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Demystifying Tipping Points

and other forms of abrupt ecosystem change

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What this paper does

This paper aims to demystify the concept of the 'tipping point' — the phenomenon whereby, beyond a certain threshold, runaway change propels a system to a new state. It introduces tipping points as applied to the climate system, ecosystems (and the services they supply) and socio-ecological systems. It then considers what causes tipping points in ecosystems and provides examples of tipping points in ecosystems and their services. Finally, it addresses the application of evidence on tipping points and other forms of abrupt ecosystem change in policy and practice.

This paper is targeted largely at policy-makers and practitioners involved in safeguarding and restoring nature, who may be well placed to address tipping points, but not necessarily well versed in the science of tipping points.

Introducing tipping points

The concept of the tipping point has become widely applied since the turn of the century, in relation to social behaviour, the climate system, ecosystems and, more recently, natural capital and ecosystem services and social-ecological systems. This short paper sets out to demystify the concept. It aims to aid understanding of tipping points and other abrupt changes, in particular in ecosystems and their services, and their relevance to societies and economies, with a view to helping decision-makers in government, business and civil society frame appropriate precautionary measures and responses.

Tipping points in the spread of ideas and behaviour

In his popular book, The Tipping Point: *How Little Things Can Make a Big Difference,* published in 2000, Malcolm Gladwell explained how ideas, trends and social behaviour spread like epidemics, and which few elements need to come together to help an idea reach the point of critical mass, where its exponential viral effect becomes unstoppable.

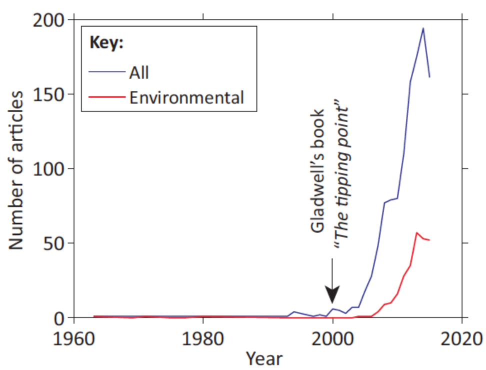
The **tipping point** is the point at which this critical mass is reached, where an idea goes from being interesting to a few, to a must-have for everyone. For example, Instagram, following steady early growth, reached a tipping point in early 2012 when, all of a sudden, the entire world seemed to need an account. In socio-economic contexts, this virus-like growth is not limited to the Internet. It happened previously, for example, with the fax machine and with the use of car seat belts.

While the term 'tipping point' was in use prior to Gladwell's book, the book prompted an exponential rise in its use in the scientific literature **(Figure 1),** in particular in relation to climate science, environmental sciences and ecology.

Figure 1. The recent rise of the term 'tipping point' in the scientific literature.

(Source: ISI Web of Science). The red line shows the number of articles that are labelled with the research field 'environmental science and ecology'. Source: van Nes *et al.* 2016.

Reprinted from Nes *et al.* (2016) with permission from Elsevier.



Tipping points in the climate system

Following this popular notion that little things can make a big difference – that, at a particular moment in time, a small change can have large, long-term consequences for a system – the term ‘tipping point’ is now frequently applied in discourse on climate change. Here, human activities resulting in greenhouse gas emissions may have the potential to push components of the Earth system past critical states into qualitatively different modes of operation, implying large-scale impacts on human and ecological systems.

> A **tipping point** in the climate system has been defined as *‘the critical point at which the future state of the system is qualitatively altered by a small perturbation’* (Lenton *et al.* 2008).

Potential tipping points have been identified both in the physical climate system itself, and in ecosystems affected by climate change. For example drier climates can lower peatland water tables, leading to irreversible changes in their ability to store soil carbon or support specialist species of plants and animals. The precise levels of climate change sufficient to trigger any given tipping point remain uncertain, but the risk associated with crossing multiple tipping points increases with rising temperature.

Large-scale components of the Earth system that may pass a tipping point as a result of climate change have been referred to as **tipping elements** (Lenton *et al.* 2008). These tipping elements include, for example, decay of the West Antarctic and Greenland ice sheets, loss of permafrost and tundra and boreal forest dieback, dieback of the Amazon rainforest and changes in ocean currents, notably, the Atlantic thermohaline circulation (THC) and the El Niño-Southern Oscillation (ENSO) **(Figure 2).**

