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Current Opinion in Environmental Sustainability

The legacy of Elinor Ostrom and its relevance to issues of forest conservation

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In 2009, Elinor Ostrom won the Nobel Prize in Economic Sciences for her contributions to the governance of commonly owned resources. She was the founder of the International Forestry Resources and Institutions program (IFRI), and the co-founder of the Center for the Study of Institutions, Population, and Environmental Change (CIPEC), and the Vincent and Elinor Ostrom Workshop in Political Theory and Policy Analysis, all of which provided lively arenas in which natural and social scientists from diverse disciplines collaborated. Forests and their transformations as well as ways to conserve them to serve people's needs was one of the urgent research topics Elinor Ostrom investigated. Her contributions were significant for forest management and conservation and informed her work on the commons and institutional diversity. Lessons from these Ostrom-led efforts proved that self-governance was possible but that it depended on multiple factors. In her work with economic experiments, Ostrom was able to replicate important findings that gave support to case studies from IFRI and CIPEC. She showed that panaceas did not exist for resource management challenges. Ostrom's work showed the value of building multinational, multidisciplinary, and comparative research bridging the social and natural sciences and the complexity of governance systems. These multiple layers and complexity are reflected in her Socio-Ecological Systems framework (SES).

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Current Opinion in Environmental Sustainability 2016, **19**:47–56

This review comes from a themed issue on **Sustainability science**

Edited by **Hal Mooney**

http://dx.doi.org/10.1016/j.cosust.2015.12.001

Introduction

Of all the anthropogenic drivers bringing about changes in our planet, one seems to have had the greatest consequence: changes in land cover, particularly changes in forest cover. Forests provide a large number of provisioning, regulating, supporting, and cultural ecosystem services that stabilize climate, protect plant and animal species, provide food and shelter to local communities, and sequester vast amounts of carbon due to the constant turnover of plant biomass and plant senescence. The ecosystem services provided by forests occur at local to global levels. For a very large part of human history, forests have changed in spatial location and composition due to natural climatic changes occurring commonly over long periods of time, such as during the Pleistocene. What has changed in the last three centuries is not the fact of land-cover change but its acceleration through the growing human capacity to deforest and transform landscapes [1•]. According to the Millennium Ecosystem Assessment, in the last three centuries global forest area has declined by 40%. Moreover, forests have disappeared in 25 countries and in 29 countries they have declined by at least 90% [2]. We know that it took several centuries for the monasteries of the Middle Ages to deforest a substantial portion of the western European landscape. Palynological data obtained in recent years show a devastating impact on forests from the agricultural activities based in monasteries in the early to late Middle Ages [3••]. By the 19th century, it was possible for homesteading farmers to move across the forested lands of North America and cut down most of the existing forests in less than a century (e.g. Indiana went from 94% forest cover in 1810 to 6% in 1920) [3••]. Comparable deforestation is now possible in a matter of a few decades due to technological capacity, favorable government policies, expansion of the agriculture frontier, commercial logging, urbanization, agribusiness pressures, infrastructure demands, and much larger populations acting simultaneously to transform forests into agro-pastoral areas. Forests and their transformations as well as ways to conserve them to serve people's needs was one of the urgent research topics Elinor Ostrom investigated. She investigated forests through a range of organizations at Indiana University: the Center for the Study of Institutions, Population, and Environmental Change (CIPEC), the International Forestry Resources and Institutions (IFRI) program, and the Workshop in Political Theory and Policy Analysis which she co-founded with her husband Vincent Ostrom in 1973 (renamed in 2012 in honor of her and her co-founder husband as The Vincent and Elinor Ostrom Workshop in Political Theory and Policy Analysis, hereafter referred to simply as the Workshop).

Forests provide a habitat for many species of economic interest, besides the important preservation of ecosystem structure and function. Forest products such as seeds and mushrooms are an important source of nutrients for human consumption, and wood and charcoal are important sources of energy in many developing countries. Forests provide large amounts of valuable nutrients for farmers when they clear forests through slash and burn methods, thereby making poor and mediocre soils yield a bountiful yield for a year or two. When practiced at low population densities, slash and burn methods of land preparation provides a sensible, low-cost way to obtain vital produce from otherwise low agricultural yield regions. Forests in North and South America, Africa, and Asia have undergone cycles of slash and burn that only became destructive and unproductive when fallows were shortened due to high population pressure, and natural restoration was not allowed to complete an adequate cycle of regrowth of secondary vegetation. According to Chhatre and Agrawal [4•], it is estimated that at last one billion people depend at least partially on forest products. Forests play important roles in protecting the very landscapes upon which humans depend.

