Tipping Points in Ecological Systems

05 – 07 March 2012 (Berlin, Germany)

Workshop report

Elisabeth Marquard & Cornelia Krug

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Dr. Elisabeth Marquard
Netzwerk-Forum zur Biodiversitätsforschung Deutschland
Helmholtz Centre for Environmental Research GmbH – UFZ
Department of Conservation Biology
Permoserstraße 15
04318 Leipzig
E-mail: lisa.marquard@ufz.de

Dr. Cornelia Krug
DIVERSITAS Head Office
Muséum National d'Histoire Naturelle (MNHN)
Maison Buffon
57 rue Cuvier - CP 41
75231 Paris Cedex 05
France
E-mail: cornelia@diversitas-international.org

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Introduction

An increasing number of ecosystems are expected to undergo abrupt and drastic transformations if the over-use of resources and other anthropogenic pressures on biodiversity prevail. Such non-linear processes that involve a radical change from one ecosystem state to another and possibly dramatic negative consequences for biodiversity, ecosystem services and human well-being have been referred to as catastrophic transitions or regime shifts that occur when ecological systems pass critical thresholds or “tipping points”.

Prominent historic examples for the transgression of ecological tipping points include lake eutrophication, desertification, species extinctions or the collapse of over-harvested populations. Such processes have been documented for marine ecosystems, forests, rangelands and agro-ecosystems. The Amazon forest, the Arctic permafrost and many coral reefs are among those ecosystems of global importance that are in acute danger to pass ecological tipping points in the near future (e.g. Leadley et al. 2010, Secretariat of the Convention on Biological Diversity 2010, Hirota et al. 2011). At the local scale, many more ecosystems may be heading toward a catastrophic shift (e.g. Conley et al. 2009, Laurance et al. 2011).

Workshop

The accumulating evidence for impending radical changes in various ecosystems and their adverse effects on human societies has resulted in an increased scientific interest in non-linear ecosystem dynamics. In particular, it seems highly desirable to identify early-warning signals that may serve as indicators for impending regime shifts and allow for counter actions when there is still a chance to halt the process. Furthermore, conservation and management strategies are needed that incorporate relevant new findings about tipping point dynamics and that have the potential to effectively prevent the occurrence of dramatic ecosystem changes.

During a 3-days-expert meeting organized by Network-Forum for Biodiversity Research Germany (NeFo) and DIVERSITAS International, ecologists from nine different countries (representing Europe, USA and New Zealand) discussed the occurrence, prediction and mitigation of "tipping points" in ecosystems. Issues covered by the workshop included:

- Phenomena that may serve as indicators for imminent tipping points;
- Options / requirements for monitoring these indicators;
- Implications of tipping point dynamics for management and restoration;
- Potential relevance of tipping points for the program of work of IPBES.

The aims of the workshop were

- to bring together scientists of different ecological disciplines and to offer them a forum for exchanging their knowledge and ideas on ecological tipping points;
- to develop ideas for follow-up activities or workshop products on ecological tipping points (such as a joint publication).

Workshop program

Day	Time	Program / Format	Keynotes	Who?
Mon, 05 March	12:30 – 13:00	Arrival / registration		
	13:00 – 13:20	Welcome / introduction		DIVERSITAS / NeFo
	13:20-13:30	Introduction of keynotes and participants		All participants
	13:30 – 14:30	Opening Keynote	Tipping points, thresholds & Co.: exploring the conceptual territory and some critical questions Kurt Jax (UFZ, Leipzig)	
	14:30 – 15:00	Coffee break		
	15:00 – 16:00	Keynote 2	Evidence for impending tipping points and their expected impacts on biodiversity and human well-being Paul Leadley (Université Paris-Sud)	
	16:00 – 17:00	Keynote 3	Early warning indicators of critical transitions Vasilis Dakos (Wageningen University)	
	17:15 – 18:45	Guided tour (in English)	"Hackesche Höfe & Scheunenviertel"	
	19:00	Dinner		Restaurant Honigmond
Tue, 06 March	09:00-09:10	Welcome to day 2		
	09:10 – 10:10	Keynote 4	Nutrients as drivers of tipping points in aquatic ecosystems Daniel Conley (Lund University)	
	10:10 – 10:45	Coffee break		
	10:45 – 11:45	Keynote 5	Empirical tests of indicators: lessons learnt for theory and practice Judi Hewitt (NIWA, New Zealand)	
	11:45 – 12:45	Keynote 6	How can we manage tipping points in rangelands? Brandon Bestelmeyer (USDA-ARS, New Mexico State University)	
	12:45 – 14:00	Lunch break		
	14:00 – 14:30	Outlook talk	Relevance for IPBES Cornelia Krug (DIVERSITAS, Université Paris-Sud)	
	14:30 – 15:30	Conclusions from talks Integration of the various aspects discussed		
	15:30 – 16:00	Coffee break		
	16:00 – 18:00	Synthesis of workshop Preparation of workshop document		
	19:00	Dinner	Get-together with the participants of the vulnerability workshop	At "Nola's" Veteranenstraße 9
Wed, 07 March	09:00 – 09:10	Welcome and introduction to the "Bridging session*"		GfÖ AK Theorie / NeFo / DIVERSITAS