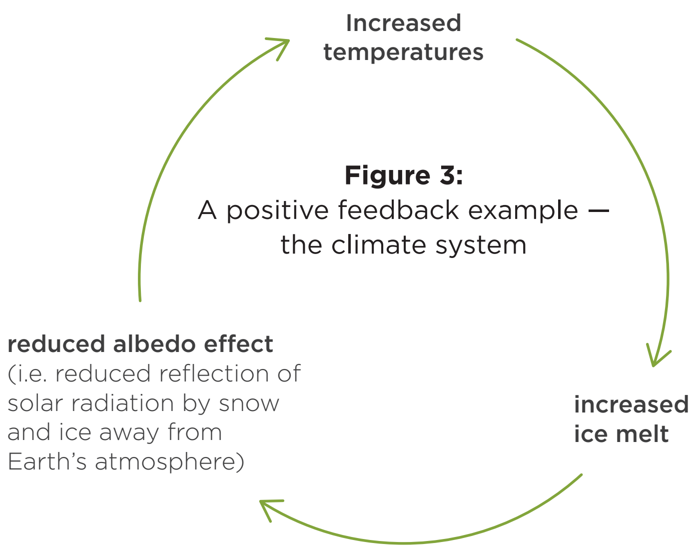
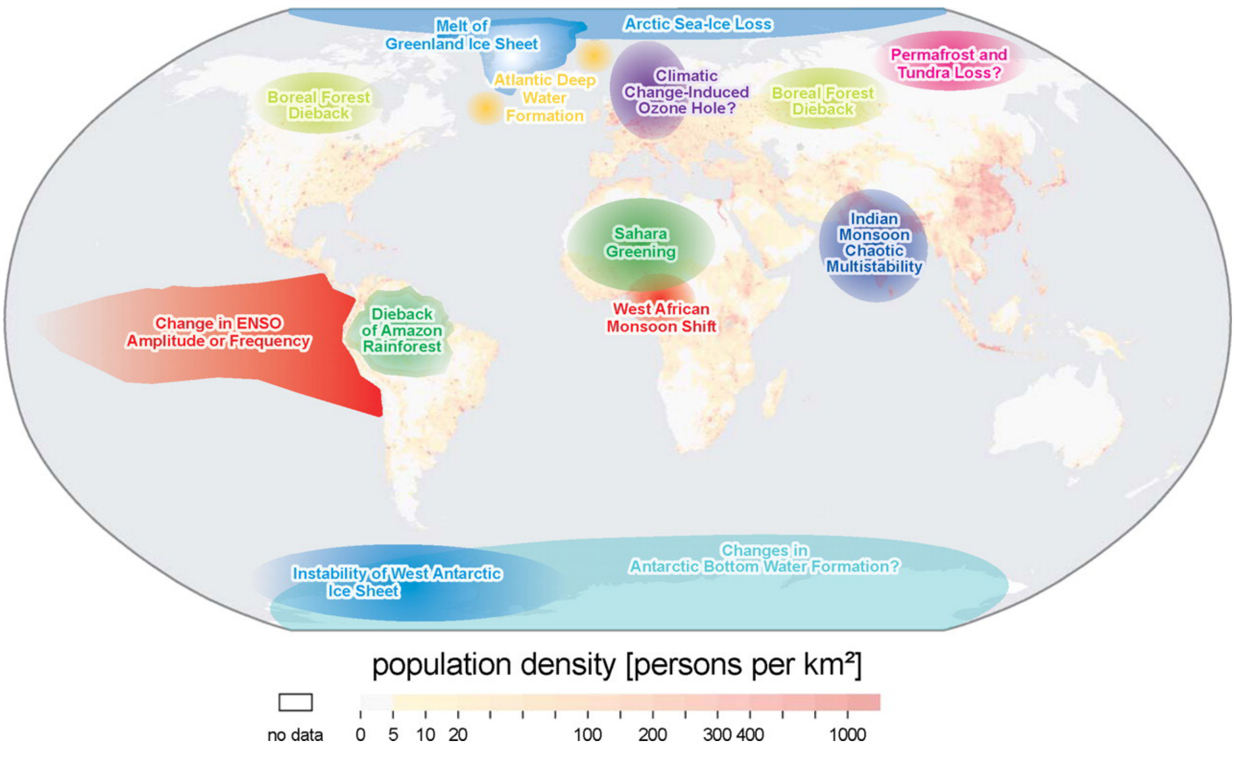


Figure 3:
A positive feedback example — the climate system

Not all such tipping points are abrupt. For example at some level of temperature rise, the melt of a large part of the Greenland and/or West Antarctic Ice Sheets will become inevitable, but the ice sheets themselves may persist for many centuries. This inevitability is driven by **positive feedback.** Critically, some tipping points – in both the physical climate system and in ecosystems – are irreversible. **Figure 3** provides an example of this positive feedback.

Figure 2. Map of potential policy-relevant tipping elements in the climate system, overlain on global population density.

