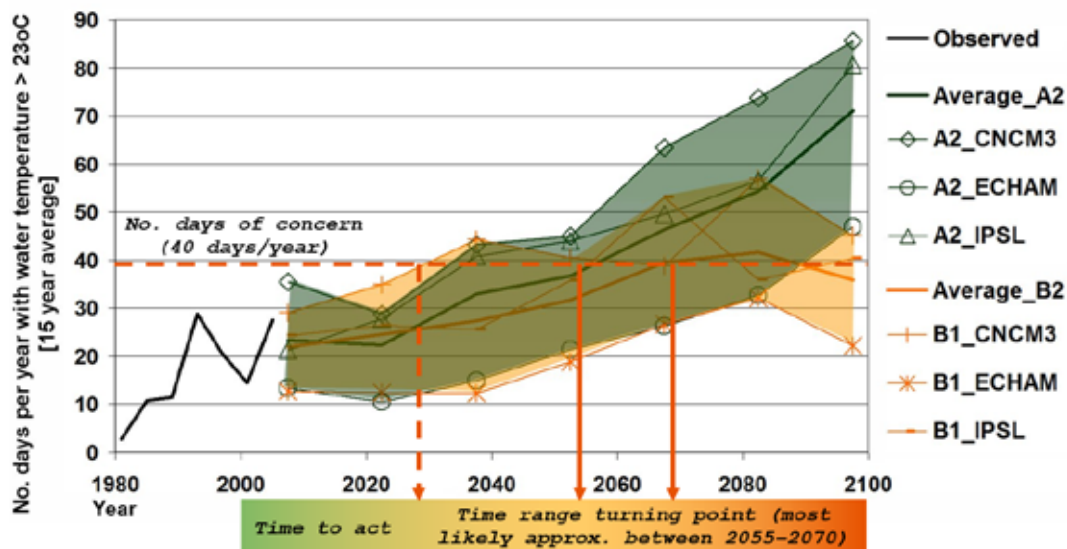
Following the inventory of critical climate conditions, it has been established that a water temperature of 23 °C is a meaningful threshold value for the success of the reintroduction programme. However, it is still largely unknown how migration depends on the duration and timing of the period that water temperatures are above this threshold. That means the finiteness of policy success may only be approximated. In short, the likeliness of an adaptation turning point increases with the number of days that the water temperature is above 23 °C.

3.3.3 Adaptation turning points and lessons

To identify turning points associated with exposure to periods with mean water temperature above 23 °C, model results were taken from Van Vliet et al. (2013). Figure 3.4 shows a distinct increase in the number of days at Lobith, where the Rhine enters the Netherlands from Germany. The figure indicates the adaptation turning point, assuming that the reintroduction of salmon becomes problematic at a doubling of the number of days with temperatures above 23 °C from the current 20 days to 40. The timing of a turning point for a salmon policy remains uncertain due to climate variability inter alia as much as local water temperature differences and the adaptive capacity of the Atlantic salmon. These uncertainties, nevertheless, may direct future research.

We can observe that the adaptation turning point is projected to fall beyond the horizon of the current action plan Salmon 2020. Although Salmon 2020 is presented as a plan for the 21st century, this raises the question as to what extent actors would want to act on the turning point assessment. Even so, further lessons emerge from the discussion of potential adaptation options.

Figure 3.4: Adaptation turning point for the reintroduction of salmon



The figure shows the number of days of daily water temperatures exceeding 23 °C at Lobith for 1980-2099 (15 year average). Thin lines show individual results for three climate models (CNCM3, ECHAM, and IPSL), coloured polygons show the range in results across the models, and the thick line shows the average result from the models for the SRES A2 and B1 climate change scenario (2000-2099) (data source: Van Vliet et al. (2013)).

On a European and national scale, temperature standards for cooling water discharge have already been defined that should safeguard the ecological status of the river. Another notable adaptation option mentioned by stakeholders is to change objectives. For instance, to give up reintroduction of the salmon and decide to take other species as an indicator of ecological improvement. The sturgeon was mentioned as an example. Policy success or failure in the end depends on the efforts of a range of organisations, operating on different scales in the Rhine River Basin.

