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International environmental law as a complex adaptive system

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Abstract Complex adaptive systems are a special kind of self-organizing system with emergent properties and adaptive capacity in response to changing external conditions. In this article, we investigate the proposition that international environmental law, as a network of treaties and institutions, exhibits some key characteristics of a complex adaptive system. This proposition is premised on the scientific understanding that the Earth system displays properties of a complex adaptive system. If so, international environmental law, as a control system, may benefit from the insights gained and from being modelled in ways more appropriately aligned with the functioning of the Earth system itself. In this exploratory review, we found evidence suggesting that international environmental law is a complex system where treaties and institutions self-organize and exhibit emergent properties. Furthermore, we contend that international environmental law as a whole is adapting to exogenous changes through an institutional process akin to natural selection in biological evolution. However, the adequacy of the direction and rate of adaptation for the purpose of safeguarding the integrity of Earth's life-support system is questioned. This paper concludes with an emphasis on the need for system-level interventions to steer the direction of self-organization while maintaining institutional diversity. This recommendation stands in contrast to the reductionist approach to institutional fragmentation and aims at embracing the existing complexity in international environmental law.

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1 Introduction

Complex adaptive systems (CASs) are everywhere. A CAS by definition is "a system in which large networks of components with no central control and simple rules of operation give rise to complex collective behavior, sophisticated information processing, and adaptation via learning or evolution" (Mitchell 2009, p. 13). Examples where CAS thinking has been useful include ecosystems (Levin 1999; Gross et al. 2006), the Earth system (Lenton and van Oijen 2002), natural resource management regimes (Rammel et al. 2007; Booher and Innes 2010), environmental law (Ruhl 1997), policy (Emison 1996; Folke et al. 2002) and governance (Duit and Galaz 2008; Cherp et al. 2011), and international investment law (Pauwelyn 2013). Despite obvious differences between these social and ecological systems, complexity theory has provided a common conceptual framework that bridges the gap between scientific understandings of the two.

In this paper, we investigate the proposition that international environmental law (IEL), as a set of treaties and institutions directed at reducing human impacts on the environment, exhibits some key characteristics of a CAS. There are two key justifications for understanding IEL *in toto* as a CAS. First, the subject matters of IEL at all scales, from species to Earth's subsystems (e.g., the climate system), display CAS-like properties. Ecosystem responses to human impacts, for example, are nonlinear, uncertain, and unpredictable (Levin 1999). Here, the traditional top-down, command-and-control approach is of limited effectiveness as it is premised on a false assumption of ecological equilibrium (Holling and Meffe 1996; Folke et al. 2002). Governance of CASs rather requires their control systems to behave like a CAS in order to be effective (Ashby 1956; Dooley 1997; Ostrom 1999; Ruhl 2008; Ahmed and Hegazi 2009; Duit et al. 2010). What has been proposed as an alternative model is *adaptive* or *polycentric* governance, which is considered to be best suited for enhancing institutional "fit" (Young 2002; Galaz et al. 2008) with the complex dynamics of Earth's social-ecological systems (Holling 1978; Berkes et al. 2003; Walker et al. 2004; Folke et al. 2005; Folke 2006; Olsson et al. 2006; Ostrom 2010). This emerging governance model is "ecological" and draws heavily from complexity theory (Ostrom 1999; Folke et al. 2002; Gunderson and Holling 2002; Duit and Galaz 2008; Duit et al. 2010).

Second, there are good reasons to believe that IEL is already some kind of CAS (regardless of its effectiveness); hence, it is logical to approach IEL through the lens of complexity theory. Empirical research has advanced considerably since scholars first began pondering whether a distinctive system of IEL emerged, not just more random norms about environmental protection (e.g., Birnie 1977; Kiss and Shelton 1986; Freestone 1994; Boyle and Freestone 1999; Najam et al. 2004; Bodansky 2006). For example, it has been observed that multilateral regimes evolve (Bodansky and Diringer 2010; Young 2010) and to some extent mutually adjust (Galaz et al. 2012b; Kim 2012). Furthermore, Kim (2013) showed that 747 of multilateral environmental agreements have self-organized into a complex network, which is far from random. Although it is difficult to prove IEL is a CAS, it should be useful to draw on the existing analyses and further assess IEL against some key CAS characteristics and suggest how IEL can be understood as a CAS.

Methodologically, the "IEL as a CAS" approach aims to understand how IEL *in toto* works and influences the planetary environment (c.f., Decleris 2000; Jóhannsdóttir et al. 2010). The key unit of analysis is not individual treaties or institutions, but the links that hold the system together. By filtering details and amplifying macroscopic patterns, we describe and explain emergent properties that are not reducible to the properties of individual components (Gallagher and Appenzeller 1999). This non-reductionist understanding can be used for developing system-level interventions that would enhance the *alignment* of the "maze" of international environmental agreements with the dynamics of the Earth system as a whole (United Nations Environment Programme 2012). The ultimate purpose of this exercise is to contribute to "adaptively managing the complex adaptive legal system to adaptively manage other complex adaptive natural and social systems" (Ruhl 2012, p. 1).

