COMMUNITY ESSAY

Thresholds of sustainability: policy challenges of regime shifts in coastal areas

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Author's Personal Statement:

With a bang or with a whimper? A number of studies address this key question related to the ways in which ecosystems degrade. Our angle is slightly different. In this essay, we discuss what challenges the possibility of abrupt change poses to environmental policy. As a reference, we use the concept of an ecological threshold which describes how systems can change dramatically from one state to another. Environmental experts have recognized the usefulness of the concept. Both conceptual understanding and empirical evidence from different ecosystems suggest negative and irreversible consequences of trespassing ecological thresholds. However, large gaps remain regarding how to use the concept to prevent negative or enhance positive changes. This observation motivated our review of key features of the threshold concept in order to discuss its use in policy. We draw especially on studies describing European coastal areas. We conclude that, particularly because thresholds cannot be identified and legally defined once and for all, a continuous learning process is critical. We also stress that societies will have to develop diagnostics that support such learning processes.

Introduction

Despite all human efforts so far, the Millennium Ecosystem Assessment (2005) concluded that the viability of ecosystems is rapidly decreasing over almost all of the earth. What does this mean? Will the earth gradually lose its ability to support human life as we know it, as T. S. Eliot would have it, not with a bang, but a whimper? Or do we approach a point at which the earth’s systems undergo a sudden irreversible change, the grand AH-WHOOM that Kurt Vonnegut described in Cat’s Cradle?

If we believe in Eliotian change, we have time to act gradually—one problem can be addressed at a time and we can reverse the negative trends in the way, for example, that ozone-depleting chlorofluorocarbons are being phased out. If the situation is approaching the Vonnegutian AH-WHOOM, which is the concern of many climate-change experts, then humankind is in a much more precarious situation. We are facing a need to fundamentally change our management of the earth and its resources to reduce the risk of irreparable damage before we have evidence that a threshold had been irreversibly crossed.

Whether change is gradual or sudden, there is a need to take action. The continuing degradation of ecosystems, in conjunction with a lack of innovative solutions, has been attributed to inadequate resources for environmental policies and insufficient information to guide decision makers about how to best use the available resources. Convincing proof about potential monetary and other costs of environmental damages, or savings gained from preventing harm, has been identified as critical.

In addition to the economic consequences of adverse changes, the nature of the changes needs to be understood. If ecological thresholds, once passed, are difficult or impossible to reverse, the search for prevention is much more urgent than if we are faced with smooth, gradual changes. In this light, ecological thresholds may gain particular political significance. By ecological thresholds, we refer to the level of stressors at which there is a relatively abrupt change in ecosystem quality, property, or phenomenon (Groffman et al. 2006).

This essay reviews how the concept of ecological thresholds can support policy development. Our aim is not to provide an in-depth analysis of certain cases, but to discuss a broad range of issues that should be addressed in a policy context. In a sense, we explore under what conditions the notion of thresholds can be used to mobilize social transitions. We draw especially on studies describing European coastal areas, but our ultimate aim is to identify some general cha-
The Many Facets of Thresholds

Due to various anthropogenic pressures, ecosystems may switch abruptly to new states, as demonstrated in a number of different ecosystems (Scheffer et al. 2001; Walker & Meyers, 2004). Ecological thresholds explain some of these dramatic changes. Although ecologists have explicitly studied ecological thresholds for three decades, the concept’s foundations are much older (Hugget, 2005). One can, for example, argue that already Malthus (1826) envisioned an ecological threshold where crises develop as exponential population growth passes a linear increase in food production.

Because the goal of management is often to maintain the status quo or to facilitate smooth change, it is obvious that ecological thresholds are of considerable importance. Field observations, well-planned experiments, and improved conceptual models are needed to gain a sufficient understanding for purposes of practical and effective management (Muradian, 2001; Scheffer & Carpenter, 2003; Groffman et al. 2006).