	09:10 – 09:30	Introduction round		All participants
	09:30 – 10:00		DIVERSITAS & bioDISCOVERY Cornelia Krug (DIVERSITAS, Université Paris-Sud)	
	10:00 – 10:30		Introduction of “vulnerability & thresholds” Dietmar Kraft (GfÖ AK Theorie, University of Oldenburg)	
	10:30 – 11:00	Coffee break		
	11:00 – 11:30		“Synthesis” of tipping points workshop Kurt Jax (UFZ, Leipzig)	
	11:30 – 12:00	Plenary discussion		All participants
	12:00 – 12:30	Talk	Are there diversity thresholds for cyanobacterial blooms? Robert Ptacnik (ICBM, University of Oldenburg)	
	12:30 – 14:00	Lunch break / End of tipping points workshop		

* The NeFo/DIVERSITAS Workshop on Tipping Points (05-07 March) will be followed by the workshop “Vulnerability & Thresholds in Ecology” (07-08 March, organized by the German Ecological Society, GfÖ): the "bridging session" will function as a link between the two workshops.

Brainstorming

Prior to the workshop, the participants were asked to give short intuitive answers to the following three questions:

a) Can you give a short definition of the term "tipping point"?

b) What are conditions that definitely need to be fulfilled if a transition is defined as a "tipping point"?

c) May a development be reversed, once a "tipping point" has been crossed?

The purpose of this exercise was to narrow the scope of the workshop and to get an idea about the variety among the participants. The following table summarizes the given answers.

What is a tipping point?

critical threshold; large and possibly fast change to a fundamentally different stage; regime shift (amplified by human-nature coupled dynamics); catastrophic transition that is abrupt, unexpected and usually irreversible; non-linear break between two functionally different states; unstable equilibrium, change point in the ecosystem state impacting biodiversity and the provision of ecosystem services; threshold point where a system enters another basin of attraction; small change in condition variable causes large change in response variable; a bifurcation point involving hysteresis and a strong nonlinear relationship between the driving and state variables; tipping points should be also thought for a positive change (exit from poverty traps)

Are tipping points reversible?

reversibility depends on the system and its feedbacks; tipping points are not necessarily reversible if caused by multiple drivers (multidimensional causes); if the tipping point is crossed due to an external disturbance (random shock), similar disturbances may be also possible to reverse the system state; after a tipping point has been crossed rather adaption of the management of the system and/or adaption towards new/lacking functionalities of the system's new state is needed; yes, tipping points are potentially reversible, provided that the changes are not too intense and/or to rapid (but this requires large energy input); ; no, over a long time scale (> 100 years), tipping points are not reversible

Examples for tipping point indicators:

return rates close to zero; high variance values; skewness values far from zero; elevated spectral ratios; increased autocorrelation; context dependent interpretation of state variable values under consideration of the static (geophysical or social) setting and effects of drivers; critical slowing down, signal reddening, squealing (increase variance), flickering, divergence of power laws, coherence (spatial); there is no universal indicator; increase of variance dynamics of system, shift of the central system median state, changes in interaction networks of elements within a system, satellite estimates of NDVI, (increasing) variability; change in the area of given habitats; changes in population sizes; salinity, turbidity (in water); decreasing strength/importance of 'ecosystem engineering' by key species; the question is whether we can see indicators early enough to be able to prevent transition

Summaries of oral presentations

Keynote 1: Tipping points, thresholds & Co.: exploring the conceptual territory and some critical questions

Kurt Jax (UFZ, Leipzig)

"Tipping point" is a widely but ambiguously used term in colloquial speech as well as in the social and natural sciences. Frequently, it is used synonymously to "transition" or "threshold". In this introductory talk, the conceptual complexity of the issue was illustrated and a tentative working definition for "tipping point" proposed. To this end, numerous terms related to the phenomenon of a "tipping point" were classified according to whether they describe the system (e. g. community, ecosystem, state space) or its properties (e. g. stability, vulnerability, functioning), specify when or where the change occurs (e. g. transition point, bifurcation, threshold), paraphrase the process of transition (e. g. phase shift, regime shift, qualitative change), or characterize the underlying dynamics (e. g. abrupt, irreversible, discontinuous), mechanisms (e. g. feedback, hysteresis) or causes (e. g. trigger, disturbance, event). Related terms that did not easily fit into any of these categories were "scale", "history" and "contingency". From this classification (Fig. 1) the following working definition was extracted: "A tipping point is a point at which a system experiences a qualitative change, mostly in an abrupt and discontinuous way". However, the exact meanings of "point" (in time or space?), "qualitative chance" (involving irreversibility?) as well as the importance of hysteresis or time lags remained elusive.

