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Research

Introducing Ecological Dynamics into Common-Pool Resource Experiments

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ABSTRACT. Case-study analysis shows that long-lasting social–ecological systems have institutional arrangements regulating where, when, and how to appropriate resources instead of how much. Those cases testify to the importance of the fit between ecological and institutional dynamics. Experiments are increasingly used to study decision making, test alternative behavioral models, and test policies. In typical commons dilemma experiments, the only possible decision is how much to appropriate. Therefore, conventional experiments restrict the option to study the interplay between ecological and institutional dynamics. Using a new real-time, spatial, renewable resource environment, we can study the informal norms that participants develop in an experimental resource dilemma setting. Do ecological dynamics affect the institutional arrangements they develop? We find that the informal institutions developed on when, where, and how to appropriate the resource vary with the ecological dynamics in the different treatments. Finally, we find that the amount and distribution of communication messages and not the content of the communication explains the differences between group performances.

Key Words: *common-pool resources; communication; institutional innovation; laboratory experiments; problem of fit*

INTRODUCTION

Common-pool resource dilemmas are characterized by the difficulty in excluding appropriation and the negative impact of an individual's appropriation on other's returns. Examples are forests, groundwater basins, grazing lands, and fishing grounds. An iconic image of the difficulty in coping with this dilemma is the "Tragedy of the Commons" metaphor of Hardin (1968). According to Hardin (1968), the only way to sustain resources was to privatize the resource or impose control by a central government. However, self-governance of common-pool resources has frequently been observed in field studies (Dietz et al. 2003).

One way to study the conditions under which groups are able to overcome the commons dilemma is through laboratory and field experiments (Ostrom et al. 1994, Cardenas et al. 2000). We cannot extrapolate findings from experiments directly into policy implications. But we can test the generality of observations from field studies under controlled conditions. This will help us develop a more empirically grounded theoretical framework of collective action (Poteete et al. 2010). Past experiments have shown that the ability to communicate, even without enforceable consequences for broken promises, and the ability to punish defectors, even at a cost to the punisher, contribute to cooperation in commons dilemmas (Dawes et al. 1977, Ostrom et al. 1994, Sally 1995, Ostrom and Nagendra 2006).

Although we know resource users are able to overcome collective action problems to share common resources, there is increasing interest in addressing the "problem of fit," the interplay between institutional arrangements and ecological dynamics (Folke et al. 2007, Young 2002). Studies of long-lasting social–ecological systems, such as fisheries, show that institutional rules are mainly based on where, when, and how to harvest, not how much to harvest (Schlager 1994, Wilson et al. 1994, Ostrom 2005). This suggests that an understanding of the fit between institutions and ecology needs to

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understand how human activities can match the temporal and spatial dynamics of the specific resource.

Experimental research has not addressed the problem of fit because of two limitations of current designs. First, the common resource representation used in experiments is often static, deterministic, and non-spatial. This enabled the clear analytical predictions of Nash and cooperative equilibria. Such experiments were instrumental for showing the possibility of self-governance for common-pool resources but are limited from an ecological perspective. Second, participants in experiments are typically only able to make a decision about how much to harvest from a common resource. This resonates with the focus on optimal harvest levels in resource economics (e.g., Clark 1990) and the view that this optimal harvest level can be derived directly through various policies, including quotas and permits, or indirectly through prices and taxes (Weitzman 1974). However, such direct or indirect policies on quantities have had limited success and are no panacea for environmental management (e.g., Tietenberg 2002, Ostrom et al. 2007). Moreover, as mentioned above, long-lasting social–ecological systems have institutional rules that do not focus on quantities, but on where, when and how one can harvest from the common resource (Schlager 1994, Wilson et al. 1994, Ostrom 2005).

In order to test the generalizability of field studies and to increase the relevance of behavioral experiments, we need to develop experimental environments that capture more closely the ecological dynamics. That is why we use a new experimental environment with a dynamic, spatially explicit, resource. Participants can make decisions where, when, how, and how much to harvest in a real-time experimental environment. This enables us to start investigating the interplay between resource dynamics and the type of institutional arrangements participants craft in controlled experiments. In contrast to previous experiments, in this experiment environment (Janssen et al. 2008), we do not impose a particular institutional arrangement, but let participants develop informal arrangements. We are interested to see whether different types of institutional arrangements are crafted for different variations of resource dynamics.

In our experiments, we allow participants to communicate using text messages. It has been observed in other studies that communication increases the performance of the group (Ostrom et al. 1994). Not all groups who are allowed to communicate are equally successful. In this study, the content of the communication is used to investigate what kind of arrangements groups make and how the content of the communication explains the differences between groups. This content analysis also helps us investigate the type of informal agreements groups come up with.

In sum, the experiments are performed to test three hypotheses:

1. *Informal institutional arrangements vary with ecological dynamics.*

   Field studies show that long-lasting social–ecological systems develop institutional arrangements that fit the ecological dynamics. If people take into account the ecological context, we should observe the creation of institutional rules that fit the ecological dynamics.

2. *More explicit discussion on institutional rules leads to better performance of groups.*

   If the fit between ecological dynamics and institutions is critical for the sustainability of the social–ecological systems, we expect that more detailed discussions on the institutional rules may lead to better agreements that fit the context and increase performance.

3. *Communication leads to better performance of groups and enables groups to deal with surprises.*

   We know from earlier work (Ostrom et al. 1994) that communication increases the level of cooperation. There are various hypotheses about how communication affects the group dynamics, varying from making commitments to the development of group identity (Orbell et al. 1988). If communication has an effect beyond commitment to a specific task, we may observe that groups will continue cooperative activities if the context changes.

In the following section, we introduce the experimental environment. We then discuss the experimental design, present the results of the experiments, and finally conclude the paper with the main findings of this study.