Despite their intuitive appeal, it is difficult to define a threshold exactly. The common definition refers to the level of a stressor that triggers an abrupt change in ecosystem quality, property, or phenomenon. It implies that relatively small changes in environmental drivers can produce large responses in ecosystems (Groffman et al. 2006). In toxicology, thresholds refer to something slightly different. A central task for both human and environmental toxicology is to estimate the threshold concentration beyond which a toxic effect is likely to occur (e.g., Kroes et al. 2005). Environmental stressors, such as ionizing radiation and small-sized particles (PM$_{2.5}$), are often believed to have a linear dose-effect relationship with no threshold, while a specific threshold value has been identified and used for regulatory purposes for many organic contaminants and heavy metals. Recently, the concept of hormesis has also re-emerged in toxicological discussions (Calabrese et al. 2006). Hormesis refers to low doses that can have the opposite effect of high doses, such that chemicals that have harmful biological effects in relatively large amounts can have beneficial effects in small quantities. Accordingly, the hormesis level can also be regarded as a threshold below which beneficial effects emerge.

There are many related concepts. For example, the critical load (a quantitative estimate of an exposure to one or more pollutants below which no harmful effects may occur) is widely used (e.g., Skeffington, 2006) and corresponds closely to the definition of a threshold outlined above. The concept of novel ecosystems has recently been developed to deal with what may be the result of transitions after thresholds are passed (Hobbs et al. 2006). Bottlenecks, switches, tipping points, and breakpoints are other terms used in connection with changing ecosystems.

The following sections use thresholds in a broad sense to describe nonlinear changes that can be attributed to increasing (or decreasing) pressures. As is shown, the systems can respond in many ways.

The System Responses

Ecological thresholds do not just refer to sudden jumps in a time series. They imply nonlinear dynamics, with possibilities for alternative stable states, regime shifts, hysteresis, and points of no return. In practice, it is difficult to assess whether a certain dramatic change is caused by essentially nonlinear dynamics or by stochastic events. The consequences of passing an ecological threshold can, furthermore, be of different types. A change in the mean value of a variable is only one consequence. In other cases, the variances of individual system components may increase, or mass flows and functional relationships between system components may change. The ecosystem-health approach seeks to identify several variables that, taken together, would indicate a systemic shift from a healthy to a compromised system (Rapport, 2006).

Most of the reported structural changes in marine systems have been inferred from apparent step changes in the mean values of time series of observations. While a change in the mean value of a single component can be a simple and intuitive indicator of structural change, proper statistical testing of the existence of such a breakpoint is a nontrivial task that requires quantitative tools for separating random fluctuation from nonlinear change (Andersen et al. 2006; Matías et al. 2006).

It is important to note that a linear change in one set of variables does not necessarily mean that the whole system will behave linearly. For example, it seems that even though marine physical time series describing the North Pacific are characterized by linear behavior, the changes of marine biological time series are nonlinear (Hsieh et al. 2005). Whenever a system exhibits marked nonlinear behavior in va-

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1 The research on which this discussion is based was conducted in the context of the “Thresholds of Sustainability” project that was part of the European Union’s Sixth Framework Programme. For further details refer to http://www.thresholds-eu.org.
variables of direct interest to humans, managers will have to pay attention to the possibility of sudden change. This situation calls into question the use of static interpretations of, say, maximum sustainable yield in fisheries.

Alternative stable states have been identified as one cause for relatively sudden large ecosystem shifts (Scheffer & Carpenter, 2003; Schröder et al. 2005). In these instances, the state of the system itself gradually approaches a threshold and then flips to a new state that is characterized by changes in the nature and extent of feedbacks in the system.

The concept of ecosystem health argues in a related way that sudden degradation of the state of a system occurs not as a consequence of a gradual change in a single pressure, but of the cumulative effect of a number of stressors leading to an ecosystem-distress syndrome (Rapport et al. 1985; Hildén & Rapport, 1993).

Even when trespassing a threshold suddenly changes system feedbacks, the resulting changes can be slow. Hysteresis refers to instances where there may be significant time lags between a pressure change and a corresponding change in an ecosystem. Hysteresis was originally used to describe physical systems that do not instantly follow the forces applied to them, but instead react slowly, or do not, with the passage of time, return completely to their original state. In some cases, the original environmental state can be reached after the change, but the return path is drastically different from the development that caused the altered state.

