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Research

The Role of Information in Governing the Commons: Experimental Results

Marco A. Janssen [1]

ABSTRACT. The structure and dynamics of ecosystems can affect the information available to resource users on the state of the common resource and the actions of other resource users. We present results from laboratory experiments that showed that the availability of information about the actions of other participants affected the level of cooperation. Since most participants in commons dilemmas can be classified as conditional cooperators, not having full information about the actions of others may affect their decisions. When participants had more information about others, there was a more rapid reduction of the resource in the first round of the experiment. When communication was allowed, limiting the information available made it harder to develop effective institutional arrangements. When communication was not allowed, there was a more rapid decline of performance in groups where information was limited. In sum, the results suggest that making information available to others can have an important impact on the conditional cooperation and the effectiveness of communication.

Key Words: *common pool resource; communication; conditional cooperation; information; institutions*

INTRODUCTION

The appropriation of common resources is well studied (Poteete et al. 2010). The basic question that has been considered is under what conditions do resource users maintain their common resources at sustainable levels. From decades of research, we know that there are many factors influencing the ability to self-govern the commons (Ostrom 1990, 2005). Critical factors include the implementation of monitoring and enforcement and the mutual trust relationships within the community of resource users (Poteete et al. 2010). These factors facilitate long-lasting repetitive actions that are commonly understood and well monitored.

What has not been explicitly studied is the role of the visibility of the state of the ecology and the actions of the resource users on the ability of groups to solve collective action problems. If monitoring and enforcement and trust are such critical factors in solving collective action problems, visibility of the resource users' actions and the state of the ecology are expected to have an effect on the governance of the commons.

We report on a series of laboratory experiments with a spatially explicit resource in which we manipulate the visibility of the resource and the actions of the participants. As such, we can test the effect of full or limited information on the state of the environment and the actions of the participants on the performance of collective action. We investigate whether participants create institutional arrangements that fit the level of visibility they experience. Although there are limits to the use of laboratory experiments, it may provide insights about observations from individual case studies.

An explicit study on the role of visibility may contribute to the understanding of the "problem of fit," that is, the interplay between institutional arrangements and ecological dynamics (Young 2002, Folke et al. 2007). Earlier studies show that effective institutional arrangements are based on where, when, and how to harvest (Schlager 1994, Wilson et al. 1994, Ostrom 2005), which also facilitate knowledge about when and where to monitor. Seeing somebody in the wrong spot at the wrong time with the wrong gear will be a clear violation of institutional arrangements even if no direct harvesting activities have been observed.

We provide some illustrative examples from case studies that show that the ecological conditions affect the visibility of the state of the ecology and the actions of other resource users. In certain cases, innovative institutional arrangements have been crafted in order to overcome the high cost of information collection.

When fishers harvest fish from a large territory, farmers withdraw water from a long irrigation canal, or villagers harvest from a large forest, there is no way that they can see what everyone else is currently doing. Many resource management systems developed by local users define when, where, and how authorized harvesters may harvest. Such rules are easy to monitor and enforce, and if there is more confidence that people are following the rules, others will follow them too. For example, in Maine, lobster fisheries have evolved rules that allocate permanent spots within a bay to specific fishers (Acheson 2003, Wilson et al. 2007). In many farmer-managed irrigation systems, a particular time is allocated to a specific farmer depending on their location along the canal and the size of their farm (Maass and Anderson 1986, Burns 1993, Shivakoti and Ostrom 2002). Finally, in some of the alpine commons, farmers from the valley work together at a

[1]Arizona State University, USA

set date to cut an agreed upon number of trees (Netting 1981, Stevenson 1990). Then together they carry the timber and allocate it into approximately equal stacks. The stacks are then randomly assigned to eligible households. Trees cannot be harvested at any other date.

As the examples of the case studies illustrate, the structure and dynamics of the social-ecological system affect the availability of information on the state of the resource system. This affects the ability to collect information to feed back into the governance system. Not only is information about the state of the ecology difficult to collect, it might be that the behavior of resource users is difficult to monitor in some systems. If fishers fish on the open sea on their own and come back with their catch, there is only limited information on the actual harvesting practices. For example, by-catch might not be reported. As a consequence of the difficulty of monitoring fishers, some fisheries include an official monitor on each vessel (e.g., Alaska Fisheries Science Center 2011).

We further consider past related studies on experiments of common resources that provide the context for the experimental design we use to test the effect of different levels of information on the state of the resource and the actions of participants. We then discuss the experimental design that is used in this study, and the results of the experiments in the subsequent section. Finally, we conclude with a section on the role of information on collective action in governing common resources.

PAST EXPERIMENTS ON COMMON POOL RESOURCES

Controlled experiments have been used to test specific hypotheses on self-governance of the commons that were inspired by observations from the field (Ostrom et al. 1994). The benefit of controlled experiments is the ability to test specific mechanisms. Over the years, lab experiments have challenged conventional theories in economics. People are often found to be conditional cooperators rather than selfish and rational actors (Fischbacher et al. 2001, Frey and Meier 2004). This implies that participants tend to cooperate if others do too. Furthermore, "cheap talk"—the ability to communicate without the option to make binding agreements —has a major positive effect on cooperation (Ostrom et al. 1994). Finally, costly sanctioning—giving up earnings to reduce the earnings of others—is preferred by participants, and it increases the level of cooperation (Ostrom et al. 1994).

In controlled experiments, one can control what information is made available to the participants. We extend a set of experiments on a dynamic, spatially explicit resource (Janssen et al. 2010). We discuss the specifics of the experimental environment in the next session. For now, it is important to note that we test the effect of the amount of information available regarding the state of the resource and the actions of other players on the ability of groups to self-govern their common resource. In order to define some hypotheses, we briefly discuss findings in the experimental literature on common resource dilemmas on the availability of information.

A few recent publications explored the consequences of varying the information available to the participants. When more information about the actions of others is available to participants, we see lower levels of cooperation in most studies, since more details reveal the existence of free riders (Nikiforakis 2010, Villena and Zecchetto 2010). When the information is focused on the intentions of conditional cooperators in the group, we see that more information leads to higher levels of cooperation (Chaudhuri and Paichayontvijit 2006, de Oliveira et al. 2009).

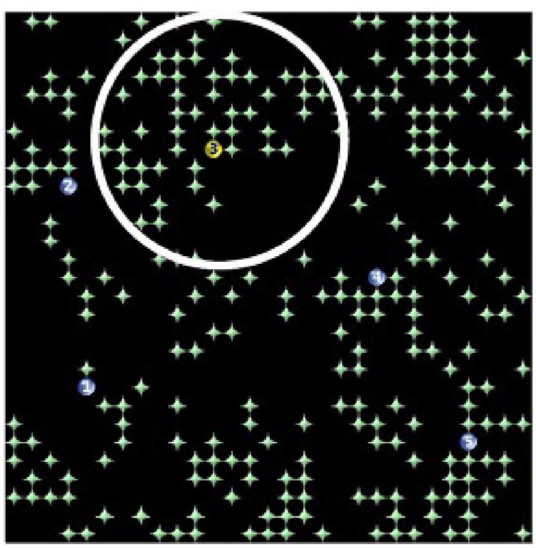
The level of information about the actions of others affects the level of cooperation. This seems related largely to information about the strategies participants are using. Previous studies did not include communication in which people could coordinate their activities. Communication has been found to increase the level of cooperation, but there are different possible explanations. Is communication effective due to the formation of group identity or due to participants making commitments to cooperate (Orbell et al. 1988, Shankar and Pavitt 2002, Buchan et al. 2006)? The explanation that communication leads to a better understanding of the experiment is not likely (Kerr and Kaufman-Gilliland 1994, Brosig et al. 2003). If communication is effective through the development of group identity and by allowing participants to make commitments on cooperation, reducing the level of information about the state of the resource or the actions of participants should not affect the results of the experiment.