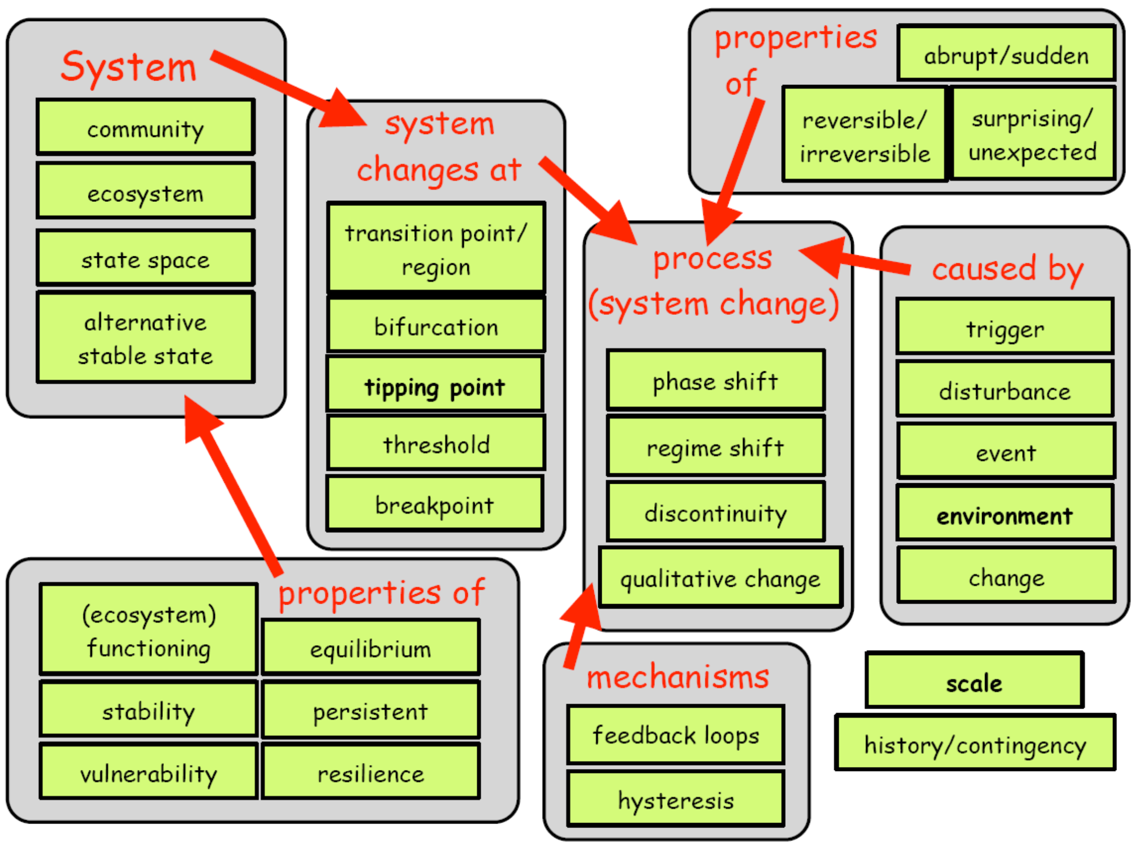

Fig. 1: Classification scheme for terms related to the notion of tipping points.

Furthermore, the following questions were suggested to be discussed at this workshop:

- What are appropriate and practicable definitions of tipping points?
- Can we deal with tipping points in general or do we have to differentiate specific classes/domains?
- Can tipping points lead to desirable or only to undesirable states?
- What temporal and spatial scales are important?
- Does the discontinuous dynamic occur in the driver or in the system state (or both)?

Keynote 2: Evidence for impending tipping points and their expected impacts on biodiversity and human well-being

Paul Leadley (Université Paris-Sud)