In particular, a CAS perspective holds the key to understanding the relationship between architecture and adaptiveness, which constitute major analytical problems for Earth system governance (Biermann 2007). Complexity scientists explain that certain system architectures, in which the components differ and where incomplete connectivity causes modularity, tend to have adaptive capacity (Scheffer et al. 2012). Examples include human brains, which are optimized for information transmission and rapid adaptation to exogenous perturbations (Sporns et al. 2004; Bullmore and Sporns 2009; Stam and van Straaten 2012). The CAS approach to IEL, therefore, has the power to contribute a theoretical explanation as to why "loose couplings" of governing institutions are desirable over other forms (Keohane and Victor 2011; Young 2011; Galaz et al. 2012b; Zelli and van Asselt 2013; Orsini et al. 2013; see also Orton and Weick 1990). In this sense, the CAS lens allows us to choose appropriate responses to fragmentation of IEL or, more broadly, institutional complexity (Oberthür and Stokke 2011; Zelli and van Asselt 2013).

In what follows, we discuss key features of a CAS and briefly review the scientific explanation of the Earth system as a CAS. We then consider in some detail how IEL can be understood as a system of treaties and institutions, which is complex and adaptive. We conclude by discussing what these imply for the future of IEL.

2 Complex adaptive systems

2.1 What is a complex adaptive system?

According to Meadows (2008, p. 2), a system is "a set of things … interconnected in such a way that [they] produce their own pattern of behavior over time." In a system, one can identify parts, the parts affect each other through flows of energy or information, and the parts together produce an effect that is different from the effect of each part on its own (Meadows 2008). It follows that a system must consist of three kinds of things: elements, interconnections, and a function or purpose.

If "the collective behavior of [the] parts together is more than the sum of their individual behaviors" (Newman 2011, p. 800), the system might be complex. If not, the system is merely complicated (Ottino 2003). Underlying all agent interactions of a complex system is often simple, deterministic rules. What makes the interactions complex is how these rules, when set in motion among the diverse components a system, produce nonlinear relationships including reinforcing and stabilizing feedbacks. Because of the nonlinearity, local interactions give rise to larger-scale behavior that is not implicit in the parts of the system. This property of complex systems is called emergence. An example is the stability of characteristics of the atmosphere (Petit et al. 1999). This appearance of emergent features happens in the absence of an external planner or controller. In other words, no one designed the system to operate in a particular way, yet it maintains its system identity. This second defining property of complex systems is called self-organization.

CASs are special cases of complex systems, although the line between them and complex systems is not clear. For the purpose of this analysis, we define CASs as complex systems with the ability to adapt to changes in the external environment as a result of experience via conditional action and anticipation (Holland 1995; Kauffman 1995; Bak 1996; Levin 1999). Adaptation occurs through an autonomous process that uses the outcomes of local interactions among diverse system components to select a subset of those components for replication or enhancement (Levin 1998, 2002). Natural selection of biological evolution is the prototypical example of such an autonomous process. Through this process, CASs constantly evolve and unfold over time in relationship to the larger environment in which they operate (Arthur 1999).

CASs are dynamic but exhibit coherence under change (Holland 1995). This critical state of stable disequilibrium is a hallmark of CASs (Bak 1996). The region where CASs operate or strive toward is called the "edge of chaos," a critical transition point between order and randomness (Lewin 1992; Waldrop 1992; Kauffman 1993; Bak 1996). It is the balance point "where life has enough stability to sustain itself and enough creativity to deserve the name of life" (Waldrop 1992, p. 12). In the context of global environmental governance, the edge of chaos essentially is where institutional stability and flexibility or resilience and efficiency maintain the right balance for effective and adaptive governance (Walker and Salt 2006; Saunier and Meganck 2007; Duit and Galaz 2008). In terms of system architecture, this point is the frontier between regular lattices and random networks (Watts and Strogatz 1998), where incomplete connectivity among institutions causes modularity or clustering.

2.2 Earth as a complex adaptive system

Earth as a whole can be considered as a *complex* system, comprised of many interwoven parts or subsystems, nonlinear feedbacks with delays, whose dynamics are characterized by critical thresholds and abrupt changes (Steffen et al. 2004). The Earth system displays emergent properties that are not fully explained by an understanding of the parts (Lenton and van Oijen 2002). For example, the relationships between greenhouse gases in the atmosphere and the temperature are not a simple cause–effect relationship, but rather a complex coupling involving several global-scale feedback loops between the atmosphere, land, ocean, and geosphere (Steffen et al. 2004). Earth's climate, therefore, is an emergent property of the Earth system.

In what sense might the Earth system be *adaptive*? Earth can be understood as comprising component ecosystems, each of which is an adaptive system (Holland 1995; Levin 1998). Ecosystems are assembled from biological parts (populations of species) that have evolved over long time and broad spatial scales (Levin 1998). The collective experiences of populations of species across a range of ecosystems over time shape the collection of parts from which the ecological community's assembly occurs (Levin 1998). But what about the Earth system as a whole: can it be considered a CAS?

