Center for the Study of Institutional Diversity

CSID Working paper

#CSID_WP_2012-006

The Role of Information in Governing the Commons: Experimental Results

Marco A. Janssen
Arizona State University, USA

April 30, 2012

The Role of Information in Governing the Commons: Experimental Results

Marco A. Janssen[a],

[a]Center for the Study of Institutional Diversity, Arizona State University, Tempe, AZ 85287-2402;

Corresponding author:
Marco A. Janssen
School of Human Evolution and Social Change, Arizona State University
PO Box 872402
Tempe, AZ 85287-2402, USA
Marco.Janssen@asu.edu; Phone: 480 965 4193; Fax: 480 965 7671

Abstract:
The performance of institutional arrangements is expected to depend on the fit between institutions and ecological dynamics. The ecological dynamics affect the ability of resource users to observe behavior of others as well as the state of the ecological systems. If ecological dynamics increase the costs of monitoring, we can expect institutional arrangements to be crafted that reduce the costs of monitoring. In case studies we see examples of how ecological dynamics affect rules for appropriation.

We present experimental results that show that information availability affect cooperation. If it is not known that others are harvesting rapidly, we see a delay in overharvesting of a common resource. Even if communication is allowed, reduced information availability makes it harder to develop effective institutional arrangements. In the discussion of the results we suggest that the fit between institutions and ecological dynamics are a consequence of the interplay between information, conditional cooperation and trust.

Acknowledgements:
Financial support for this work from the National Science Foundation via grant number SES-0748632 is acknowledged.

Introduction

The appropriation of common resources is well studied (Poteete et al., 2010). The basic question is under which conditions resource users do not overharvest their common resources. From decades of research we know that there are many factors influencing the ability to self-govern the commons (Ostrom, 2005). Critical factors include the implementation of monitoring and enforcement, clearly defined boundary rules, conflict-resolution mechanisms and ability of resource-users to participate in the rule crafting (Ostrom, 2005). These factors contribute to the development of mutual trust relationships and long-lasting repetitive actions that are commonly understood and well monitored.

In this paper the availability of information is the focus of attention. Although the multi-level framework of Ostrom (2009) implicitly includes the role of information, such as monitoring and knowledge of social-ecological systems, we will argue that an information perspective on social-ecological systems is an important one to pursue more seriously. We distinguish two roles of information availability.

The structure and dynamics of the social-ecological system affect the availability of information on the *state of the resource system*. In some systems, such as fisheries, the state of the system is more costly to derive. This affects the ability of collecting information to feed back into the governance system. Not only is 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 will argue that the attributes of social-ecological systems that affect information availability is an important component to understand the "problem of fit," the interplay between institutional arrangements and ecological dynamics (Folke et al., 2007, Young, 2002). The importance of information availability may also explain why successful social-ecological systems show that institutional rules are mainly based on where, when, and how to harvest (Schlager ,1994; Wilson et al., 1994; Ostrom, 2005). By controlling the position, timing and technology the cost of information collection can be reduced. Seeing somebody at 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.

Many long-lasting social-ecological systems include ingenious ways to craft institutional arrangements that enable them to sustain a common resource. We provide a series of illustrative examples that show that successful institutional arrangements are crafted to minimize the costs of monitoring given the ecological and social contexts. First, rules are crafted that fit a particular resource system in regard to its boundaries and ecological functioning so as to sustain use over time. Furthermore, rules are crafted in ways to make them easy to follow and easy to determine whether other resource users are also following them or not. When the costs of monitoring performance are kept low, resource users can gain a sense of confidence that rules are being followed on a day-by-day basis without having to invest substantial time and monetary resources in monitoring.

One of the major challenges that users of large natural resources face is how to see enough of each other's behavior so that they can gain assurance that no one is regularly cheating. 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 easier to monitor and enforce, and if there is more confidence that people are following the rules, others will follow them too.