3.4. Other Case Examples

Climate-Related Vulnerabilities of African Smallholder Farming

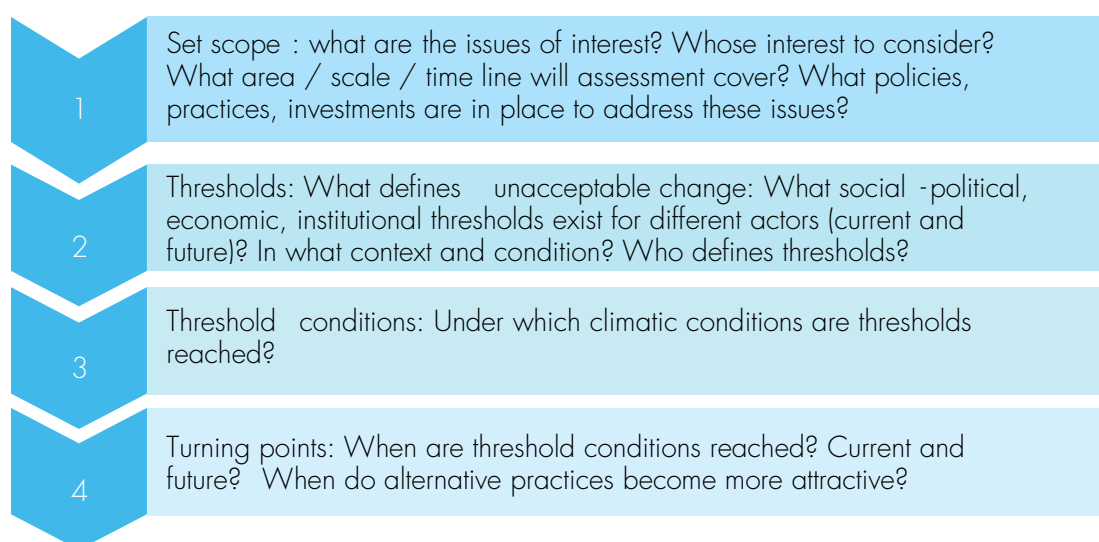
Smallholders in Africa are vulnerable not just to climate but also to a myriad of stressors that increase both their exposure and sensitivity. In Ghana, bushfires and forest clearance in the 1980s forced communities to abandon the once lucrative business of cocoa farming. Instead, communities resorted to maize production. Attempts to re-establish cocoa farms after the bush fires were unsuccessful, mostly because of the decline in soil fertility and rainfall as also high rates of deforestation. Adaptation options to help improve soil fertility and boost maize production included planting of early maturing crops, different crop varieties, and planting of drought tolerant crops. Notably, it also included changing of planting times, construction of a fire control lines, and intercropping. The Adaptation Turning Points theory could be explored in the context of the timeliness of actions, their sustainability over time, and who benefits when and how?

4. HI-AWARE Proposed Methodology

In the previous sections we brought to light why it is critical to understand how existing social-technical, behavioural, and institutional norms as well as development goals are being undermined by climate change and, why this can form the contextual basis for action.

Figure 4.1 outlines the broad steps introduced in the previous sections. It also serves as a proposed framework for guiding the turning point assessments in HI-AWARE.

Figure 4.1: Steps in adaptation turning point assessment



Determining a threshold is context-specific and complex, for it involves multiple climatic conditions or stresses and multiple resources impacted by climatic conditions. The threshold varies according to climatic conditions that are driven by social-political, economic, institutional, and other factors. There are examples in real world situation wherein policies have performed well, whereas in another context they have failed or have resulted in maladaptation.

Given the above set of steps and research questions, and depending on the questions being answered and the scales of operation, there is a multiplicity of ways in which a turning points methodology might evolve. These could be top-down ways of carrying out the assessments where a thorough review of policies and plans, and an understanding of societies risk acceptance would help define the thresholds for the ATPs. This methodology would require an understanding of changes in the climate, of various policies and plans, and how the goals of these plans are impacted by or depend on different climate conditions. In addition, participatory modes using scenario development exercises with various stakeholders could be used for the assessment of ATPs. This would be a bottom-up mode of discussion. However, there could be challenges related to stakeholder exposure and the understanding of risk and response timings.