Vernadsky (1998) defined the biosphere in terms of the role the biota plays in modifying the chemical composition of the atmosphere, ocean, land surface, soil, and substrate. Consistent with Vernadsky's early empirically based studies, it is now well established that the biota play a significant role in Earth's biogeochemical processes (Steffen et al. 2004). The Gaia hypothesis (Lovelock and Margulis 1974) proposed that the biota play the critical role in regulating Earth's physical environmental conditions and maintaining them in a condition fit for life. Strong evidence of planetary self-regulation comes from the 420,000-

year isotope record contained in the Vostok ice core (Petit et al. 1999), which shows the regular pattern of inferred atmospheric carbon dioxide, methane concentrations, and temperature through multiple glacial–interglacial cycles. The tightly constrained upper and lower bounds of all these variables are a typical feature of a CAS.

Lenton and van Oijen (2002) argued that the biotic dimension of the Earth system fulfills the CAS criteria of Levin (1998) as it contains sustained diversity and individuality of components (populations of organisms), localized interaction among these components (food webs), and at least one autonomous selection process (natural selection). The biosphere (*sensu* Vernadsky 1998) can be understood as an emergent property of the Earth system *in toto* as it represents the consequence of interactions between life and the physical environment. The Earth system therefore shares the generic CAS properties identified by Arthur et al. (1997) including dispersed interaction, the absence of a global controller, cross-cutting hierarchical organization, continual adaptation, perpetual novelty, and far-from-equilibrium dynamics (Lenton and van Oijen 2002).

Scientific debate continues as to the extent to which biota and ecosystems regulate versus influence Earth's environmental conditions, and the relative strength of biological processes compared with the other physical components of the Earth system, including those processes that involve exchanges of energy and matter among the Earth's subsystems. However, the extraordinary extent to which over geological time periods the biota and Earth's chemistry have coevolved (Williams 2007) supports the proposition that the Earth system is complex and, in many ways, adaptive. Irrespective of the precise mechanisms by which the Earth system exhibits at least apparent self-regulation, the facts are that Earth has kept within the general boundaries supportive of life since the onset of life, the biota has both adapted to and altered Earth's chemistry, energy balance and climate subsystem, and our species, *Homo sapiens*, have evolved and flourished within an even narrower set of planetary environmental conditions—called "planetary boundaries" or "safe operating space" by Rockström et al. (2009).

With the rise in technology and population growth, humans are now a major forcing factor on the Earth system (Steffen et al. 2007). The Earth system has been altered by human societies to the extent that global environmental degradation is evident and planetary boundaries are being exceeded or threatened (Steffen et al. 2004; Millennium Ecosystem Assessment 2005; Intergovernmental Panel on Climate Change 2007; Rockström et al. 2009). As there is a limit to the resilience of any CAS, if pushed hard or persistently enough, the Earth system may undergo a phase transition through which a radically new system architecture is installed, which will then be locked in through a path-dependency effect. In fact, scientists argue this is indeed what has happened at the planetary scale since the Industrial Revolution (Steffen et al. 2004). Human actions triggered a regime shift in the Earth system from the climatically stable Holocene to a new and largely unknown geological epoch named the Anthropocene (Crutzen 2002; Steffen et al. 2007, 2011).

The view of the Earth system as a CAS has significant implications for the future of IEL (c.f., Duit and Galaz 2008). Global environmental changes are inherently unpredictable; hence, our governing institutions need to be sufficiently flexible and able to rapidly adapt when necessary to, for example, nonlinear changes. At the same time, institutions must be stable and rigid enough to ensure that humanity stays within the "safe operating space." The right balance between these contrasting properties is achieved and maintained in a CAS, and hence the proposition IEL should be designed as one. The way forward necessarily involves gaining a detailed understanding of the existing institutional network as a system. Without this, well-intended reforms could backfire and undermine current attempts to create a new, adaptive form of IEL (Galaz et al. 2012a).

3 Understanding international environmental law as a complex adaptive system

Building on our definition of CAS, here we try to understand IEL as a CAS in three steps: (1) as a *system*, (2) as a *complex* system, and (3) as a complex *adaptive* system. We assess IEL against the established criteria reviewed in Sect. 2.1.

3.1 International environmental law is a system

The first question is whether IEL constitutes a *system* of interdependent components in functional relationships, rather than merely a random collection of discrete norms and institutions. Considerable advances have been made in recent years in analyzing the relationships between international institutions: overlaps (Rosendal 2001), interactions (Young 2002; Oberthür and Gehring 2006), interlinkages (Chambers 2008), broader consequences (Underdal and Young 2004), regime complexes (Raustiala and Victor 2004; Keohane and Victor 2011), conflicts (Wolfrum and Matz 2003), clusters (Oberthür 2002; von Moltke 2005), nexus (Hussey and Pittock 2012), polycentricity (Ostrom 2010; Galaz et al. 2012b), and complexity (Oberthür and Stokke 2011; Zelli and van Asselt 2013). Although most analyses were done at a dyadic level (i.e., between two institutions), they collectively suggest that there may be a larger systemic structure emerging from dyadic relationships.