In the Maine lobster fishery, for example, rules evolved to allocate permanent spots within a bay to specific fishers (Acheson, 2003; Wilson et al., 2007). In this fishery, the map of where everyone is supposed to have the authority to put down lobster pots is common knowledge. If you drew up a pot in your territory that was not yours, this would give you authority to challenge the person who fished there in error. It is said that the first time a fisher finds a pot illegally placed in his or her own territory, the fisher would tie a bow on it to inform the others that they were not following a rule. If that did not work, sanctions could escalate and eventually someone might lose a boat if they did not eventually conform to the rules and norms of their local bay.

Many farmer-managed irrigation systems allocate a particular time to a specific farmer depending on location along the canal and size of farm (and resulting contributions to maintenance of the system) (Burns, 1993; Maass and Anderson, 1986; Shivakoti and Ostrom, 2002). The frequent routine is to allocate a certain time block to a farmer in a specific order either from the head-end to the tail or from the tail-end to the head of the system (Meinzen-Dick, 2007; Tang, 1992). In either case, that means that when the water transfers from Farmer A to Farmer B both will be at their distribution point so that Farmer A gets as much water as possible but Farmer B is able to start watering crops on time. This brings the two most important actors for making this rule enforced to the canal at the same time. Again, this is an ingenious way to enable two key participants to monitor what is happening locally and to enforce any observed rule infractions.

In some of the Alpine commons, quite different norms developed over time related to the harvesting from forested areas. Farmers from the valley that jointly own the Alpine commons, work together at a 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. This set of norms makes it very easy to control harvesting of stationary resource units from a larger territory. Labor is shared and concentrated on one time a year to cut the trees. It is clear that anyone who cuts at another time is breaking the agreement. Then, everyone has an incentive to make the stacks equal since they will be allocated by lottery to those participating. Again, simple norms that allocate labor and outcomes fairly make it very easy to know when someone is harvesting outside of agreements.

The rules that have developed on most of these long-lasting social-ecological systems also enable participants to chide one another gently if they do find someone who is not following the rules. As mentioned above related to the Maine lobster fishery, these initial gentle chides can escalate over time into graduated sanctions that can become pretty severe. Everyone can make an honest error. So there is the problem of gaining assurance that most people are following the rules most of the time as well as giving people a chance to make an error without being thrown out of the community. Most of the long-lasting resource governance systems do involve some form of graduated sanctioning where the initial reaction is interpersonal discussion about why someone is breaking the rule (Ostrom, 1990). These graduate up to being quite severe sanctions but usually the resource users do not have to impose severe sanctions on each other as being called to task in the first place is usually enough to make someone conform. Further, sometimes people just make mistakes. Being shown that others notice their mistake reassures them that they are in a community that is following the rules in the main and consider the rules to be important. This increases their own trust that cooperating with others and following these rules increases their own long-term benefits.

The case study examples show that the ecological conditions affect the visibility of the state of the ecology and the actions of other resources. To overcome the costly information availability innovative institutional arrangements are crafted. Information availability matters to governance of common resources, but to test some more specific mechanisms we can use experiments.

Controlled experiments have been used to test specific hypotheses on self-governance of the commons 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 found not to make decisions in social dilemmas as if they are selfish and rational, but instead are often found to be conditional cooperators (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 performed by participants and it increases the level of cooperation (Ostrom et al., 1994).

In controlled experiments one can control which information of the experiment is available for the participants. In typical common pool resource experiments the participants get information about the total extraction of the group, the state of the common resource, and their own individual earnings.

A few recent publications explored the consequences of varying the information available to the participants. Villena and Zecchetto (2010) show that more specific information about the actions of other participants in the experiment reduces the level of cooperation. Observing that some individuals do not cooperate can reduce the level of cooperation in the group. This observation is in contrast with Chaudhuri and Paichayontvijit (2006) who show that more detailed information about the decisions of participants lead to an increase of cooperation. The more detailed information provided insights into the level of conditional cooperators within the group. In Villena and Zechetto (2010) participants see in the full information treatment the decisions of all participants, so that more information is derived on the distribution of highly cooperative and not cooperative participants. In Chaudhuri and Paichayontvjit (2006) the full information treatment is focused on the level of conditional cooperators in the group before they make their decisions.