In this paper, we review some of Ostrom's experience with IFRI, CIPEC and the Workshop and specifically her contributions through these organizations to the study of forests' use and conservation. IFRI addresses how local communities across various parts of the world (12 countries) were able to create and manage their forests sustainably. CIPEC, created later than IFRI, focused on why some forests were degrading and others doing better in the Americas (North, Central and South) across three types of forest ecosystems (temperate deciduous, tropical dry, and tropical moist forests). From the Workshop, she used experimental economics to replicate in the lab, the overharvesting behavior predicted by economic theory, but also ways to prevent it by using institutional[1] arrangements inspired by her experience and the experience of some of her colleagues in the field,[2] including forest settings.

It is important to note that Ostrom also contributed to other groups that she was associated with: the Commons Property Network, the Resilience Alliance, and the Center for the Study of Institutional Diversity at Arizona State University. All these other organizations benefited from the energy and commitment of Elinor Ostrom to these issues with a red-thread constituted by her efforts to show how pervasive the role of institutions were and how they serve to elucidate how human communities self-organized to deal with social dilemmas and tragedies of the commons, to name just two. However, because of the scope of this paper, we do not intend to describe her enormous contributions for these other organizations and programs. But we recognize that her work in the three academic homes at Indiana as well as her work with other groups provided the setting for Ostrom's work on institutions, and the development of her approach to the Socio-Ecological System framework [5••,6••] within the context of what was happening to forests across the world.

Central to Ostrom's work was to understand how some communities were able to manage their resources in a successful way while other fail to do so. In Ostrom's seminal book *Governing the Commons* [7••], she investigated different common-pool resources (CPRs)[3] and concludes, as opposed to Hardin [8•], that some local communities were able to manage their resources, including forest, in a sustainable way, whereas resources managed by private tenure or by the State did not always lead to sustainable management. Ostrom identified a set of 'design principles' that were common in communities that were self-governing their natural resources in a sustainable way. All these communities created different institutional arrangements at the local level that were respected by community members as well as others not directly involved in the community, and that were successful in the long run.[4] Ostrom described this as the 'emergence' of collective action for managing the commons. As we will describe later, her work with IFRI allowed her to investigate different forests around the world.

The work of Ostrom and Moran in CIPEC was motivated by the question: why some forested areas seem to be thriving and growing back their forest landscapes, while other areas seem to be experiencing rapid losses of forests or degradation. Given the role of human action, and institutions or the lack of them, it behooves one to understand the variables that account for forest restoration as well as forest loss. Since human populations and institutions play such key roles, they needed to understand how different

[1] Institutions, as defined by Ostrom [8], are formal and informal rules in use. Institutions determine what people may do, must do, or cannot do in specific situations.

[2] Different types of forest governance are used to manage forests all over the world — in some places national parks have been created as a strategy to guarantee the forests' preservation; in other scenarios, forests have been allocated to private owners to manage them; in other places rural communities have demonstrated that they have the capacity to create rules to manage the forests in successful ways; other forests are co-managed by different actors. It was, then necessary to identify the existing institutions to manage forests and determine the social, ecological, political, and economic outcomes.

[3] Forests are common-pool resources. In general, Ostrom [8] described a CPR as a natural or man-made resource system that has two main characteristics: the first is that it is difficult or very expensive to exclude people from using it and get benefits from it; the second is that anything one user takes out of the system reduces the amount available for everyone else.

[4] This initial list of design principles was later not considered sufficient. Agrawal [48] expanded the list of principles, and Cox et al. [49] systematically studied case studies aiming to identify the design principles.

human groups organize, or not, to achieve their goals of balancing their needs to produce food, shelter, and income from forested areas with their need to conserve forests to be able to use them in long-term sustainable fashion.

While IFRI and the Workshop had a clearly social science orientation in how they went about their work, CIPEC inserted a more explicit environmental dimension to the research, and thus became the natural home for the development of interdisciplinary discussions on socio-ecological systems (SES). These discussions in turn spilled over into debates in IFRI and the Workshop. It is important to remember that the boundaries between these three organizations were fluid, and they reflected a single-minded concern by Ostrom to investigate the role of institutions in natural resource management.