EXPERIMENTAL DESIGN

Our experiments focused on understanding the effect of limited information regarding resource availability and the actions of other participants on collective action in a social-ecological system. We investigated a real-time dynamic resource-harvesting setting (Janssen et al. 2008, 2010). The reason for Janssen et al. (2010) to include spatial and temporal dynamics in a laboratory experiment was the empirical observation from case study analysis that spatial and temporal dynamics are critical features of ecological systems that affect the specific institutional arrangements (Janssen et al. 2007). To test findings from observations of social-ecological systems in controlled experiments, we needed to include more complex dynamics of the common resource (Janssen 2010). The software used for this experiment is open-source and available at http://commons.asu.edu/. Detailed instructions are available in the appendix of this article.

In our experiments, participants appropriated renewable tokens from a shared renewable resource environment (Fig. 1). Each group was made up of five participants who shared a 29 x 29 grid of cells. In the initial state, 25% of the grid space was filled with tokens, thus 210 tokens. The avatars were initially placed in the middle row of the screen with equal distances between the avatars. In order to collect a token, a participant had to position their avatar on the location of that token and explicitly press the space bar. Participants were allowed to collect tokens for four minutes. Each token harvested was worth US$0.02. We distinguished two situations by how the information on the screen was presented. In the first situation, participants had complete information on the spatial position of tokens and could watch the harvesting actions of other group members in real time. Furthermore, the players saw the total harvested tokens of all participants at the top of the screen. In the other situation, we showed only the tokens and avatars within a radius of six cells. This represented a situation of reduced information availability. The environment outside this radius was depicted as black. Only when another avatar was within the radius could one see the total amount of harvested tokens of this other player at the top of the screen.

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 are colored blue. The white circle represents the limited vision. The yellow player sees only the information within the circle. The environment outside the circle is black.



Every second, empty cells had the potential to generate new tokens. The probability that a given empty cell would generate a token was density-dependent on the number of adjacent cells with tokens. The probability p_t was linearly related to the number of neighbors: $p_t = p \cdot n_t/N$ where n_t was the number of neighboring cells containing a green token, N was the number of neighboring cells (N = 8), and p = 0.01. If an empty cell was completely surrounded by eight tokens, it would generate a token at a higher probability than an empty cell that abutted only three tokens. At least one adjacent cell must have contained a token for a new token generation to occur. Therefore, if participants appropriated all of the tokens on the screen, they had exhausted the resource and no additional token generation would occur. By designing the environment in this manner, we captured a key characteristic of many spatially dependent renewable resources. The optimum level of appropriation depended on the initial starting conditions and probabilistic renewal of the empty cells. Janssen et al. (2010) estimated the optimal group-level harvest amount to be 665.

We defined the following hypotheses to guide our design and analysis of the experiments:

• Hypothesis 1: With limited vision, participants will overharvest the common resources at a slower rate than with full vision.

Previous experiments have shown that most participants in social dilemma situations can be identified as conditional cooperators (e.g., Fischbacher et al. 2001, Frey and Meier 2004). Conditional cooperators are more likely to cooperate if they expect others will do so too (de Oliveira et al. 2009). The participants' decisions might be influenced by their expectations of what others will do. In various previous studies, providing more information so that free-riding can be observed reduced cooperation (Nikiforakis 2010, Villena and Zecchetto 2010). When we reduced the visibility of others, we expected this would take longer to detect free-riding behavior. As such, we expected a lower level of harvesting when there was a limited vision.

• Hypothesis 2: Communication increases cooperation, and there is no difference in the effect of full vision versus limited vision on periods with communication.

Communication has been found to increase cooperation, probably due to the formation of group identity or the expressed commitment to cooperate (Orbell et al. 1988, Ostrom et al. 1994, Shankar and Pavitt 2002, Buchan et al. 2006). Communication via chat messages was allowed for four minutes before the harvesting period for groups with both limited and with full vision. As such, changing the visibility would not affect the expected results.

Table 1. Experimental design.

Name	Number of groups (individuals)	Vision	Practice	Periods 1–3	Periods 4–6
NC-C	6 (30)	Radius	Individual resource	No communication (NC)	Communication (C)
C-NC	7 (35)	Radius	Individual resource	Communication (C)	No communication (NC)
NC-C	5 (25)	Full	Individual resource	No communication (NC)	Communication (C)
C-NC	4 (20)	Full	Individual resource	Communication (C)	No communication (NC)

To test Hypothesis 1, we performed experiments with limited vision and with full vision. To test Hypothesis 2, we had to perform periods with and without communication for the same groups. We decided to use both possible designs, namely first periods without communication and then periods with communication, and then in the reverse order. When we started without communication, we should have seen an increase in harvesting when communication was allowed. If we found differences in the effects of limited and full vision in rounds with communication, this might have been caused by the differences in the groups' experiences in rounds without communication. Therefore, we also included experiments in which we started with communication, and then after a number of periods switched to no communication.

We tested four treatments in an AB-BA, AC-CA format in which each treatment consisted of three periods of four minutes without communication and three periods of four minutes with communication using text chat. We tested the effect of information availability by doing experiments with full vision and with limited vision (a radius of six cells). Furthermore, we varied when agents could communicate in order to test Hypothesis 2.

Table 1 shows the four different treatments, and for each treatment, the number of groups that participated is listed. The first treatment was the condition in which participants had limited vision during the whole experiment and could not communicate during the first three periods of the experiment. In the last three periods of the experiment, players could communicate for four minutes by sending text messages before each period started. The second treatment was the same as the first treatment, except that we had communication during the first three periods and not in the last three periods. Janssen et al. (2010) found that communication has a long-term effect, even after communication is removed. We tested whether this held with limited vision. The third treatment was the same as the first treatment, except that participants could see the whole screen instead of the information within a radius of six cells only. Comparing treatment three with treatment one enabled us to test the effect of limited vision. The fourth treatment was the same as the second treatment, except that players could now see the whole screen.

Each experimental session consisted of participants harvesting in six periods of four minutes each. Groups that quickly appropriated all of the tokens on the screen exhausted the resource and had to wait for time to expire before continuing to the next period. Communication among participants occurred during text-chat sessions. During four-minute sessions, participants could send public text messages to others in their group. Each participant was identified by an avatar number, which remained the same throughout all periods, and allowed individuals to associate the witnessed actions of other group members during a harvesting period with the discussions during the communication sessions.

EXPERIMENTAL RESULTS

General statistical results

During the Spring 2010 semester, 115 participants took part in 23 group experiments at the Tempe campus of Arizona State University (ASU). All participants were undergraduate students at ASU who were recruited by sending out invitations to a random sample from a database of more than 1500 potential participants in social science experiments. The average age was 19.8 years, and the average earning was US$14.28 for a one-hour experiment.