In a different approach, de Oleveira et al. (2009) first determined whether participants are selfish actors or conditional cooperators using a one-shot public-good game. This was measured by asking participants how much they would invest in the public good given different possible levels of investments of others. A selfish rational player would invest nothing, regardless of the proposed investments of others. A conditional cooperator will increase their investment in the public good if the level of investments by the rest of the group is higher. Most of the participants are identified as conditional cooperators through this methodology. A week later the same participants are invited back for a group experiment. Participants are then sorted into homogenous or heterogeneous groups, and, depending on the treatment, they are either informed or not informed of the group distribution. Not surprisingly, homogenous groups of conditional cooperators achieved higher levels of cooperation, but the level of cooperation was even higher when the group distribution is known by the participants at the start of the experiment.

Which information is provided to the participants is important. Nikiforakis (2010) shows in public good experiments that providing participants feedback on the earnings of their peers leads to less cooperation compared to the condition where feedback is given on the contributions of their peers. Note that these information differences do not affect the incentive structure.

The level of information about the actions of others affects the level of cooperation. This seems largely related to information about the strategies participants are using. Previous studies did not include communication in which people could coordinate their activities. In this paper we study the effect of information in a spatially explicit real-time common-pool resource experiment. Janssen et al. (2010) show that communication, in contrast to costly sanctioning, was crucial to derive high levels of cooperation. The explanation was that this more complex dynamic environment requires communication to derive a common approach to the collective action problem.

The reason for Janssen et al. (2010) to include spatial and temporal dynamics in a laboratory experiment is 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 need to include more complex dynamics of the common resource (Janssen, 2010).

Although we discuss in this paper lab experiments performed with undergraduate students in Western universities, the basic findings from those laboratory experiments are verified in field experiments with participants who manage actual natural resources on a daily basis (e.g. Cardenas 2000; Vollan, 2008; Rustagi et al. 2010).

In typical field experiments on common resources, the traditional simple resource game is used without spatial or temporal dynamics. Yet, in recent years field experiments have started to include more relevant ecological dynamics (Castillo et al., 2011; Prediger et al., 2011; Janssen et al. in review).

In the rest of the paper we will first discuss the experimental design that is used in this study. Then we will discuss the experimental results. Based on the insights from the experiments and the examples from case studies we continue a discussion on the role of information using a more formal approach. The paper is closed with a concluding section.

Experimental design

Our experiments are focused on understanding the effect of limited information of the resource availability and the actions of other participants on collective action in a social-ecological system. We investigate a real-time dynamic resource-harvesting setting (Janssen et al., 2008; 2010). The software used for this experiment is open-source and available at http://commons.asu.edu.

In our experiments, participants appropriate renewable tokens from a shared renewable resource environment. Each group is made up of five participants who share a 29 x 29 grid of cells. In the initial state, 25% of the grid space is filled with tokens, thus 210 tokens. The avatars are initially placed in the middle row of the screen with equal distances between the avatars. In order to collect a token a participant must position their avatar on the location of that token and explicitly press the space bar. Each token harvested is worth $0.02 USD. We distinguish two situations by how the information on the screen is presented. In the first situation, participants have complete information on the spatial position of tokens and can watch the harvesting actions of other group members in real time. Furthermore, we see the total harvested tokens of all participants at the top of the screen. In the other situation we show only he tokens and avatars within a radius of six cells. The environment outside this radius is depicted black. Only when another avatar is within the radius one can see the total amount of harvested tokens at the top of the screen.

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

We tested four treatments in an AB-BA, AC-CA, format in which each treatment consists of three periods of no communication and three periods of text chat communication. A major difference between the treatments is the visibility, i.e., full information or only a radius of six cells. (see Table 1). When participants have the opportunity to use text chat communication, they communicate for four minutes before a period begins. In this case, participants are identified by their randomly assigned identification numbers, which remain constant throughout the experiment.