IFRI and the institutional dimensions of change in forest ecosystems

The IFRI network is a unique international and interdisciplinary network that studies local, commonly held forests[5] to comprehend how institutions and socioeconomic conditions may affect forest condition over time. The importance of common forests is undeniable since they account for 18% of the forests of the world [9]. IFRI was first established at the Workshop with the support of the Food and Agriculture Organization of the United Nations. The program was moved to University of Michigan in 2006 to ensure its continuity [10]. IFRI work is conducted in collaboration with partner organization called Collaborating Research Centers (CRCs). Currently IFRI is working in 12 countries and at 357 forest sites (http://www.ifriresearch.net). Besides the diversity of researchers, forests, and countries, IFRI uses a common protocol that was established in 1992–1993 (10 forms that constitute the IFRI protocols)[6] [10]. The CRCs received training at either Indiana University or University of Michigan.[7] Each CRC leads the research in its own country, including the selection of IFRI sites and has the exclusive use of the data during the first year.[8] The idea is that sites should be visited once every five years; the information collected goes from forest mensuration to information about forest user groups, forest uses, and information at the community level. IFRI has an IFRI database that is shared with all CRCs in the network.

The IFRI protocols were originally on the basis of the Institutional Analysis and Development[9] (IAD) framework developed by Ostrom; therefore the information collected is very solid in theoretical terms and can be used to study a particular case or to do comparisons among cases. The IFRI methodology has contributed to studying human impacts on forests. Central to the forests studied and to IFRI is the concept of institutions, vital for human social organization, and in part responsible for shaping natural resources. IFRI allows researchers to study what types of institutions local communities design to manage their forests, but by answering that question it also addresses issues of sustainability, equity, rights, and democracy [11–13], issues of great interest to Ostrom as well.

Supporting Ostrom's design principles [7••], the research from CIPEC and IFRI has shown that in order to have good forest governance, independent of the type of institution managing the forest, it is necessary to have a common goal and an approach that is shared and respected among different stakeholders apart from the direct forest users. As Vélez [14] noted, one of the biggest advantages of the land titling process to afro-colombians along the Pacific Coast of Colombia is that titling gave the community the right to create rules to manage their territory, including their forests and, more importantly, provided them with a legal right to exclude other groups from having access to their territories. So now that these communities have the rights to their forests, they are starting to think about ways to manage them.

Even more challenging is to find ways to protect forests and the livelihoods of people in and around them when powerful groups[10] have other ideas for using those forests. The hierarchy around the management of forests plays an important role in the way forests look today and will look in the future. A successful case of this, documented by Batistella [15], was the protection of forests held by rubber tappers in a sea of colonist cattle ranches in Rondônia. The institutions created by rubber tapper user groups were able to fend off efforts by neighboring cattle ranchers to cut down forests, and these were the only islands of forests remaining after 20 years of settlement. On the contrary, in countries like Peru and Colombia, mining is supposed to play such an important role in the country's 'development' that forests, independent of who owns them, are being seriously jeopardized. The same is happening with the construction of hydroelectric dams in the Amazon and Africa —where national energy policy trumping local rights and local needs [16]. To find ways to maintain forests in the face of the hierarchical development model is crucial if we want to guarantee the existence of forests and healthy environments in the future as well as to protect the livelihoods of communities that live in and around them.

[5] IFRI also studies forests owned and managed by national government and private forests.

[6] The protocols are available at www.ifriresearch.net.

[7] Nowadays all the training happens at the University of Michigan.

[8] The data are available to the coordinating center the second year, and after the third year the data become available to the whole network.

[9] The framework is a meta-theoretical framework that identifies action situations, patterns of interactions and outcomes, and an evaluation of these outcomes.

[10] Powerful groups can be the State, industries, or armed groups

Many authors signaled the importance of context to shape decisions among forest users. Dietz and Henry [2] go further by disentangling three definitions for context, and specifying that all definitions have an impact on the commons. The first definition is ''interaction' in statistical analysis — the effect of one variable. . .depends on other factors' [2:13189], for example how users' forest uses may depend on whether or not it is easy to access the community where people live. Context may also mean that regional and national governments and the larger political economy shape local actions and responses to actions. This may be called 'extra-local arrangements' and is linked to the hierarchies that we mentioned earlier. Dietz and Henry [2] consider this topic a high priority for future research because it is the extra-local influences that may be more efficiently influenced by policy. The third and last definition relates to social networks, and their importance for collective action and management of the commons.