Fig. 2 shows the number of tokens harvested on average for each treatment in the first period of the experiment. Groups with communication harvested more tokens than groups without communication, which is in line with earlier findings (Ostrom et al. 1994, Janssen et al. 2010). With communication, groups could coordinate and define informal rules on how to harvest the resource. Groups with limited vision harvested more tokens than groups with full vision. This is support for Hypothesis 1 and suggests that in groups with limited vision, participants who have high expectations of cooperation do not realize until late into the period that some participants are harvesting faster than anticipated. In groups with full vision, the expectations are quickly adjusted, thereby leading participants to follow a higher rate of harvesting.

Fig. 2. Average number of tokens collected by groups in the first period of the first treatment. NC: no communication; C: communication; LV: limited view; FV: full view. The standard deviation of the groups is depicted as error bars.

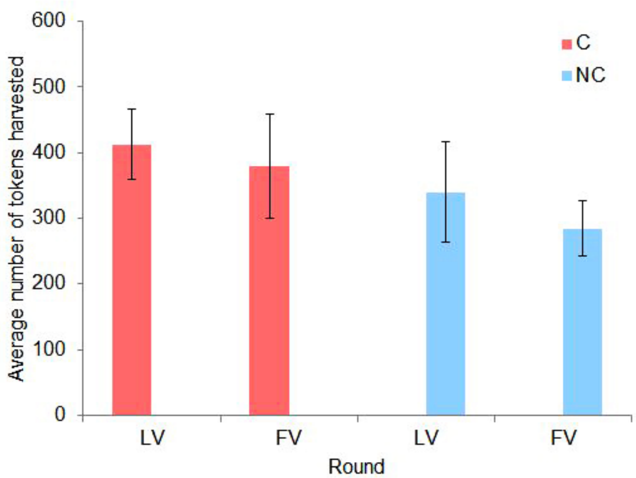


Fig. 3 shows the average resource size for each treatment for each period. For example, at the right top (B) is the treatment NC-C-FV. This means that there was no communication in the first three periods of the experiment, while there was full vision during the whole experiment. Each period, the resource got depleted more quickly (the green line is below the red line). When communication was allowed, there was an increase in the resource size. This was caused by coordination and informal rule-crafting among the participants, which reduced the level of overharvesting experienced at the start of the experiment. At the end of each of these periods, the participants depleted the resource since they had agreed that it benefited them to collect all the tokens from the resource before the period ended. Participants knew the length of the period, and the seconds left during a period were displayed at the top of the screen. Participants could earn more as a group if they did not harvest quickly at the beginning, which allowed the resource to grow.

When participants started with communication, they did not wait collectively to let the resource grow, but they also did not harvest the resource rapidly. Over the periods, the resource level stayed at a higher level. When communication was not possible anymore, on average the resource levels did not change much. The results with full vision are in line with those of Janssen et al. (2010).

The resource dynamics were different when there was limited vision. If participants started with periods without communication, the decline of the resource seemed to be slower compared to the full vision case. Over the periods, the rate of decline increased. When communication was allowed, the resource remained at a higher level but not as high as with full vision. When participants started with communication in a limited vision treatment, there was a significantly lower resource level when communication was removed compared to the full vision treatment.

Fig. 4 shows similar trends as discussed above in terms of the number of tokens harvested. Communication seemed to lead to an increase in performance over the periods, especially when there was full vision, while not being able to communicate led to a reduction of performance over the periods when vision was limited.

We used a number of nonparametric tests to test for statistical differences between the treatments. To test the effect of full versus limited vision, we used a two-tailed Mann-Whitney test. We applied the test to the group earnings during the first period for the sample with full vision and the sample with limited vision, and found a significant difference (p = 0.08). This means that the periods with full vision led to lower numbers of tokens being collected compared to the first period of experiments with limited vision. To test the effect of introducing communication, we used the Wilcoxon matched-pairs signed-ranks test to compare the earnings in rounds three and four. We found a significant increase in tokens earned for full vision (p = 0.06) and limited vision (p = 0.03). We used this test because it is suitable to test whether two related samples (earnings of the same group in different rounds) are different.

Was there a significant difference between the communication groups in period one whether they experienced full or limited vision? Using a two-tailed Mann-Whitney test, we found no significant difference (p = 0.34). This supports Hypothesis 2. Communication led to higher levels of cooperation; thus, stopping communication may also reduce the harvest levels. We used the Wilcoxon matched-pairs signed-ranks test to assess the effect of not allowing communication after period three, and we found in both treatments a significant decrease in performance between period three and four for limited vision (p = 0.08) and full vision (p = 0.06). Hence, stopping communication led to a lower level of earnings in subsequent periods.

The nonparametric test compared samples but did not assess the effect of the treatments over different periods. Fig. 4 indicates that there were learning effects due to multiple periods of communication or multiple periods without communication. To test this, we used a multi-level mixed effect linear model to control for the possibility that groups had different error distributions. The value of χ^2 in Table 2

Fig. 3. Resource availability at given times. The diagrams show the average remaining level of the resource for the groups of each treatment. Each diagram shows a treatment condition, and each line represents a particular period. The treatment is a combination of two sets of three periods of a specific condition. The names for these conditions are noted in the upper left of each display: NC: no communication; C: communication; LV: limited view; FV: full view. A treatment A-B refers to condition A for the first three periods and B for the last three periods. The colors and shapes referring to data of each period are noted in the upper right.

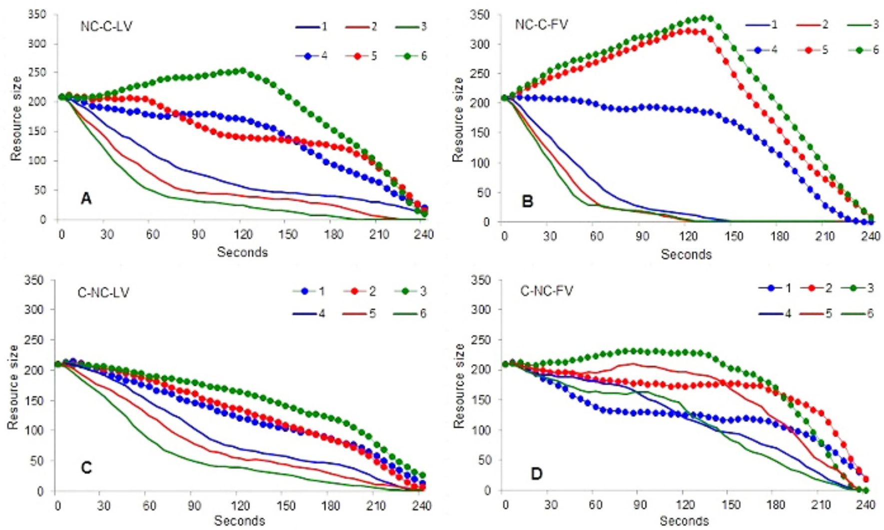
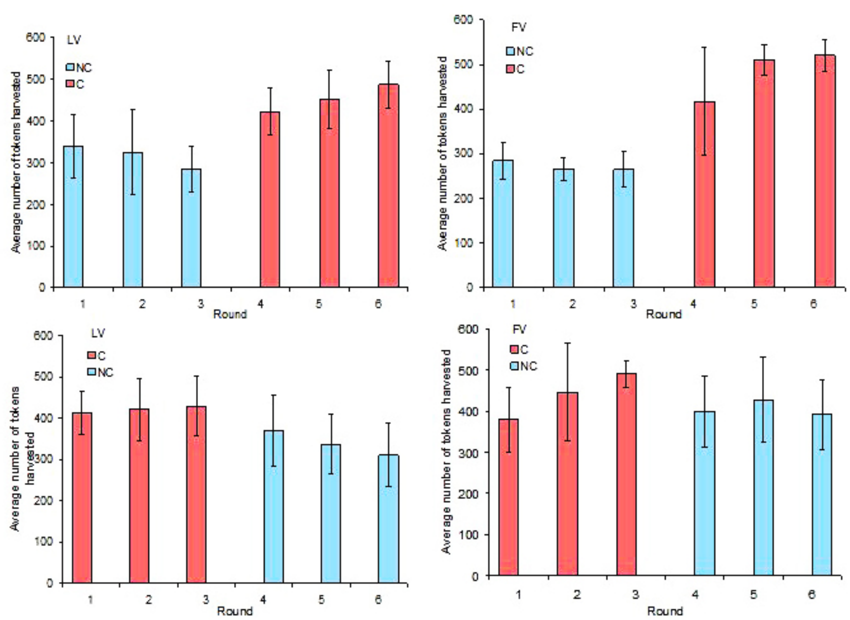