We allowed participants to vote for allowing to sanction each other at a cost. This would be in rounds with communication. If costly sanctioning is 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.

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)

Each experimental session consists of participants harvesting in six periods of four minutes each. Groups that quickly appropriate all of the tokens on the screen exhaust the resource and must wait for time to expire before continuing to the next period.

Communication among participants occurs during text-chat sessions. During four-minute sessions, participants can send public text messages to others in their group. Participants are identified by their avatar numbers, which remain the same throughout all periods, allowing individuals to associate the witnessed actions of other group members during a harvesting period with the discussions during the communication sessions.

Based on the literature, we define the following conjectures to guide our analysis of the experiments.

- *Conjecture 1: With less information participants will less quickly overharvest the common resources.*
  If participants are not able to see all the actions of others, it will take a longer time before participants observe others harvesting at a higher rate, or observe resource scarcity. Conditional cooperators who expect a high level of cooperation will continue to harvest at a slower rate with less information.
- *Conjecture 2: There is lower performance of groups in communication rounds when information is limited.*
  If participants cannot see the actions of others, it is more likely that some participants will not follow the agreed upon strategies. Even though there is no formal way to enforce agreements, a full vision of the screen provides the opportunity to monitor everybody, and feel that they are being monitored. The perception of being monitored will lead to a higher level of cooperation (Bateson et al. 2006; Burnham and Hare, 2007). With limited vision, the informal monitoring effect is reduced.
- *Conjecture 3: If participants start with communication rounds, the level of earnings in rounds 4-6 is lower than rounds 1-3 when information is limited, in contrast to full vision situation.*
  With full vision the norms that have been established during rounds of communication will largely persist. If information is limited, we expect that those norms will break down since people do not feel being monitored.

In other words, the difference of earnings with and without communication is expected to be less profound if information availability is limited compared to the situation of full information. Furthermore, without full information norms are expected to break down when communication is not possible anymore.

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 of 1500 potential participants in social science experiments. The average age was 19.8 years old and the average earnings was 14.28 dollars for a one-hour experiment.

Figure 1 shows that in each treatment participants harvest all tokens at the end of the four-minute round. This is not surprising since participants knew the length of the round and the seconds left during a round were displayed at the top of the screen. Participants can earn more as a group if they do not harvest quickly at the beginning, allowing the resource to grow.

The results with full vision are in line with Janssen et al. (2010). When participants cannot communicate they rapidly deplete the common resource, and this depletion goes faster over the rounds. When communication is introduced the participants initially withhold from harvesting to let the resource grow. In the last minute of the round, the resource is consumed. Over the rounds, the participants improve their coordination to let the resource grow.

When participants start with communication they do not wait collectively to let the resource grow, but they also do not decline the resource rapidly. Over the rounds, the resource level stays at a higher level. When communication is not possible anymore, we see that on average the resource levels do not change much.

The resource dynamics are different when we have limited vision. If participants start with rounds without communication, the decline of the resource seems to be slower compared to the full vision case. Over the rounds, the rate of decline increases. When communication is allowed, the resource remains at a higher level, but not as high as with full vision.

When participants start with communication in a limited vision treatment, there is a significantly lower resource level when communication is removed compared to the full vision treatment.

Figure 2 shows similar trends as discussed above in terms of the number of tokens harvested. Communication seems to lead to an increase in performance over the rounds, especially when there is full vision, while not being able to communicate leads to a reduction of performance over the rounds when vision is limited.

Using a two-tailed Mann-Whitney test we do not find a difference between the distribution of group earnings in the first round with full and limited vision (p-value = 0.12). When we allow communication, there is a significant increase of tokens earned for full vision (p-value = 0.06) and limited vision (p-value = 0.03) in round four compared to round three using the Wilcoxon Matched-Pairs Signed-Ranks Test.