3.1.1 Elements—a system consists of component elements

The body of IEL primarily comprises separately negotiated and institutionalized norms and treaties (Kiss and Shelton 2004; Birnie et al. 2009; Sands and Peel 2012). According to one source (Mitchell 2013), we have over 2,000 bilateral and multilateral environmental agreements. These agreements typically contain specific prescriptions for addressing an environmental problem with a transboundary scope. They vary to a significant degree in terms of their subject matters, objectives, legal nature, memberships, regulatory mechanisms, underlying jurisprudence, and so on. Some are relatively widely scoped whiles others are more specialized, focusing on a particular problem such as persistent organic pollutants, threatened species like the polar bear, or a special ecosystem such as wetlands.

It has been observed that modern multilateral environmental agreements are increasingly acting like legally independent organizations with "autonomous institutional arrangements" that usually comprise a conference or meeting of the parties with decision-making powers, a secretariat, and one or more specialist subsidiary bodies (Churchill and Ulfstein 2000; Ulfstein 2012). Gehring (2007, p. 496) similarly observed that these agreements have become "autonomous sectoral systems of international law, which increasingly internalize the management of conflicts about the interpretation of commitments as well as the treatment of cases of non-compliance." Some scholars argued that these treaties perceive and behave as if they have "sovereignty" in an institutional sense (United Nations Environment Programme 2001; Kim and Bosselmann 2013). The legal autonomy of the treaties has been emphasized repeatedly because "importing" rules between treaties with different state memberships is perceived as an erosion of national sovereignty (Wolfrum and Matz 2003; van Asselt 2012).

3.1.2 Interconnections—a system consists of interacting elements

To say IEL is a system assumes that there are meaningful relationships among its components. Given this, one factor that confers on IEL the status of a system is the secondary rules of international law that defines the relationships among myriad norms and institutions (Bodansky 2006; Cardesa-Salzmann 2012). The Vienna Convention on the Law of Treaties of 1969 provides some fundamental international norms, such as *lex specialis* and *lex posterior,* for resolving treaty conflicts (Borgen 2005; Borgen 2012). In addition to these universal maxims, many contemporary multilateral environmental agreements have conflict clauses into their texts (Matz-Lück 2008). Such clauses regulate the extent to which the duties and obligations of the parties arising under existing agreements shall prevail or are modified or derogated by the agreements incorporating the conflict clause (Matz-Lück 2008).

De facto relationships arise when multilateral environmental agreements interact institutionally, often because their subject matters are interdependent. An example is the interaction between the UN Framework Convention on Climate Change and the Convention on Biological Diversity regarding terrestrial ecosystems that play a role in both climate change mitigation and biodiversity conservation (e.g., Doelle 2004; Kim 2004; Locke and Mackey 2009; van Asselt 2012). Individual institutional interactions vary in kind and effect, ranging from cooperative, neutral, to disruptive (Gehring and Oberthür 2006; see also Biermann et al. 2009) (disruptive relationships should not be confused with fragmentation, which refers to cases of non-interaction). A number of general principles are in operation to guide institutional interactions, including the principle of systemic integration (McLachlan 2005), the principle of mutual supportiveness (Sanwal 2004; Pavoni 2010), and the "duty not to transfer damage or hazards or transform one type of pollution into another" (e.g., UN Convention on the Law of the Sea 1982, article 195).

In order to enhance institutional cooperation and coordination, the conferences of the parties, the highest decision-making authorities of multilateral environmental agreements, are often required to "[s]eek and utilize, where appropriate, the services and cooperation of, and information provided by, competent international organizations and intergovernmental and non-governmental bodies" (UN Framework Convention on Climate Change 1992, article 7.2(l)). Secretariats similarly engage in "integration by stealth" (Biermann and Siebenhüner 2009) with the secretariats of other relevant international bodies (e.g., UN Framework Convention on Climate Change 1992, article 8.2(e)). There are at least 350 secretariats as at 2013 (Mitchell 2013), many of which entered into formal institutional arrangements with one another for the purpose of enhancing cooperation and coordination. Sometimes, memoranda of cooperation are signed to set up for more detailed joint work plans or programs for a set period of time. Multiple secretariats can establish informal forums such as the Joint Liaison Group among the three so-called Rio Conventions with the purposes of exchanging information, exploring opportunities for synergistic activities, and increasing coordination.

The cases of institutional interactions typically involve the flow of information. Treaty and administrative bodies exchange information, both formally and informally, on shared substantive issues (United Nations Environment Programme 2010). They share reviews and lessons learned regarding their functioning and frequently consult each other on administrative or legal issues that arise. Some interconnections in systems are more tangible than the exchange of information. The Secretariat of the Convention on Biological Diversity requests assistance for parties' deliberations during meetings, for example, on climate change-related issues. Secretariats have also entered into arrangements, whereby they can share staff or consultants (United Nations Environment Programme 2010). Furthermore, a number of major secretariats regularly participate at other's conferences of the parties as observer organizations. A notable example is the Convention on Biological Diversity Secretariat, which often chairs side events and organizes press conferences in international climate change conferences. Both the virtual and more concrete relationships between treaty secretariats speak to functional connections that further support the system status of IEL.