In the light of the accumulating evidence for human-induced climate changes as well as severe anthropogenic destructions of ecosystems, the political demand for knowledge on tipping point dynamics has grown. In 2009, the CBD asked for a scientific assessment of tipping points that may lead to drastic negative changes in ecosystem states or services at global or regional scale within the next decades. Using models of socioeconomic developments (e.g. IPCC SRES scenarios, MA scenarios, GEO4 scenarios), projections of the development of direct pressures and of their impacts on biodiversity and ecosystem services were made (e. g. Pereira et al. 2010) and particularly vulnerable ecosystem types or regions were identified. From a much wider list of potential tipping points the following 10 were selected for detailed analyses (in alphabetical order): Amazonian forest, Arctic, coastal systems, coral reefs, fisheries, marine plankton, Mediterranean forest, Miombo woodlands, Sahel-Sahara, and tundra (Leadley et al. 2010, p. 11). A relatively broad definition was adapted that specified tipping points to “include[s] situations where changes in ecosystem functioning are significant enough to have important impacts on biodiversity or ecosystem services at regional to global scales, and that meet any one of the following four criteria: (1) The overall effect of a global change driver is amplified by positive feedback loops; (2) There is a threshold beyond which an abrupt shift between alternate ecological stable states occurs; (3) The changes induced by the driver are long lasting and hard to reverse; (4) There is a significant time lag between the dynamics of the drivers and the expression of impacts, causing great difficulties in ecological management (Ibid, p.12). In the technical report for the GBO3, a short summary is given for each of the potentially threatened ecosystem types or regions analyzed in detail that included a description of the envisioned tipping point mechanism(s) and its impacts on biodiversity and ecosystem services as well as a rating of the degree to which the mechanisms are understood and the certainty in the projections. Furthermore, key actions for preventing the tipping point to occur are proposed.

The GBO3-findings (Leadley et al. 2010, Secretariat of the Convention on Biological Diversity 2010) were repeatedly discussed with CBD delegates (e.g. at the COP 10 in Nagoya, Japan) and found partly entry into the formulation of the Aichi biodiversity targets. However, there is still a lot of work ahead to make tipping points more politically relevant.

In terms of knowledge generation, necessary steps for improving biodiversity models and scenarios include (Leadley et al. 2010, Pereira et al. 2010, EU COST Harmbio, Tokyo IPBES workshop 2011, Annapolis IPBES workshop 2012, etc., Dawson et al. 2011, Bellard et al. 2012):

• Socioeconomic Scenarios

- Create scenarios that explicitly take into account biodiversity
- Generate scenarios based on policy maker & stakeholder input
- Develop a framework for cross-scale consistency between regional & global scenarios

• Models of biodiversity and ecosystem services

- Define common metrics for models and data (parameterization, validation, policy relevance)
- Intercomparison of models to better understand models & quantify uncertainty
- Couple biodiversity and ecosystem services in models
- Link and harmonize regional and global analyses
- Account for a wide range of drivers
- Include species interactions

• Scenarios + Models

- Develop models with dynamic feedbacks between scenarios, models of drivers, models of biodiversity & models of ecosystem services
- Evaluate tipping points in coupled human-environment systems

Keynote 3: Early warning indicators of critical transitions

Vasilis Dakos (Wageningen University)

Recent advances in theoretical and experimental research suggest that tipping point dynamics are accompanied by particular phenomena that may serve as indicators for their imminence. Among the most intensively discussed indicators are particular signals in time series, spatial patterning and critical population densities (Dakos et al. 2008, Biggs et al. 2009, Scheffer et al. 2009, Brock & Carpenter 2010, Dakos et al. 2010, Bailey 2011, Carpenter et al. 2011, Seekell et al. 2011, Dakos et al. 2012b). In this talk, the phenomenon of critical slowing down and the suitability of its implications (increased recovery times, increased variance and increased auto-correlation) as early-warning indicators are discussed. It is shown that prolonged recovery time is a more robust early-warning indicator than increased variance or auto-correlation (Dakos et al. 2011). However, even though prolonged recovery time seems to be a frequent phenomenon in dynamical systems prior to critical transitions, it may not reveal the exact point in time at which the transition will occur, nor will it forecast the magnitude of the event. Instead, early-warning indicators based on critical slowing down are retrospective and real time testing tools. They may give indications about the resilience of a system and its relative proximity to a critical transition (Dakos et al. 2012).

Keynote 4: Nutrients as drivers of tipping points in aquatic ecosystems

Daniel Conley (Lund University)

Nutrients are an important driver for critical transitions in aquatic ecosystems. For example, eutrophication in Denmark is largely driven by high loads of nitrogen and phosphorus. Temperature, O_2-saturation and water exchange are further determinants of the biogeochemistry and biology of water bodies. Where nutrients stimulate algal growth (that is not compensated by grazing), a self-accelerating process may lead to increased turbidity and benthic respiration, increased sediment erosion and resuspension and ultimately to a catastrophic regime shift that results in hypoxia (Duarte 1995).

Hypoxic "dead zones" have now been reported from more than 400 coastal systems (Diaz and Rosenberg 2008). They are driven by the human footprint but reported only where data are available. Under anoxic conditions, ammonium (NH_4^+) and dissolved inorganic phosphorous (DIP) are released from sediments. When they are mixed into surface waters they can enhance algal blooms. Thus, once a zone has become hypoxic, it may stay hypoxic for a long while. In Danish waters, hypoxia has worsened in recent years although the loads of total nitrogen in the waters have declined. With global warming, a further spread of hypoxic zones is expected in the North- and Baltic Sea (Conley et al. 2011).