We do not find a significant difference in round one for both types of vision conditions if participants can communicate using a two-tailed Mann-Whitney test (p-value = 0.34). When we do not allow communication anymore we find in both treatments a significant decrease of performance between round three and four using the Wilcoxen Matched-Pairs Signed-Ranks Test for limited vision (p-value = 0.08) and full vision (p-value = 0.06).

Figure 1: 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 for no communication, C for communication, LV for limited view and FV for 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.

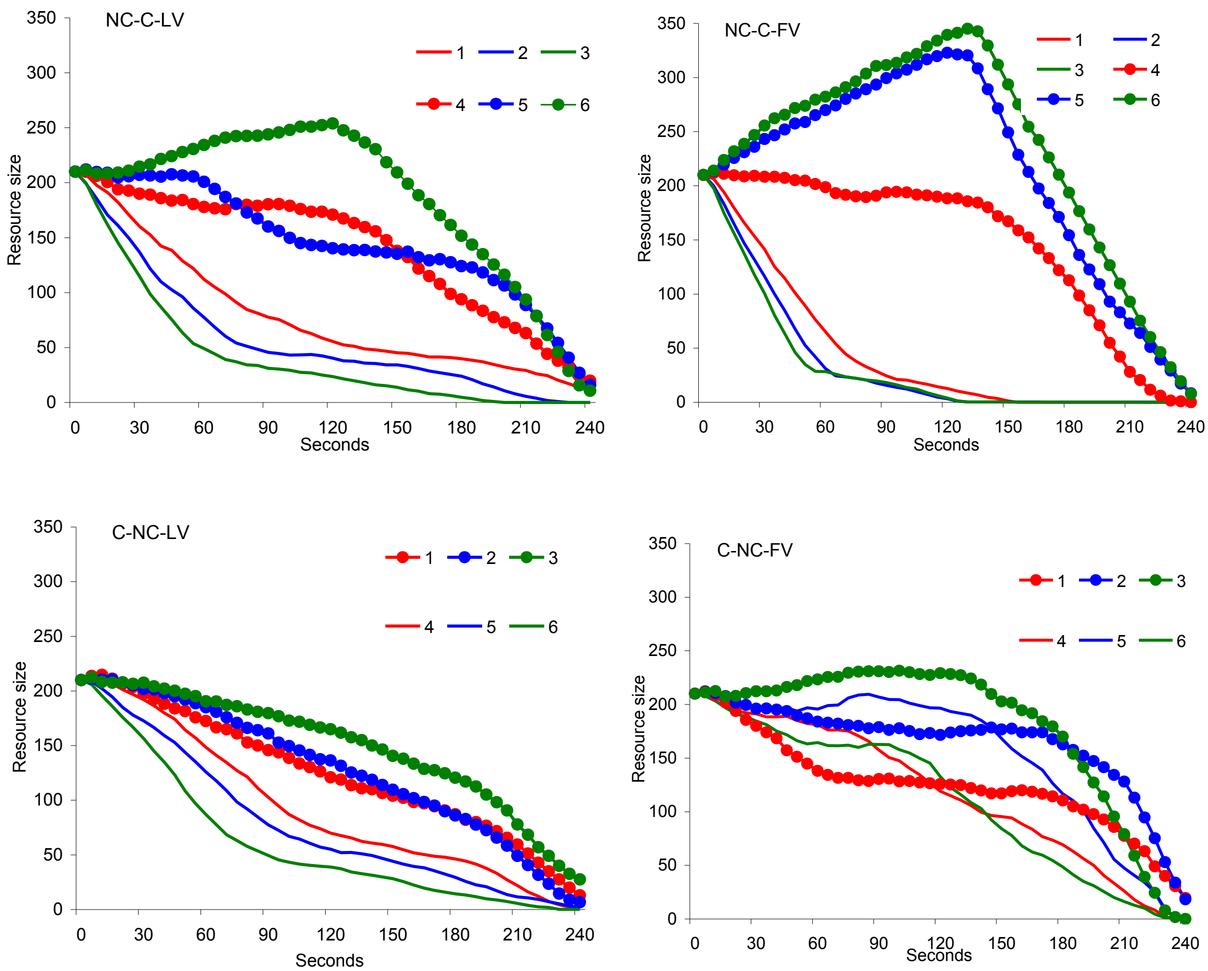
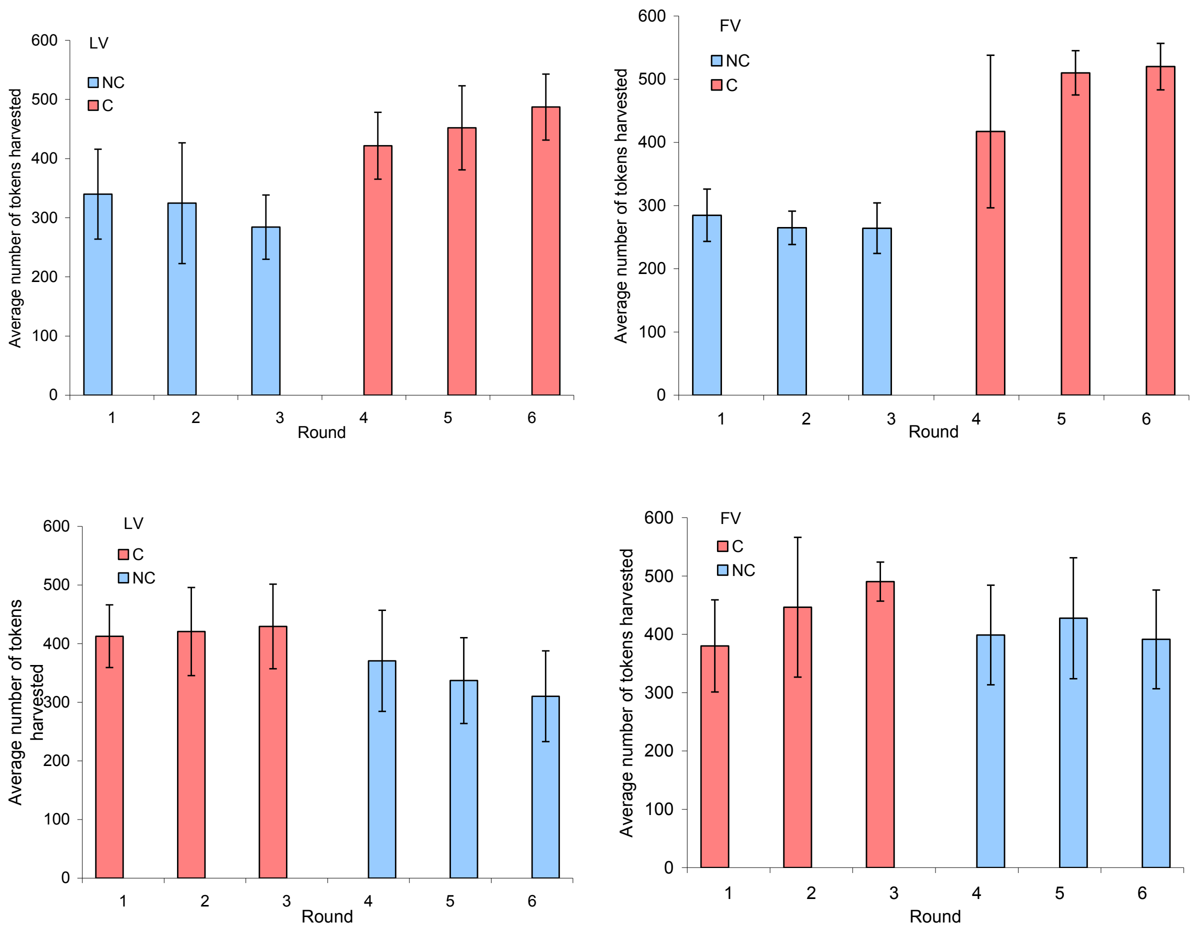


Figure 2: Average number of tokens collected by groups per period. Each diagram shows a treatment condition. The treatment is a combination of two sets of three periods of a specific condition. The names for these conditions are noted in the upper left of each display: NC for no communication, C for communication, LV for limited view and FV for full view. The standard deviation of the groups is depicted as error bars.



