Munck af Rosenschöld, J., N. Honkela, and J. I. Hukkinen. 2014. Addressing the temporal fit of institutions: the regulation of endocrine-disrupting chemicals in Europe. *Ecology and Society* **19**(4): 30. http://dx.doi.org/10.5751/ES-07033-190430

Research

Addressing the temporal fit of institutions: the regulation of endocrine-disrupting chemicals in Europe

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ABSTRACT. The concept of temporal fit between biophysical systems and institutions has lately received great attention by scholars interested in environmental governance. Although we agree that the concept of temporal fit is a valuable approach for highlighting the temporal challenges of governance systems, we argue that the concept is currently lacking precision with regard to temporal complexity. We build on Barbara Adam's work on "timescapes" to offer a more nuanced account of temporal fit and misfit. We illustrate the analytical usefulness of our approach by examining the regulation of endocrine-disrupting chemicals (EDCs) within European Union's Registration, Evaluation, Authorisation, and Restriction of Chemicals (REACH), a case with amplified temporal challenges. We suggest that, when addressing temporal fit, two points require greater attention. First, similar to time, temporal misfits are complex. In REACH the temporal misfit is linked to four temporal features, time frame, sequence, tempo, and timing, contributing to the insufficiency of EDC regulation. Second, the temporal features are interlinked and feed back into each other, which strengthens the temporal misfit further. In conclusion, we propose that environmental impact assessment could be used as a tool to circumvent the regulatory paralysis of EDC regulation in Europe.

Key Words: *endocrine-disrupting chemicals; institutional fit; REACH; temporal fit; time; timescape*

INTRODUCTION

Endocrine-disrupting chemicals (EDCs), or substances that adversely interfere with the hormonal systems of living beings, have been on the political agenda in most industrialized countries since the early 1990s (Krimsky 2000, Vogel 2004, Hecker and Hollert 2011). The use of EDCs is widespread and can be found in numerous consumer goods, such as cosmetic and pharmaceutical products. However, despite a deeply felt concern and massive efforts by the scientific community and nongovernmental organizations to evaluate the effects of EDCs (see e.g., Kortenkamp et al. 2011), regulatory communities worldwide have been slow to incorporate the chemicals posing endocrine concerns into existing legislations (Vogel 2004, Hecker and Hollert 2011, Honkela et al. 2014). Although some argue that the slow detection of EDCs stems from the novel nature of the chemicals (e.g., Scheffer et al. 2003), others argue that because EDCs embody a wide range of temporalities, such as vast time frames as well as nonlinear dose and effect relationships, governing EDCs within the current risk assessment paradigm focusing on quantitative data and methods is highly challenging (Adam 1998, Held 2001).

We view the slow regulatory response as a temporal misfit between EDCs and the institutional setting. Institutional fit refers here to the proposition that a high degree of fit between the institutional setting and the biophysical system leads to environmental governance that performs well over time and is robust against shocks and perturbations (Young and Underdal 1997, Folke et al. 2007, Young 2008). Research on institutional fit has become increasingly popular and articles on the topic have been published frequently in *Ecology and Society,* including a recent special feature (see Farrell and Thiel 2014). In this paper we focus on a particular form of institutional fit, temporal fit, that is concerned with the temporal connection between institutions and the biophysical systems. A temporal misfit can, consequently, be defined as a case in which an "[i]nstitution [is] formed too early or too late to cause desired ecosystem effect(s)" (Galaz et al. 2008:151). A temporal misfit may also refer to the conflicting time frames between policy-makers and those of the environment (Folke et al. 2007). The time frame of politics, with its short-term election cycles, may be too short to manage natural resources sustainably, but at the same time, the time frame may be too long when there are quick changes in the ecosystem and the institutional response to these changes is too slow (Wandel and Marchildon 2010). Thus, assessing how institutions and biophysical systems are temporally linked is certainly crucial for understanding the resilience and robustness of social-ecological systems.