When a threshold has been passed, it may be impossible to recover the system’s original state. For example, certain species can survive in a degraded environment for some time, especially if temporary conditions, such as the weather, are favorable. Eventually these species will, however, go extinct. This inevitability of extinction is what ecologists call extinction debt (e.g., Hanski & Ovaskainen, 2002). Extinction is perhaps the most fundamental ecological threshold and is usually seen as irreversible, a point of no return, even though it is in theory possible to reintroduce a locally extirpated species with the help of gene banks, zoos, or the introduction of individuals from elsewhere (see Caro, 2007). However, the loss of a species may drastically alter the ecosystem itself. Even if the species is reintroduced, it may not be able to establish viable populations because the ecosystem dynamics have changed.

Thresholds Are Not Fixed Points

Thresholds can be characterized as points or zones on an axis measuring the pressure on an ecosystem. Representing thresholds as fixed points that are constant over different places and times is, however, misleading because natural systems vary. Therefore, it will not be possible to determine an ecosystem breakpoint with the exactness of, for example, a toxicity test in which all variables except the stressor are kept constant.

Systems often shift gradually from one state to another rather than changing suddenly at a specific point (Huggett, 2005). An analogy can be found in the first and second order transition of physical systems. In a first order transition the actual threshold level, such as the boiling point of water, is exactly defined. In second order transitions only the definitive loss of characteristics, such as the loss of magnetism in iron as a consequence of heating, is well defined, whereas the process is distinguished by an accelerating change towards the loss.

Perception of the threshold depends on the timescale. Timescales relevant for everyday life or policy making may be much too short for certain regime shifts, such as some impacts of climate change that may transpire over hundreds or thousands of years. However, on geological or evolutionary timescales these changes are quite rapid. Other modifications, such as lakes that shift from clear to turbid, standing water that becomes overgrown by floating plants, or coral reefs that lose color, can occur within timescales that are easily grasped by citizens, policy makers, and journalists because they correspond to human scales (Adam, 1998; Lyytimäki, 2007). At the other end of the spectrum are changes that occur so fast that humans do not typically think of them as thresholds. For example, the succession of bacterial species in decaying organic material is likely to pass unnoticed. Due to this variability, studies describing ecological thresholds must be done at different temporal, spatial, and structural scales (Groffman et al. 2006).

Ecological Thresholds in Coastal Areas

Some examples of regime shifts in coastal waters are well documented, but many more have probably occurred, or are likely to occur, if pressures increase (Walker & Myers, 2004). Examples include regime shifts from early pioneer stage vegetation to late successional stage vegetation caused by enhanced nitrogen loss, sulfide toxicity and nutrient accumulation, and massive coral bleaching; the latter can occur for various reasons including exceeding an ocean temperature threshold (Adema et al. 2002; Bellwood et al. 2004; Graham et al. 2006).

Some of the mechanisms underlying regime shifts are reasonably well known. For instance, the loss of plant communities on the sea floor can be attributed to increasing nutrient concentrations that
stimulate the growth of phytoplankton and epiphytic algae, and their expansion in turn shades seagrasses and macroalgae (Krause-Jensen et al. 2007b). Duarte et al. (2007) describe a threshold of light attenuation of 0.27 m⁻¹, setting a depth for seagrass in the Mediterranean.

Similarly, an analysis of a large dataset from Danish coastal waters demonstrates that the cover of macroalgal communities in deeper water decreases markedly along a eutrophication gradient (Krause-Jensen et al. 2007a). The analysis indicates that algal biomass initially responded slowly to increasing eutrophication, but showed a more marked response at nitrogen concentrations around 35-40 µM, indicating a second order transition.