A statistical analysis in Table 2 shows that communication plays an important role in the effects. If there is communication, the performance of groups improves over the rounds. If communication is not possible but has happened in previous rounds, there is also a positive effect. This means that the earnings do not drop to the level of experiments where groups start without communication. Hence communication has a lasting effect. The coordination, learning and trust building that happened partly persist when communication is not possible anymore. If there is no communication, in each round without communication the earnings are reduced (column 2). This indicates that participants harvest more effectively over the rounds. If communication is possible, participants increase their earnings for each round of communication. This shows the continuing improvement of coordination and other processes as a consequence of communication.

In column 3 we include the specific effects of limited vision. There is not an additional positive effect of communication when vision is limited. However, when there is no communication, there is a strong positive effect of limited vision. This is seen in rounds 1-3 when the vision was limited (Figure 1 and 2). The learning effect due to communication is stronger in the experiments with limited vision.

In column 4 we test the effect of the number of messages participants send to each other. This number varies from 17 to 77 among the four-minute chat sessions. The average number of chat messages is 50.3. In

Table 2, column 4, we show that there is a modest positive effect of the number of chat messages on the level of earnings.

Table 2. A multilevel mixed-effects linear regression is performed with the gross number of tokens that groups collected for 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. 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 No Communication is not zero when there is no communication in the first round, 1 for the first time in this condition, 2 for the second time, and 3 for the third time. Learn Communication, Learn Past Communication, and Learn Limited View are defined in the same way. The dummy limited View * No Communication is 1 in rounds of treatments with a limited vision without communication. The dummies for Communication and Past Communication are defined in the same way.
.

Independent variables	Dependent variable: tokens harvested by group (std. error)		
Constant	**319.816*** (25.539)**	**271.101*** (32.164)**	**271.925*** (31.669)**
Communication	**60.745** (27.498)**	**85.862** (34.535)**	38.428 (42.117)
Past Communication	**100.460*** (32.897)**	**167.857*** (34.411)**	**166.002*** (33.997)**
Learn No Communication	**-19.864* (10.201)**	-7.915 (11.671)	-7.915 (11.531)
Learn Communication	**33.273*** (7.213)**	**53.056*** (10.135)**	**52.551*** (10.017)**
Learn Past Communication	**-20.545* (10.201)**	-6.606 (12.452)	-6.606 (12.303)
Learn Limited View * Communication		**33.479** (13.185)**	**-35.188*** (13.057)**
Learn Limited view * No Communication		**21.905* (13.241)**	**-21.905* (13.083)**
Limited View * No Communication		**90.298** (39.518)**	**96.207** (39.012)**
Limited View * Communication		39.934 (36.809)	39.178 (36.208)
Limited View * Past Communication		-30.204 (39.889)	-34.945 (39.336)
Total Chat			**1.010* (0.527)**
- Log Likelihood	722.053	709.519	707.706
Number of Decision Periods	132	132	132
Wald χ^2	267.36 (P<0.0001)	359.12 (P<0.0001)	371.57 (P<0.0001)
Variance Contributions			
Session	47.847 (3.232)	42.999 (2.904)	42.484 (2.868)
Group	55.270 (9.475)	53.769 (9.054)	52.537 (8.852)
χ^2	60.47 (p-value = 0.000)	69.45 (P=0.000)	69.09 (P = 0.000)