The assessment may also choose to consider the concept of adaptive capacities in certain cases, given that as adaptive capacities would change, so would the turning points and the timing for adaptation. It is now widely recognised that activities necessary to enhance adaptive capacity can also promote sustainable development and

vice-versa (Smit and Wandel 2006; IPCC, 2014). Building adaptive capacity is both a function of development and of improving risk-management (IPCC, 2014). In this context, it becomes important to understand the relative importance of different kinds of interventions (climate and not-climate related) in building adaptive capacity including actions that address development. These could be social-developmental policies like poverty alleviation, reducing risks related to famine and food insecurity, enabling/implementing public health, and mass literacy programmes). They could also involve conventional climate-impact risk management (like alert systems, disaster relief, crop insurance, and climate forecasts). These interventions would need to be understood in a wider context, because they would then frame when thresholds would be reached in the future. The latter is important information to be used in developing adaptation pathways (HI-AWARE Research Component 5).

Within each assessment, the tools may also differ depending on information, model availability, and the context in which the turning points are being defined. Table 4 1 provides an overview of methods and tools, which can be used in assessing adaptation turning points. Method selection in case studies is to be guided by the data and tools available and necessary to perform the assessment. This will result in the use of different methods and tools, depending on the case. Important factors will be the availability of suitable (transient) scenario projections, impact models, literature, and actor and expert opinion. The selection of tools and available information will have a bearing on the assessment, which will have to be discussed as part of any assessment of adaptation turning points.

Table 4.1: Methods and tools, which can be used in case studies to assess adaptation turning points

Assessment Step	Potential methods and tools ^{*)}
1. Set scope / Select issue	Team discussion, interviews, literature review of existing vulnerability assessments, policy review
2. Identify social-cultural-political thresholds	Review of policy documents, actor interviews, workshop / focus group. For HI-AWARE: review of critical moment assessment and drivers of vulnerability, see also Section 2.3
3. Identify climatic conditions for reaching thresholds	Literature review to identify threshold values, statistical regression, expert consultation, transient-impact model simulation
4. Identify when turning points are reached	Analysis of multi-transient scenario model runs in combination with literature review of threshold sensitivity, extrapolation of statistical regression model, risk assessments based on expert opinion and harmonisation of existing literature. Participatory scenario development exercises

*) As part of HI-AWARE tools will be delivered, from which analysts can make their selections

Table 4 2 offers examples of potentially relevant turning points in the context of HI-AWARE. A more comprehensive review of potentially relevant thresholds and turning points is future work.

Table 4.2: Examples of possible turning point assessments in HI-AWARE

Step	Basin	National / regions / geographic zones	Regional	Transboundary
1. Setting scope / Issue	Health issues related to heat stress	Food security Development goals	Migration	Transboundary water treaties
2. Social-political thresholds	Work productivity reduction Well-being (mortality / heat stress related illnesses)	Yield of staple and selected cash crops Crop and region-specific thresholds Relative suitability of new varieties	Loss of land and bank erosion (Gandaki, Teesta)	Discharge threshold in transboundary water agreements ^{**)}

3. Method to identify threshold climatic conditions and examples of thresholds	Literature review Interviews combined with local observations. E.g., 5 consecutive nights over 28°C ^{*)}	Literature review Crop model runs E.g. temperature threshold for winter wheat production (Indus) Snowfall patterns for fruit production (Muree-Indus, Upper Ganga, Gandaki Teesta) Onset monsoon, especially in triple crop systems Flood duration Temperature threshold new vegetables / bitter and sweet buckwheat (Gandaki), olive, grapes (Indus)	Hydrological models, expert opinion, stakeholder interviews, observations	Hydrological modelling, taking into account climatic factors and other scenario parameters
4. Methods and data for identifying turning points	Downscaled HI-AWARE scenarios. Output: location specific or spatially explicit ^{*)}	Combination with HI-AWARE scenarios. Note: region (crop) specific	Modelling and statistical extrapolation	Output: location specific time interval

^{*)} Maps have been created for the number of nights above 28° and 30 °C. This threshold could be refined (See Figure 3.3).