Subsystems indicated could exhibit threshold-type behaviour in response to anthropogenic climate forcing, where a small perturbation at a critical point qualitatively alters the future fate of the system. They could be triggered this century and would undergo a qualitative change within this millennium. Question marks indicate systems whose status as tipping elements is particularly uncertain. Source: Lenton *et al.* (2008). *Copyright 2008 National Academy of Sciences.*



Tipping points in ecosystems and other forms of abrupt ecosystem change

Applied to ecosystems, the term **tipping point** has been used loosely as a metaphor for the phenomenon that, *beyond a certain threshold, runaway change propels a system to a new state* (van Nes *et al.* 2016). More precisely, it refers to any situation where accelerating change caused by a positive (i.e. self-enforcing) feedback drives an ecosystem to a new state, with significant changes in biodiversity, natural capital and/or ecosystem services. An example of such a positive feedback is provided in the **Figure 4.**

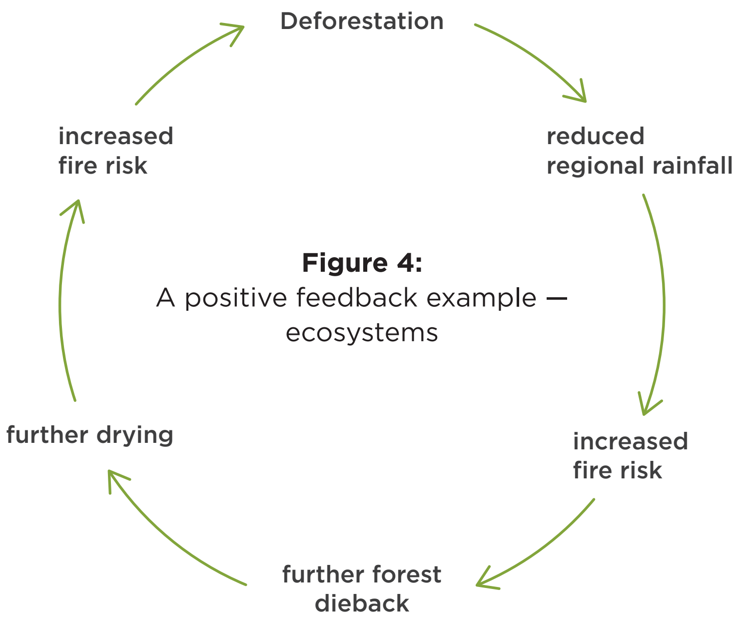


Figure 4:
A positive feedback example — ecosystems

It is the existence of a **positive feedback** process that drives accelerating change that differentiates the concept of a tipping point from other forms of abrupt ecosystem change. Together, tipping points and these other forms of abrupt change can be referred to as ecological thresholds.

An ecological threshold is the point at which a relatively small, endogenous change, or an external disturbance to the system, leads to an abrupt change in an ecosystem quality, property or phenomenon (Groffman *et al*. 2006). Ecological thresholds represent a non-linearity of the responses in ecological or biological systems to pressures caused by human activities or natural processes.

It is worth stressing here that the term 'tipping point' refers to a specific type of ecological threshold, where the abrupt change is driven by a positive feedback mechanism. Tipping points are of particular concern, in comparison with other forms of ecological threshold, because, as a result of the positive feedback, a small environmental change can push a system 'over a cliff', resulting in accelerating change over time. This has been particularly documented, for example, in small lakes.

Tipping points are challenging to identify for ecosystems because the feedback mechanisms are hard to identify and to test. However, this does not mean that they are not happening. The collapse of food webs in agricultural land indicated by the recently recorded declines in insect numbers, farmland birds and bats might be a good example of this – a tipping point that might be happening that we are not fully aware of. While identifying tipping points and other types of ecological thresholds can be challenging in practice, evidence increasingly indicates that nonlinear threshold responses could be widespread (Watson *et al*. 2018).

Changes in ecosystems that take place once a tipping point has been reached can be long lasting and hard to reverse, or may be irreversible. Often, there is a significant time lag between the pressures driving the change and the appearance of impacts, creating difficulties in ecological management.

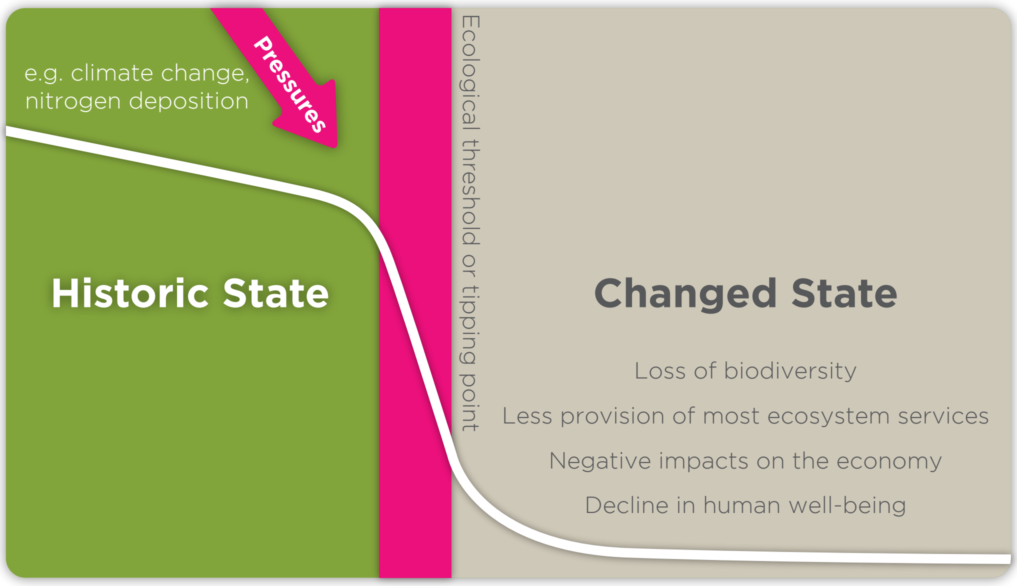
Tipping points in socio-ecological and socio-economic systems