Although the concept of temporal fit is useful for highlighting the temporal challenges of institutions, we argue that previous studies using the concept have not paid sufficient attention to the complexity of time. Time can be seen as a redefinable collection of numerous temporal features, such as time frame, tempo, and timing (Adam 2004; B. Adam 2008, *unpublished manuscript,* http://www.cardiff.ac.uk/socsi/futures/conf_ba_lueneberg170608.pdf). Time can thus be conceptualized and interpreted in various ways depending on the observer. Referring to Barbara Adam's work on timescapes (Adam 1998, 2000, 2004; B. Adam 2008, *unpublished manuscript*), our aim is to clarify the concept of temporal fit by diagnosing the multiple features of time and their implications for EDC governance. We concentrate on a specific case that is currently the most central issue in EDC governance, namely, the reliance on quantitative risk criteria as a base for regulation. We explore the issue by referring to the European Union's (EU's) Registration, Evaluation, Authorisation, and Restriction of Chemicals (REACH) regulation and the challenges of adopting criteria that warrant regulation. In this paper we treat institutions as consisting of three dimensions: regulative, normative, and cognitive (Scott 2001). In our case this means that

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institutions include both the formal regulatory instruments of the EU as well as the informal norms and conventions that guide how these instruments are implemented.

THE REGULATION OF ENDOCRINE-DISRUPTING CHEMICALS IN THE EUROPEAN UNION

The story of EDCs began in the late 1980s with the American natural scientist Theo Colborn (Krimsky 2000). Before Colborn, there was some evidence of disturbances in reproductive function among animals as well as humans because of the use of chemicals. Colborn recognized that the problems that many of the organisms living in the Great Lakes area manifested were caused by a diverse group of chemicals with the capacity to mimic and/or obstruct the hormone function of biological organisms. This idea formed the basis for "the environmental endocrine hypothesis" (Colborn et al. 1996, Krimsky 2000). This hypothesis essentially amounts to a new theory of environmental disease based on the guiding concept that some chemicals can interfere with the body's natural hormones (Krimsky 2000). At the time of Colborn's discovery, however, traditional toxicologists were generally ill-informed about the dose-response effects of hormones (Krimsky 2000). Endocrine systems are based on self-regulating feedback systems, and thus monotonic dose-response curves (the higher the dose, the greater the response) do not as a rule apply (Krimsky 2000).

EDCs have several effects on the hormonal systems of living beings. The central EU policy document *State of the Art Assessment on Endocrine Disruptors* (Kortenkamp et al. 2011) lists the following effects, among others: for male humans, the Testicular Dysgenesis Syndrome involving a number of problems with male reproduction; for female humans, precocious puberty, lowered fecundity, lowered fertility, and adverse pregnancy outcomes, polycystic ovaries syndrome, endometriosis, uterine fibroids; and for both males and females, cancer (breast, prostate, testis, and thyroid). Furthermore, scientific evidence points to several critical temporal windows of susceptibility for foetuses. Although the research is highly uncertain, there are strong indications that similar patterns of critical temporal vulnerabilities are present in all "wildlife" categories addressed by Kortenkamp et al. (2011), i.e., other mammals, birds, fish, and invertebrates. In addition, EDC scientists as well as researchers developing new technologies for the monitoring and assessment of hormonally active substances have identified serious environmental consequences from releasing them into the environment (Hyötyläinen and Riekkola 2007, Kortenkamp et al. 2011, Krysiak-Baltyn et al. 2012). Finally, recent research on EDCs has demonstrated that geographical differences matter. Whether or not adverse effects will occur depends not only on the specific compounds found in a particular area, but on the specific mixtures these compounds happen to form as a result of agriculture, industry, and consumption patterns (Krysiak-Baltyn et al. 2012).

EDCs thus offer a prime example of so-called new generation risks, or systemic risks with epistemic uncertainties (see Renn 2008). They are systemic, as the specific risks to human health and the environment have complex consequences for the larger socio-cultural context. The epistemic uncertainties derive from the lack of knowledge about fundamental phenomena underlying the chemical impacts. For new generation risks, quantitative risk assessment is particularly laborious, because specific outcomes and their probabilities are largely unknown, leaving few legitimate grounds for regulation. To illustrate precisely how challenging this might be, we can refer to an incident in the U.S. Congress noted by Jason Vogel. During a committee hearing on pesticide safety, U.S. Congressman Mike Synar famously stated that "[a]lmost 20,000 pesticide products have been under review since 1972 and only 31 have been reregistered. At this rate it will take us to the year 15,520 A.D. to complete. I believe in good science. What I don't believe in is geologic time" (quoted in Vogel 2004:286). Nevertheless, new generation risks are at the same time often characterized by a considerable amount of experiential evidence collected and articulated by experts, commonly expressed as alternative scenarios describing the pathways and management of the uncertainties. Even in the absence of exact evidence of impacts, some analysts believe the situation justifies reasonable concern over public safety and warrants precautionary policy action (Vogel 2004, Hukkinen 2008).