^{**)} This would hold for basins where agreements and policies exist. As such, the methods presume when there is no agreement, there will be no imperative to act upon. In those cases it may also be particularly challenging to find a commitment to work on climate change adaptation. We also realise that hydrological data are politicised and an assessment might be particularly sensitive.



5. Discussion: Points of Attention for the Assessment

5.1. Social-political Thresholds of Interest

Starting the assessment from an existing policy process and practices facilitates the engagement of actors and provides a well-communicable starting point for framing the assessment. At the same time, a comprehensive analysis of climate change impacts and possible adaptation turning points requires putting this policy process into a wider perspective, including an exploration of the various ways stakeholders frame the issues to be addressed as well as future plans. It may also require understanding the climate risks and current adaptive capacities of various stakeholders and how these affect the turning points.

Policy goals are not always clearly defined, especially with respect to the potential impacts of climate change on ecosystems. Turning points for engineered systems (like dikes, dams, and gates) are relatively well delimited by norms and standards. Definition of such norms and targets for natural or social systems seems more complicated and has been less attempted in policy making. Also, there are complexities arising from how thresholds could be perceived differently by different stakeholders and how they would be dependent on priorities of stakeholders at their particular levels at a particular time.

The identification of thresholds requires insight and creativity from the analyst to select issues and policies that are sufficiently well defined for further analysis. Often more general policy objectives have to be simplified. For example, an analysis of food security may be meaningfully approximated by focussing on the production of major staple crops (cf. Section 3.1). At the same time, such focus could over-simplify adaptation needs.

5.2. Climatic Conditions for Reaching Thresholds

Although climate scenarios and impacts are documented in HI-AWARE, detailed knowledge linking social political thresholds and social ecological system behaviour under changed climate conditions may be lacking. This may make it difficult to assess turning points, even when climate data are available.

Another complexity arises when climate scenarios and the uncertainty bandwidth are understood, but thresholds in social political and cultural respects are expressed qualitatively.

5.3. Adaptation Turning Points

The occurrence of turning points is often found to depend on a complex of factors and scales. A statement about whether or not an adaptation turning point will be reached, will always have to indicate clearly which set of policy objectives and societal preferences it refers to and what drivers of change are considered. The more stakeholder preferences are related to climate change indirectly, the more difficult determination of adaptation turning points will be.

On the other hand, exposing existing uncertainties and ambiguities may also be an asset, because it may well foretell any resistance when trying to execute adaptation plans. If policy agreements and/or policy objectives are absent, this may indicate two things. Either experimenting, monitoring, and investing in 'general resilience' (Walker et al., 2009) are an appropriate and feasible response, or, indeed, there is no consent to a planned response. The latter may also be the case if policy failure is projected to fall beyond the planning and responsibility horizon of actors.

Finally, decision support for sustainability under climate change has the difficulty of dealing with (deep) uncertainty (Hallegatte et al., 2012). This arises not only from uncertainty in scientific models or incomplete understanding of particular natural or societal processes, but also from the presence of multiple valid, and sometimes conflicting, ways of framing a problem. We want to test in HI-AWARE whether the assessment of adaptation turning points can produce information that is legitimate, salient, and credible for decision-making. Adaptation governance has an important role to play in the definition and renegotiation of rules and policy objectives untenable under climate change. Credibility may result from the elicited social political preferences, which the assessments combines with impact projections to assess when and how likely it is that unacceptable conditions occur. It is also aided by the intensified efforts of researchers and policy-makers to coproduce knowledge that includes values and criteria from both stakeholders and scientists (cf. Cash et al., 2006; Hanger et al., 2013).