The IFRI research has been fundamental to demonstrate that self-governance and local monitoring and rule enforcement are very important in maintaining forests all over the world [17••]. Supporting this point, Gibson *et al.* [18] analyzed 178 forest groups and 220 forests from the IFRI database and found that regular monitoring and rule enforcement are necessary conditions for successful resource management. The authors compare the efficacy of moderate versus regular monitoring, finding that regular monitoring has a positive effect on forest conditions. Chhatre and Agrawal [4•] support this finding: in studying enforcement and its relation with forest conditions in 152 case studies, the authors found that the probability of regeneration of the forest increases with the level of enforcement.

Tucker [11], in a summary of what we have learned from CIPEC and IFRI, identified factors that are associated with sustainable forest governance, not only in common property regimes but also in public and private tenure systems: local people need secure rights to land and forests; institutions need to fit the local context; and monitoring and enforcement are very important for success. Without the capacity and willingness to monitor and enforce, all types of tenure and institutional arrangements will fail to protect natural resources. Tucker [11] also identified a series of 'contingent variables' that interact with the factors already mentioned. Among these variables she identifies that a governance system needs flexibility to adapt to the fact that forests are not static, and the way users view it over time change as well; the need to create partnerships between different actors including the forest owners; and finally the fact that there are no panaceas to how to manage forests [18,19••]. This last point, the lack of panaceas, was one of the most important themes that Ostrom kept reminding readers in her later years.

Human–environment research in CIPEC

The work of CIPEC was very much framed within the framework explored earlier in IFRI, the Workshop, and the call for a human dimensions of global change research agenda elaborated by the National Research Council (NRC) [20•] and the ongoing work jointly developed by the International Geosphere-Biosphere Program and the International Human Dimensions Program [21]. A panel of scientists met and produced over the next several years a Science Plan to guide the work of the international community [22]. Similar, but varying to some degree, were the research priorities defined by the NRC. The first major guiding document to appear from this expert panel was the 'rainbow book,' *Global Environmental Change: Understanding the Human Dimensions* [20•]. This book defined a broad set of priorities that identified *land use and land cover change as the top research priority* but that listed in detail other important questions that deserved attention, such as environmental decision making, integrative modeling, environmental risk analysis, and studies of population and environment. Many of the recommendations of this book served as guidance to funding agencies, and led to the creation of human dimensions centers of excellence. The book provided a framework for Moran and Ostrom in cobbling together the specific focus on forest conditions as shaped by demographic, institutional, and land use considerations. CIPEC was funded by The National Science Foundation and led by Ostrom and Moran.

At the creation of CIPEC, Ostrom and Moran sought the engagement of faculty and students from the School of Public and Environmental Affairs (SPEA) at Indiana University to bring much needed expertise in forest ecology, hydrology, and soils. As an interdisciplinary school, this brought a large number of natural scientists already familiar with working across disciplinary boundaries with the social scientists who were leading the Center effort. The population element (the P in CIPEC) of this human–environment interaction brought to the table also colleagues from the Population Institute for Research and Training (PIRT) at Indiana University and consideration of demographic factors that might be implicated in the fate of forests. Faculty from political science, history, sociology, anthropology and geography were brought on board to engage with the ecology group to advance the proposed work. It is commonplace in ecology to suggest that human populations are a major disturbance in forest ecosystems, and thus that it was important to have population study be a central part of the design of the variables to study. Both of these elements, demography and ecology were relatively new to both IFRI and the Workshop, and the research in CIPEC informed the subsequent work of both IFRI and the Workshop, as the collaborations with demographers and ecologists continued from that time onwards. On the other hand, CIPEC benefited tremendously from the

earlier work of IFRI. It can be said that CIPEC would not have been possible without the previous research done by Ostrom with IFRI — and the standardized protocols developed by IFRI became essential tools for CIPEC. IFRI and CIPEC contributed to Ostrom's path-breaking work with approaches that complemented each other.

The questions posed by the human dimensions agenda were new questions that reached beyond the traditional disciplinary concerns and thus extended the value of social science to all of society. Unlike traditional disciplinary research, for example, human dimensions research demanded a multiscaled approach to research. This was rarely the case with discipline-based research and was thus a broadening of the way the social sciences can contribute to our understanding of the world around us. The work on human dimensions linked the biological, physical, and social sciences thereby making social sciences centrally important not only to other social scientists but to the rest of the sciences. This point was not missed by Ostrom who found the challenge very energizing and who became ever more adept at addressing the concerns of the natural sciences and how to bring institutional analysis to considerations of the socio-ecological system.