EDCs have been the focus of intense work within the EU over the last 20 years. The European Commission (EC) strategy specifies several actions to be taken, such as promoting research on EDCs, international co-operation, and informing the public. In addition, various new tests and methods for conducting risk assessments are being developed at international and national levels. The EU's EDC strategy is divided into short-, medium-, and long-term measures (EC 1999). The long-term measures include the development and adoption of legislative instruments and policy actions that enable hazard identification, risk assessment, and risk management of EDCs (Hecker and Hollert 2011). EDC risk management is governed by a variety of European Community legislations. Under REACH (EU 2006) there are general provisions for safe use that apply to all chemicals; however, if a specific substance is identified as a "Substance of Very High Concern," it can be included in the so-called authorization scheme as an EDC on the basis of a case-by-case assessment (Article 57(f) EU 2006). Also, the new regulation concerning plant protection products (EU 2009) includes criteria for approval of substances with known endocrine-disrupting impacts on human health and the environment.

However, at the time of drafting the legislation, the numerous knowledge gaps, uncertainties, and complexities regarding how EDCs influence living organisms led to a delay in establishing clear definitions and criteria for the identification and management of potential EDCs (Hansen et al. 2007). Acknowledging these shortcomings within REACH, a review of the authorization process for EDCs is currently under construction. In addition, the EC was mandated to present a draft of scientific criteria for determining endocrine-disrupting properties and their impacts on human health exclusively by 14 December 2013 (Danish Ministry of the Environment 2011). In September 2013, however, the Commission announced that EDC criteria would not be announced until an impact assessment has been undertaken. In January 2014, the EC expected this new process to take at least one more year (Martín de la Torre 2014). As of today, it is still unclear what this assessment will entail.

The paralysis encountered in European efforts to regulate EDCs reflects the more general difficulties of governing new generation risks. To summarize, the dilemma with EDCs appears to be that although there is considerable societal pressure to regulate them

now, quick regulation is impossible for lack of quantitative evidence of risk. To produce such evidence takes time, which postpones regulation and only increases the societal pressure to regulate now. Many environmental predicaments characterized by extraordinary complexities and uncertainties display a similar vicious circle between scientific evidence and policy action: action now requires adequate evidence, but to produce adequate evidence takes time and makes acting now impossible. Climate change (Frodeman 2011) and the salinization of irrigated land (Hukkinen et al. 1990), for example, have been found to be plagued by similar paralysis. Although the general policy dilemma is known, solutions to break it vary depending on the factors that maintain the dilemma.

METHODS

In this paper we use the work on timescapes by Adam (1998, 2000, 2004; B. Adam 2008, *unpublished manuscript*) to make sense of the numerous temporal dimensions of EDC governance. In essence, a timescape can be depicted as a "cluster of temporal features, each implicated in all the others but not necessarily of equal importance in each instance" (Adam 2004:143). Adam lays emphasis on the relationship between the temporal and spatial; time as well as the understanding of time becomes contextual. Similar to the concept of landscape, the basic idea of a timescape is that the temporal sphere is the result of a series of events, both natural and man-made. The timescape thus becomes a collection of social, natural, and cultural times. However, the main focus of the timescape approach is not so much on pinpointing the ontology of time, but rather how time is used and how time affects the ways in which we deal with societal problems (Adam 2000). Adam lists seven temporal features that can be found in a specific setting:

- *Time frame - in what time frame? - bounded, beginning & end, day, year, life time (of, for example, a flea, a human being, an oak tree or nuclear isotope), generation, historical/geological epoch, etc.*
- *Temporality - how? - process world, internal to system, ageing, growing, irreversibility, directionality;*
- *Timing - when? - synchronisation, co-ordination, right/wrong time;*
- *Tempo - at what speed? - pace, rate of change, velocity, intensity, or: how much activity in any given timeframe?*
- *Duration - how long? - extent, temporal distance, horizon: no duration means instantaneity, the moment in time;*
- *Sequence - in what order? - succession and priority: no sequence means simultaneity, at same time;*
- *Temporal Modalities - when? - individual and/or collective past, present & future.* (B. Adam 2008:2, *unpublished manuscript*)

Adam argues that these timescape features coexist and influence each other. For example, the tempo of a certain activity is directly related to the timing with other activities. The speed of the work of a team in a firm may be too quick or too slow compared to that of a related team causing inefficiencies in the production process (Ancona and Chong 1996, Pérez-Nordtvedt et al. 2008). Furthermore, Adam (2004) points out that the way in which we conceptualize a given context we aim to study influences the temporal scope. One particular activity can be seen as linear when studied for a shorter period of time, but when seen in a larger context that same activity follows a cyclical logic. For example, the passing of days can be seen as a linear process of a sequence of days or as a recurring event of mornings, afternoons, nights, Mondays, and weekends. Thus, the timescape approach highlights the contextual nature of time.