THE EXPERIMENTAL ENVIRONMENT

The experimental environment we use in this study provides the participants with the decisions how much, where, when, and how to collect tokens. This enables us to investigate the type of informal institutions crafted. Participants interact in real time to harvest tokens from a spatially explicit renewable resource. Participants move their avatars on the screen and make decisions about where to go on a grid to collect tokens, how to collect tokens, and how fast to move on the screen (Fig. 1). Therefore, they make hundreds of decisions during the few minutes of each round in an experiment instead of one decision per round. If they overharvest the resource, they will face an empty screen after a while. To delay the collapse of the virtual commons, they need to cooperate and collect tokens wisely in a coordinated spatial and temporal manner.

In the experiment, groups of four participants share a renewable resource that grows on a 28 x 28 spatial grid of cells. They can collect tokens during five rounds, each of which lasts 4 min. The length of a round is known to the participants and a clock on the screen shows how much time is remaining for that round. As we would expect, there are some end-of-round effects caused by knowing how much time remains. In earlier experiments with this environment, the duration was not known and we found that this uncertainty led participants to grab as many tokens as soon as possible (Janssen et al. 2008, Janssen and Ostrom 2008).

Participants move their avatar by pressing the arrow keys (left, right, up, and down). There are two ways of collecting tokens, using an implicit or explicit mode. In the implicit mode, a green token is collected automatically by moving the avatar onto the location of the token. In the explicit mode, the participant also locates the avatar on the location of the token but (s)he only collects the token if the space bar is also pressed. With the explicit mode, one can move one’s own avatar around without harvesting tokens. This enables participants to harvest using a checkerboard pattern, which is the optimal spatial pattern for this set of experiments. Each token harvested is worth $0.02.

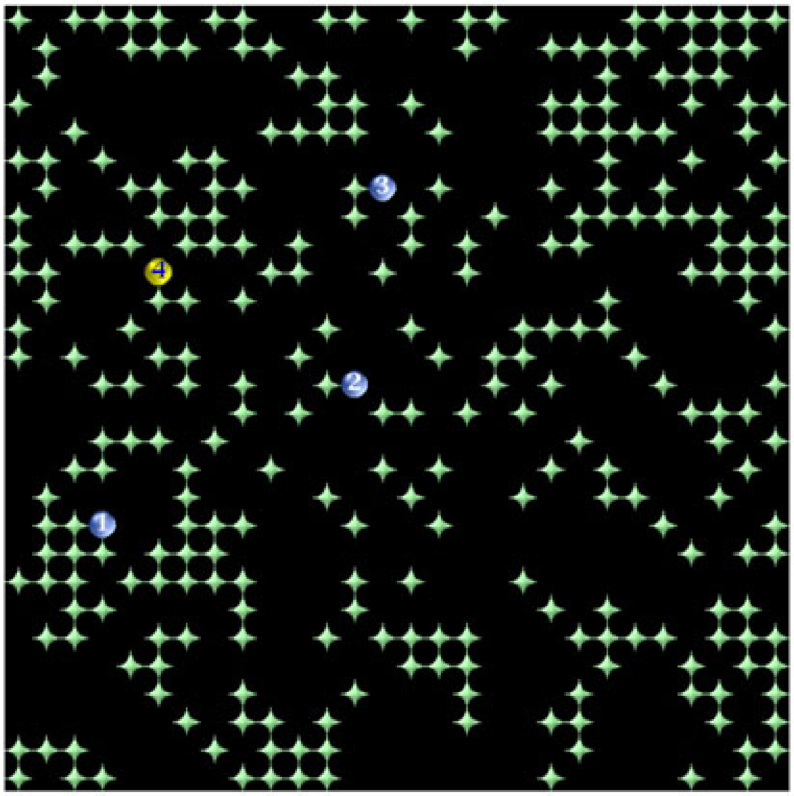
The resource renewal rate is density dependent. As the number of green tokens around an empty cell increases, the probability increases that in the next time-step a green token will appear on the empty cell (see Fig. 2). The probability p_t is linearly related to the number of neighbors: $p_t = p*n_t/8$ where n_t is the number of eight nearby neighboring cells containing a green token. The parameter p is defined after a series of pre-tests in such a way that the renewal of the resource is quick enough to be observed by the participants, but sufficiently slow that the participants face a dilemma choosing between immediate, individual benefits and longer-term, group benefits. If participants quickly collect as many tokens as they can, there will be no tokens remaining on the screen. Once every token has been harvested, no further opportunity exists for any new token to be created.

Some of the readers of this journal may find the resource dynamics we introduced rather simplistic. However, for participants in our 1-h experiments, the inclusion of spatial and temporal dynamics itself was already a challenge to comprehend. The resource dynamics were explained to the participants. Furthermore, they could practice with the experimental environment before the experiment began.

Participants do not receive information on the individual earnings of other participants in the group, but after the round is completed, they do receive information about the average earnings of the participants in their group. In some of the rounds where we allow costly punishment, the earnings of each individual are shown after the round when they have made their punishment decision.

Due to the richness of the experimental environment, it is suitable to study how participants craft institutional rules in a complex environment. Although it is difficult to precisely determine the total quantity of resource units available, the participants can see resource renewal patterns. This enables them to craft innovative arrangements for allocating space and time to one another as a way of using the common resource. Thus, this experiment enables us to examine institutional innovation in a virtual, dynamic resource. Participants developed various norms that mainly focus on dividing the “turf” in equal amounts or the timing of their harvesting (Janssen and Ostrom 2008). Janssen and Ostrom found that a broad

Fig. 1. Screenshot of the experimental environment. The green diamond-shaped tokens are the resource units. The dots are the avatars of the participants. The participant sees his/her own avatar colored yellow, and the avatars of others colored blue.