Recent research on social-ecological systems (SES) (e.g. Milkoreit *et al.* 2018) has contributed to the growth and definition of the use of the term 'tipping point' in integrated systems in which humans are part of nature. Consisting of both human societies and the environment, SES can exhibit sudden and unexpected changes that could have significant impact on natural capital stocks (NC) and the flows of ecosystem services (ES) essential for people and their wellbeing (Biggs *et al.* 2012). A decline in natural asset stocks (or 'assets') can result in an abrupt decline in the flow of ecosystem services and the value of the benefits that arise from these services **(Figure 5).**

The term 'tipping point' has also been applied to climate-driven abrupt change in socio-economic systems, such as the collapse of winter sports tourism, farmland abandonment and sea-level rise-induced migration (van Glinkel *et al.* 2020).

Figure 5. Tipping points in natural capital.

Anthropogenic pressures, such as land cover change, pollution or climate change, can lead to a change in the condition or state of an ecosystem. These changes can happen abruptly, representing an ecological threshold. Where such thresholds are caused by a positive feedback mechanism, they are referred to as tipping points. Source: Newton *et al.* 2019.



What causes ecosystems to reach tipping points?

Tipping points in complex systems have sometimes been interpreted as equivalent to critical transitions, phase transitions or fold bifurcations (Lenton *et al.*, 2008, Scheffer *et al.*, 2009; Ashwin *et al.*, 2012). Such concepts derive from theories of dynamical systems, including bifurcation and catastrophe theories.

Application of these theories has highlighted a number of ways in which tipping points can occur, as a result of change in the external conditions of a system, or a change in the intrinsic properties of the system itself (Ashwin *et al.*, 2012, van Nes *et al.*, 2016).

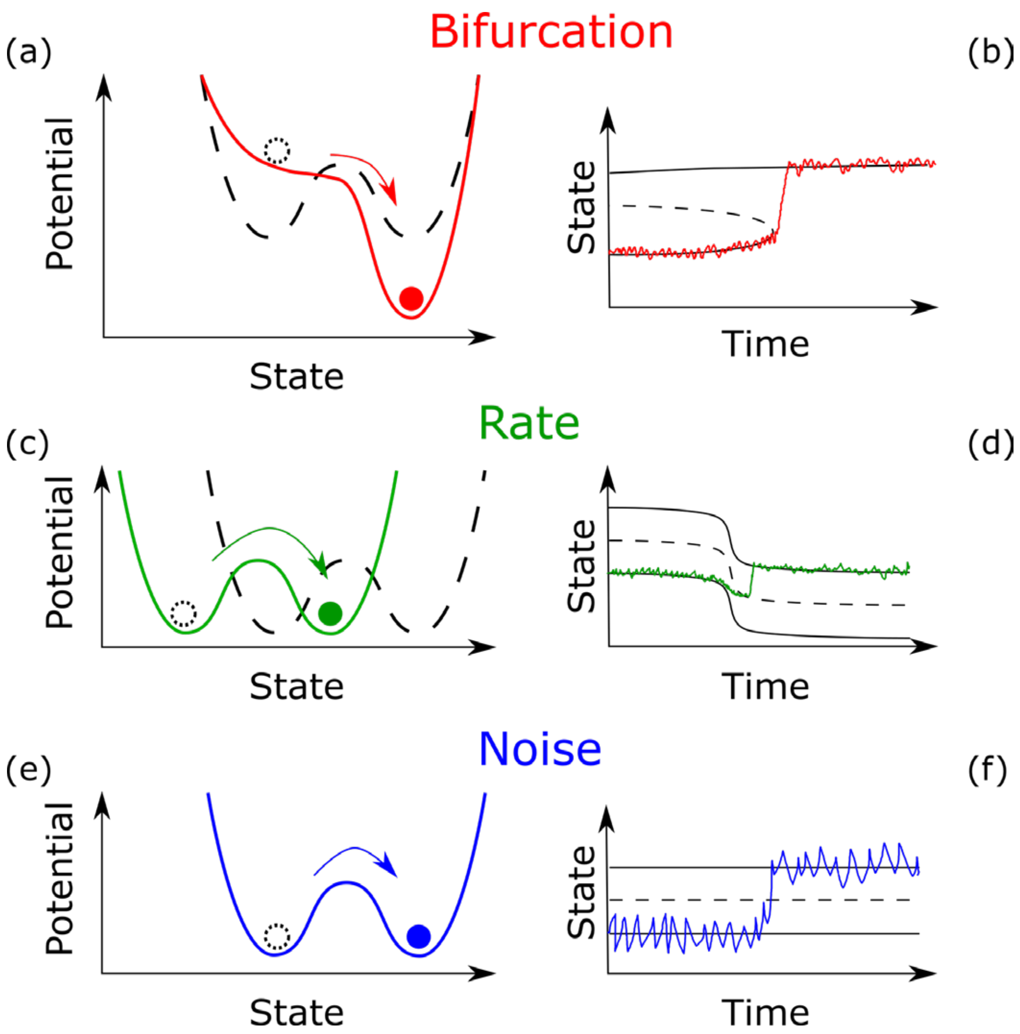
According to these theories, the mechanisms that cause tipping points have been classified into three different categories: **bifurcation-, rate- and noise-induced tipping.** These are illustrated in **Figure 6.**