Work on human dimensions requires comparison and multidisciplinary approaches. This offers the potential for more robust tests of the applicability of site-, region-, or nation-specific findings. By testing things cross-nationally, cross-regionally, and cross-locally, the results are more likely to be robust and theory is thereby strengthened. The human dimensions research agenda challenges most of the social sciences (except geography, which already is sensitive to this) to develop new spatially explicit ways to select cases for comparative analysis, to determine sampling frames in a spatial context, and to model results that are spatially informed. This is true as much for the social sciences as for ecology, which is developing spatial ecology as a field of study and thereby revolutionizing the way environmental scientists think about population ecology and community ecology.

Undertaking these challenges was an awesome task. It required working in large teams of scientists from different disciplines, rather than working alone as is more common in the social sciences and even in ecology. To be successful, Ostrom and Moran insisted at the start of CIPEC meetings, to leave one's 'weapons' (our favorite theories, our past training) at the door, and to choose the right tools, theories, and methods for the questions being asked (without regard for what discipline they came from). The goal was to pick the right one for the job at hand, even if it meant that team members would need to learn all sorts of new approaches that were not part of their earlier academic training. It was a challenging and exciting task, one that ensured continuous growth in one's skills and perspectives, an open approach to research, without sacrificing rigor, and ensuring that the research speak to the questions society needs answers to. This is not to say that it was easy. It took well over a year and a half for the team to negotiate distinct terminologies, and to start sharing of theory and methods and to comfortably work together across the disciplines. The group established reading groups to discuss a range of theories that offered potential in guiding the research (many of these are discussed in chapter 2 of Moran and Ostrom [3••]). As Tucker suggests 'Each data collection method complements the other by compensating for any weakness and together permitting a more holistic analysis' [11:693]. The goal was to force each and every member of the group to become familiar with the work of disciplines and theories other than their own, and to learn what they might offer to the research tasks the group had defined. This was largely successful and it was a lovely sight to see political scientists talking about soil types, ecologists talking about common-property institutions, and anthropologists examining demographic data such as life-course tables.

CIPEC began with extended discussions on methods and measures that the team could agree on across the forest ecosystem types, across different cultural and national boundaries, and that would facilitate the eventual task of comparison. Considerable weight was given to the availability of remotely sensed data (from air photos to earth-observing satellites such as Landsat) since this permitted work at a variety of spatial and temporal scales, could be scaled up and down from small areas to large regions, and made the task of spatially explicit research clear from the start. While Ostrom had not used satellite images before, Moran brought this dimension to CIPEC from his earlier work in the Amazon and land use, and Ostrom took to it with alacrity. To choose sites for research, therefore, the team insisted that those candidate areas, besides fitting within the three main forest ecosystem types they focused on (tropical dry forests, tropical moist forests, and temperate deciduous ecosystems), must have cloud-free time-series remotely sensed data that could be obtained to facilitate land-cover change analysis over large areas, to complement the local studies that would be undertaken in the field. These remotely sensed data, largely Landsat Thematic Mapper (TM) data at 30-m resolution, would be further enhanced by data overlays using geographic information systems developed to handle data layers such as soil class information, vegetation types, hydrologic network, topography, and other information coming from sources such as the demographic census (see chapters on methods in Moran and Ostrom [3••] for details).

CIPEC took advantage of the IFRI field protocols to obtain data from people on a range of issues such as demography, forest uses, local institutions, economy, history of land use, and their relationship to other user

groups in the ecosystem and local region. This was both innovative and rare. The social sciences have often been reluctant to agree on widely applied protocols to standardize data collection across sites because of the potential for overlooking distinctive local cultures, linguistic differences, and ways of responding to questions. The design of these common protocols permitted, over the 8 years of CIPEC, to collect data at 50 sites in 12 countries and to generate over 400 publications — many of them of a comparative nature (http://www.indiana.edu/~cipec). All these data were collected in a spatially explicit fashion using GPS instruments to locate precisely on the ground the data that were obtained. To ensure accurate classification of the land-cover analysis using satellite data, a large number of 'training samples' were obtained for each land-cover class of interest. Training samples are detailed descriptions of a land-cover type, with a precise geolocation using a GPS that can be used to train the computer to recognize like classes on the image. A substantial number of these are reserved for later use to arrive at an accuracy assessment of the land-cover classification.

A good example is the paper that won the Cozzarelli Prize given by the National Academy of Sciences for the best paper published in PNAS in 2006 for Ostrom's paper with Harini Nagendra [17••] showing the value of remote sensing in identifying anomalies in institutional management of forests. She co-authored many other papers with colleagues from CIPEC using remote sensing as a tool in the analysis of forest conditions.