Using a timescape approach to analyze the temporal misfit of EDC governance captures the diverse range of temporal features existing in a particular context and analytically divides them into examinable entities. Furthermore, the approach brings to the fore the temporal conflicts of contemporary society. According to Adam (2004), these conflicts derive from an exhaustive control and simplification of time, the imposing of industrial clock time on environmental time, giving rise to unintended and adverse consequences. Although the timescape features are linked to each other, they are "not necessarily of equal importance in each instance" (Adam 2004:143). Thus, in our analysis we will inductively discern certain temporal features relevant for our particular case, i.e., criteria for authorization of chemicals, from interviews and workshop transcripts.

The empirical data for the analysis were collected in the research project "Innovative environmental regulation with expanded expertise: Integration of facts and values in expert deliberation over environmental monitoring in the Baltic Sea (RegEx)" between 2010 and 2012. Three types of data were collected: (1) Thematic interviews with central EDC experts from Finland (n = 15) and Denmark (n = 12). The interviewees were chosen with snowball sampling, starting from Finland and moving over to Denmark. In both countries representatives from researchers, regulatory agencies, industry, and NGOs were interviewed. (2) Recordings of three Nordic expert (EDC scientists, policy makers, and other stakeholders) workshops on EDCs held in Copenhagen, Denmark in 2010; from three deliberative Finnish expert workshops on EDCs held in Helsinki, Finland in 2011-2012; and from a Nordic expert workshop on EDCs and nanomaterials held in Helsinki, Finland in 2012. (3) Secondary literature on the history and regulatory challenges of EDCs.

The thematic interviews and workshops were recorded and transcribed. The second author participated actively in all the Nordic expert workshops and was the main organizer of the Finnish expert workshops. The results of the Nordic workshops have been reported by Danish (Tørsløv et al. 2011*a*, *b*) and Finnish (Ahtiainen and Väänänen 2012) authorities. The data were analyzed according to the basic principles of qualitative text analysis (see e.g., Silverman 2004). We especially looked for indications and representative examples and quotes of timescape features by means of themes coding (Silverman 2004). Based on the resulting categorization we identified a number of mechanisms that maintain the status quo in the European EDC regime and proceeded to explore the interconnections between them. We hypothesize that the regulatory paralysis of EDCs is an emergent phenomenon maintained in large part by a temporal misfit between institutions and biophysical systems. Our

qualitative data and earlier research by others on the topic caution us against arguing for a causal relationship between the temporal misfit and regulatory paralysis. We rather strive to describe the mechanisms by which different aspects of the temporal misfit contribute to the observed inability to regulate EDCs.

RESULTS

From a temporal perspective, the current situation of the EDC regulatory regime in the EU is intriguing. Reverting to universal criteria for defining exactly what EDCs are across all specific regulations, and by so doing disregarding a number of complexities and uncertainties pertaining to the workings of EDCs (mechanisms, spatio-temporal aspects, socioeconomic aspects, and so on), forms in itself a central part of the basic mismatch between environmental time and industrial time as conceived by Adam (2004). In other words, the challenge of regulating EDCs involves temporally aligning the chemicals and their impacts on living beings with the institutions that are set out to control them. According to a potency-based suggestion for criteria for EDCs, an EDC "[should] be an exogenous substance or mixture that alters function(s) of the endocrine system and consequently *causes* adverse effects in an intact organism, or its progeny, or (sub)populations" (DE-UK 2011:8, emphasis added). By doing this it should satisfy the following four criteria:

> *› adverse effects to have been seen in one or more toxicity studies of acceptable quality, in which the substance was administered by a route relevant for human exposure.*
>
> *› a plausible mode-of-action/mechanistic link between the toxic effects of concern and endocrine disruption.*
>
> *› the effects seen in experimental animals to be judged to be potential relevance to human health.*
>
> *› serious adverse effect(s) related to endocrine disruption to have been produced at a dose at or below the relevant guidance value for the application of Category 1 "Specific Target Organ Toxicity-Repeated Exposure, STOT-RE" classification & labelling.* (DE-UK 2011:8)