Fig. 4. Average number of tokens collected by groups per period. Each diagram shows a treatment condition. The treatment is a combination of two sets of three periods of a specific condition. The names for these conditions are noted in the upper left of each display: NC: no communication; C: communication; LV: limited view; FV: full view. The standard deviation of the groups is depicted as error bars.



suggests this had a significant effect, so it was important to use a multi-level model. A linear model was used to test the effect of different treatments over the periods on the level of group harvesting. The model basically consisted of a number of dummy variables. It took into account whether communication was possible or not, whether there was limited vision or not, and whether groups had already communicated or not. For each sequence of three rounds in a certain condition, we tested whether there was a learning effect. If there was a learning effect, each round would have had a predictable change in the group's harvest.

Table 2. A multilevel mixed-effects linear regression performed with the gross number of tokens that groups collected during each period. The independent variables are a set of dummy variables: whether participants could communicate during the period, whether participants could have communicated during the first three periods, and whether participants' vision was limited. Learning is tested by the effect of experiencing the same condition during multiple periods by including a dummy variable that indicates whether it is the first, second, or third time in this condition. Learn is 1 for round 1, 2 for round 2, and 3 for round 3. Learn is also 1 for round 4, 2 for round 5, and 3 for round 6. Learn (Com & FV) is not zero when there is communication and full vision. The dummies for communication and limited vision (Com & LV), and the rounds without communication (No Com & FV) and (No Com & LV) are defined in the same way.

Independent variables	Dependent variable: tokens harvested by group (std. error)
Constant	299.605*** (27.770)
Communication	59.720*** (22.541)
Past Communication	98.409*** (15.299)
Limited Vision	35.938 (32.048)
Learn (Com & FV)	52.043*** (9.379)
Learn (Com & LV)	20.278*** (8.200)
Learn (no Com & FV)	-6.320 (9.379)
Learn (no Com & LV)	-29.816*** (8.200)
Total Chat	
- Log Likelihood	717.494
Number of Decision Periods	132
Wald χ^2	298.33 ($P < 0.001$)
χ^2	63.74 ($P < 0.001$)

* P < 0.1, ** P < 0.05, *** P < 0.001

The results of the statistical analysis are shown in Table 2. It shows that communication in the current and past rounds had a significant effect. The effect of past communication was important. It means that if communication was not possible, but there had been communication in a previous period, there was an increase of about 90 tokens in that round. This suggests that communication had a lasting effect on the group dynamics, and confirms earlier findings that communication might be important due to the formation of a group identity. The positive effect of a limited vision was not significant. Fig. 4 shows that there might be positive and negative consequences of limited vision. The group earnings were higher in the first rounds when vision was limited, but the effect of communication was less sustainable when communication was not allowed anymore.

The learning effects differed for each context. When there was full vision, each period of communication led to a significant increase of about 52 tokens harvested (Learn [Com & FV]). The effect of communication was less positive when there was limited vision since the earnings increased by only about 20 tokens each period. Hence, communication was more than twice as effective if there was no limit to the information available on the actions that people actually performed.

When participants could not communicate, there was a different effect in groups with full and with limited vision. When vision was limited, there was a rapid reduction of the earnings of about 29 tokens per period. There was only a small, insignificant reduction per period when participants had full vision.

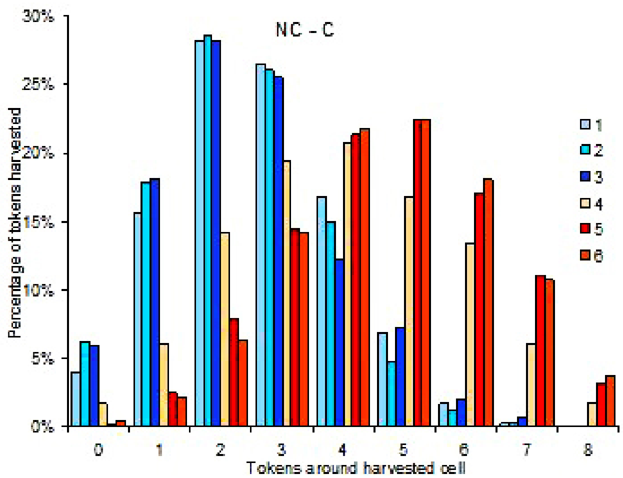
How do we interpret the results and what might be an explanation? When groups had limited vision or full vision, communication enabled them to discuss effective strategies and develop a group identity. However, when the vision was limited, participants could not verify whether others were keeping their promises. Participants also knew they were not being observed when they did not see other avatars on the screen. As a consequence, promises made might have been more likely to be broken. Other studies have shown that the perception of being monitored leads to a higher level of cooperation (Bateson et al. 2006, Burnham and Hare 2007). As a consequence, we should have been able to observe a difference in individual decisions when participants were observed by others or not, as we evaluate in *EXPERIMENTAL RESULTS: Harvesting decisions*.

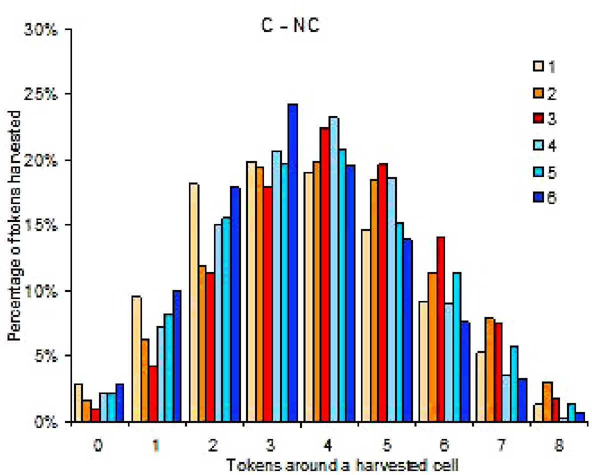
If participants were largely conditional cooperators, we should have seen that the level of information available had a significant effect. Our analysis confirmed this and showed that this was especially the case when we had a number of periods in the same condition. Communication was more effective with full vision, and not being able to communicate was damaging for the group when the vision was limited. With full vision, actions could be monitored and confirmed, and there were fewer opportunities for breaking promises.

Harvesting decisions

When we looked in more detail at how participants harvested tokens, we detected interesting patterns. For each harvesting event, we counted the number of tokens around the cell that was harvested. When we plotted the distributions for the full vision treatments, we saw that for experiments where the periods started without communication, the distributions were biased toward cells with a small number of tokens on the neighboring cells (Fig. 5). It seems that the occurrences of tokens with many neighboring tokens were reduced quickly so that only tokens with none or a few tokens on neighboring cells could be harvested. When communication was allowed, the distribution shifted toward a larger number of tokens on neighboring cells. This meant that participants were more deliberate about harvesting tokens in locations that stimulated renewal.