The CIPEC work yielded important insights that contributed to the development of land change science, human–environment research, and the burgeoning work on sustainability science. In Moran and Ostrom [3••] the various collaborators contributed papers on theory, methods, and applications to forest ecosystem management from the lessons learned. These are summarized in the first chapter of that book: the substantial costs of developing standardized protocols across the natural and social sciences; the importance of spatially explicit data collection to address scale issues; that scale matters; that context matters; the difficulty of defining what a forest is; that property owners under any tenure regime can design successful institutions; that biophysical limitations such a steepness provide a necessary but not sufficient degree of protection to forests; that there are glaring omissions in some data collection; that population growth is not necessarily correlated with loss of forests under local conditions; that policies need to consider how differently forest change processes may be at different scales; and that we need a better understanding of the determinants of forest transition theory. One of the most important lessons, discussed in the final chapter of this synthesis book, was that it was possible to sustain disciplinary rigor and develop interdisciplinary skills at the same time; that the interdisciplinary approach takes time and cannot be hurried but is worthwhile; that using standardized protocols across sites are a must to carry out comparative research; and that fieldwork of natural and social scientists together has enormous payoffs in facilitating collaboration and mutual respect.

Common-pool resource dilemmas in experimental economics

The seminal CPR experiments conducted by Elinor Ostrom, James Walker, and Roy Gardner [23••,24] were the first static laboratory economic experiments simulating the decisions of a group of users faced when managing a CPR, i.e. addressing the social dilemma between cooperation and free riding. These first experiments were conducted in a laboratory with students from Indiana University. The authors found that participants in the experiments were overharvesting beyond the Nash equilibrium, thus behaving as Hardin predicted, when they were not able to communicate and in the absence of any other institutional arrangement. However, the authors also found that when participants were allowed to communicate, even just once, they were able to escape from the tragedy of the commons, even though from the perspective of non-cooperative game theory, this communication is 'cheap talk' and does not change any of the incentives of the games. In this communication process, participants cannot enforce any agreement made during the game.

Ostrom, Walker, and Gardner [23••,24] noticed that communication improved the cooperation levels among participants but that the level of cooperation varied dramatically across groups — identifying the fact that more research needed to be done to understand why and when communication works, and more importantly how that cooperation can be sustained over time. Another institutional setting tested by these three authors was the role of sanctioning, in which participants were allowed to use some of their earnings to pay a fee to impose a fine on another participant. Once again, the prediction from the standard economic model is that participants will maximize their income (material payoffs), and that they will not incur any costly punishment. Ostrom *et al.* [24] found the opposite was true, that participants used sanctioning mechanisms to impose a fine on participants who were extracting a lot from the CPR. Their results also show that participants were using the mechanism more often if the fee was smaller and the fine was higher. Ostrom [25] summarizes other main findings found in these experiments: First, even though participants will cooperate, cooperation diminished over time in repeated iterations; Second, beliefs about what others will contribute affects one's decisions; Third, the frame of the game affects the cooperation rates. These first experiments reflected findings already observed in case studies (for example that communication works, that people use costly monitoring systems), including the fact that self-governance was not

only possible, but also that it can happen very often (reported in Poteete *et al.* [26••]). The experiments have been replicated in other labs, showing results that are robust, and therefore giving internal validity to the findings. As noted by Wilson [27], these initial findings have been updated with other economic experiments. For example, Chaudhuri [28], found that it is now clear that conditional cooperation is common, and therefore that it is a strategy that users of natural resource follow in the game setting and in the field. The author also finds that if participants can choose their own group, they will cooperate more.

Since these first experiments in the lab, CPR experiments have been replicated in the field [29•,30–32] with real users of natural resources all over the world. Field experiments increase the external validity of experiments as compared to lab experiments by recruiting participants from a much diverse population and with experience in the task they are asked to perform in the experiment [33•]. Many of these experiments have focused on forest users and their management of forests, and provided insights as to the conditions facilitating or impeding the use and conservation of forests. Ostrom was very enthusiastic and encouraged several scholars she came into contact with to pursue these field experiments. Cardenas [30] conducted CPR experiments with forest users in three villages in Colombia; his results showed that in the absence of institutions or communication, participants extracted on average units very close to the Nash equilibrium. When communication was allowed, the cooperation at the group level increased. He also identifies that other variables such as economic dependence and the level of wealth seem to have an influence in the way participants behave in the experiment. Additionally in Cardenas *et al.* [29•] the authors found that external regulations, such as a fine, may crowd out people's extraction since when facing a regulation participants increase their extraction level in comparison with the rounds with no regulations. Ghate *et al.* [31] conducted a series of CPR experiments with eight forest communities in India. The authors report that these communities have a long tradition of sharing norms and a high level of trust, so not surprisingly these factors influenced the decisions in the game from the very beginning. Participants in these experiments were cooperating even in the absence of communication or any other institutional setting. When communication was allowed, it homogenized the group decisions, creating less economic disparities among participants. The findings described from experiments in the field are in the same direction as the results from case studies in the sense that context matters and, therefore, that the context of the participants influences their decisions during the game [34–36] and demonstrated once again Ostrom's point that there are no institutional panaceas.