None of the studied ecosystems go back to where they were, although nutrient loadings were heavily reduced. This strongly suggests that baselines are shifting. However, contemporary management efforts are often targeted toward a status that doesn't ever return. New management strategies are therefore needed for ecosystems that have passed thresholds and have undergone critical, irreversible transitions.

The FP6 project "THRESHOLDS" (coordinated by Carlos Duarte) aims at (1) developing operational tools to identify threshold behavior, thresholds and point-of-no-return value (primarily for nutrient driven eutrophication); (2) exploring the use of these tools through case studies to set policy targets in nutrient and contaminant inputs to coastal ecosystems; and (3) economic evaluations and policy development. An increase in the awareness of tipping points has been achieved, but the implementation into policy remains a major challenge.

Keynote 5: Empirical tests of indicators: lessons learned for theory and practice

Judi Hewitt (NIWA, New Zealand)

To be able to provide advice to managers in a framework which incorporates the probability of threshold dynamics we need to be able have practical empirical measures of approaching tipping points. In this context we need to think about whether we can translate theoretical concepts into empirical measures, whether we know enough about our systems and whether warnings can be gained early enough for management actions. In this talk, these ideas were discussed with reference to marine benthic case studies (Thrush et al. 2008, Hewitt & Thrush 2010, Thrush et al. 2012). In particular, the question "Which indicator will be useful for managers?" was dealt with under consideration of the following aspects: Is the warning early enough? Can we empirically measure them? Do we know enough? Case studies were presented in which temporal variability of community composition and recovery rates after disturbance were considered as early-warning indicators. They provide evidence for increased temporal variability of community composition before a transition to an alternate community type occurred (Hewitt and Thrush 2010). Furthermore, they suggest that the occurrence of a tipping point may depend on the sensitivity of particular key species with a disproportionate effect on biodiversity and ecosystem functions to a certain stressor.

Although the necessary data for early warning-indicators will not be available in many cases we may be able to determine whether a system is predisposed to have threshold responses. In this case, management could be adapted to maintain resilience or to provide ecological buffers. For improving our ability to measure early-warning signals empirically, long-term monitoring programs, the collection of large-scale spatial data as well as the identification of key species and their sensitivities to stressors are of critical importance.

Keynote 6: How can we manage tipping points in rangelands?

Brandon Bestelmeyer (USDA-ARS, New Mexico State University)

Using the grassland-shrubland transitions in south-western US (Black grama grassland) as an example, a practical approach to a management solution for a tipping-point-prone ecosystem is presented (Bestelmeyer et al. 2009). It is based on ecological site characterization and the development and refinement of state-and-transition models. A participatory process is proposed in which 1) ecoregional stakeholder organizations are involved, 2) ecoregional (general) state-and-transition models are developed (capturing the general mechanism of state change, including the biophysical and social processes, and integrating scientific findings as well as local knowledge), 3) the general model is tailored to the specificities of a particular ecological site (ecosites-models), 4) the ecological states at the site are mapped, 5) a management plan is set up and applied, and 6) the management is evaluated based on monitoring data. Ideally, the results of 6) should be transmitted to the ecoregional stakeholders and serve to confirm or adapt the management plan.

This scheme is illustrated with empirical data and the experimental findings on the effect of soil type, drought, initial foliar cover and grazing on the long-term development of black grama grasslands. The following conclusions are drawn:

- Tipping points occur via a wide variety of mechanisms and are highly context dependent.
- A participatory method for describing context-dependence is available (in particular for land type mapping in terrestrial ecosystems).
- State-and-transition models are a suitable tool to synthesize and communicate knowledge about the alternative states of an ecosystem and causes of state transitions (Bestelmeyer et al. 2011).
- In order to make spatially explicit predictions and management plans, it is necessary to develop context-specific state-and-transition models and indicators and to evaluate management effects on slow variable or state variable indicators.
- It is crucial to bridge organizations that can coordinate such activities at regional scales.

Outlook talk: Relevance for IPBES

Cornelia Krug (DIVERSITAS, Université Paris-Sud)

The intergovernmental platform on biodiversity and ecosystem services (IPBES) has been established during the second session of the plenary meeting held in Panama City in April 2012. Currently, its first work programme is being developed (see http://www.ipbes.net/component/docman/doc_download/496-work-programme.html?Itemid=58 for the review document on the draft elements of the IPBES work programme and http://www.ipbes.net/plenary/intersessional.html for further details on the intersessional process). IPBES is envisaged to have four functions (Fig. 1):

1) identify and prioritize key scientific information needed for policy makers
2) perform regular assessments of knowledge on biodiversity and ecosystem services
3) support policy formulation and implementation
4) prioritize key capacity-building needs to improve the science-policy interface

The recent global biodiversity outlook highlighted the likely occurrence of, as well as the risks associated with, tipping points in a variety of ecosystems (Leadley et al. 2010, Secretariat of the Convention on Biological Diversity 2010). As the transgression of ecological tipping points is expected to have severe consequences for biodiversity and the provision of ecosystem services in a variety of ecosystems, and the projection, monitoring, prevention and management of these processes needs to be scientifically examined with great urgency. Identification of tipping points will feed in all four functions of the IPBES work program, in particular in functions 1 ("identification of new/key knowledge") and 2 ("perform assessments"), while development of indicators for potential tipping points will contribute to functions 2 and 3 ("support policy formulation").