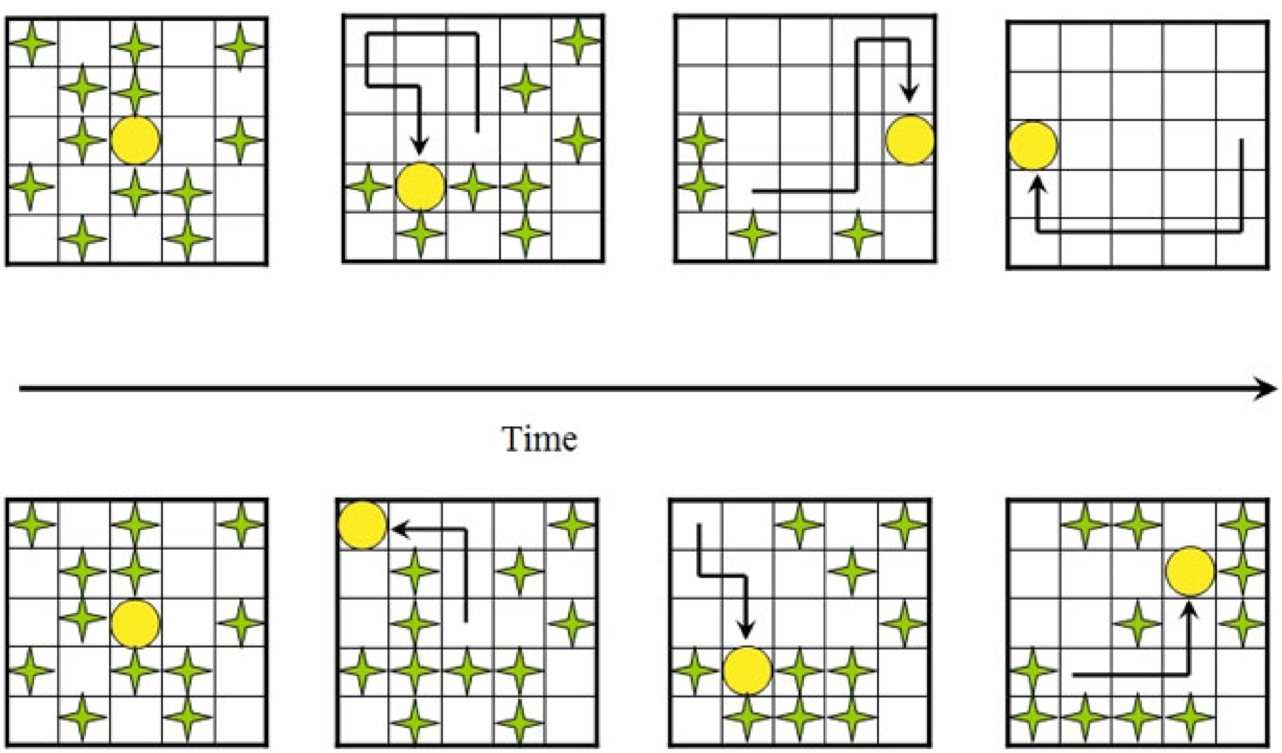


diversity of institutional arrangements was established, especially among groups with inexperienced participants. Experienced participants who took part in earlier experiments with treatments on private property were more likely to divide up the resource in equal parts.

In previous experiments with a similar environment, we found that communication among participants increased performance in a common-pool resource (Janssen and Ostrom 2008). These communication experiments were face-to-face conversations. In this paper, we report on experiments where the participants can only exchange text messages. They do not know the identity of the persons who are in their group. Consequently, we can analyze all the content of the communication and potentially analyze why some group do better than others. In contrast to Janssen and Ostrom (2008), participants can use costly punishment and, therefore, can make credible threats when arrangements are made. Finally, we explore here different resource growth rates.

In Bochet et al. (2005), different forms of communication in public-good experiments are compared. In line with other studies, face-to-face communication increased cooperation considerably. They also found that communication through text messages in a chat format, preserving anonymity and excluding facial expression, was almost as effective as face-to-face communication. On the other hand, just exchanging numbers of proposed investments via computer terminals was found to be ineffective. The relatively similar effect of exchanging text messages with the current

Fig. 2. Four snapshots of two harvesting strategies by two different types of participants in a hypothetical situation of a 5x5 resource, where resource units are depicted by star-shape objects. On the top row in the figure above, the participant moves his/her avatar (circle) eight steps per time period. There is almost no time for regeneration, and a participant following this strategy overharvests the resource by the fourth snapshot. On the bottom row, the participant moves his/her avatar only four steps per time step, and the resource has time to regenerate because enough tokens remain. After four time steps, the resource has not significantly declined, and a participant following this strategy can continue to harvest for many more time steps.



generation of participants in laboratory experiments supports our decision to use text messages as a way to communicate in laboratory experiments.

EXPERIMENTAL DESIGN

The experiment is designed to learn more about how groups develop informal arrangements to govern a spatially explicit common resource (see Appendix 1 for the instructions). Although we know that cheap talk—communication without the ability to make enforceable commitments—increases cooperation, we were especially interested in the type of informal institutional arrangements participants developed and how they differ among the treatments.

We began the experiment with an individual practice round in which we asked participants to collect tokens during a 4-min period on a 14 x 14 spatial grid. They could restart the distribution of the tokens during this practice round. They did not share the resource with somebody else and did not know they would do so later in the experiment. After this practice round, the first round is again an individual round, but this time they cannot reset the distribution of tokens. After this first round, we announce that they will share a resource that is four times bigger with three other participants in the room with whom they have been randomly matched. We had two, three, or four groups at the same time in the experimental laboratory depending on the number of participants who responded to our invitation.

The second round is a “no communication” round. After the second round we introduce two new aspects. The participants are told that they can reduce the tokens of other participants in their group after the round is finished. At a cost of one token, they can reduce the amount of tokens of another participant by two tokens, up to a maximum of 50 tokens per other participant. We tested whether they understood this procedure with some quiz questions. When everybody answered the quiz questions correctly, we continued with a communication period. They were told that before each of the next rounds they could communicate for 5 min by exchanging text messages on the computer screen. They could chat about whatever they wanted as long as they did not threaten each other with any consequences after the experiment was over, and as long as no promises about side payments were made. Moreover, they were not allowed to reveal their real identity. We monitored the chat communication to confirm these rules were followed. Rounds three, four, and five were all the same: first, communication for 5 min, then collecting tokens for 4 min, and then an opportunity to subtract tokens from other participants if desired.