New projects like the one led by Krister Andersson at University of Colorado at Boulder and funded by the Coupled Natural-Human Systems (CNH) program at NSF (DEB-1114984) are expanding the use of experiments in the field. This project looks at ways in which local communities craft institutions to manage their local forest, and what are the effects on the forest and their users of the implementation of different institutions. In order to accomplish these tasks, this interdisciplinary team created three field economic experiments that in combination with ecological information, surveys, focus groups and interviews will provide new insights about tropical forest management.

The economic experiments conducted in the lab and in the field together with case studies have helped in the creation of a contemporary theory of collective action led by Ostrom's pioneering work in this area [7••,23••,24]. This work has been a particular focus of advances at the Center for the Study of Institutional Diversity at Arizona State University that Ostrom helped create. As described by Janssen [37], the economic models implied that individuals were only motivated by the maximization of their income and therefore that individuals were selfish and rational. Experiments and empirical evidence have shown that all people are not selfish, and in fact that many are conditional cooperators, and that human preferences change over time, depending on the circumstances and that they give considerable weight to other individuals in society. Poteete *et al.* [26••] emphasized the importance of the micro-situational variables and the context, and their importance in the decision-making process.

The future

Research on forests and therefore on SES, as Ostrom saw it, differed from disciplinary research in a number of important ways. SES research must be inherently interdisciplinary given the complexity of factors that must be taken into account. No discipline offered an adequate array of theories, methods, and concepts to provide integrative analysis and modeling capabilities. The work must be multinational in scale, otherwise one is likely to erroneously think that what one sees as processes in one country, region, or village apply to the globe. This forces an agenda oriented toward comparative research wherein one must collect comparable data in a number of nations and regions so as to sample the diversity of biophysical, economic, demographic, institutional, and social processes. Because the earth is such a complex entity, this means that the work must be spatially explicit so as to be able to anchor the work precisely on the earth's surface and understand what is site-specific from what is generalizable. Because the agenda is driven by a concern with changing dynamics, the work must be multi-temporal and have historical depth. The depth will vary with the question and processes of interest, so that some scientists operate in temporal scales of millennia, while others work

in terms of centuries and decades. This led, for example, to collaboration with others in the LUCC community and other communities concerned with the generalizability of the Forest Transition Theory [38•]. Moran was Lead Scientist of Focus 1 of the LUCC Program, while Ostrom was on the Scientific Advisory Committee of the International Human Dimensions of Global Change Program (IHDP), and together they interacted with a large community from both natural and social sciences to address these issues of interdisciplinary global change research within which the SES framework developed over the years [39].

Because methods within disciplines vary, processes examined will vary not just in time and spatial scales but also in scale of analysis (from local to regional to national to global). It is well known, but rarely analytically addressed, that explanations for processes vary by the scale at which they are studied [40]. Thus, specificity of what scale is being explained is essential, but it is also necessary for each analysis to make an effort to scale both up and down from the scale of interest so the effort and investment is useful to other scientists in the community working at other scales. Finally, because the work is about an impending environmental crisis of global, and local, proportions, the work must keep in mind the relevance and importance of the research in informing policies which might reverse current negative outcomes and favor sustainability of human–environment interactions. These are all issues that Ostrom worked on and stressed as important in her teaching and collaborations with colleagues.

An important contribution of Ostrom in her late years was her proposal for a social-ecological systems framework that reflected the hierarchical qualities of complex SES [6]. The main components of the system, i.e. what she characterized as the first-tier variables of an SES system are: First, resource systems; Second, resource units; Third, actors; Fourth, governance systems; Fifth, external social, economic, and political settings; and Sixth, related ecosystems. Additionally, the SES framework structures how the components interact (AS) and the outcomes of those interactions (O). Each one of the first-tier components is decomposed into a second tier that contains variables that can be divided into new tiers [41]. The fact that the SES has these different tiers and components facilitates the design of hypotheses and the comparison of case studies. The SES framework has been updated since it was formulated (e.g. [41,42]) with enhancements that clarify the criteria for ordering tiers, refining concepts, and defining outcome metrics [43]. Other researchers are starting to use the SES framework adapted to the forest systems they study and are contributing to making the ecological rules used in the framework more operational and integrated with the social and institutional rules of the Ostrom SES framework [44].