6. Conclusion

In this framework document we examine why it is important to understand how existing social technical, behavioural, and institutional norms as well as development goals are being undermined by climate change and how this can form the contextual basis for action. To satisfy the information needs of decision-makers, adaptation assessments can be inverted - starting from an adaptation problem in its decision context rather than from climate projections (cf. Reeder and Ranger, 2011). This differs from the more typical practice of impact studies driving adaptation studies. Instead we look at the issues from a decision-making and development context and first ask what policies, plans, and practices are of interest to actors, and then look at the climate science (climate scenario context) to understand until when these policies and practices may sustain.

The framework document focussed on the specific situation where a decisive threshold in the performance of policies and practices is reached due to climate change. This includes the situation in which new practices have become more attractive than current. We called this situation an adaptation turning point.

We showed early examples of an adaptation turning point assessment for HI-AWARE. The methodology will be tested in the upcoming work and serve as an input to developing adaptation pathways in HI-AWARE (subject of a separate HI-AWARE Working Paper). Assessment of adaptation turning points will encourage critically looking at what climate change scenarios can tell about the likeliness of impacts and vulnerabilities of specific concern. Furthermore, in times of uncertainty, flexible policies and measures may delay a decisive climate impact. Thus, larger structural investments for adaptation could be planned for when more information is available about the extent of climate change and development ambitions.

Ultimately, we hope our work provides a starting point for a dialogue between science and policy about why people care, how much change people can handle and when there is an imperative to act, so that correction can be made timely and losses or damages may be prevented.



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8. Annexures

Annex A: Definitions from literature of Tipping Points, and Thresholds

A.1 Tipping Point

Table 8.1: Overview of definitions of tipping point by various authors

Definitions of tipping point	Remarks	Reference
The term 'tipping point' commonly refers to a critical threshold at which a tiny perturbation can qualitatively alter the state or development of a system. Here we introduce the term 'tipping element' to describe large-scale components of the earth system that may pass a tipping point.	Offers a formal definition, introducing the term 'tipping element' to describe subsystems of the earth system that are at least sub-continental in scale and can be switched-under certain circumstances- into a qualitatively different state by small perturbations. The tipping point is the corresponding critical point in forcing, and a feature of the system at which the future state of the system is qualitatively altered.	(Lenton et al., 2008)
The term tipping point is introduced in climate change research literature to indicate the point where a system change initiated by an external forcing no longer requires the external forcing to sustain the new pattern of change. Also explored for political economic tipping points / (major changes that cannot be easily undone but, instead, create a new stable system)		(Lindsay and Zhang, 2005; Russill and Nyssa, 2009) in (Kwadijk et al., 2010; Huntington et al., 2012)
A tipping point is defined as a situation in which an ecosystem experiences a shift to a new state, with significant changes to biodiversity and the services to people it underpins, on a regional or global scale. Tipping points also have at least one of the following characteristics: <ul style="list-style-type: none"> • The change becomes self-perpetuating through so-called positive feedbacks. For example, deforestation reduces regional rainfall, which increases fire-risk, which causes forest dieback and further drying. • There is a threshold beyond which an abrupt shift of ecological states occurs, although the threshold point can rarely be predicted with precision. • The changes are long-lasting and hard to reverse. • There is a significant time lag between the pressures driving the change and the appearance of impacts, creating great difficulties in ecological management. 	Includes icons for different characteristics. In this definition, tipping points are very similar to regime shifts in the resilience alliance definition.	(Secretariat of the Convention on Biological Diversity, 2010)

The moment of critical mass, the threshold, the boiling point.	Popular book that seeks to explain the 'mysterious' sociological changes that mark everyday life. Looking at changes like epidemics, it describes the 'three rules of epidemics' (or three 'agents of change') in tipping points of epidemics: The Law of the Few [connectors, mavens, salesmen], The Stickiness Factor, The Power of Context.	(Gladwell, 2000)
Suggests to define tipping points as the point or threshold at which small quantitative changes in the system trigger a non-linear change process that is driven by system-internal feedback mechanisms and inevitably leads to a qualitatively different state of the system, which is often irreversible.	Paper review literature on tipping points to create the foundation for a discussion within the SES research community about the appropriate use of the term, especially the relatively novel term 'social tipping point.'	(Milkoreit et al., 2018)