Fig. 5. Distribution of the number of tokens in the neighboring cells at the moment a token is harvested. Distributions are given for each round. Both figures are for the full vision treatments. NC: no communication; C: communication.

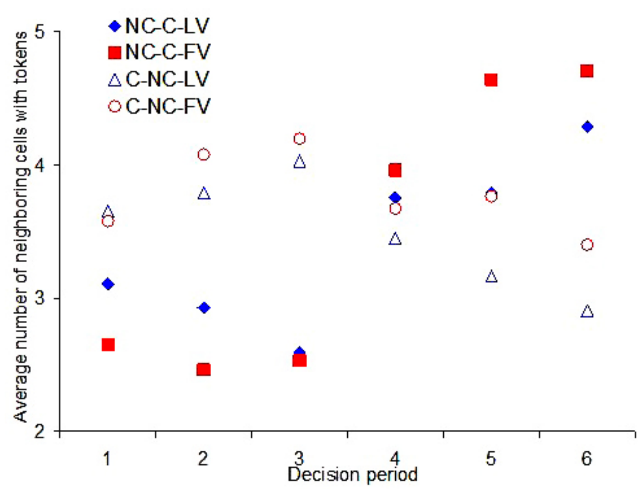




When experiments started with communication periods, we saw a different pattern. Harvesting was more focused on tokens with many neighboring tokens. The distribution was biased toward cells with a higher number of neighboring tokens than in the no communication periods in the no communication-communication (NC-C) treatments. Interestingly, the distribution did not change when communication was no longer allowed. The norms governing when to harvest tokens seemed to persist.

When we looked at the treatments with limited vision, we saw a similar pattern, however, with one interesting difference. There was a sharp decline if the experiment started with communication periods (Fig. 6). In fact, the distribution of the number of tokens on the neighboring cells in period 6 (C-NC) became similar to the distribution of the first period in experiments that started without communication (NC-C) (p = 0.05, Kolmogorov-Smirnov test). This was not the case for the full vision experiments. The hypothesis that both distributions (period 1 of NC-C-FV and period 6 of C-NC-FV) were the same was rejected using the Kolmogorov-Smirnov test (p = 0.19).

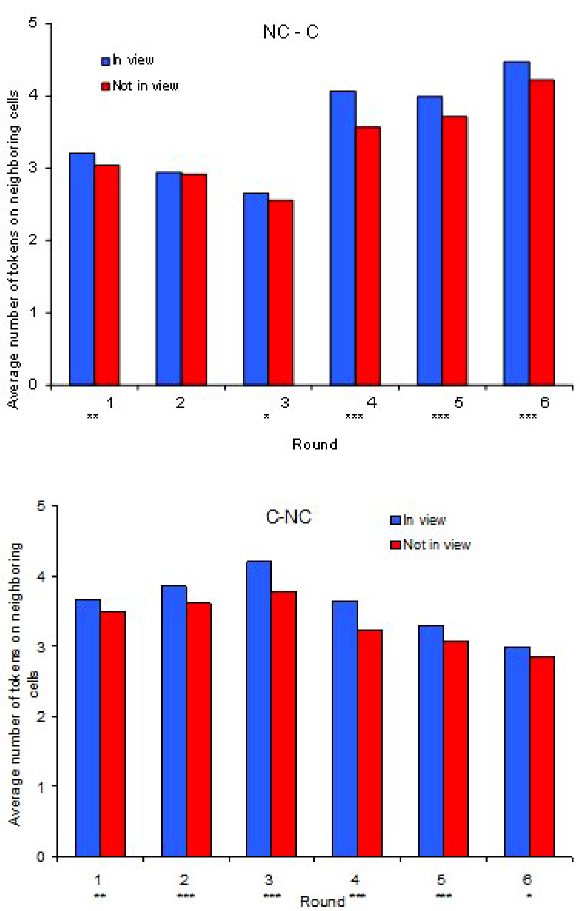
Fig. 6. Average number of tokens in neighboring cells at the moment of harvesting for each treatment in each of the six rounds. NC: no communication; C: communication; LV: limited view; FV: full view.



When we tested the distributions of period 1 for the experiments that started without communication for limited vision and full vision, the hypothesis that they were the same was rejected (p = 0.12, Kolmogorov-Smirnov test).

In the limited vision treatment, we could distinguish two different harvesting situations: one where the harvester could be seen by other participants who were within the vision radius, and one where the harvester had no other participant within the vision radius. We tested whether the distributions were different among the harvesting events in which others were within the field of vision or not. Fig. 7 shows the average number of tokens on neighboring cells. The average number of tokens was lower when participants could not be observed by others. This was especially significant in periods with communication. This indicates that participants were more eager to harvest tokens when there were only a few tokens around if others could not see their actions. We expected that communication would lead to a certain norm on when to harvest. But when participants could not be seen by others, they were often tempted to harvest tokens with a lower number of neighboring tokens than had been established in the norm.

Fig. 7. Average number of neighboring cells with tokens at the moment a token is harvested. For each round, the average number is given when participants can be seen by somebody else or not. At the bottom of the figure, the level of significance of the difference between the two distributions is provided: * $P < 0.1$, ** $P < 0.05$, *** $P < 0.001$. NC: no communication; C: communication.



Communication analysis

All the chat messages were read, and the type of communication was very similar to that found in earlier studies with this experimental environment (Janssen 2010, Janssen et al. 2010). In most groups, participants discussed not to “eat” single tokens in order to allow regeneration of the resource. Furthermore, they coordinated to divide up the resource in five equal parts: four corners and one in the middle. Some groups decided not to harvest at the beginning of the period to allow the resource to grow. Most groups agreed to get “crazy” around the final 30 seconds in order to collect all the remaining tokens on the screen. No differences were observed in the types of informal rules the participants created. But as seen in the observed behavior, the level of compliance with the informal arrangements was lower in the experiments with limited vision.

DISCUSSION

The spatial and temporal dynamics of ecological systems affect the information available on the condition and use of the common resources. Information availability might be an organizing factor to explain the problem of fit between institutional arrangements and ecological dynamics.

Our series of lab experiments show that information availability has a significant impact on outcomes. When experiments started without communication, there was a higher level of earnings when participants had limited vision. This result can be explained by the often-observed conditional cooperation behavior of participants, i.e., participants cooperate if they expect that others will do so as well. If participants expect others will harvest at a modest rate, limited information will delay the observation that some of the participants seem to harvest more.

In most social dilemma experiments, most participants can be classified as conditional cooperators (Fischbacher et al. 2001), and this explains observed cooperation in actual social-ecological systems (Rustagi et al. 2010). If conditional cooperation depends on expectations about the behavior of others, such as compliance to social norms, the quality of information is a key component to explain the level of cooperation. If players were making decisions unrelated to the actions of others, such as those who are pure egoists and pure altruists, we would not see an effect from limited vision on our experimental results. But there was a difference. With more information, participants harvested faster when there was no communication. This might be explained when participants expected a higher level of cooperation and adjusted their expectation based on the observed behavior of others.