If the adopted definition is based on potency, as has been suggested by some countries, the space for regulatory action will be narrow; chemicals would only be assessed insofar as they would be of relevance for human health. If the criteria will be based on more generic properties of chemicals regardless of issues of potency, the space for regulatory action is broadened to encompass effects on other living organisms (Danish Ministry of the Environment 2011). However, regardless of which definitions and criteria are adopted, one can expect the regulatory process to face significant temporal challenges regarding the observed effects on human and environmental health as documented in the "State of the Art" report (see Kortenkamp et al. 2011). This is not least due to the demand of causation, which is included in all existing suggestions for definitions of EDCs (e.g., IPCS 2002).

It could be argued, however, that it is not the criteria as such that form the core problem, but rather the varying interpretations of them by different scientific advisory bodies. Furthermore, as already evidenced by regulatory action with regard to nonylphenol, for example, some chemicals would seem to meet the demand for strong, but not definitive, evidence of causality. We agree that a few select chemicals might indeed meet the standards as explicated in the documents above. As evidenced by the case of bisphenol A, however, even in such "successful" cases, not only do regulatory responses vary significantly across countries and legislations, but in all those settings, the scientific-political processes typically take a very long time (see e.g., Brewer and Ley 2014). Thus, given the many controversies and delays, from the point of view of temporality even a success is in many senses simultaneously a failure. In the case of mixtures, this basic situation of contestation and delay gets even more accentuated.

On a general level we can thus discern a temporal misfit between EDC impacts and the institutions that are designed to manage them. We will next deconstruct this temporal misfit using the timescape approach. We focus on four specific temporal features relevant in this case, time frame, sequence, tempo, and timing, thereby shedding light on the complexity of the temporal misfit of EDC regulation within EU's REACH.

Time frame

With regard to time frame, the REACH case highlights that the time frame of the process to regulate EDCs is significantly longer than that of the chemicals' adverse impacts. EDCs, and especially their mixture effects, can arguably be seen as a "wicked problem" (Rittel and Webber 1973). Because of their complex nature, wicked problems lack exhaustive definitions and therefore correspond badly with ready-made decision-making templates (Brown et al. 2010). Wicked problems also challenge traditional knowledge production by transgressing disciplinary boundaries (Huutoniemi and Tapio 2014). Within the field of endocrine disruption, there are vast and numerous knowledge gaps and complexities, which in turn lead to a number of various uncertainties (see e.g., Stirling and Gee 2002). However, for regulatory purposes only forms of evidence that can prove the existence of a causal relationship between the purported endocrine disruptor, or a mixture of them, and the observed effects in living beings are accepted. As formulated by a Finnish expert in the first workshop on EDCs in 2011:

> *As we all know, we have the world's tightest chemical regulation, REACH, which applies in the European Union and where you start from specific substances, the goal is to find out their basic properties by 2018. And it forms the basis for regulation, toxicity properties and so on. But then we have these mixture effects, we just haven't figured out how we could regulate or manage these, for if you assume that we have about 100,000 substances in commercial use in Europe, then you realize that there are a limitless number of mixture effects, and how you could get to these, well, we are trying to find out, but as for now there is no solution.* (WS1-FI)

Sequence

The question of sequence becomes central, as the imperative that scientific determination of harm must precede regulatory action (Vogel 2004) is central in the regulation of EDCs in REACH. This sequence has historical roots and corresponds to a modern linear conceptualization of science and its relationship to policy making (e.g., Jasanoff 1990). Despite differences in the U.S. and EU institutions, most importantly the demand for screening versus establishment of universally applicable criteria to enable an authorization process, the basic second-order institutional rule that governs the formation of regulatory rules is the same in both

contexts (see Honkela et al. 2014). As one of the Finnish interviewees formulated the question in the EU:

> *The problem now is that we don't have those methods for researching EDCs, the OECD is the main forum, when the OECD countries get to gather all that knowledge and knowhow, then we can agree on testing methods, and then those methods can get integrated into the EU chemical regulation, and then we can expect that the other large countries, such as the U.S., Japan, and others, do the same. But it's a long, long road.* (INT 9-FI)

Sequence was addressed directly also in a Danish expert interview:

> *We can always find needs for new research and so on but of course, at one time you have to decide what is the scientific evidence now and can we react on that or should we just sit on our chairs and wait until we have the true evidence. And in my opinion this has dramatic consequences. I mean if our suspicion is, well, is correct, then it has dramatic consequences in both for the health, human health area, also for the environment but also it has very big economic consequences, so therefore I think we need to take a more precautionary approach to this and we should not wait until we have the true evidence but we should react before that.* (INT 18-DK)

Sequence is directly related to the challenges of chemicals assessment because establishing a causal relationship between dose and impact is one criterion for acting upon EDCs; the regulatory time frame is highly dependent on the sequential structure of the science-policy relationship. The imperative of the science-regulation sequence thus presents a significant challenge for achieving a fit between institutions and EDCs.