We designed four different treatments. We compare high growth rate vs. a low growth rate of the resource. And we compare a homogenous resource in time and space, with treatments where the resource growth is changing, and where resource growth varies according to location. This enables us to explore the consequences of different degrees of severity of resource scarcity and complexity of the resource dynamics. The following treatments are distinguished (Table 1):

- High growth rate. A relatively high regrowth of the resource, which starts at the optimum density of tokens on the screen (50%)

- Low growth rate. By reducing the regrowth probability by half and the initial density to 25%, this environment is more challenging than the previous treatment. To maximize earnings, participants should initially let the resource regrow undisturbed to 50% density.

- High growth rate/low growth rate. The first three rounds have the high regrowth situation. After the second communication round, and before they start round 4, we announce that we have changed the regrowth rate and the initial amount of tokens on the screen. Will they be able to adapt?

- Spatially mixed growth. In this case, the regrowth of the resource is not spatially uniform. It has a high growth rate and 50% initial density at the top half of the screen and a low growth rate and 25% initial density at the bottom half of the screen.

At the end of the experiment, participants complete a survey while the experimenters prepare the payments. We asked participants a short set of questions to derive basic demographic information, such as their major, sex, age, and whether they were satisfied with the payments and understood the instructions.

The real-time spatial environment makes it difficult to calculate precisely the Nash and cooperative equilibria. Theoretically, it would be best to keep the average density of the tokens to 50% distributed in a checkerboard diagram and harvest all the tokens in the last seconds of the round. A group of selfish participants would collect as many tokens as fast as possible. Simulations with simple cooperative and selfish rational strategies have been performed to estimate the earnings in Nash and cooperative types of equilibria (Appendix 2). The upper boundaries of the number of tokens individuals can collect if they cooperate are the following: 155 tokens for the low-growth case, 257 tokens for the mixed growth case, and 360 tokens for the high-growth case. A group of selfish individuals leads to an average number of tokens collected per person of 50 tokens for the low-growth case, 77 tokens for the mixed-growth case, and 106 tokens for the high-growth case. The resulting cooperative earning, including the $5 appearance fee are given in Table 1. Appendix 2 also shows the increased performance of a selfish participant in a group of unconditional cooperators.

Table 1. The four experimental treatments. Note: The label for the groups is given in parentheses.

Treatments (groups)	T1. High Growth (H1–H6)	T2. Low growth (L1–L4)	T3. High growth – Low growth (HL1–HL6)	T4. Mixed growth (M1–M6)
Resource dynamics	High growth *P* = 0.02 and an initial amount of 50% of the tokens on the screen.	Low growth: *P* = 0.01 and an initial amount of 25% of the tokens on the screen.	Low growth for rounds 1–3 and high growth for rounds 4 and 5	Mixed growth: Top half of the screen: high growth; bottom half of the screen: low growth
Practice	14x14 individual resource			
Round 1	14x14 individual resource			
Round 2	28x28 grid shared by four people			
Round 3–5	Each round starts with 5 min of text chat. Then 4 min of collecting tokens in the 28x28 grid resources shared by four people. After the round, there is a chance to subtract others' tokens.			
Earnings—Nash solution	$20.2	$12.1	$16.3	$18.4
Maximum earnings —cooperative solution	$41	$20.5	$30.7	$32.8

EXPERIMENTAL RESULTS

We performed this series of experiments in the Fall 2006 and Spring 2007 semesters in the Computer Assisted Research Laboratory at Arizona State University. Twenty-two groups of four participants were involved in the communication experiments, for a total of 88 participants. The average age of participants was 21 years. One-third of the participants were female. The earnings (including the $5 appearance fee) varied from $5.48 to $35.86 and were, on average, $21.78. We will first present some summary statistics before we go into detail for a number of issues.

General statistical results

In all treatments, we see a significant drop in the average earnings in round 2 (no communication) compared with round 1 (individual round) (Table 2). A one-way ANOVA test shows that this is significant for the high-growth-rate treatment, $F(1,18) = 5.24$, $p = 0.03$; and the mixed-growth-rate treatment, $F(1,10) = 17.35$, $p = 0.002$, although not for the low-growth resources, $F(1,10) = 3.63$, $p = 0.09$.

After the first round of communication, the average earnings increase significantly (high-growth rate: $F(1,18) = 9.41$, $p = 0.007$; low-growth rate: $F(1,10) = 5.24$, $p = 0.03$; and mixed-growth rate: $F(1,10) = 31.57$, $p = 0.0002$). There is no significant improvement between rounds 3 and 4, and between rounds 4 and 5. As the first round of communication is most instrumental to increase the group performance, our analysis of the impact of communication focuses mainly on this first communication round. From other experiments in which we had multiple rounds of no communication, we know that the increase in the first communication round is not due to a learning effect (Janssen et al. 2010; Janssen et al., unpublished manuscript). Moreover, Janssen and Ostrom (2008) report on experiments where participants were brought back to the experiment and performed the same way in the no-communication round.

Table 2. Average number of tokens collected at the group level for each round and treatment. The standard deviation is given in parentheses.