3.1.3 Function—a system is more than and different to the sum of its parts

Do international environmental legal norms collectively give rise to an emergent function of IEL that are not fully explained by an understanding of the individual norms? Bodansky (2010) outlined three general types of functions that are served by IEL: (1) an increase in the demand for cooperation or the political will among states to establish effective regimes; (2) the supply of agreements that effectively exploit whatever level of demand or political will exists; and (3) enhancement in the capacity of states to respond (Bodansky 2010). These can be considered as emergent functions as they are not specified in any one treaty or institution and are something different from the effect of each individual one.

Another kind of emergent functional property would be whether IEL has a definable boundary and a degree of autonomy or at least distinctive operation from international law *per se*. An argument against IEL having system status is it lacks a systematically codified single treaty or group of treaties, unlike other domains such as trade and human rights law (Brownlie 2005; Birnie et al. 2009). Boyle (2007, p. 127), for example, argued that IEL is "nothing more, or less, than the application of international law to environmental problems and concerns."

However, the institutional landscape that has emerged overall suggests that IEL has, to a significant degree, become a distinct and autonomous system (Bodansky 2006; Bodansky et al. 2007). Some date this moment back to the 1972 Stockholm Conference (Ellis and Wood 2006; Sands and Peel 2012). Freestone (1994) argued that the Earth Summit in 1992 signalled the emergence of a system of IEL, rather than simply more international law rules about the environment. The Rio Process accelerated the emergence of a discrete discipline of IEL with its own distinctive principles, its own mechanisms, and instruments designed to address issues that are different in kind from other issues of international law (Boyle and Freestone 1999). It can be argued, therefore, that IEL is distinct from international law, not simply in the sense of addressing a discrete set of problems through a discrete set of substantive rules, but also in the stronger sense of having its own characteristic structure and legislative and administrative process, and its own set of conceptual tools and methodologies (Bodansky 2006). As noted by Long (2010, pp. 47–48):

> International environmental law is a body of 'special' international law in that the various [multilateral environmental agreements] all seek to address problems involving the human relationship to the natural world. The field has developed a certain level of coherence through incorporation of unifying principles in nearly every major [multilateral environmental agreement], such as the obligation to avoid transboundary harm and the principle of common but differentiated responsibilities. Viewed as a part of the landscape of international law generally, then, it is justifiably understood as a closely connected and deeply intertwined field of law.

IEL can be considered a *system* of treaties and institutions, even though this system lacks either a dedicated umbrella international organization or an international dispute settlement process with the ability. Furthermore, we can conclude that IEL is more than a simple sum of its institutional elements as something different is emerging through complex interactions among their treaties and institutions.

3.2 International environmental law is a complex system

In terms of the overall structure, IEL has been described as a decentralized network of embedded, nested, clustered, and overlapping institutions (Young 1996). This web of institutions is becoming increasingly congested as a result of *ad hoc* treaty-making, and accordingly, the United Nations Environment Programme (2012) called it a "maze." The overall structure and evolutionary dynamics of this alleged maze was analyzed by Kim (2013), who created a series of agreement-level connectivity maps by using cross-references in multilateral environmental agreement texts as links. This dynamic treaty citation network started with a single node in 1857 and grew to 747 nodes with 1,001 links by 2012.

Despite the piecemeal approach to environmental treaty-making, the majority of the 747 multilateral environmental agreements have self-organized into an interlocking network that exhibits several important properties of complex networks that are found in the real world (Kim 2013). For example, the emergent treaty network is a "small world" where most agreements can be reached from another agreement in the network within a reasonably small number of steps (Watts and Strogatz 1998). The network also has a relatively small number of highly connected "hubs," implying that treaties have interacted preferentially (not randomly) with others that are already well connected (Barabási and Albert 1999). By observing how the average path length and clustering coefficient have changed over time, Kim (2013) argued that complexity emerged in 1992 coinciding with the Earth Summit.

It is important to note that the complex system of multilateral environmental agreements has not arisen from collective bargaining or institutionalized decision-making at the aggregate level. Rather, agreements have self-organized and complexity emerged spontaneously. The overall structure has incrementally evolved from, and is continuously shaped and reshaped by, the numerous decentralized decisions taken within individual institutions and the interaction effects arising therefrom (Oberthür and Gehring 2011). There is no single legislative will behind this IEL system: each multilateral environmental agreement is a *de facto* lawmaker (Churchill and Ulfstein 2000; Brunnée 2002; Wiersema 2009). Independently formed, heterogeneous norms and institutions that interact with a few non-randomly selected others make up the *complex* system of IEL.

Furthermore, as the network representation of Kim (2013) showed, new agreements were not negotiated on a clean institutional slate (Raustiala and Victor 2004). IEL forms a multilayered, historical construct, where later agreements typically build on one or more previously existing agreements. In this sense, extant institutional arrangements constrain and channel the process of creating new rules, hence the content of new treaties and institutions (Raustiala and Victor 2004). The IEL system, therefore, is likely to demonstrate path dependence, which is an important feature of complex systems.

3.3 International environmental law is a complex adaptive system

Complexity *per se* does not necessarily guarantee that a system is adaptive (Mitchell 2009). The key characteristic of an adaptive system is feedbacks and, in response, changes in institutional behavior (Ruhl 2008). Observations can be made at two levels: individual treaty regimes and IEL as a whole.