Table 8.2: Example of contributions to the concept of tipping point from various disciplines

Disciplines	Typical contribution / insights	Reference
Sustainability science	Links to adaptability. Human environment systems are complex and adaptive, but there are limits to their adaptability. One result is the apparent ubiquity of threshold or 'tipping point' behaviours in such systems.	(Levin and Clark, 2010)

A.2 Turning Point

Table 8.3: Overview of definitions of turning point by various authors

Definitions of turning point	Remarks	Reference
Turning point may refer to: A point at which the derivative changes sign. See stationary point, in mathematics A climax (narrative), in narrative structure A discrien, one of the two marked points on a cursus or classical-period race-track	(mathematics) A turning point may be either a local maximum or a minimum point. If the function is smooth, then the turning point must be a stationary point. However, not all stationary points are turning points. (note: the image of the curve with local max/min is often used as illustration of a tipping point). The turning point of a narrative work is its point of highest tension or drama or when the action starts in which the solution is given	wikipedia
Defines an adaptation turning point as a situation in which a social political threshold is reached, due to climate change induced changes in the biophysical system. Social political thresholds here include formal policy objectives as well as informal societal preferences, stakes and interests, such as willingness to invest and protection of cultural identity.	The specific situation where, due to climate change, current governance agreements will no longer be able to meet their objectives and alternative strategies have to be considered. If such a situation is thinkable, climate change becomes particularly relevant to decision-makers.	(Werners et al., 2015)
Signifies choice / a transition to be made / fundamental change	Factors are within human control and therefore environmental and economic catastrophes are preventable or avoidable	(Mesarovic and Pestel, 1974)

Table 8.4: Overview of contributions to the concept of turning point from various disciplines

Disciplines	Typical contribution / insights	References
	Much less formalized as 'tipping point'. Used frequently in paper (titles) without being defined or specifically addressed in subsequent text. Mostly it signifies a change / transition in a plot, an insight, or an opinion (e.g., a turning point in a war).	(Mesarovic and Pestel, 1974; Shmelev and Popov, 1990)
Risk assessment	Links to classification of value systems in cultural theory	(Stirling, 1998)
Economics	Notion of an (environmental) Kuznets curve (EKC). The EKC hypothesizes that the relationship between income and the use of natural resources and/or the emission of wastes has an inverted U-shape. According to this specification, at relatively low levels of income, the use of natural resources and/or the emission of wastes increase/s with income. Beyond some turning point, the use of natural resources and/or emission of wastes decline/s with income. A turning point here implies that economic growth can improve both living standards and environmental quality. Business cycle turning points: the major turning points in each of the countries' history have been associated with well-known global shocks. Includes turning point analysis	(Richmond and Kaufmann, 2006) (Duffy, 1944; Altug and Bildirici, 2010)

Climate-econ	In line with the above: Concern about climate change has prompted several analysts to estimate the relationship between income and energy consumption and carbon emissions using a quadratic specification (Bruyn et al., 1998; Schmalensee et al., 1998; Herrick, P. (2008) Turning points of closeness in the sibling relationship. Baylor University, Waco, USA. The results generally are consistent with the notion that the relationship between income and energy use and/or carbon emissions contains a turning point. (But this turning point often is well beyond the largest value for income in the regression sample.)	(Richmond and Kaufmann, 2006) (note: concludes that policy makers should not depend on turning points in relationship between income and energy use or carbon emissions to reduce either)
Social science	Turning point analysis. Research method to study (family) relationships. Studies conducted by examining perceptions of events that cause a relationship to change dramatically or shift directions in important ways	(Baxter and Bullis, 1986; Bullis and Bach, 1989)
Social cognition theory	Argues we interpret and predict other peoples' behaviour by looking at past events or turning points within the relationship. Yet turning points are an individual-level phenomenon, because two individuals may interpret the same event differently. Turing points are also self-reflective because individuals must think about and interpret the event with their own cognitive abilities	Herrick, 2008
Traffic	Traffic sign / U- turn	