Furthermore, a gap analysis conducted by UNEP in preparation for IPBES (UNEP 2009) revealed that considerable knowledge gaps exist in regard dynamic interactions between drivers of change, ecosystem and human wellbeing, in particular at regional, national and local scales. In its gap analysis, UNEP also highlighted a "need for more integrated quantitative models, scenarios and indicators that will aid understanding of not only biodiversity and ecosystem services, but also the relevance of biodiversity and ecosystem services to human well-being". The scenario synthesis conducted for the GBO3 highlights a need to improve the understanding of the interrelationships between biodiversity, ecosystem services and human well-being, thus increasing the robustness of model projections and scenario development. Further research into tipping points will contribute to closing these knowledge gaps, and will further fundamental understanding of dynamic relationships between global change drivers and biodiversity and ecosystem services.

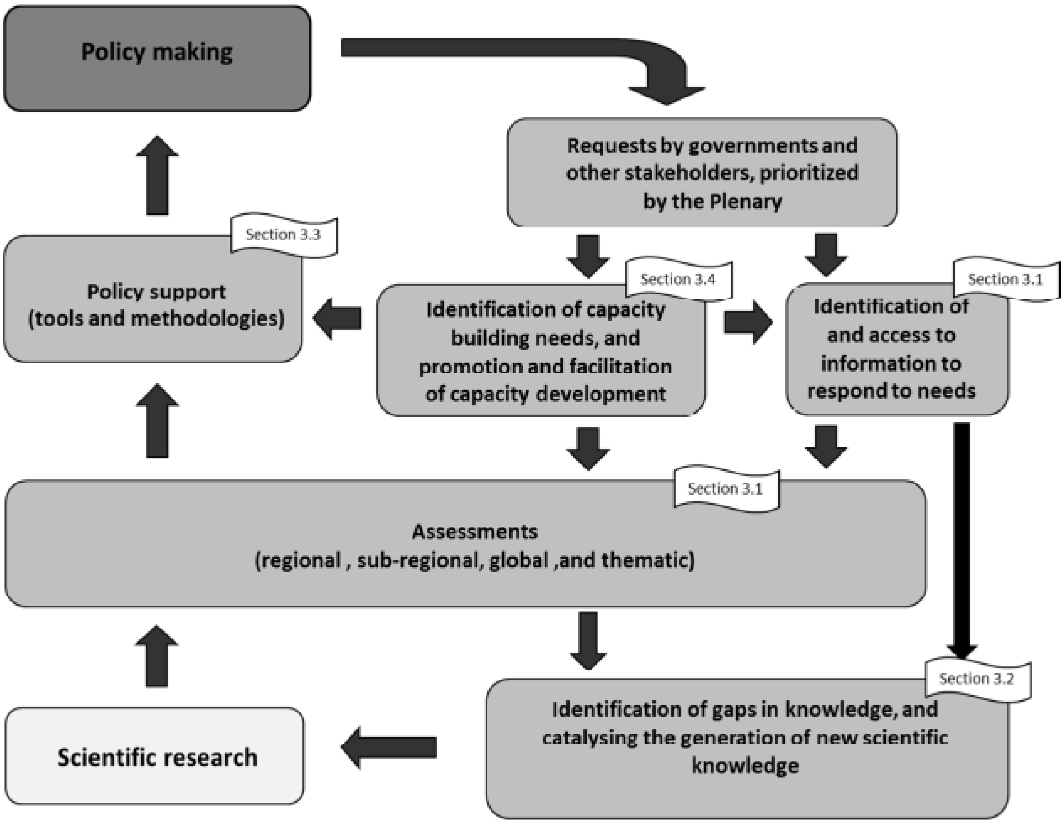

Fig. 1: Envisaged functions of IPBES and the role of scientific research. Source: IPBES work programme elements – draft for review:

http://www.ipbes.net/component/docman/doc_download/496-work-programme.html?Itemid=58

Break-out groups

The participants formed three groups to discuss the following aspects of the workshop topic in more detail: 1) indicators for impeding tipping points, 2) management and mitigation of tipping points, 3) relevance of tipping points in the context of IPBES and other science-policy interfaces.