Here, the basic concept is that the possible state(s) of the system are represented as well(s) or valley(s), separated by a hilltop. The ball then represents the current state of the system, which at equilibrium resides in one of the wells. In this figure, the 'potential landscape' refers to the complete shape of wells and hilltops – the term derives from mathematics and can be used to describe the underlying dynamics of the system. For all types of tipping, we can consider the same start position: two wells separated by a hilltop with the ball in the left well.

In the case of **bifurcation tipping,** a smooth change in an external parameter (e.g. nutrient input) causes an ecosystem's current state to lose stability over time (the valley gets shallower), until it reaches a point at which the state becomes unstable, causing an abrupt shift to a new, alternate, steady state. This is represented in **Figure 6 (a)** in which the well the system originally occupies (left-hand well, dashed line) slowly deforms and shallows, indicating that the ecosystem state is becoming more untenable as the tipping point is approached. At the tipping point the well disappears (red line, left-hand side) leaving the ball no other option but to fall into the other well, representing some new alternative stable steady state. Bifurcation tipping points can be detected by the use of early warning signals (van Nes *et al.* 2016).

Figure 6: Bifurcation, rate- and noise-induced tipping points.

(a), (b) bifurcation; (c), (d) rate-induced and (e), (f) noise-induced. Figures (a), (c) and (e) display the potential landscape before tipping (black-dashed lines) and after tipping (coloured solid lines), were the ball represents the current state of the system. Figures (b), (d) and (f) sketch possible times series data (coloured) overlaid on a diagram of the stable (black solid) and unstable (black dashed) states. *Reproduced by permission, Copyright 2020 Paul Ritchie.*



Such bifurcation tipping points are often termed *catastrophic* and *irreversible* because of a phenomenon known as *hysteresis,* meaning that the system cannot be restored by retracing the same path. Rather, the external parameter that forced the tipping must be pushed back significantly further than the threshold value that caused the tipping.

In the case of **rate-induced tipping,** the potential landscape itself shifts. This is represented in **Figure 6 (c)** in which the ball (representing the state of the ecosystem) is forced to move up the side of the well as it lags behind the shift in landscape (in this case, from right to left), struggling to adapt to the changing conditions. With a sufficiently fast rate of change, tipping occurs, as the system is no longer able to adapt and transitions over the 'hilltop' to the alternative stable state (the right-hand well).

In the case of **noise-induced tipping, Figure 6 (e),** the shape and position of the well remains constant. It requires a large perturbation (e.g. a major pollution event), or a series of perturbations in the same direction (e.g. successive mortality events in a population) to cause the ball (the state of the ecosystem) to traverse the 'hilltop' and shift to the alternative stable state. Because noise-induced tipping points involve unforeseeable perturbations, rather than a gradual change in the stability of the system, their timing cannot be forecast using indicators (van Nes *et al*. 2016), although their likelihood can be assessed.

Most tipping points are a combination of bifurcation and noise induced tipping, such that less noise is needed to cause tipping when closer to a bifurcation.

While these theoretical ideas are well developed mathematically, and have successfully been applied to climate and to some ecosystems, their relevance to understanding dynamics in other ecosystems is still the subject of debate (Newton 2021).

Examples of tipping points in ecosystems and their services

Evidence of tipping points now exists at local to global scales, across decadal to centennial time scales for many subsystems of the Earth, including the climate system. Similar shifts linked to ecosystems have been documented in social, political and economic domains (Biggs *et al*. 2012). **Boxes 3** and **4** provide examples of tipping points in ecosystems and their ecosystem services from the UK and beyond.