A.3. Threshold

Table 8.5: Overview of definitions of turning point by various authors

Definitions of threshold	Remarks	References
A threshold is defined as a point between alternate regimes in ecological or social ecological systems.	When a threshold along a controlling variable in a system is passed, the nature and extent of feedbacks change, such that there is a change in the direction in which the system moves. A shift occurs when internal processes of the system (rates of birth, mortality, growth, consumption, decomposition, leaching, etc.) have changed such that the variables defining the state of the system begin to change in a different direction, towards a different attractor. In some cases, crossing the threshold brings about a sudden, large and dramatic change in the responding variables, while in other cases the response in the state variables is continuous and more gradual. Includes a diagram of regime shift categories, illustrating all of the possible interactions between social (S) and ecological (E) systems in relation to threshold shifts.	(Resilience Alliance and Santa Fe Institute, 2004)
A breakpoint between two regimes of a system		(Walker and Meyers, 2004)
[implicit:] Quantitative thresholds: value beyond which the system is likely to switch to an undesirable state / reach a tipping point / there is a high risk of dramatic biodiversity loss and accompanying degradation of a broad range of ecosystem services	Characteristic of tipping points. Thresholds, amplifying feedbacks and time-lag effects lead to 'tipping points'. They are widespread and make the impacts of global change on biodiversity hard to predict, difficult to control once they begin, and slow and expensive to reverse once they have occurred.	(Secretariat of the Convention on Biological Diversity, 2010)
A minimum level of threat or concern for people to start contemplating the benefits of possible actions and ruminate on their competence to perform them actually (Schwarzer, 1992, p. 235).	Adaptation appraisal, by contrast, comes after the risk perception process, and only starts if a specific threshold of threat appraisal is exceeded (Grothmann and Patt, 2005).	

Table 8.6: Overview of contributions to the concept of threshold from various disciplines

Disciplines	Typical contribution / insights	References
Mathematics	Threshold described as 'saddle-node' or 'fold' bifurcation	
Medical sciences		
Biodiversity / ecology	<p>Some concrete thresholds. Yet, there is a lack of understanding of key thresholds for social and ecological systems. Many of these thresholds are only recognised and understood after they have been passed.</p> <p>Functional thresholds (in evolutionary progress).</p> <p>Water clarity often seems to be hardly affected by increased nutrient concentrations until a critical threshold is passed, at which the lake shifts abruptly from clear to turbid (Scheffer et al., 2001).</p>	(Secretariat of the Convention on Biological Diversity, 2010)
Resilience alliance	<p>Database of thresholds & regime shifts http://www.resalliance.org/183.php</p> <p>Alternate regimes are separated by thresholds that are marked by levels of controlling (often slowly changing) variables where there is a change in feedbacks. It is the changed feedbacks that lead to the changes in function and therefore structure. Linked to adaptability: the ability to alter the shape of the basins, that is move the positions of thresholds or <..></p> <p>Measurements and predictions of ecological thresholds have broad-tailed and changeable probability distributions. Often, passive monitoring-and-control systems are unable to learn as fast as the thresholds move. In such situations, prediction and optimisation have little use, and will have to be replaced by risk spreading and insurance strategies to maintain options and sustain social ecological systems in the face of surprise, unpredictability, and complexity (Folke et al., 2002)</p>	http://www.resalliance.org/564.php
Sustainability science	Links to critical load, carrying capacity	
Climate adaptation	Critical limits as to how far analogues of past and present adaptation experiences are relevant for adaptation to future climate change as a result of inter-related phenomena. There may well be nonlinearities, or critical thresholds, in the climate change impact or response function of natural and social systems.	(Adger et al., 2003)
Contingency planning	'Contingency planning' is at heart just a slightly more complex form of 'front-end' decision-making, modified only by a relatively narrow and inflexible range for 'back-end' adjustments-within parameters specified at the front end, when certain triggering thresholds (also specified at the front end) are met. Contingency planning, in short, offers little opportunity for learning and even less for rigorous scientific experimentation; ordinarily these are much more open-textured undertakings.	Cited in (Karkkainen 2005)

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