	Treatment			
Round	T1	T2	T3	T4
Round 1	972.75 (100.76)	336.00 (47.94)	810.67 (134.30)	610.83 (46.40)
Round 2	835.75 (138.81)	274.00 (63.75)	681.33 (20.68)	453.5 (80.06)
Round 3	1057.75 (22.20)	423.00 (65.92)	853.33 (163.42)	677.33 (55.79)
Round 4	1070.25 (23.37)	468.00 (34.27)	427.5 (96.98)	678.67 (77.06)
Round 5	1137.75 (50.11)	482.33 (26.42)	417.5 (69.50)	696.17 (81.07)

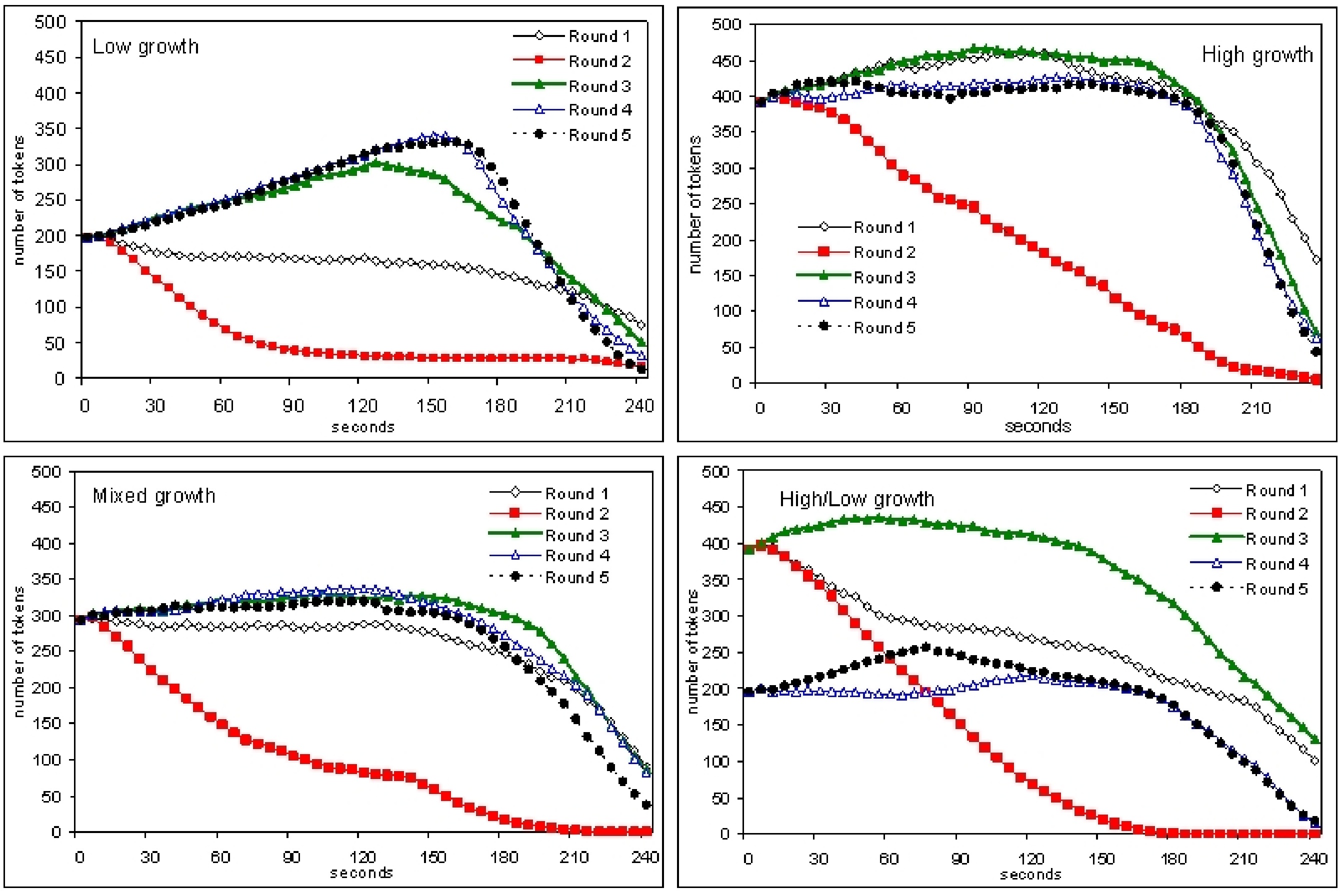
Not surprisingly, in treatment 3 where participants unexpectedly faced a low regrowth rate and 25% initial density of tokens in round 4, the number of tokens collected dropped significantly ($F(1,10) = 30.13$, $p = 0.0003$). Interestingly, the drop in round 4 is to a similar level as round 3 in the low-growth-rate treatment ($p = 0.93$). Subsequent discussion between rounds 4 and 5 in experiments HL1-6 does not change the level of tokens collected. As the participants discussed the high-growth-rate experiment for two rounds before being confronted with a low growth rate, and had similar outcomes as the low-growth case, this suggests that the specific coordination of token collection is less important than the fact that they had a group discussion. This echoes the importance of group identity as suggested by Orbell et al. (1988).

Note that the participants developed different solutions to the problem in different treatments. In the slow-growth L1–L6 experiments, the arrangement was to wait for 2 or 3 min and let the resource replenish. In the fast-grow Hl1–HL6 experiments they slowed down the collection of tokens. We will discuss this in more detail below.

Resource dynamics

Figure 3 shows the average level of tokens on the screen for the different treatments. It shows the rapid decline of tokens in round 2 (no communication) compared with other rounds. It also shows the different responses in rounds 3, 4, and 5 for the low-growth vs. the high-growth treatments. In the low-growth treatments, the basic strategy of participants is the wait to let the resource replenish, whereas in the high-growth case the level of resources is maintained at the 50% density. If the aim is to maximize the earnings, the optimal strategy in the low-growth case is not to harvest for about the first 2 min, except tokens that have eight neighboring cells occupied by tokens until a density of 50% is reached. In the high-growth-rate case, the optimal strategy is to keep the token density at 50%. As the time remaining in the experiments is known to the participants, it is not surprising to observe a rapid decrease of the resource in the last minute of the experiment until no tokens are left at the end of the round (Appendix 3).

Fig. 3. Average number of tokens on the screen for the four different treatments and each round.



Punishment

Like other studies, we find that participants used the costly punishment option. But it was not used very much. The maximum that somebody's tokens can be reduced by is 50 tokens. The total number of times that a participant could subtract tokens is 792; however, only seven participants made use of this option for a total of 13 times. Note that 792 is derived by multiplying 22 (groups) times 3 (rounds in which punishment could be used) times 4 (participants in each group) times 3 (others in the group a participant could punish).