Research has demonstrated that thresholds are not universal constants that can be linked to stressors, but depend strongly on context. For example, Phaeocystis colonies form recurrent high-biomass harmful algal blooms in the Eastern Channel and Southern Bight of the North Sea. These blooms develop in spring between the early spring and summer diatom blooms. The long-term diatom biomass and the spring dominance of Phaeocystis colonies over diatoms were determined by the combined effect of the North Atlantic Oscillation and freshwater and continental nitrate carried by the Scheldt (Breton et al. 2006). In this case, a nonlinear but monotonic relationship was found between Phaeocystis colony bloom magnitude and winter nitrate (NO₃) enrichment, though not for winter phosphate (PO₄) enrichment. This observation points to the key role of NO₃ in determining the height of Phaeocystis blooms. By contrast, in the Baltic Sea a vicious circle of eutrophication is largely driven by phosphorus loading (Vahtera et al. 2007). Springtime algal blooms fuel summertime phosphorus release from sediments, favoring in turn blue-green algae (Tamminen & Andersen, 2007). In this system, nitrogen fixation by cyanobacteria can be highly significant with up to 500 kilotons or more of nitrogen fixed. The contribution can thus exceed the total estimated mean riverine input (MARE, 2001).

In coastal and transitional waters one encounters systems that can shift between states and for which the health of any one state may be debated. The Ringkøbing Fjord on the west coast of Denmark clearly displays transitions that indicate thresholds (Håkanson & Bryhn, 2007). This lagoon’s water salinity is driven by sluice management. From 1995 to 1997, a dramatic change took place because of a small change in water salinity due to the implementation of a new sluice practice. The ecosystem changed from a nutrient-driven turbid green water to a grazing-controlled clear water. This regime shift has major implications for ecosystem management (Petersen et al. 2005). The fjord is now closer to many environmental objectives, even though the improvements were not caused by a reduction of anthropogenic pressures, such as nutrient discharges. However, the southern part of the lagoon is designated as a Ramsar site under the Convention of the Wetlands and as a Special Bird Protection Area under the European Union Birds Directive. Several of the birds forage on the water vegetation, which has decreased dramatically. Return to the previous turbid green state would be an obligation from the perspective of bird protection, but would not be admissible under the European Union Water Framework Directive. This contradiction between nature conservation and environmental protection may eventually be solved by the gradual increase in macrophyte coverage.

Ecological Thresholds and Sociotechnical Transitions

Regulatory authorities, the public, and other actors tend to ignore information on thresholds due to economic interests, institutional barriers, or deeply rooted personal beliefs if a threshold of adverse change has not previously been reached (Hukkinen, 1999; Harremoës et al. 2001). This initial resistance against the very idea of thresholds must be overcome if the concept is to be of any use.

The notion of nonlinear change is not a recent idea. Most mythological tales and beliefs describe nonlinear dramatic changes in the state of the earth and heavens. Examples include the biblical flood, the Ragnarök of the Norse sagas, and the Ramayana in Asia. Nevertheless, human minds tend to revert to linear reasoning, intuitively trusting developments to be foreseeable and continuous. One way of overcoming the conflict between information on thresholds and the way everyday life is conducted is to demonstrate ecological thresholds through analogies and parallels. For example, displays of the consequences of algal blooms in water bodies distant from a target audience can increase awareness, but are clearly not sufficient to trigger action.

Despite numerous examples of the dramatic emergence of adverse conditions in coastal waters, the ability of the human mind and institutions to defy and ignore facts perceived as unwanted can efficiently inhibit, or at least delay, mobilization of preventive or corrective actions. For example, in the Gulf of Finland and the Archipelago Sea, local degradation of coastal waters was documented for many years, but only when the blooms of cyanobacteria became widespread, readily observable, and recurring was forceful action taken, not only by government but also by private firms. A special foundation was
set up to channel voluntary donations aimed at reducing emissions from Russia by improving wastewater treatment plants (see John Nurminen Foundation, 2007).