3.3.1 Multilateral environmental agreements are dynamic institutional arrangements

Multilateral regimes have typically evolved over time through trial and error (Bodansky and Diringer 2010). They can become deeper (e.g., Convention on International Trade in Endangered Species of Wild Fauna and Flora), broader (e.g., Antarctic Treaty System), more integrated (e.g., UN Convention on the Law of the Sea), or along multiple dimensions (e.g., World Trade Organization) (Bodansky and Diringer 2010; see also Young 2010).

This process has been made possible through a three-tiered approach of framework agreement, protocols, and annex/appendices that enable flexibility and adaptability by providing for the negotiation of protocols and allowing legal amendments or other modifications (Klabbers 2008; Brunnée 2012). For example, the UN Framework Convention on Climate Change provided an institutional setting for the Kyoto Protocol to be negotiated that set emission reduction targets for specific greenhouse gases for its parties. Another example is the 1972 London Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, whose "black and gray list" approach was replaced by the "reverse list" approach under the 1996 London Protocol, where all dumping is prohibited, except for the wastes on the list. While between 1857 and 2012 there were 515 parent agreements adopted, during the same period, 219 protocols and 437 amendments were negotiated, which often modified or specified the contents of their parent agreements (Mitchell 2013). It is notable that the proportion of amendments has gradually increased over time, which is possibly an indication of the treaty system's increasing adaptive capacity.

Although some of the adaptability and flexibility is reflected in the rise of framework conventions, much of the change comes from the ability of the conferences of the parties to respond to new information, especially scientific information about the state of the target environmental phenomenon (Huitema et al. 2008; Wiersema 2009). Contemporary multilateral environmental agreements, in comparison with traditional intergovernmental organizations, are more informal and flexible, and often innovative in relation to norm creation and compliance (Churchill and Ulfstein 2000). Through negotiations, state members can collectively make adaptive decisions that are evidence-based. For example, the 7th Conference of the Parties to the UN Framework Convention on Climate Change adopted the Marrakesh Accords in one of its decisions to specify rules relating to land use, land-use change and forestry, which is a major greenhouse gas inventory sector under the Kyoto Protocol. In the 17th Conference of the Parties held in Durban, South Africa, these rules were significantly altered through negotiation based on the lessons learnt from the Marrakesh rules' implementation (Grassi et al. 2012). Other examples include the Conferences of the Parties to the Convention on International Trade in Endangered Species of Wild Fauna and Flora regularly revising its endangered species list in light of updated information on species' conservation status. The revisions adopted by these conferences are, however, legally non-binding, hence constitute "soft law." However, due to their quasi-legal nature, soft law instruments are generally more adaptive and progressive than legally binding treaty texts, and therefore play a significant role in IEL.

As reviewed here, environmental treaties no longer represent static contractual agreements among states at a particular point in time (Gehring 2007). Instead, they are dynamic institutional arrangements, which establish ongoing regulatory or legislative processes (Gehring 2007) and are *de facto* lawmakers (Brunnée 2002). The result is that in most international environmental regimes, the treaty text itself represents just the tip of the normative iceberg (Bodansky et al. 2007). The majority of the norms are adopted through relatively flexible and dynamic processes, thus providing the system with adaptive capacity.

An important institutional arrangement for treaty evolution is subsidiary bodies that are commonly established to provide the Conference of the Parties with scientific and technical advice relating to implementation of multilateral environmental agreements. Examples include the Subsidiary Body for Scientific, Technical and Technological Advice of the Convention on Biological Diversity, whose principal functions include providing assessments of the status of biological diversity. Such a treaty body effectively functions as a core unit in a feedback process that provides information on the effects of the treaty on its subject matter back to the decision-makers in a timely manner. In some cases, external bodies aid the feedback process, such as the Intergovernmental Panel on Climate Change that supports the UN Framework Convention on Climate Change and the Scientific Committee on Antarctic Research for the Antarctic Treaty System, respectively.

More subtle and policy-driven changes in existing law may arise through the process of interpretation (Boyle 2007; Gardiner 2012), reflecting the notion that treaties are living instruments that should be interpreted in light of contemporary conditions. Article 31(3)(c) of the 1969 Vienna Convention on the Law of Treaties provides a powerful means in this regard (McLachlan 2005). It requires that the interpreter of a treaty takes into account "any relevant rules of international law applicable in relationships between the parties," and it may include other treaties, customary rules, or general principles of law. This dynamic approach to interpreting treaties provides additional adaptiveness in a way that builds a more coherent system.

3.3.2 International environmental law as a whole is adaptive

Each treaty or institution may be capable of learning from the experiences of its state members in applying negotiated rules, but what about the system of treaties and institutions as a whole? In what sense might IEL *in toto* be adaptive? To answer this question, we can look for evidence that the IEL system is in some sense coevolving with its external environment by inducing changes on itself and improving the institutional "fit" with the Earth system dynamics. In this context, "coevolving" means adaptive changes in response to feedbacks and interactions, the "external environment" includes both the social system out of which the legal system arises and the state of the natural environment, and "fitness" refers to more effectively addressing the environmental problems.