In the communication rounds, one of the first topics of discussion was the opinion that participants should not make use of the option to reduce tokens. People argued that nobody would benefit from "stealing" tokens. This was generally agreed upon. Some participants also responded in the survey that they found that one of the other participants did not stick to the agreements made during the communication rounds and reduced the tokens of other participants. From the survey responses, we also learned that a few times the participant did not know why (s)he subtracted tokens from another participant. Maybe (s)he thought they should have to type in some numbers.

Although the option to reduce tokens was almost never used, this does not mean that observed disobedience of agreed-upon arrangements was ignored. In the discussions, there are evaluations of past behavior, including observations of others not following the rules. For example, the following discussion took place after round 4 in a low-growth-rate resource experiment.

Avatar C: “u guys started early”
Avatar D: “somebody started moving before 70secs”
Avatar C: “hey rules r rules ok?”
Avatar A: “well i took my area. i didn't pilfer anyones”
Avatar C: “70 means 70 not 78”
Avatar D: “yea dumbass”
Avatar B: “yeah”

Communication analysis

In order to study the type of institutional arrangements the participants came up with, if any, we analyze the communication content. Moreover, we expect that a more explicit discussion on these arrangements will explain differences in performance between the groups. To analyze the content of the communication we coded each line of the about 3300 text messages exchanged between the participants. We developed a code book that captures the topics of discussion. The author and a research assistant were the coders. Both independently coded a few sessions first and then compared their agreements via kappa scores (Cohen 1960). A kappa score quantifies the agreements between two coders beyond chance. It divides the observed probability of success and the probability of success by chance. A value of one means perfect agreement, whereas values above 0.6 indicate a good agreement between coders. The code book was adjusted when unclear definitions of categories were observed. When the final code book was agreed upon, the entire data set of text messages was coded (Appendix 4). Table 3 presents the frequency of the different categories observed and the agreement between the coders for the entire data set.

In the first communication round, participants tend to focus initially on a general strategy beneficial to the entire group and then they may develop some more specific strategies. In the second and third communication rounds, there is only discussion on specific strategies that they urge one another to follow and an evaluation of what has happened in the past rounds (Table 4). Another topic discussed at the start of the communication process is the option to reduce other participants’ tokens (punishment), which is generally agreed not to be a good idea to pursue. The participants argue that it is in nobody’s best interest to “steal” tokens.

In the low-growth-rate treatment, there is relatively more discussion about time-based strategies, mainly how long to wait until they can start harvesting. They sometimes discuss how long to wait before starting to harvest and agree on a specific time, say after 2 min. In the mixed-growth-rate treatment, there is a lot of discussion on space-based strategies. Initially, they divided up the space in four equal parts, but those who got quadrants at the bottom of the screen started to argue that they want to change locations. This leads to a discussion on potential rotation schemes or dividing up the space vertically.

In treatments where cooperation provides relatively more benefits than other treatments (the low-growth and the mixed-growth treatment), the participants devoted more discussion to explicit strategies. This is in line with the findings of Pavitt et al. (2005). They discuss communication patterns in common-pool resource dilemmas for different levels of regrowth of the common resource and find that participants discuss more about the game strategy and less about the game itself if cooperation leads to a relatively greater benefit.

Statistical analysis

What affects the level of tokens collected? We performed ordinary least squares regression analyses to test the significance of demographic factors on the number of tokens collected. Table 5 shows a modest sex and academic discipline effect in the individual round, round 1. Male students and economics students collected more tokens than others. However, in round 2, the no-communication round, the level earnings was lower when more males were in the group. This may indicate a competitive nature of the male participants and is in line with findings from previous experiments (Gneezy et al. 2003, Janssen et al. 2008). The number of economics-oriented participants has a positive effect on the level of tokens collected. After communication between rounds 2 and 3, however, neither sex nor academic major continues to have a significant effect. Group discussion negates the impact of the individual characteristics of the participants. Consequently, we now discuss what effect communication has and which elements of the discussion explain group differences.

Table 3. The average number of lines of text messages for the different categories distinguished. The agreement of the two coders is quantified by the kappa score. A kappa score above 0.8 suggests very good agreement, and a kappa score between 0.6 and 0.8 suggests good agreement.

Topic category	Average number per round per group	Kappa score
Discussion, past rounds (evaluative)	4.2	0.92
Discussion, past rounds (procedural)	0.8	0.74
Punishment (positive)	0.3	0.74
Punishment (negative)	2.3	0.78
Punishment (general threats)	0.4	0.70
General strategy (temporal)	1.0	0.75
General strategy (spatial)	1.2	0.66
General strategy (mode)	2.2	0.63
General strategy (general)	1.4	0.84
Specific strategy (time: proposed)	0.4	0.77
Specific strategy (time: discussion)	6.9	0.82
Specific strategy (space: proposed)	0.3	0.70
Specific strategy (space: discussion)	7.6	0.80
Affirmation	0.5	0.66
Experiment (intent)	0.7	0.81
Experiment (procedures)	1.8	0.75
Experiment (software)	1.2	0.78
Experiment (uncertainty)	0.1	0.81
General discussion	9.4	0.75
Off topic	7.4	0.85

Table 4. The percentage of text messages classified in one of the nine main categories for each treatment and round.

	High growth			Low growth			High/low			Mixed		
	3	4	5	3	4	5	3	4	5	3	4	5
Past rounds	1	12	20	2	11	20	1	13	14	1	15	13
Punishment	5	4	1	16	5	3	14	3	2	13	6	0
General strategy	16	1	5	21	3	10	31	8	10	19	4	1
Time	17	8	20	15	32	17	5	19	18	4	11	12
Space	21	21	4	14	11	13	9	9	5	35	19	32
Affirmation	2	1	0	2	2	2	0	0	1	1	10	0
Experiment	9	12	5	4	9	7	4	4	12	9	9	8
General	19	19	18	14	13	12	29	24	22	18	12	21
Off topic	10	21	28	13	14	17	7	20	16	1	23	13

The effect of communication

The number of lines of text communication has a modest effect on the relative earnings increase in round 3 compared with round 2 (Table 6). More important, however, is whether all participants contribute to the discussion. We included the Gini coefficient of the number of lines contributed to the discussions by the different participants, and found that groups who have a more even contribution from group members have a greater increase in earnings after a round of communication. Echoing the findings of Pavitt et al. (2005), we do not find any specific topic of discussion leading to increased performance.