This type of work remains a rarity among SES and other human dimension scholars, but it was an important dimension of the development of a conscious incorporation of ecological research into Ostrom's thinking and research. The criticism that a lot of SES till date remains weak on the ecological dimensions [45,46] is a result of the resistance of many in the community to this integration (both social and natural scientists), as well as the origins of the SES in the IAD framework which emerged from a purely institutional focus that did not include environmental variables. Ostrom, for one, was supportive of integrating ecology in this work and throughout the life of CIPEC was informed by these insights. That ecology did not make its way fully into the SES framework proposed by Ostrom speaks to the strong institutional dimensions and origin of her work — a deficiency that colleagues and students are now addressing [see for example [45,46]] We can expect that the E in SES will be a focus of attention by scholars who recognize the value of the SES framework, and also the need to keep making it more applicable to the challenges posed by complex socio-ecological systems.

Concern for policy implications was always at the heart of Ostrom's preoccupations as a scholar. One area that she had some concern with was the growth in recent years of Payments for Ecosystem Services (PES) policies and specifically for forest REDD+ as an emerging incentive-based policy approach that has gained worldwide implementation aiming to protect forests and enhance livelihoods of forest dwellers. The concerns regarding these incentives are diverse; some authors like Sierra and Russman [47] do not find differences in forest cover between farms of beneficiaries of PES and those of non-beneficiaries in Costa Rica. Other authors (e.g. [48]) have other concerns regarding the PES implementation, since the beneficiaries may often be people that are better off than the ones not getting the payment, due to the programs' onerous requirements such as having clear land title. Finally, another factor to be worried about is the fact that we do not know how the payment may affect users' behavior once the payment is removed. As described earlier, economic experiments have shown that economic incentives may crowd out intrinsic motivations to protect the environment from those receiving the incentive [49,50], thus the implications for the forest could be disastrous in the long term by undermining favorable pro-environmental attitudes.

A big contribution of Ostrom, has been to systematically observe forests and how they are changing over time. However, a big challenge for the future is to have a research agenda that goes beyond case studies, experiments, and small-N studies. Throughout her work, Ostrom aimed at large-n studies to increase the power and generalizability of findings. IFRI was a major tool in doing this and it continues to increase the n of local

studies but one needs to encourage scientists to go beyond small forest areas and small local communities and begin to include some 'new commons,' such as urban forests and more attention to large tracts of public lands administered by government but with public access.

Another legacy from Ostrom is the need she saw to scale up the findings of collective action in local communities to regional and planetary scales [51]. As noted in DeFries *et al.*'s BioScience piece, the global change community needs to reorient itself from a focus on biophysically oriented analysis and give more attention to the needs of decision makers from household to global scales. A key element for future research that Ostrom's legacy leads us to consider is to understand human motives so that forest protection and other pro-environmental goals (such as response to climate change) can be achieved [52]. Translating robust science that brings together natural and social sciences into policy remains a challenge, but one that Ostrom addressed and showed everyone how to begin to do it, and why giving value to the local people who manage resources is one way to make progress. It was a privilege to work with Ostrom at Indiana University — she brought passion, commitment and a degree of collegiality and cooperation such as we have never seen before or since. She understood what it took to have cooperation and trust, and she lived by it. Her contributions to SES, the governing of the commons, and institutional analysis will stand the test of time and will continue to stimulate the scholarly community for decades to come.

Acknowledgements

The authors wish to thank the National Science Foundation which provided funds from 1996 to 2004 to E. Moran and E. Ostrom to lead the efforts by CIPEC to advance knowledge of human dimensions of global change research. They also thank Indiana University's support for CIPEC, IFRI, and the V. and E. Ostrom Workshop in Political Theory and Policy Analysis at Indiana University which supported the foundational work reported here. Maria Claudia Lopez thanks the many colleagues at the Workshop, including the late E. Ostrom, for providing a productive place in which to work on institutions during her postdoctoral fellowship period (2007–2009), and for subsequent collaborative work with many of them. Both authors thank Harold Mooney for the invitation to take part in this special issue, and to the two referees who provided valuable comments to improve the manuscript. Only the authors, however, are responsible for any deficiencies that may be found herein.

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