Tempo

In our analysis tempo involves the slowness of knowledge production due to ex-post evaluation of chemicals. The strikingly slow tempo of knowledge production is a result of the mismatch between classical toxicology on the one hand, and the extremely complex workings of the endocrine system and the EDCs on the other. First, the rule of a linear dose-response relationship states that the greater the dose, the greater the adverse health effect. EDCs typically have significant effects at liminal doses, whereas greater doses might have no effect at all. Second, the rule of uniformity of effects states that a chemical cannot have opposite effects, although they can of course be multiple. An EDC can have estrogen-like effects at one point in an organism's developmental process and antiestrogen effects at another. Third, the rule of threshold effect states that no health effect occurs when exposure is below the threshold level. As mentioned earlier, EDCs do have such an effect.

Grappling with this mismatch between the dominant toxicological logic and the observed complexity of endocrine disruption in itself forms a central impediment to knowledge production, as is clearly evident in the "State of the Art" report (Kortenkamp et al. 2011). Recent debates do not seem to involve any lessening of this basic tension (e.g., Berlaymont Declaration, http://www.brunel.ac.uk/__data/assets/pdf_file/0005/300200/The_Berlaymont_Declaration_on_Endocrine_Disrupters.pdf). As a Finnish and a Danish interviewee formulated this issue:

> *If you consider the issues effecting reproductive health, they are such that they come with great delays, and they are hard to ever prove conclusively. If you for instance think of how long it took to establish the link between smoking and lung cancer, which is as evident as anything can be, and then you consider that here we have as an endpoint something considerably more unspecific, well, then establishing the links might be impossible. And then you need to base the decision on a broader foundation.* (INT 7-FI)

> *Well, it is difficult, because it's very hard to say that because you're exposed to this lotion when you are a teenager or a child and you might not be able to have children when you are 30 or 35, so I mean the cause and effects... it's very hard to prove in humans, so I don't think there's anybody saying that actually because you are using these chemicals now, then you actually will get cancer or will have endocrine disrupting changes in your body when you get older.* (INT 26-DK)

Thus, the slow tempo of knowledge production feeds into the slow tempo of regulation. The slow tempo of regulation can evidently be seen as a fundamental obstacle to addressing the temporal fit of the EDC regime.

Timing

Finally, in our analysis timing involves the incapability of temporally aligning regulation and the cycles of EDC impact. As a result, regulatory interventions risk being taken when there are no impacts or not taken when impacts are present. A Finnish interviewee explicates the relationship between the complexity of mixture effects and periods of fetal vulnerability:

> *If you then consider fetuses, then it is clear that there are windows of vulnerability, so that if a fetus is exposed to a spike of mixtures during the most vulnerable period, then such a disaster might ensue [refers to hypospadia, a malformation of the genitals]. Then again if you look at fetal development in general, then probably the window is larger, but if you look at testicular cancer it might be very narrow. And for cryptorchidism [the absence of one or both testes from the scrotum] and hypospadias they might be in slightly different places and much more narrow. Also, for the development of sperm probably postpartum exposure is highly significant as well.* (INT 7-FI)

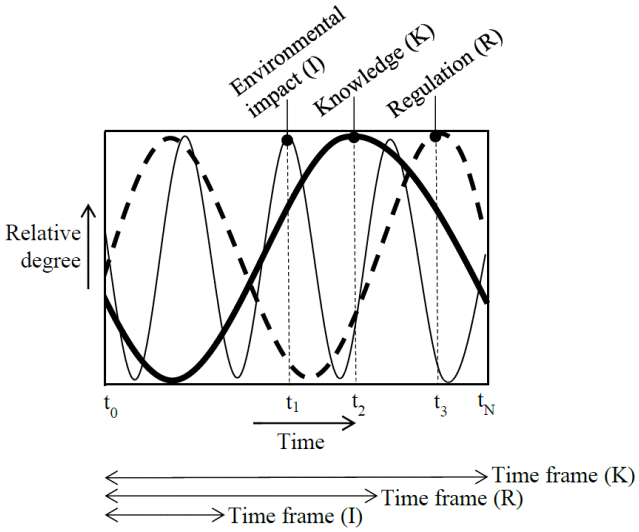
Timing is closely related to sequence and tempo because they both reproduce a rigid regulatory structure with low adaptive capacity. In the EDC case this becomes highly evident when studying the temporally complex characteristics of EDCs. As has been highlighted earlier, the adverse impacts of these chemicals are variable in time during specific periods of vulnerability. This poses significant challenges for the rigidly sequential and slowly adaptive regulatory framework of EDCs.