In any evolutionary process, there must be generation of new alternatives, selection among new and old combinations of attributes, and retention of those combinations that are successful in a particular environment (Ostrom 1999). In natural systems, mutation introduces multiple forms into a given system, and through natural selection, the forms that are best fitted to the system's environment become the norm in the population (Mayr 2001). By analogy, the evolution of a legal system can be seen as involving the "innovation of forms" and the "emergence of norms" (Trujillo 2004, p. 528; see also D'Amato 2005, 2009). The process of choice in a legal system always involves a degree of experimentation.

Variations among treaties or institutions can be understood as a result of experimentation in the IEL context. When drafting a new international agreement, for example, states experiment with different norms, institutional forms, and regulatory mechanisms (Guzman 2005; Lejano 2006; Bodansky and Diringer 2010). States then select those actions arising in treaty negotiations that prove most useful and formulate them as rules and precedents of the IEL system. The time at which such new norms ripen can be determined by the status of ratification of international agreements that incorporated the norms or the existence of *opinio juris*, that is, by testing whether states were acting under a belief that their actions were required by IEL.

Through the iterative process of experimentation, some norms and institutions become popular and authoritative while others never come into force and perish. For example, some international environmental norms, such as intergenerational equity, the precautionary principle, and common but differentiated responsibilities, have grown in influence in IEL. Others, such as the duty not to transfer damage or hazards or transform one type of pollution into another, have been less influential and by comparison have withered on the vine. A similar process can be observed at the level of international environmental agreements. Whereas the UN Convention on the Law of the Sea, for example, has become one of the most cited authoritative texts around which order is established (Kim 2013), the International Convention for the Prevention of Pollution from Ships of 1973 never came into force, and the Kyoto Protocol was never ratified by a major greenhouse gas emitter (i.e., the United States).

It can be concluded that the IEL system as a whole has adaptive capacity, but the adequacy of the direction and the rate of system-level adaptation can be questioned. The self-organizing processes do not necessarily imply that IEL has been able to adapt to the constantly changing planetary *biophysical* environment and in particular those changes driven by human impacts. Given the loose feedback between Earth system science and international environmental policy, institutional responses have been more strongly influenced and constrained by international politics rather than scientific knowledge (Axelrod 2011). Having the IEL system to adapt to global environmental changes may require transforming the legal system from merely a reflection of socio-politically agreed standards to something that proactively leads the change in social norms, as informed by science and guided by ethics. How to achieve this by maintaining the balance between stability and flexibility in the IEL system is the key challenge.

4 Implications for the future of international environmental law

Where does this analysis leave us? What can we gain from understanding IEL as a CAS? Our exploratory review suggests that we have an emergent *system* of IEL and need to be better nurturing this *de facto* system (e.g., Haas 2004; Najam et al. 2004; Kanie 2007). Despite the piecemeal approach to environmental treaty-making, IEL is not a purely chaotic, randomly organized, fragmented collection of norms and institutions. Rather, it has a deep underlying coherence, a functional, albeit minimal, structure and continuity. Major implications that follow from this are outlined below.

The emergence of a system has important implications for how we should approach the so-called problem of institutional fragmentation. The literature on fragmentation generally assumes that institutional proliferation has led to fragmentation, which needs to be *managed* for a clearer order (e.g., Zelli and van Asselt 2013). On the contrary, the "IEL as a CAS" approach highlights that institutional proliferation does not necessarily imply fragmentation (Kim 2013) and fragmentation does not necessarily imply anarchy (Galaz et al. 2012b). In fact, in most real-world complex systems such as the Internet, there are far more disconnects among system components than there are connections and yet the systems maintain coherence under change. If a system has few connections, it may be operationally efficient in the short term but vulnerable in the face of external pressures and new circumstances. System with many redundant connections may appear less efficient but can be more resilient in the longer term (Walker et al. 2004).

The above supports the case for strengthening the existing decentralized system. Centralized institutions have been called "unecological" as they run counter to the principle of requisite variety, lack sufficient flexibility, and inhibit random mutations (Haas 2004). On the contrary, decentralized institutions are "ecological" in the sense that they have diverse components and are constantly changing through self-organization. Therefore, the CAS approach highlights the need to embrace, rather than to reduce, the complexity of IEL (Axelrod and Cohen 1999). IEL should be further nurtured as a CAS and let it self-organize toward the right balance of stability and flexibility (Duit and Galaz 2008) and resilience and efficiency (Walker and Salt 2006).

The decentralized treaty network could be strengthened in practice through implementing secondary rules of international law, which we mentioned earlier, such as the principle of systemic integration (Kim 2012; Kim and Bosselmann 2013), the principle of mutual supportiveness (Sanwal 2004; Pavoni 2010), and the duty not to transfer or transform harm or hazards (e.g., UN Convention on the Law of the Sea 1982, article 195). Furthermore, one could strengthen organizational ties such as the duty to cooperate and coordinate among treaty bodies or other institutional arrangements (Chambers 2008; Scott 2011).