It is becoming increasingly common to translate ecological information into monetary terms to increase the policy relevance of ecological insights. The success of the Stern Report (2006) on the likely financial impacts of climate change appears to confirm the effectiveness of this approach. However, although nearly all human economic activities ultimately depend on ecosystem services, the economic calculus can be a double-edged sword. In Belgium, a survey of beach users indicated that they were each willing to pay only €16.39 (US$23.19) per year for a program that guarantees a low level of foam caused by *Phaeocystis* blooms and only €8.40 (US$11.88) per year for an intervention that entails a middle level of foam (Longo et al. 2007). Thus, even if hypothetically a million beach users would benefit from additional wastewater treatment, the sums would be small in comparison with the costs. For example, the neighboring Netherlands invested the equivalent of €4.5 billion ($6.4 billion) between 1970 and 1994 in wastewater treatment (Kemp, 2001).

External costs and benefits generated by alternative land and water use in threshold situations can differ widely. It is essential to consider not only the direct losses associated with a change, but also time lags, uncertainty, and points of no return. Valuations of specific water-based environmental issues include the impacts of eutrophication, food-web disruptions, and hypoxia. Some valuations have also estimated the value of specific goods and services, such as recreation and carbon sequestration (Taylor et al. 2006). However, the sums are in many cases rather uncertain and are not always likely to provide a rigorous cost-benefit argument for the avoidance of thresholds. The maintenance of ecosystems in a healthy state is also a political and moral issue. Therefore, awareness and economic considerations need to be supported by legislation, rules, and norms.

Although rational arguments can be presented for management systems that avoid thresholds, it is not evident that societies and policies are capable of handling thresholds in any systematic way. In fact, shifts in rules, legislation, or norms often follow only after an undesirable ecosystem change. In some cases, ecological changes can induce profound sociotechnical transitions, fundamental nonlinear shifts from one dynamic equilibrium to another (Loorbach & Rotmans, 2006).

Sociotechnical transitions are no less complicated than nonlinear ecosystem changes. They arise as a set of connected changes that reinforce one another but take place in several different areas and at various scales, such as macrolevel cultural changes, mesolevel institutional changes, and microlevel changes in beliefs and attitudes. For example, extensive media coverage in Finland of intensive algal occurrences during the summer of 1997 increased pressure to improve the monitoring and communication about algal blooms, both in the country’s inland waters and in the Baltic Sea. As a result, in 1998 a nationwide monitoring program was launched that has provided the media with easy-to-use information (Lyytimäki, 2007). In this case, the intensive algal blooms were the trigger that, together with gradually increased public awareness about eutrophication, changed the social process (Peuhkuri, 2002).

The interplay between ecological thresholds and social system transitions can be described using the concept of panarchy, a term created as an antithesis to the word hierarchy (Gunderson & Holling, 2001). Panarchy views coupled human-natural systems as a cross-scale set of adaptive cycles that reflect the dynamic nature of human and natural structures across time and space. Sudden shifts in ecosystem states can induce changes in human understanding of the way the systems need to be managed. These modifications, in turn, may alter the institutions that carry out management and, as a result, prompt new changes in ecosystems. In these cases, the concept of thresholds is useful in policy, but only post festum—as a way to interpret an otherwise confusing situation and to understand and justify changes.

One way of understanding both ecological thresholds and sociotechnical transitions is to see them as periods when the intensity of changes is different from regimes previously and after (Adam, 1998). This concentration of changes can create possibilities to induce large-scale transformations. However, both sociotechnical transitions and ecological thresholds are characterized by many factors beyond human control (Meadowcroft, 2005; Shove & Walker, 2007). Even if the system is rapidly changing and transient, it is often very difficult to guide it along a particular trajectory. As Gallopín et al. (2001) argue, nonlinearity, plurality of perspectives, emergence of properties, self-organization, multiplicity of scales, and irreducible uncertainty are fundamental properties of complex socio-ecological systems.

**Thresholds in Policy Implementation**

Dealing with thresholds without convulsive change requires information on ecological thresholds in sustainability policy. It is a challenging task. First, although thresholds can be assumed to exist in many ecological systems, they are not universal in the sense that one could use them as a fixed reference in legislation. Second, even when there is compelling evi-
dence of threshold behavior, it remains difficult to specify the level in advance. Prescient and reasonably precise diagnostics of an approaching threshold are needed in order to take precautionary action in time. Intervention that came too early could result in a waste of scarce resources. Third, it is difficult to communicate the need for mitigative action early and convincingly without being accused of “crying wolf.”