The effect of limited vision might not be the same for each participant. Although we did not have independent information on the level of conditional cooperation for each participant, we expect that unconditional free riders had a relative benefit with limited information compared to those who were conditional cooperators. Since unconditional free riders can benefit for a longer time from the lower harvest levels of others, they will receive a relative higher share of the group harvest. This distributional effect of limited information would be interesting to explore more systematically with an agent-based model.

Although communication is a key factor in increasing cooperation in common pool resource experiments, there are different possible explanations varying from improved understanding to a sense of belonging to a group. A change of vision will not affect the impact of communication if the effect of communication is about improving the understanding of the experiment or deriving a sense of belonging to a group. In our experiments, groups with communication learned to increase their earnings at a slower rate if vision was limited. This suggests that the effect of communication relates to other types of information that can be derived. An explanation is that communication provides opportunities for coordination and expectation formation on the actions of others. When information is limited, informal arrangements made during the communication periods cannot be monitored. The lack of monitoring may reduce the level of compliance. In fact, participants harvested more single tokens when they could not be seen by others. Hence, the effectiveness of making informal arrangements depends on the ability to monitor the actual behaviors.

The experiments showed that limited information had an effect on the performance of groups, although we did not see participants crafting different informal regulations with different levels of information. A few groups started to group together in the middle of the screen so that they could verify that everyone was waiting for the resource to grow at the start of the period. We expect that limitations on information availability will stimulate institutional arrangements that are easier to verify, such as the use of certain technology. More specific experiments need to be done to confirm this.

To conclude, the quantity and quality of information on actors and resources might become an organizing framework to study the fit between institutions and ecological dynamics. Experiments and formal models might be used to determine the conditions that affect the performance of groups in solving collective action problems. In the current information age, looking at the problem of governance of social-ecological systems from an information perspective might also lead to novel methods of improvement. Does sharing of information on resource extraction, such as photos of harvest activities or GPS tracking of resource users, help increase cooperation? If resource users are largely conditional cooperators, sharing information on cooperative behavior might reinforce cooperative behavior.

Responses to this article can be read online at:
http://www.ecologyandsociety.org/issues/responses.php/5664

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Appendix 1: Experimental protocol

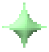
In this appendix you find the information participants receive during the experiments. It includes of text on the screen of the experiments, as well as some screen shots of the software.). The software used for this experiment is open-source and available at http://commons.asu.edu.

As you will see allowed participants to vote for allowing to sanction each other at a cost. We did not include sanctioning in the discussion of the paper since groups did not vote in favor for using sanctioning. If costly sanctioning would be allowed, participants could click on the number of the avatar they would like to sanction. Two tokens will then be removed from the earnings of the other participant, at a cost of one token to the person who sanction. Costly sanctioning was elected in two of the three rounds in only one group. This was in the treatment of full vision in rounds two and three with communication. We decided to exclude the results of this group and not include costly sanctioning in the analysis. We verified the effect of this omission, and found not a significant effect of excluding this group from the analysis on our conclusions.

Welcome Screen Instructions

Welcome to the experiment. The experiment will begin shortly after everyone has been assigned a station.
Please **wait quietly and do not close this window or open any other applications.**

General Instructions
Welcome. You have already earned 5 dollars by showing up at this experiment. You can earn more, up to a maximum of 40 dollars, by participating in this experiment, which will take about an hour to an hour and a half. The amount of money you earn depends on your decisions as well as the decisions of other people in this room during the six rounds of the experiment.

You appear on the screen as a yellow dot . You move by pressing the four arrow keys on your keyboard. You can move up, down, left, or right. You have to press a key for each and every move of your yellow dot. In this experiment you can collect green diamond shaped tokens  and earn two cents for each collected token. To collect a token, move your yellow dot over a green token and press the **space bar**. If you move over a token without pressing the **space bar** you do NOT collect that token.

The tokens that you collect have the potential to regenerate. After you have collected a green token, a new token can re-appear on that empty cell. However, the rate at which new tokens will appear depends on the number of adjacent cells with tokens. The more tokens in the eight cells around an empty cell, the faster a new token will appear on that empty cell. In other words, **existing tokens can generate new tokens.** To illustrate this, please refer to Image 1 and Image 2. The middle cell in Image 1 denoted with an X has a greater chance of regeneration than the middle cell in Image 2. When all neighboring cells are empty, there is **no chance for regeneration.**

Image 1

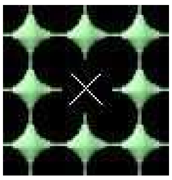
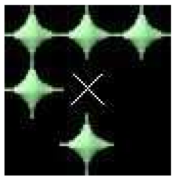


Image 2



Your vision is limited in this experiment. The area that is visible to you will be shaded.

Practice Round Instructions
You will now have four minutes to practice with the experimental environment. The decisions you make in this round will NOT influence your earnings. At the At the beginning of the practice round 25% of the cells are occupied with green tokens. The environment is a 13 x 13 grid of cells.

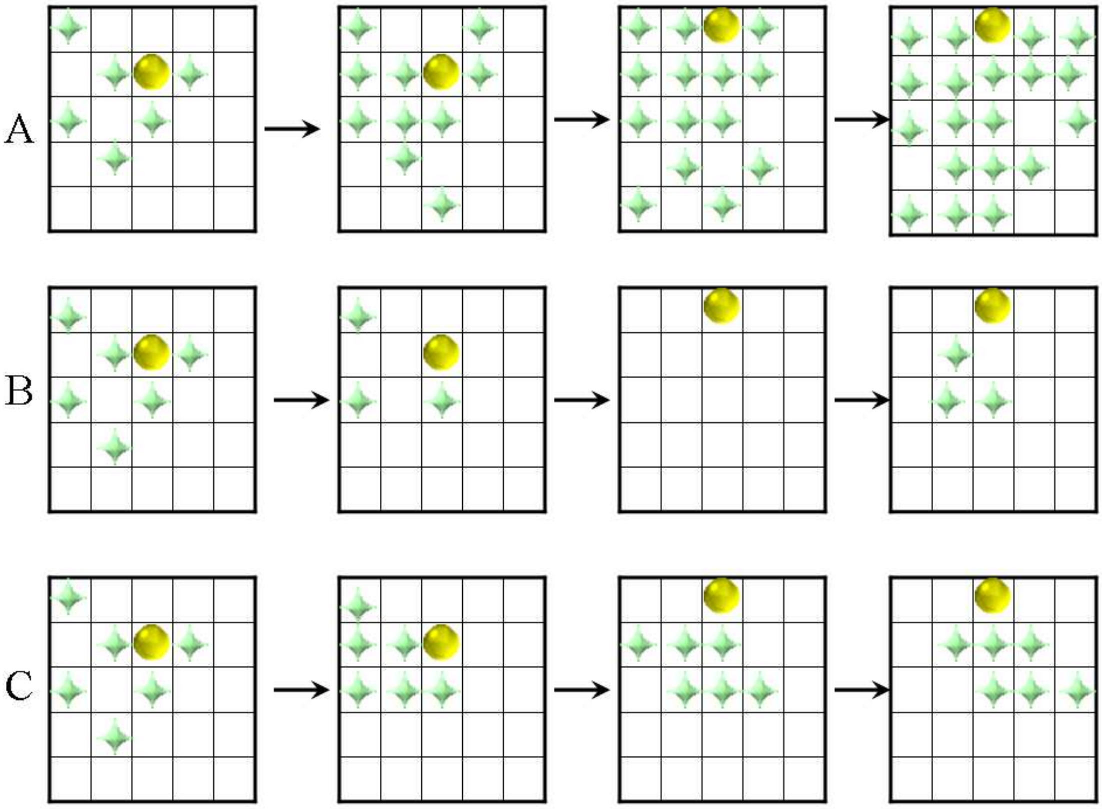
During this practice round, and **only during** this practice round, you are able to reset the tokens displayed on the screen by pressing the **R** key. When you press the **R** key you will reset the resource to its initial distribution, randomly filling half of the cells.