Guiding questions for the discussions were:

- How may the scale-dependency of effects (temporal and spatial) be appropriately taken into account?
- What could be possible approaches to connect natural science and socio-economic tipping points?
- What is the applicability of indicators in natural ecosystems?
- Are there any general conclusions to be drawn from our current knowledge about tipping point dynamics for management practice?
- What are the chances for restoring ecosystems? What are the consequences of shifting baselines?
- What is the potential of these issues for a review article or a conceptual note in a scientific journal?

A main result of the break-out group discussions was the commonly developed idea for setting-up a data base that provides a catalogue of tipping points and a classification of ecological systems prone to tipping point dynamics and of their (potential) drivers. The aim would be to compile a list of examples, and to derive generalities from them, e. g. with regard to the susceptibility of systems to tipping points (vulnerability), possible indicators and possible management options (result of the indicator and management break-out group). Furthermore „best practice“-examples should be collected that illustrate where and how scientific studies of tipping points have informed the policy process. From them, guidance for a better science-policy dialogue on impending tipping points should be extracted (result of the science-policy break-out group).

Suggestions for the classification system of the tipping point data base included

- to differentiate between predominantly externally driven and predominantly internally driven systems (building on the hypothesis that a system is triggered more by external drivers under extreme abiotic conditions and triggered more by internal drivers under less extreme conditions); possibly linked to the C-S-R-idea (are externally driven systems more at the R-angle of the system and internally driven systems more at the C- or S-angle?)
- to differentiate between important traits of composing organisms such as their ability to disperse or their stress coping strategies (stress tolerators vs. stress avoiders)
- to differentiate slow from fast drivers, direct from indirect drivers and single main drivers from sets of multiple important drivers

However, two main data bases on ecological thresholds and regime shifts already exist. These are:

- Resilience Alliance and Santa Fe Institute. 2004. Thresholds and alternate states in ecological and social-ecological systems. Resilience Alliance. (Online.)
  URL: http://www.resalliance.org/index.php/thresholds_database

This data base assembles examples of thresholds and regime shifts (102 entries in September 2012) that are characterized by a standardized set of 24 descriptors (including the variables along which they occur, the variables that change, and the factors that drive the change as well as a spefication of the certainty of the shift [demonstrated or proposed]; see Walker and Meyers 2004).
In addition, the database provides a bibliography with publications relating to ecological thresholds and regime shifts.

- Regime Shift data base of the Stockholm Resilience Centre
  URL: http://www.regimeshifts.org

This data base includes 18 different types of regime shifts that have been documented in social-ecological systems and links them to numerous detailed and basic case studies. For example, if the regime shift type "hypoxia" is selected, one may extract general information on the phenomenon (drivers, impacts and key attributes as well as management options) as well as on 295 case studies of hypoxia that have been conducted all over the globe (access date: 24-09-12). References are given for each example.

What could be the added value of another "tipping point data base"?

Both existing data bases are focused on the description of the systems undergoing the regime shift, and less on the characterization of the tipping point itself. They are also lacking indicators for the regime shifts observed.

The data base proposed would thus add value to the already existing data bases by

- providing a direct categorization of the tipping points (and tipping point behavior)
- facilitating the development of early warning indicators based on tipping point characteristics (statistical indicators, species- and community-related indicators)
- focusing on management implications

The data base could potentially help to anticipate tipping points. Ideally, it should further include a toolbox with criteria for decision makers and feed into a spatially explicit decision support system. The latter would be aimed at global policy makers, with the aim to connect policy interests to measurable indicators.

Résumé and Outlook

“Tipping point” has become a widely used expression in the context of global change, particularly since Lenton et al. published their groundbreaking paper “Tipping elements in the Earth’s climate system” in 2008. According to Lenton et al. (2008), tipping elements are “subsystems of the Earth system that are at least subcontinental 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 […] at which the future state of the system is qualitatively altered”.

In biodiversity research, the “tipping point” expression has been popularized by its usage in the biodiversity scenarios synthesis for the Global Biodiversity Outlook 3 (Secretariat of the Convention on Biological Diversity 2010). In this context, it describes dramatic changes of ecosystems that involve a discontinuous response of an ecosystem to external drivers, are hard to reverse and have serious negative consequences for biodiversity and humankind on a subglobal to global scale (Leadley et al. 2010). Besides that, “tipping point” may also be used in a more restricted or more general sense (e. g. only for changes in ecosystems characterized by hysteresis or for critical transitions in non-ecological systems such as human brains or financial markets).

During this 3-days-expert meeting on “tipping points” the phenomenon of abrupt changes in ecological systems was explored from the scientific perspective. Cutting-edge research was presented covering a very broad spectrum of methods (ranging from theoretical to observational and experimental studies) and ecosystems (ranging from marine benthos to arid savannas). The great variety of different backgrounds and ecological disciplines among the participants was particularly stimulating for the discussions during the entire workshop.