Box 1: **Ecological and socio-economic tipping points in UK peatlands**

The Valuing Nature Programme's Peatland Tipping Points project looked at a range of socio-economic and policy drivers that could trigger tipping points in ecosystem services, and changes in ecosystem function that might trigger abrupt changes in the use of and value placed on peatlands by different stakeholders.

The project identified two potential tipping points linked to changes in land management and climate change. First, a significant increase in upland grazing (e.g. as a result of increased policy emphasis on UK food self-sufficiency) could lead to an abrupt and potentially irreversible reduction in peat accumulation. Second, climate change may lead to years where there are very few Tipulids (crane flies or daddy longlegs) which could lead to a crash in populations of ground nesting birds (notably Golden Plover *Pluvialis apricaria*), which rely on these insects as prey.

The project also investigated whether changes in peatland condition might lead to tipping points or abrupt changes in the way people use and value peatlands. The research found strong support for rewetting and restoration of damaged peatlands in England (80% of those surveyed in the North Pennines), based on climate, water, wildlife, culture and economic benefits. However, rewetting could lead to abrupt changes in patterns of recreational use, with walkers and cyclists less keen on the more boggy conditions and placing a negative value on restored bogs.

The project also found that a payment of £100/ha/year might be sufficient to trigger a behavioural tipping point in terms of widespread uptake by landowners of peatland restoration schemes. Research with stakeholders suggest that such a level of payment would reflect the full value of fully functioning peat bog – including values relating to local history, biodiversity, freedom and tranquillity.

Box 2: **Example of tipping points in a globally distributed ecosystem: kelp forests**

Kelp forests are found along 25% of the world's coastlines, where they engineer their surrounding ecosystems and provide an abundance of food sources. They provide multiple ecosystem services including fishing, tourism, coastal protection and climate control, estimated to be worth US$0.5–1.0 million/km².

However, 38% of kelp forests worldwide have declined over the past 50 years. Kelp forests can be driven to collapse, becoming dominated by 'turf' algae. This smaller, less structured vegetation does not provide the same wealth of ecosystem services. Drivers towards this turf-dominated state include gradual warming, eutrophication and pollution and invasive species.

In most cases, significant kelp loss is observed before temperature-induced mortality alone would cause loss, suggesting a combination of stressors drive the collapse. For example, increased temperatures increase the growth of epiphytes which coat the kelp in encrusting colonies, eventually reducing kelp tissue strength. In addition, abrupt events, such as heat waves and overharvesting, may help push the system into the turf state.

In the kelp-dominated state, feedback loops such as kelp shading and mechanical abrasion limit the growth of other vegetation. However, these feedback loops weaken with the warming-induced gradual loss of kelp. The subsequent growth of turf algae establishes different feedback loops which favour further turf growth and inhibit kelp growth.

It is to be expected that ecosystem services supplied by kelp forests are related in a more-or-less linear manner to the health of the ecosystem. A tipping point collapse in these services is therefore likely to parallel a tipping point in the kelp ecosystem itself.

Addressing tipping points in policy and practice

Why TPs are of concern

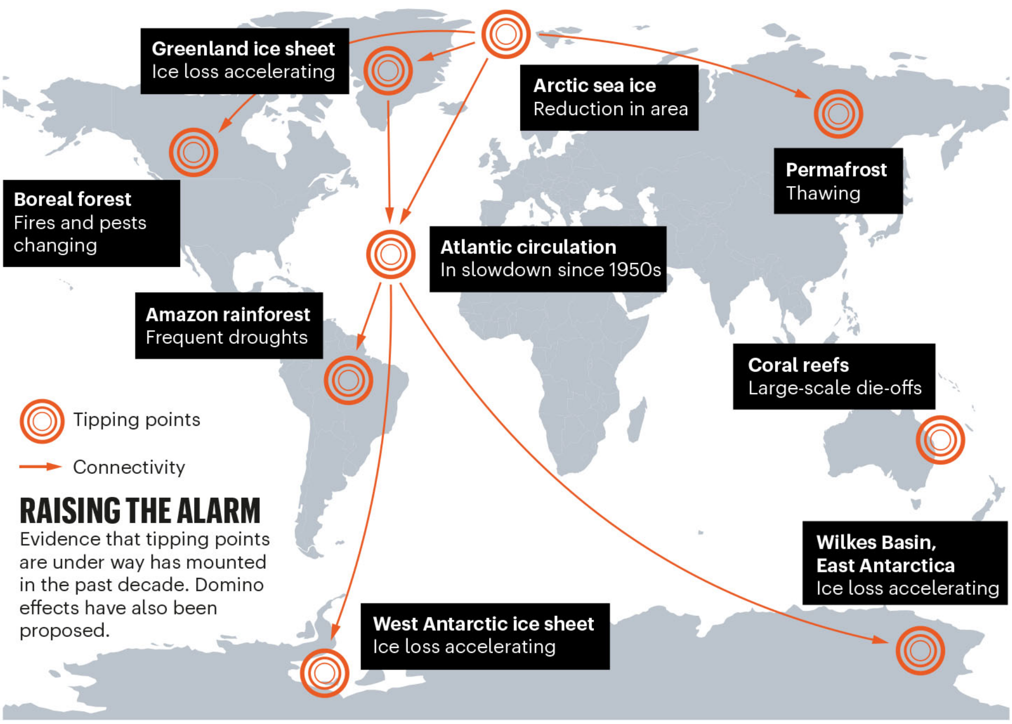
Tipping points are a major concern because of their potentially large and often irreversible impacts on climate and biodiversity, on natural capital stocks and ecosystem service flows, and thereby on socio-economic systems and human well-being. It can be extremely difficult for societies to adapt to abrupt and potentially irreversible shifts in the functioning and character of ecosystems and the related ecosystem services on which they depend[1].