Summary of results

The temporal misfit we have identified in our case is illustrated in Figure 1. The temporal misfit is made of four interrelated temporal features: time frame, sequence, tempo, and timing. These temporal features are further linked to three key variables in EDC governance: environmental impact, knowledge, and

regulation. The temporal misfit can be explained by the relationship between the relative degrees of each variable and how these variables are situated in time.

Fig. 1. Temporal misfit in time frame (the time frame of regulation is longer than that of the adverse impact of chemicals), sequence (scientific knowledge of adverse impacts must precede regulatory action), tempo (the rate of knowledge production on adverse impacts is slower than the rate of emergence of complex new impacts), and timing (the cycles of regulation and impacts do not match). Knowledge, regulation, and impact are mutually dependent variables, and variation in the degree of knowledge, regulation, and impact is relative. A low point in the degree of knowledge, for example, does not mean there is no accumulation of knowledge over time, it only refers to a temporary knowledge deficit in relation to environmental impacts and regulatory needs.



Temporal misfit in

- ***time frame***: time frame (I) < time frame (R) < time frame (K)
- ***sequence***: $I_{max}(t_1)$, $K_{max}(t_2)$, $R_{max}(t_3)$
- ***tempo***: number of K_{max} < number of R_{max} < number of I_{max} during $t_0 \rightarrow t_N$
- ***timing***: $R_{max}(t_i) \neq I_{max}(t_i)$ and $R_{min}(t_i) \neq I_{min}(t_i)$

DISCUSSION

Our analysis indicates that a key factor of the temporal misfit between EDC science and regulation is the reliance on criteria as the basis for action. EDC governance is deeply ingrained in the current "reductionist" scientific paradigm (Soto et al. 2009) or what Vogel (2004) calls the "Scientific Testing and Regulatory Paradigm," which places heavy emphasis on rigid scientific proof before taking regulatory action. The underlying assumption is that more knowledge leads to more control and that ignorance today can be offset by enhanced capabilities tomorrow. Although the EU's REACH has reversed the burden of proof from government to producers, the basic assumptions of the paradigm nevertheless remain (Hansen et al. 2007). This poses significant problems for the regulation of EDCs because the influence of these chemicals can be acutely and directly toxic, but more often they have indirect, hormonal effects with significant time lags between exposure and observed adverse outcome (Adam 1998, Vogel 2004). Furthermore, such hormonally active chemicals can interact and give rise to so-called mixture effects, or combination effects (e.g., Council of the European Union 2009).

We suggest that one way to solve the regulatory paralysis, especially with regard to mixture effects, is to reframe the notion of scientific evidence. We are reminded of many other fields of environmental governance in which science is brought to bear on environmental issues with less emphasis on absolute quantification and more emphasis on expert judgment. Environmental impact assessment (EIA), which is conducted prior to large-scale projects with typically poorly quantifiable and incommensurable impacts, is a case in point. The International Association for Impact Assessment (IAIA) has defined EIA as "the process of identifying, predicting, evaluating and mitigating the biophysical, social, and other relevant effects of development proposals prior to major decisions being taken and commitments made" (IAIA 1999). In addition to allowing for multiple criteria for validity of information, a strength of EIA is that it can be applied to projects and operational procedures (project EIA) as well as legislative proposals, policies, and programs (strategic EIA), that is, precisely the multiple aspects of emerging substances of concern such as EDCs.