What, then, are the key requirements for the thresholds concept to be useful in policy implementation and management of coastal waters? At an operational level, the following conditions can be identified.

1. Responsible authorities, the public, and other actors (including researchers engaged in the study of the systems) must acknowledge that the state of the system can change rapidly and that it can be costly or impossible to act after the apparent signs of degradation have been observed.
2. Estimates of the economic consequences of passing a threshold, as well as of managing the system to remain within the bounds of recognized thresholds, should be available.
3. A set of diagnostics must exist that can provide early warnings of impending losses in the healthfulness of the system before a threshold of dramatic change is reached, and spur an interest in monitoring actual system changes.
4. Organizations and institutions must be in place with the capacity and mandate to take action, but also to debate and (re)interpret research findings to maintain a learning process.

Despite the uncertainties, ecological thresholds, or assumed thresholds, are at present often translated into clear-cut and absolute limit values. Such procedures are an attempt to make threshold-like concepts amenable to systematic management and correspond to the first condition above. Environmental policy and law has introduced exact limit values for nutrient concentrations and various chemical substances, as well as for pressures such as toxic emissions. Although the threshold has not been used explicitly as a legal concept in European Union legislation on marine and coastal waters, many of its environmental standards and programs are implicitly based on assumed, but ultimately unknown, thresholds.

Quantitative estimates provide regulators and other authorities with rules to decide on whether certain actions or conditions can be allowed. Although these limit values are based on the best available scientific knowledge of potential ecological and health thresholds, significant uncertainties are often associated with the estimates. The challenge is that what appears a purely ecological or biological question can have significant economic and social consequences. The social cost can be rather high for such precautions as introducing large safety factors in the limit values to ensure special protection for sensitive areas or parts of a population (Hildén, 2006). In such instances, confidence should be reasonably high with respect to the appropriateness of such a legally binding limit value as compared with other management methods. The evidence that limit values are always appropriate is far from convincing (Assmuth & Jalonen, 2005).

Diagnostics are needed because thresholds are not constant and some ecosystems are more resilient than others. Standards, on the other hand, are generally fixed across a wide range of ecosystems. Furthermore, knowledge about thresholds is unavoidably incomplete. Responding to a risk of exceeding a threshold by strict precautionary actions is usually not politically popular, but management difficulties also arise if irreversible damages occur due to the neglect of incomplete or uncertain information. The legitimacy of a thresholds-based policy is thus dependent on the existence of reliable and commonly accepted diagnostics. It is highly unlikely that any single diagnostic would be adequate for this purpose. Instead, an ecosystem health-based approach that uses several sources of data to discern adverse change is more appropriate (Rapport, 2006).

Diagnostics on approaching thresholds are, of course, useless unless an institutional actor is empowered to take action. This situation places demands on the organizations that are created to manage ecosystems. For example, in the European Union the Water Framework Directive and the future Marine Strategy Directive play key roles. Such legislation has to address two fundamental questions related to thresholds. First, how can “good environmental status” be specified? Second, what action should be taken to avoid slipping from good to moderate status or to return from moderate or worse to good?

Answers to these questions must be part of management strategies, which must assess measures in terms of economic feasibility and political acceptability. Assessment and evaluation frameworks are being developed to take into account specific results and tools that make the systems manageable. They include:

- Methods for devising quality indicators and identifying thresholds and points of no return (e.g., Austoni et al. 2006).
- Methodologies supporting socio-economic assessment of externalities in the presence of threshold effects (Taylor et al. 2006).
Examples of drivers and sources of pressures that may be associated with threshold effects (e.g., Vasas et al. 2007).

Examples of avoidance and mitigation measures aimed at influencing drivers to reduce pressures to levels that minimize the risk of exceeding thresholds (e.g., Duarte et al. 2007).