Why would the content of discussions not relate to the relative improvement in earnings after communication? This study focuses on what information is exchanged between participants; future research may focus on how the information is exchanged. One possible reason is that each discussion does not necessarily lead to better coordination. For example, in one of the groups in the mixed-growth treatment, one participant convinced other participants that the tokens regrew from the center of the screen. Therefore, the participant argued that the tokens on the outside of the screen needed to be collected first and then one needed to wait for the tokens to regrow. Because the earnings were more equal in round 3, three of the four group members experienced an improvement in their earnings and were convinced to continue this strategy although the group-level earnings only improved slightly. Thus, communication does not guarantee that correct information is exchanged.

Another significant effect resulting from communication was the positive effect of male participants in round 3 (Table 6). Although the participants do not know each other's identity—but they may guess their sex from the text exchange–it is striking that a greater number of male participants in a group leads to a greater increase in group earnings compared with the no-communication round. One reason for this is the observed sex difference in negotiations, where women are less eager to take the initiative to improve their situation (Babcock and Laschever 2003). Another reason is the greater drop in tokens collected in the no-communication round for groups dominated by male participants. In the no-

Table 5. The statistical estimation of the relationship between individual and group number of tokens collected with demographic variables gender and major.

	Number of tokens collected			
	Round 1 (individual)	Round 2 (individual)	Round 2 (group)	Round 3 (group)
Constant	202.318***	181.917***	867.138***	846.125***
Dummy – mixed growth	-63.451***	-67.701***	-277.244***	-249.226
Dummy – low growth	-138.599***	-112/64***	-459.712***	-528.686***
Dummy – econ major	24.476**	27.225*		
Dummy male	18.883**	-14.447		
(fraction) econ major			201.640**	602.62
(fraction) male			-245.115	1206.602
N	88	88	22	22
F	43.201	20.940	38.253	17.720

*** $P < 0.01$
** $P < 0.05$
* $P < 0.1$

communication round the situation might be perceived as a competitive environment, where male participants are found to be more aggressive (Gneezy et al. 2003). Text communication may change the perceived problem, and the sex effect disappears (Table 5).

Informal rules

What were the informal institutional arrangements derived in the first communication round, and how did this affect the earnings? We classified each group as to whether they had mentioned the following three items: make use of the explicit mode; specific statements when to start collecting tokens, and specific spatial allocations where participants were allowed to harvest. Although we can identify those lines in the discussion, we cannot know for sure that every group member agreed, understood or noticed these statements. Nevertheless, this exercise leads to interesting differences among the treatments (Table 7). In the high-growth-rate treatment, the main topic specifically mentioned was to use the explicit mode, something that cannot be observed by others. In the more challenging low-growth and mixed-growth treatments, arrangements were made that could be observed by the participants themselves. In the low-growth treatment, specific statements on how long to wait before starting the collection of tokens were discussed in five of the six experiments. In the mixed-growth treatment, there was significant discussion about where to harvest and how to allocate the space, and four out of six experiments had specific allocations of the space.

Table 6. The statistical estimation of the relationship between relative increases of tokens collected in round 3 vs. round 2 and the communication patterns.

	Relative increase of tokens collected in round 3 versus round 2	
	Round 3	Round 3
Constant	0.895 ***	0.965 ***
Dummy – mixed growth	0.326 ***	0.243
Dummy – low growth	0.386 ***	0.309 *
Fraction male	0.606 ***	0.577 **
Total chat entries	0.006 *	
Gini chat contributions	-2.978 ***	-3.08 **
Past rounds		0.003
Punishing		0.012
General strategy		0.003
Specific time		-0.005
Specific space		0.010
Affirmation		0.095
Experiment		0.013
General		-0.002
Off topic		0.013
N	22	22
F	10.345	5.260

*** $P < 0.01$
** $P < 0.05$
* $P < 0.1$

Despite the specific statements of how, when, and where to harvest tokens, such statements did not have a significant effect on the level of earnings (Table 8). We get the same findings when we only have one dummy variable indicating whether there are explicit statements or not.

We checked whether this was caused by violations of the statements, but found that almost each informal norm was violated by some participants. As no formal arrangements were established, for example by voting on specifically stated rules, we are not sure whether all participants saw these informal arrangements or norms as their guiding principle, or whether these informal rules were well understood by all group members. As the informal norms also varied in their specificity, it was not possible to quantify the level of violation.

CONCLUSIONS

A real-time and spatially explicit renewable resource experiment was used to study informal efforts to develop institutional arrangements to improve returns obtained from the commons. The treatments used in these experiments varied in the resource growth rates and the spatial and temporal distribution of regrowth. As observed in case studies, we find that participants develop institutional arrangements restraining when, where, and how to appropriate resources instead of how much. The type of arrangements they developed fit with the ecological dynamics. When resource growth is low, harvesting pressure is reduced over time; when resource growth is spatially diverse, more attention is given to the spatial locations of where to harvest.

Communication by text messages was analyzed to explore how differences in communication patterns affect the performance of groups. We find that communication by text messages increases the performance of groups in all treatments. Content analysis of the communication results in the finding that the topic of communication does not explain the differences in increased earnings among groups after group discussions, which is in line with Pavitt et al. (2005). The communication process itself and the composition of the group do have a significant effect. Groups have a relatively greater increase in earnings after communication when they exchange more messages, especially if the contributions are evenly distributed among the group. When groups are confronted with a surprise before they have the chance to discuss the consequences of their strategies (a low growth instead of a high growth of the resource), the groups adapted their strategy and avoided overharvesting of the common resource.