Although the effectiveness of EIA to protect environmental interests as well as its value-neutral assumptions have come under critique from scholars emphasizing that "its fundamentally rationalist approach is out of step with the realities of decision making" (Jay et al. 2007:298), researchers have begun to look beyond the deterministic function of EIA. The focus here is on EIA's role in creating discursive spaces that facilitate the engagement of public actors in the decision-making process (Rozema et al. 2012). From this perspective EIA has the potential to increase not only the legitimacy of the process as a whole, but also the capacity for social learning among the participating actors (Wilkins 2003, Runhaar et al. 2010). The EIA process can thus serve as a means to consider alternative options for manoeuvre and to broaden the areas of discussion (Saarikoski 2000, Stirling and Gee 2002). Seeing the EIA process as a largely social endeavour utilizing a wider scope of data and input can thus enable more well-rounded attempts to reduce regulatory morasses.

Bearing this in mind, we contend that EIA would be a more appropriate framework for considering scientific evidence on EDCs, especially relating to mixture effects. It would enable reframing what constitutes scientific evidence in the context of a precautionary regulatory process: acknowledgement of the limits of knowledge, attention to research and monitoring next to models and laboratory tests, attention to indirect causes of harm, participation by relevant stakeholders, and reflection on alternative options (Stirling and Gee 2002). Rather than requiring quantitative risk assessments of EDCs, a possible solution could thus be to grant a panel of regulatory experts, EDC scientists, and civil society organizations the power to deliberate and agree over the criteria and implementation details of the regulation of particular classes of EDCs.

More generally, what kind of insights does our case offer for the concepts of temporal fit and misfit? Our findings suggest that we

need to pay considerably more attention to what we mean by time and understand that time is a multifaceted concept. We have put forward a more inclusive approach to studying temporal (mis)fit where the notion of fit involves various and coexisting temporal features in social-ecological systems. Furthermore, we argue that we need to pay special attention to the feedback processes between temporal features. In our case, for example, the slowness of knowledge production in the European EDC regime is closely related to the sequential structure of the science-policy interface, the imperative that no regulatory action can take place before adequate scientific evidence of chemical impacts. We can thus identify instances where the different temporal features are closely interlinked and influence each other, thereby strengthening the temporal misfit further.

Our findings from the EDC governance regime are in line with earlier research emphasizing the need for understanding interactions across temporal scales (e.g., Folke et al. 2007, Paavola et al. 2009). However, few studies to date have specified the interactions between temporal features. We argue that utilizing the concept of timescape (Adam 1998, 2000, 2004; B. Adam 2008, *unpublished manuscript*) constitutes a fruitful approach to studying these interactions. The research on timescapes stresses that the particular object of study dictates which temporal features are most relevant and, furthermore, encourages the researcher to carve out the temporal dynamics of the issue that one wants to solve. In accordance with Ostrom's (2007:15181) appeal to move "beyond panaceas," the concept of timescape stresses the importance of context and the danger of overly deterministic accounts of time. Acknowledging that time can be conceptualized as a redefinable combination of different temporal features, we argue that an integration of the concept of timescape with temporal fit presents a fruitful tool for making sense of the complex dynamics of time in social-ecological systems.

CONCLUSION

We have addressed the concept of temporal fit by analyzing the temporal challenges related to the governance of EDCs in Europe. We argue that the concept of temporal fit is valuable for understanding the temporal challenges of governance, but that it would benefit from a more comprehensive approach to studying time. Two points in particular require attention when addressing temporal fit: (1) the complexity of temporal misfits and (2) the interlinkages between temporal features. Both aspects loom large in our analysis. We identified four temporal features linked to the temporal misfit in the EDC governance regime: time frame, sequence, tempo, and timing. The timescape approach emphasizes that time should not be treated as a one-dimensional concept, but rather as an assemblage of temporal features whose composition depends on the specific case at hand. This also applies to analyses of temporal fit: our study has shown that temporal misfits are coupled to the interdependencies between temporal features. We conclude that the introduction of environmental impact assessments (EIA) in EDC governance could serve as a means to address the temporal misfit between institutions and EDCs.

Responses to this article can be read online at:
http://www.ecologyandsociety.org/issues/responses.php/7033

Acknowledgments:

We thank the participants of the Environmental Policy Research Seminar at the University of Helsinki and two anonymous reviewers for valuable comments on the manuscript. Financial support from the Finnish National Doctoral School in Environmental Social Science (YHTYMÄ), the Maj and Tor Nessling Foundation Grant no. 2013194 and the Academy of Finland Grant no. 140830 are gratefully acknowledged. A previous version of the paper was presented at the 10th Biennial Conference of the European Society for Ecological Economics, Lille, France, 18-21 June 2013, and at the RGS-IBG Annual International Conference, London, United Kingdom, 28-30 August 2013.

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