Single measures are, however, not likely to solve the problems related to thresholds. Measures must be integrated into packages, taking into account that they interact in several ways: in some cases they are substitutable and in other instances a more pluralistic strategy is needed. If positive synergies between measures are in place, the final effectiveness of a combination of measures could even be higher than the sum of the individual measures. In all situations, there is a need to build in mechanisms to ensure learning opportunities. It is not possible to assess in advance the effectiveness of all measures and their combinations. Therefore, thresholds management must be part of ongoing feedback processes that make it possible to revisit fundamental assumptions about the relationships that constitute socio-ecological systems.

Concluding Remarks

The concept of ecological thresholds is essential in alerting users of natural resources to the risk of irreversible changes and in demonstrating the challenges in changing adverse conditions to acceptable ones. The concept is not, however, without problems. The difficulties in identifying thresholds, the lack of suitable indicators, and the deficiencies of externality valuation in thresholds situations are some factors that complicate the concept’s use in a policy context. Ecological thresholds related to a certain system can have large variations because of the interactions between external and internal changes and pressures. There is a need to understand the diversity of systems and the variability in them (Håkanson et al. 2007).

Although several examples serve as warning signals, the assumption that ecosystem responses to pressures are often nonlinear has not yet been extensively reflected in policy making. One reason is that the evidence has not yet been validated on a sufficiently large scale (Lindenmayer & Luck, 2005; Groffman et al. 2006). Research on ecological thresholds has so far concentrated mainly on the characteristics of possible thresholds. Further case studies and conceptual research are clearly needed to critically examine the existence and attributes of such limits, as well as to formulate advance diagnostics to identify them.

Research on ecological thresholds will improve policy making only if we are able to identify and implement better methods of interaction between scientists and decision makers. It is not only a question of efficient consultation, but also entails selecting understandable indicators, visualizing the data, conveying insights to intended target groups at the appropriate time, and evaluating the effects of communication. The question is also one of conducting research that can produce answers relevant for policy making in the first place and that can convince decision makers early in the maturation of a particular problem. One-way communication from scientists to decision makers is often insufficient to achieve this objective (Clark & Dickson, 2003). Interaction among different stakeholders is needed to find policy-relevant research questions, to guarantee the timeliness of communication, and to ensure that the key messages are understood and acted upon in an appropriate way.

The role of the media can be critical in learning to live and deal with thresholds. Public attention is an increasingly important factor influencing thresholds information in policy making. Without substantial media consideration new (or even old) issues are unlikely to gain the political traction to mobilize the resources required to implement possible solutions (Hannigan, 1995). However, not all issues highlighted in the media are warranted. Intensive media attention can be devoted to true warnings or false alarms and there is no definitive way to separate them (Mazur, 2004). Research focused on identifying ecological thresholds can help at times to distinguish between legitimate concerns and more illusory ones, but it is naïve to expect that this information will be treated in an undistorted way in the media.

There is currently a mismatch between the way that scientists formulate problems and the way they are construed by policy makers (e.g., Turnhout et al. 2007). While the scientific community tends to address specific questions, policy is driven by broad issues and more general concerns. To avoid this incongruity, it seems necessary to involve all key stakeholders from an early stage in the policy-development process. Furthermore, all relevant data should be available and communicated in a clear and accessible form, including information that highlights the uncertainties associated with the scientific evidence. The role of scientists when assisting policy development should be to provide the best evidence available to inform the development of the policy, to help to monitor the effects of current policies, and to provide solutions to unexpected events and policy failures.

Several attempts have been made to develop a common language between the natural and social
sciences to incorporate ecological indices into policy processes and to add humans into the “equation” (Hughes et al. 2005; Groffman et al. 2006; Turnhout et al. 2007). The translation of research into usable policy information and the rendition of policy into specific research questions remain, however, challenging tasks.

To summarize, evidence is accumulating that threshold behavior characterizes many systems, but this does not mean that thresholds are found in every system or in every situation. Even when they exist, it remains difficult to identify them and to predict when the critical limits are likely to be reached. But based on our current knowledge of ecological thresholds, the poet T. S. Eliot was not completely right. While many systems may change with a whimper, others can undoubtedly change with a bang or with a grand AH-WHOOM. Humankind should learn to cope with this possibility.

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