Evidence is mounting that tipping points could be more likely than was thought, have high impacts and are interconnected across different biophysical systems, potentially committing the world to long-term irreversible changes.

1 https://biodiversity.europa.eu/topics/tipping-points

Figure 7: Raising the alarm.

Evidence that tipping points are under way has mounted in the past decade. Domino effects have also been proposed. Source: Lenton *et al.* 2019.



Of particular concern are the feedbacks between climate change and land – as highlighted by the recent IPCC Special Report on *Climate Change* and Land (Jia *et al*. 2019). The interconnectedness of the Earth's biophysical systems could lead to cascading effects with a tipping point in one major system increasing the likelihood of a tipping point in others **(Figure 7).** The evidence from tipping points alone suggests that we are in a state of planetary emergency requiring urgent further international action (Lenton *et al*. 2019).

Making appropriate use of the evidence

The concept of ecological thresholds has significantly aided our capacity to predict the controls over ecosystem structure and functioning (Selkoe *et al*. 2015). Evidence of tipping points and other forms of abrupt ecosystem change – both those that have occurred, and those predicted to occur through modelling – can and should be influential in shaping public policy and decision-making.

Evidence on tipping points and ecological thresholds is equally relevant to the private sector, in terms of security of supply chains and physical assets. Evidence might be applied to inform corporate risk registers and/or in the course of natural capital assessments which provide information on impacts and dependencies on natural assets. A key issue for the private sector is that of permanence in carbon and ecosystem markets. Tipping points and other ecological thresholds have the potential to undermine the credibility of these markets if they lead to abrupt changes in the provision of ecosystem services that landowners are contractually obliged to provide to investors.

Evidence can be applied to pre-empt tipping points and other forms of ecological threshold and, where feasible, to restore ecosystems that have passed ecological thresholds.

The appropriate response to an approaching or apparent ecological threshold differs depending on what the driver of change is, and on whether or not the threshold represents a true tipping point involving a positive feedback mechanism.

An ecological threshold could be caused by a driver (e.g. climate change) intensifying in a non-linear way. In this case, one would need a policy response to address the change in the driver.

However a tipping point is driven by an internal feedback within the ecosystem, often interacting with a change in an external driver. So, the appropriate policy response might include addressing this internal feedback, and/or the external driver. To return to our previous example of positive feedback, reduced rainfall due to climate change might lead to increased fire risk and forest dieback, leading to further drying and further increase in fire risk and so further forest dieback. In this case, reducing fire risk is an appropriate short-term policy response, thereby interrupting the internal feedback mechanism. Addressing climate change is also an appropriate policy response, but its effectiveness is inherently longer-term.

Avoiding predicted tipping points and other forms of ecological threshold involves enhancing the resilience of ecosystems. Research can characterize tipping points for specific ecosystems, identify indicators to monitor these ecosystems, and suggest management strategies to enhance resilience. For example, recent research in Europe has done this for forest and pond ecosystems.[2]

2 Biodiversa (nd) Measures to increase ecosystem resilience and avoid tipping points. www.biodiversa.org/policybriefs

Dealing with uncertainty in tipping point evidence

Tipping point evidence – whether past tipping points or modelled predictions – involves uncertainty. As for all natural phenomena, the evidence may involve two kinds of uncertainty (van der Bles *et al*. 2019). One is known as aleatory uncertainty due to the fundamental randomness of the world ('aleatory' means 'random'). This generally relates to future events, which we *can't know* for certain – such as the timing of a future tipping point and the alternate state of an ecosystem that might follow.

A second kind of uncertainty, known as epistemic uncertainty, involves uncertainty about the facts, numbers or science. This generally, but not always, relates to past or present phenomena that we currently don't know, but could, at least in theory, know or establish – such as the precise cause of a tipping point that has already happened, and how the change might be reversed. Modelling the future risks of tipping points can also contain a strong element of epistemic uncertainty, in that further knowledge would revise our predictions.