Please do not communicate with any other participant.
If you have any questions please raise your hand. Do you have any questions so far?

Before we begin the practice round you need to answer the following questions correctly. You can only continue when you have answered all questions correctly. If an error is made you will need to answer the questions again.

Which of the statements is **incorrect?**
A. Your decisions of where to collect tokens affects the regeneration of tokens.
B. When you have collected all tokens on the screen, no new tokens will appear.
C. Tokens grow from the middle of the screen.
D. In order to collect a token you need to press the space bar while your yellow dot is on a cell with a token.

Which sequence of situations is **not possible**?



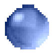
A
B
C

If you have any questions please raise your hand.

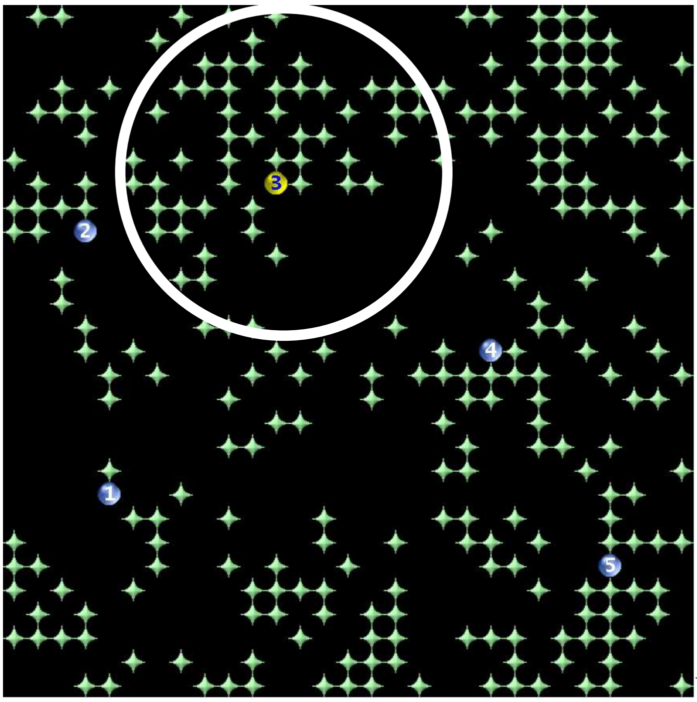
Round 1 instructions
This is the first round of the experiment. The length of the round is 4 minutes. Like in the practice round you can collect green tokens. This time you earn **two cents** for each token collected. This time you **cannot** reset the distribution of green tokens.

In this round the renewable resource will become five times bigger. You will share this larger environment with four other players in this room that have been randomly selected. One group's resource environment is distinct from the other groups.

Each of you has been assigned a number from 1 to 5. These numbers will remain the same throughout the experiment but you will **not** be able to identify which person in the room has been assigned which number, so your anonymity is guaranteed.

The other four players will appear on the screen as blue dots  with a white number embedded in the dot. On the top right corner of the screen you can see how many tokens each player has collected. On the top left corner of the screen you can see a clock that displays the remaining time in the round.

[*In experiments with limited vision the following is added:*
Since you can only see the resource within your vision you may neither see all the other participants nor all the resource units. The figure below indicates the vision range compared to the whole environment



]

Do you have any questions so far?

[Rounds 2 and 3 are the same as round 1]

Round 4 Instructions
Round 4 is the same as the previous two rounds with two exceptions.

Before the next round starts you can anonymously communicate by text messages for four minutes with the other participants in your group. You can use this opportunity to discuss the experiment and coordinate your actions to improve your earnings. You may not promise side-payments after the experiment is completed or make any threats. You are also not allowed to reveal your real identity. We are monitoring the chat traffic while you chat.
During the next round you will have the option to reduce the earnings of another participant at a cost to your own earnings.

- If you press the numeric key 1-5 corresponding to another participant, you will reduce the number of tokens they have collected in this round by two tokens. This will also reduce your own token amount by one token. The decision whether or when to use this option is up to you.
- When you reduce the number of tokens of another participant, they will receive a message stating that you have reduced their tokens. Likewise, if another participant reduces your number of tokens, you will also receive a message. These messages will be displayed on the bottom of your screen.
- If your tokens are being reduced or you are reducing another participant's tokens, you will receive some visual cues. When you are sanctioned your yellow dot will turn red briefly with a blue background. The participant sanctioning you will turn purple with a white background.
- You may sanction other participants as long as there are tokens remaining on the screen and while both you and the other participant have a positive number of tokens collected during the round. **Each time** you press the numeric key corresponding to another participant your token amount is reduced by **one**, and their token amount is reduced by two. **Note**: You can only remove tokens from a participant that is visible to you.

The length of this round is four minutes.

If you have any questions please raise your hand. Do you have any questions so far?

Before the next round begins you must complete the quiz below. You can only continue when you have answered all questions correctly. If an error is made you will need to answer the questions again.

Each time I press the numeric keys between 1-5 my tokens will be reduced by:
- 0 tokens
- 1 token
- 2 tokens
- 4 tokens

Each time I press the numeric keys between 1-5 the number of tokens of the corresponding participant is reduced by:
- 0 tokens
- 1 token