Some major themes and questions discussed were:

- Tipping points raise special societal interest in ecological phenomena and deteriorating environments. This makes the concept “appealing”.
- Given limited resources, should research focus on those tipping points which are difficult to reverse or study all tipping points?
- How to match the needs of managers on a local to regional level with often rather theoretical or experimental research?
- How far can we generalize about different types of systems?
- Can we develop a typology of tipping points? This might include a typology of system characteristics (which systems are more prone to system shifts?) and a typology of drivers / triggers and their interactions
- What are reliable and feasible warning indicators? (decreased return time of the system, increased variability in space and time)
- Shifting baselines: can or should we try to reverse systems that have passed tipping points to their “original” states?
- How context-specific are the results of observational or experimental studies?
- How to deal with the issue of “scale”?
- Ecological and social time-lags of tipping points and their management were discussed

- How to communicate the concept in a differentiated way in science-policy dialogues (and avoid misuses?)
- Importance of societal choices, goal-setting

The development of a data base that categorizes ecological systems prone to tipping points as well as the potential drivers, indicators and mitigation or management options seemed desirable in order to deduce generalities about the tipping point phenomenon. However, the added value of such data base to already existing data bases needs to be clarified further and duplicated efforts should be avoided.

Along with the increased scientific interest in the phenomenon of abrupt system changes a growing political demand asks for strategies to prevent or mitigate these changes. A compilation of best practice examples could provide useful guidance for improving the science-policy dialogue on tipping points.

Certainly, the scientific knowledge that is already available on tipping points, possible indicators as well as mitigation and management options is very relevant to the programs of work of the CBD and of IPBES. For example, tipping point prone ecosystems need to be protected more decidedly and the monitoring of their development and of potential tipping point indicators needs to be secured. Furthermore, mitigation and management strategies need to be developed and implemented to safeguard the integrity of ecosystems and to prevent or alleviate poverty and dysfunctioning of human societies. Therefore, the generation of new knowledge on tipping points is important and should be implemented in future research strategies. Furthermore, an efficient science-policy dialogue on tipping points needs to raise the awareness of policy-makers to the urgency of interventions and policy implementations but also the awareness of scientist to what knowledge is actually demanded by involved in the daily political work.

Thus, this workshop intended to stimulate the scientific work on tipping points asks for being complemented by further activities that also involve stakeholders of the political arena.

NeFo and DIVERSITAS thank all participants for their individual contributions to the workshops and are particularly grateful to the keynote speakers for their oral presentations. NeFo acknowledges its funding by the German Ministry of Education and Research.

Participants

Name	Institution	Country
Adrian, Rita	Leibniz-Institute of Freshwater Ecology and Inland Fisheries (IGB)	Germany
Bestelmeyer, Brandon	USDA-ARS / New Mexico State University	USA
Blenckner, Thorsten	Stockholm Resilience Centre / Stockholm University	Sweden
Brotons, Lluís	Centre Tecnològic Forestal de Catalunya CTFC	Spain
Cierjacks, Arne	Technical University Berlin	Germany
Conley, Daniel	Lund University	Sweden
Dakos, Vasilis	Wageningen Univiversity	The Netherlands
Diekmann, Rabea	Hamburg University	Germany
Engel, Jan	Jena University	Germany
Fetzer, Ingo	Helmholtz Centre for Environmental Research - UFZ	Germany
Fischer, Wiltrud	PT-DLR, Project Management Agency	Germany
Hewitt, Judi	National Institute of Water and Atmospheric Research (NIWA)	New Zealand
Hickler, Thomas	Biodiversity & Climate Research Centre (BiK-F) / Frankfurt University	Germany
Jax, Kurt	Helmholtz Centre for Environmental Research - UFZ	Germany
Kraft, Dietmar	ICBM, Oldenburg University	Germany
Krug, Cornelia	DIVERSITAS International / Université Paris-Sud	France
Leadley, Paul	DIVERSITAS International / Université Paris-Sud	France
Marquard, Elisabeth	NeFo / Helmholtz Centre for Environmental Research - UFZ	Germany
Navarro, Laetitia	University of Lisbon	Portugal
Neßhöver, Carsten	NeFo / Helmholtz Centre for Environmental Research - UFZ	Germany
Neumann, Rosmarie	NeFo / Helmholtz Centre for Environmental Research - UFZ	Germany
Ransijn, Johannes	University of Copenhagen	Denmark
Scharfenberger, Ulrike	Leibniz-Institute of Freshwater Ecology and Inland Fisheries (IGB)	Germany
Temperton, Vicky	Research Centre Jülich	Germany
Thonicke, Kirsten	Potsdam Institute for Climate Impact Research - PIK	Germany
Vandevalle, Marie	Helmholtz Centre for Environmental Research - UFZ	Germany
Wagner, Carola	Leibniz Institute for Baltic Sea Research Warnemünde	Germany
Walz, Ariane	Potsdam Institute for Climate Impact Research – PIK	Germany

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