This uncertainty is not unique to tipping points science. All knowledge on which decisions and policies are based is shrouded with epistemic uncertainty, of various types and degrees.

In interpreting evidence around tipping points, it is important to clarify *what the uncertainty relates to* (e.g. the hypothesis, and/or the numbers involved) and *why is there uncertainty* (e.g. because of unavoidable natural variation, difficulties of measuring, and/or limited knowledge about the underlying processes) (van der Bles *et al*. 2019).

Scenarios are a common way of communicating uncertainty relating to tipping points. Different scenarios may be based on different assumptions to express epistemic uncertainty. Aleatory uncertainty or randomness may be modelled to show a range of plausible outcomes based on our understanding of underlying processes, which can be represented as alternative scenarios.

As with other areas of science, care should be taken to avoid drawing policy recommendations from single tipping point studies and to synthesize evidence across multiple studies instead, e.g. using meta-analysis and other forms of evidence synthesis. This proviso applies equally to restoration measures to redress the passing of ecological thresholds – **see Box 3** for an example of this from the Peatlands Tipping Points project.

Box 3: **An example of using evidence across multiple studies to inform policy and practice**

The Peatland Tipping Points project tackled the challenge of how to measure the effects of restoration, given that it is currently very difficult to combine measurements from studies in different sites to understand the effects of management or restoration at national scales. Measurements from individual sites may provide conflicting evidence about the effect of restoration on carbon, water or wildlife. The researchers worked across the peatland community to agree a core set of variables that should be measured across as many research and monitoring projects as possible. The hope is that this will lead to more standardized data that can be synthesised to generate more evidence-based policy and practice in future.

Limits to understanding and the need for precautionary approach

Our understanding of how basic abiotic and biotic drivers interact to alter the values of ecosystem services and benefits as tipping points are reached and exceeded, remain limited. The dynamics in most cases cannot yet be predicted with enough precision and advance warning to allow for specific and targeted approaches to avoid them, or to mitigate their impacts. Responsible risk management therefore requires a precautionary approach to human activities known to drive ecosystem change.[3]

Further, care should be taken in shaping policy simply with a view to avoiding tipping points and other forms of ecological threshold. If we wait to see clear tipping points or other forms of ecological threshold in response to anthropogenic pressures, we risk overlooking the gradual and cumulative degradation of the environment. This again points to the need to apply the precautionary principle in minimising damage to ecosystems.

3 https://biodiversity.europa.eu/topics/tipping-points

References

Biggs, D., Hall, C.M., Stoeckl, N. 2012. The resilience of formal and informal tourism enterprises to disasters: reef tourism in Phuket, Thailand. *Journal of Sustainable Tourism* **20**(5), 645–665.

Gladwell, M. 2000. *The tipping point: how little things can make a big difference.* Little, Brown.

Groffman, P.M., Baron, J.S., Blett, T. *et al.* 2006. Ecological thresholds: the key to successful environmental management or an important concept with no practical application? *Ecosystems* **9**, 1–13.

Jia, G., Shevliakova, E., Artaxo, P., De Noblet-Ducoudré, N. *et al.* 2019: Land–climate interactions. In: Shukla, P.R., Skea, J., Calvo, E. *et al.* (eds.) *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems*. In press.

Lenton, T. M., Held, H., Kriegler, E. *et al.* 2008. Tipping elements in the Earth's climate system. PNAS **105**(6), 1786–1793.

Lenton, T.M., Rockstrom, J., Gaffney, O. *et al.* 2019. Climate tipping points – too risky to bet against. *Nature* **565**, 592–595.

Milkoreit, M., Hodbod, J., Baggio, J. *et al.* 2018. Defining tipping points for social-ecological systems scholarship — an interdisciplinary literature review. *Environmental Research Letters* **13**(3), 033005.

Newton, A.C., Watson, S.C.L., Evans, P. *et al.* 2019. *Trends in natural capital, ecosystem services and economic development in Dorset.* Bournemouth University, Poole, UK.

Newton, A.C. 2021. *Ecosystem collapse and recovery.* Cambridge University Press, Cambridge, UK.

Scheffer, M., Bascompte, J., Brock, W.A. *et al.* 2009. Early-warning signals for critical transitions. Nature **461**(7260), 53.

Van der Bles, A.M., van der Linde, S., Freeman, A.L.J., *et al.* 2019. Communicating uncertainty about facts, numbers and science. *Royal Society Open Science* **6**: 181870. http://dx.doi.org/10.1098/rsos.181870

van Nes, E.H., Arani, B.M., Staal, A. *et al.* 2016. What do you mean, 'tipping point'? *Trends in Ecology & Evolution* **31**(12), 902–904.

Watson, S. C., Grandfield, F. G., Herbert, R. J. and Newton, A. C. 2018. Detecting ecological thresholds and tipping points in the natural capital assets of a protected coastal ecosystem. *Estuarine, Coastal and Shelf Science* **215**, 112–123.

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