There is some indication that results of this study confirm earlier findings of the benefit of group discussion, which seems to relate to the formation of group norms and group identity (Orbell et al. 1988, Ostrom et al. 1994). Specific arrangements how, when, and where to collect tokens does not explain group differences. We see groups referring to themselves as a team. When the seconds of the chat period count down to zero, we see many participants wishing other group members good luck or typing “go team!” As we see in round 4 of treatment 3, where the participants were surprised with a lower growth rate and initial distribution, their earnings were statistically similar to the low-growth treatment of round 3 although they had no specific discussion on what to do in a different environment.

Debate remains about why communication alone leads to better results (Buchan et al. 2006). In some experiments with a relatively simple payoff function, research has shown that increased performance with communication is not due to better understanding of the experiment (Edney and Harper 1978, Kerr and Kaufman-Gilliland 1994). In common-pool resource experiments, where a more complex, quadratic harvesting equation originally posited by Gordon (1954) has been used for the payoff function, participants spent time initially making sure they understood what harvesting level was the equivalent of the group optimum and how to allocate that to individuals (Ostrom 2006, Simon and Schwab 2006). Orbell et al. (1988) conclude that two possible explanations exist for the effect of communication: (a) group discussion enhances group identity or solidarity, and (b) group discussion elicits commitments to cooperate. Shankar and Pavitt (2002) come to a similar conclusion and suggest that voicing of commitments and development of group identity and norms seem to be the best explanation for previous experimental results. In future experiments, we plan to investigate the different potential roles of communication on collective action of common resources.

Table 7. Number of groups with explicit discussions on the use of explicit mode, when to start or stop harvesting, and where to harvest.

	Mode	Time	Space
High growth rate (10)	7	5	3
Low growth rate (6)	3	5	2
Mixed growth rate (6)	1	2	4

The kind of arrangements that were discussed in groups relate to the dynamics of the resource. In the high-growth-rate treatment, where participants experience a more forgiving common resource than other treatments, the informal norms relate mainly to which mode to use for collecting tokens. Using the explicit mode would slow down the rate of harvesting, but other participants cannot observe which mode one is using. In the low-growth-treatment where the initial situation is a modest depleted state, the informal norms focus on the recovery of the resource. Finally, the mixed-growth treatment focuses mainly on spatial allocations to distribute areas where one should harvest while the resource regrowth is not uniform. We see the differences in arrangements echoed in the observed spatial and temporal patterns of the token collection. However, group differences within the same treatment cannot be explained by differences in the specificity of the arrangements they have made. In future experiments, we plan to have participants create formal institutional arrangements that they have to acknowledge their agreement. This will enable us to analyze formal institutional arrangements for different ecologies.

This paper shows the first steps in a journey to systematically investigate the effect of resource dynamics on self organization of institutional arrangements. New experiments are underway where we include disturbances and mobility of the resource units, as well as the creation of formal institutional arrangements. This will enable us to test the robustness of repeated findings of field observations in a controlled setting. Questions that we aim to address relate to whether the incentive structure caused by the ecological dynamics and information availability is sufficient to explain the observed patterns. If we cannot replicate stylized facts from the field, cultural or historical processes may play a significant role. For example, field experiments in rural villages in Colombia and Thailand that mimicked the upstream–downstream dilemma of irrigation systems produced the same results when replicated with university students in Bogota and Bangkok (Janssen et al. 2009a). The main factor explaining the results was the trust participants expressed in other members of the community. This suggests that the social context, and not the experience with resource management , affects the outcome of the decisions made in the experiments. Other studies have shown that the degree of market integration affects the decision making in one-shot social dilemmas (Henrich et al. 2005).

Over the last few decades, we have derived improved understanding of how people make decisions in commons dilemmas. The traditional predictions from non-cooperative game theory have been rejected. We lack a generally accepted unified theory of how people make decisions in these situations. An improved theoretical framework is desirable if we want to go beyond panaceas of public policies applied to environmental resources. Such a framework may cover individual behavior, the micro-situational variables, and the broader context (Poteete et al. 2010). This requires a better understanding of how ecological dynamics affect the decisions people make. Experiments, in the laboratory or in the field, can be useful tools that can contribute to deriving relevant insights to build up a broader theoretical framework of collective action.

Table 8. The statistical estimation of the relationship between relative increase in tokens collected in round 3 vs. round 2 and the occurrence of explicit discussions on how, when, and where to collect tokens.

	Relative increase of tokens collected in round 3 versus round 2	
	Without rules	With rules
Constant	0.895 ***	0.931 ***
Dummy, mixed growth	0.326 ***	0.289 *
Dummy, low growth	0.386 ***	0.396 **
Fraction male	0.606 ***	0.627 **
Total chat entries	0.006 *	0.005
Gini chat contributions	-2.978 ***	-3.039 **
Mode		-0.003
Time		-0.062
Space		0.063
N	22	22
F	10.345	5.611

*** $P < 0.01$
** $P < 0.05$
* $P < 0.1$

To conclude, our findings suggest that when participants have the option to craft institutional arrangements on when, where, and how to appropriate a resource, they do so, and those arrangements fit the ecological dynamics of the resource. This confirms, in a controlled setting, observations from field studies of long-lasting social–ecological systems. More work needs to be done to understand how sociocultural context and cognitive processes affect how people make these proposed arrangements.

Responses to this article can be read online at:
http://www.ecologyandsociety.org/vol15/iss2/art7/responses/

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Appendix 1. Instructions for Experiment

Please click here to download file 'appendix1.pdf'.

Appendix 2. Optimal Strategies

Please click here to download file 'appendix2.pdf'.

Appendix 3. Harvested tokens over time.

Please click here to download file 'appendix3.pdf'.

Appendix 4. Code book content analysis of chat communication

Please click here to download file 'appendix4.pdf'.