- 2 tokens
- 4 tokens

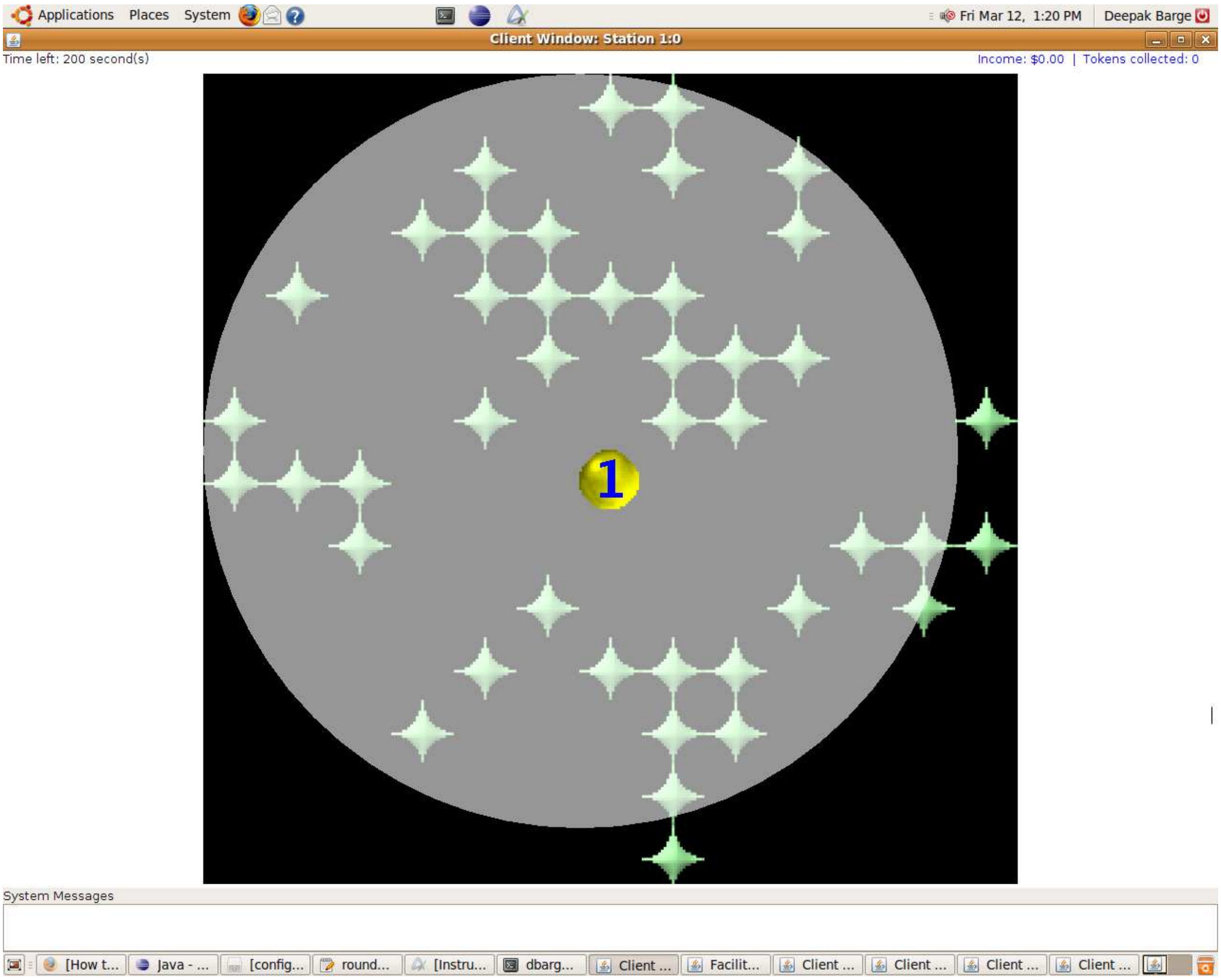
The background of your yellow dot turns blue. What does this represent?
- You collected a token
- Another participant is subtracting two tokens from you
- You are subtracting two tokens from another participant
- You are moving too fast

Every time I press the numeric keys between 1-5:
- Two tokens are subtracted from my tokens collected this round
- One token is subtracted from my tokens collected this round
- The background of my yellow dot turns blue momentarily
- My yellow dot is paused for two seconds

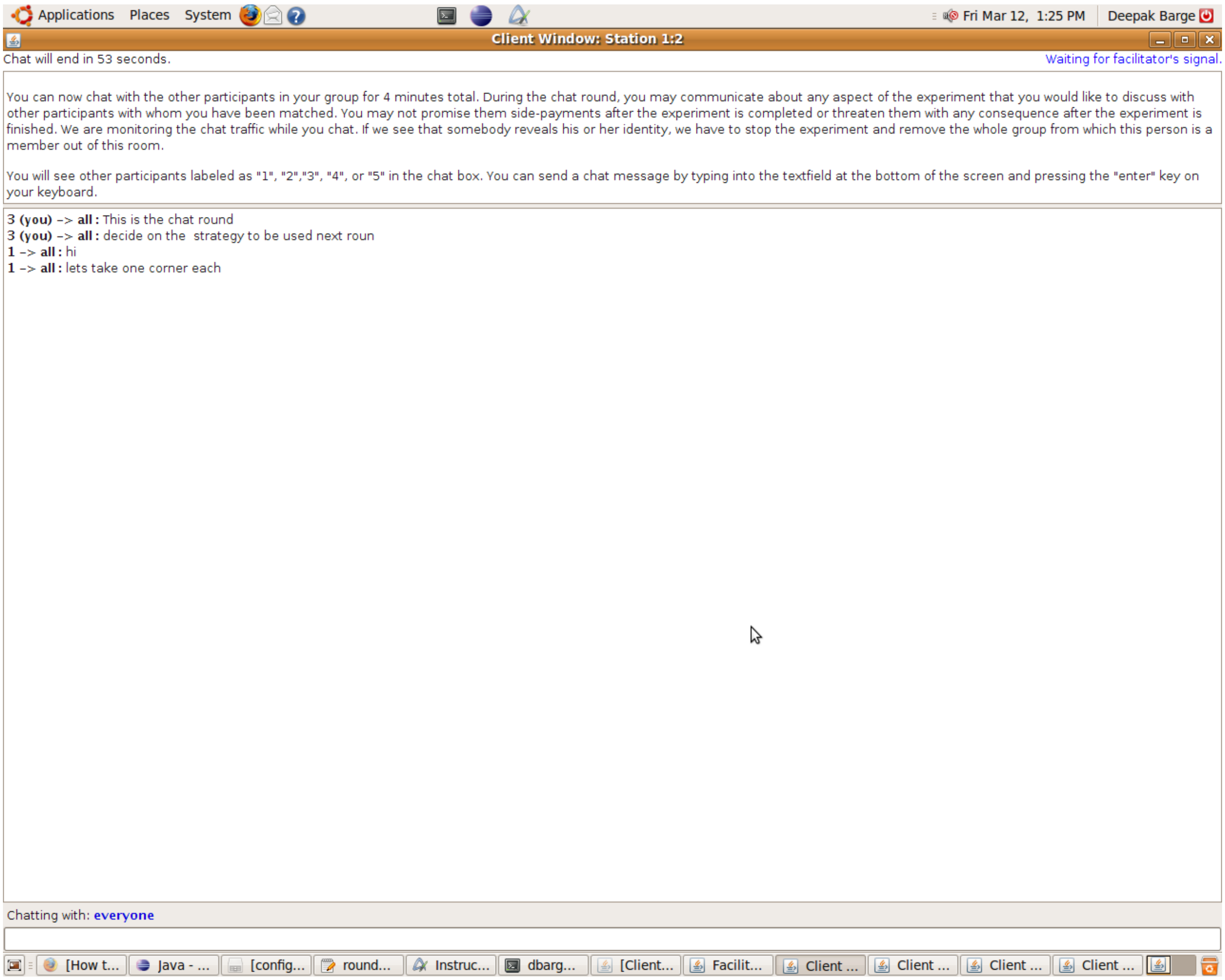
[Rounds 5 and 6 are the same as round 4]

Screenshots of experimental environment with limited vision

Practice round



Chat screen


Applications Places System
Fri Mar 12, 1:25 PM
Deepak Barge
Client Window: Station 1:2
Chat will end in 53 seconds.
Waiting for facilitator's signal.
You can now chat with the other participants in your group for 4 minutes total. During the chat round, you may communicate about any aspect of the experiment that you would like to discuss with other participants with whom you have been matched. You may not promise them side-payments after the experiment is completed or threaten them with any consequence after the experiment is finished. We are monitoring the chat traffic while you chat. If we see that somebody reveals his or her identity, we have to stop the experiment and remove the whole group from which this person is a member out of this room.
You will see other participants labeled as "1", "2","3", "4", or "5" in the chat box. You can send a chat message by typing into the textfield at the bottom of the screen and pressing the "enter" key on your keyboard.
3 (you) -> all : This is the chat round
3 (you) -> all : decide on the strategy to be used next roun
1 -> all : hi
1 -> all : lets take one corner each
Chatting with: everyone
[How t... Java - ... [config... round... Instruc... dbarg... [Client... Facilit... Client ... Client ... Client ... Client ...

Screen during harvesting of tokens of group with limited vision from perspective of player 5.