Furthermore, the CAS perspective highlights the need to *steer* the direction of treaty system self-organization. Currently, the system is adaptive to exogenous changes but not necessarily to the dynamics of human impacts on Earth's life-support systems. There are two feedback loops that need to be strengthened in this regard. First, the IEL system needs a stronger reinforcing (positive) feedback loop from the biophysical environment (e.g., planetary boundaries) to its decision-making nodes. An existing example is the Intergovernmental Panel on Climate Change (Hulme and Mahony 2010), which periodically reviews the state of the climate system and provides information to the international climate regime in support of evidence-based policy formulation.

Second, in order to avoid internal dysfunction, the IEL system needs an appropriate high-level goal. For example, actions taken to protect a part of the environment may result in unintended transfers and transformation of pollutants between subsystems (Teclaff and Teclaff 1991). The goal of a system is a powerful leverage point that helps give direction to a system's self-organizing ability and feedback loops (Meadows 2008). By analogy, in order to direct an economic system toward desired macroscopic outcomes (such as "keeping the market competitive"), the self-organizing aspects of the market must be complemented by feedbacks, which are directed by a high-level goal. The feedbacks here could come from goal-oriented central agencies that modify local rules of interaction that inhibit each business from eliminating its competitors. Similarly, in ecosystems, the goal of keeping populations in balance and evolving trumps the goal of each population to reproduce without limit (Levin 2002; Meadows 2008).

The notion of goal is used in the context of the IEL system to mean a single, legally binding, superior norm (Kim and Bosselmann 2013). Currently, the IEL system lacks a clearly agreed common goal to which each of the MEAs must contribute to and not transgress. In this sense, the IEL system *in toto* may not yet constitute an effective control system for global environmental sustainability (Jóhannsdóttir et al. 2010; see also Proelss and Krivickaite 2009). The key to the next stage in the evolution of the IEL system is for the international community to negotiate and establish a primary, overarching goal that all multilateral environmental agreements must act in agreement with and contribute to, irrespective of their individual specific objectives (Kim and Bosselmann 2013). An example of such a goal would be "to maintain global ecological integrity" as defined by the nine planetary boundaries of Rockström et al. (2009).

5 Conclusion

A CAS is a large network of interacting elements connected in a particular pattern of organization from which arises the ability to adapt to external change by learning from experience (Holland 1995; Levin 2002). Here, we investigated the question of whether IEL, as a set of norms, treaties, and institutions, exhibits the characteristics of a CAS. If so, the legal system may benefit from the insights gained and from being modelled in ways more appropriately aligned with the functioning of the Earth system itself. Theoretically, the benefit exists because, in a turbulent environment where change is constant, complex dynamics are best handled by a complex adaptive organization (Dooley 1997; Ostrom 1999).

This exploratory review has found some indications that IEL has evolved into a CAS. Despite the *ad hoc* approach to environmental treaty-making, a system has emerged spontaneously (Najam et al. 2004; Kim 2013), whose overall structure is usefully complex rather than dysfunctionally fragmented. Heterogeneous treaties and institutions, many with their own decision-making power and limited (yet adaptive) learning ability, interact in the absence of an external authority. The self-organization of the legal system is taking place through a process of norm-generation and norm-selection, which can be likened to natural selection in biological evolution.

It is not clear from our analysis, however, that the IEL system has been sufficiently adaptive to human-forced global environmental change *in toto*. There is growing evidence that, despite the accumulating body of IEL, global environmental conditions continue to deteriorate (Millennium Ecosystem Assessment 2005; Cordell et al. 2009; Hanjra and Qureshi 2010; Secretariat of the Convention on Biological Diversity 2010; Gattuso and Hansson 2011; Levermann et al. 2013). A demonstrable need exists to enhance the overall performance of IEL through major institutional reforms (Biermann et al. 2012; Bosselmann et al. 2012; Kanie et al. 2012).

Our review suggests that the key architectural problem of IEL may not be institutional proliferation or fragmentation *per se* (c.f., Koskenniemi and Leino 2002). IEL as a system has a deep underlying structural continuity with some degree of self-organizing capacity. Therefore, the problem needing attention is the lack of a goal in the sense of a single, legally binding, superior norm that can serve to steer all environmental treaties and institutions toward a common end. Such a goal-oriented approach to global environmental governance would facilitate adaptability and flexibility of the IEL system within the constraints of the legal norm (Kim and Bosselmann 2013). Additional IEL reforms could be fruitfully implemented, which build upon this recommendation. For example, the relationships between treaties and institutions could be strengthened through upholding the principle of systemic integration, the principle of mutual supportiveness, and the duty not to transfer or transform environmental harm. There are strengths to the IEL system that arise from it being a decentralized system (Kanie 2007); hence, significant performance improvement can be expected from reforms that help create a stronger interlocking network of treaty obligations (Chambers 2008; Scott 2011).

These reform measures would take us a step closer to a system of IEL fit for the Anthropocene. This next generation of IEL, tentatively named here as "Earth system law," would embrace its own complexity along with that of its subject matter. To that end, there may be benefit in stepping back and taking a look at the larger picture to consider the ultimate purpose of the IEL system.

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