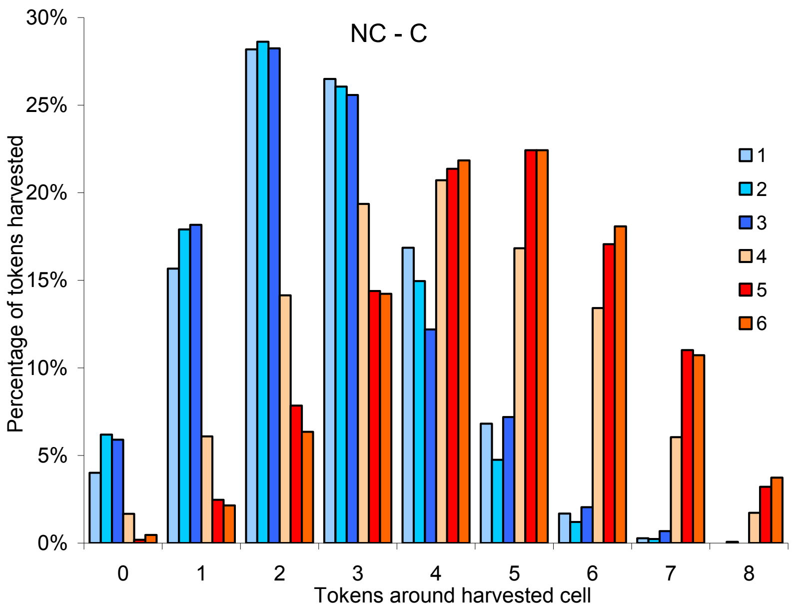
* P < 0.1, ** P < 0.05, *** P < 0.001

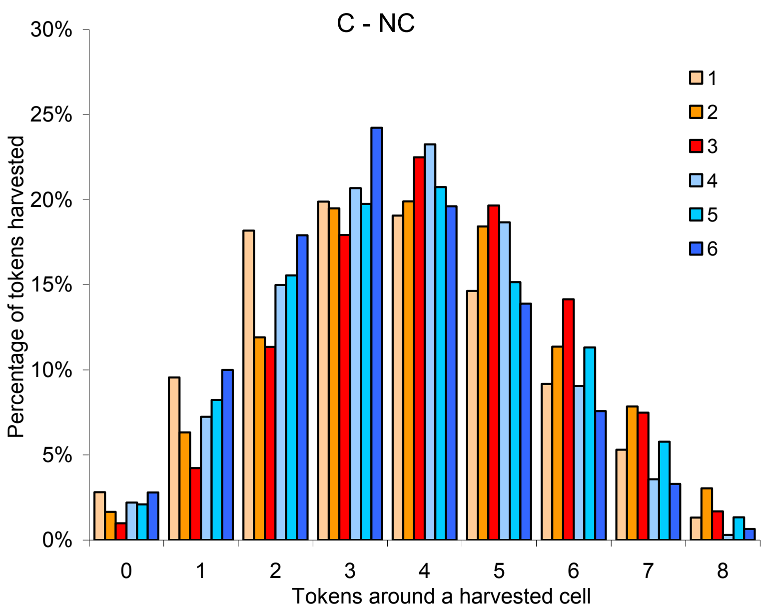
Harvesting decisions

When we look in more detail at how participants harvest tokens, we detect interesting patterns. For each harvesting event we count the number of tokens around the cell that is harvested. When we plot the distributions for the full vision treatments we see that for experiments where the rounds started without communication, the distributions are biased towards cells with small number of tokens on the neighboring cells (Figure 3). It seems that the occurrences of tokens with many neighboring tokens are reduced quickly so that only tokens with none or a few tokens can be harvested. When communication is allowed, we see that the distribution shift toward a larger number of tokens on neighboring cells. This means that participants are more deliberate about harvesting tokens in locations that stimulate renewal.

When experiments start with communication rounds, we see a different pattern. Here we see that the harvesting is less focused on harvesting tokens with many neighboring tokens. But the distribution is biased toward cells with a higher number of neighboring tokens than in the no communication rounds in the NC-C treatments. Interestingly, the distribution does not change when communication is not allowed anymore. The norms governing when to harvest tokens seem to persist.

Figure 3: 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.

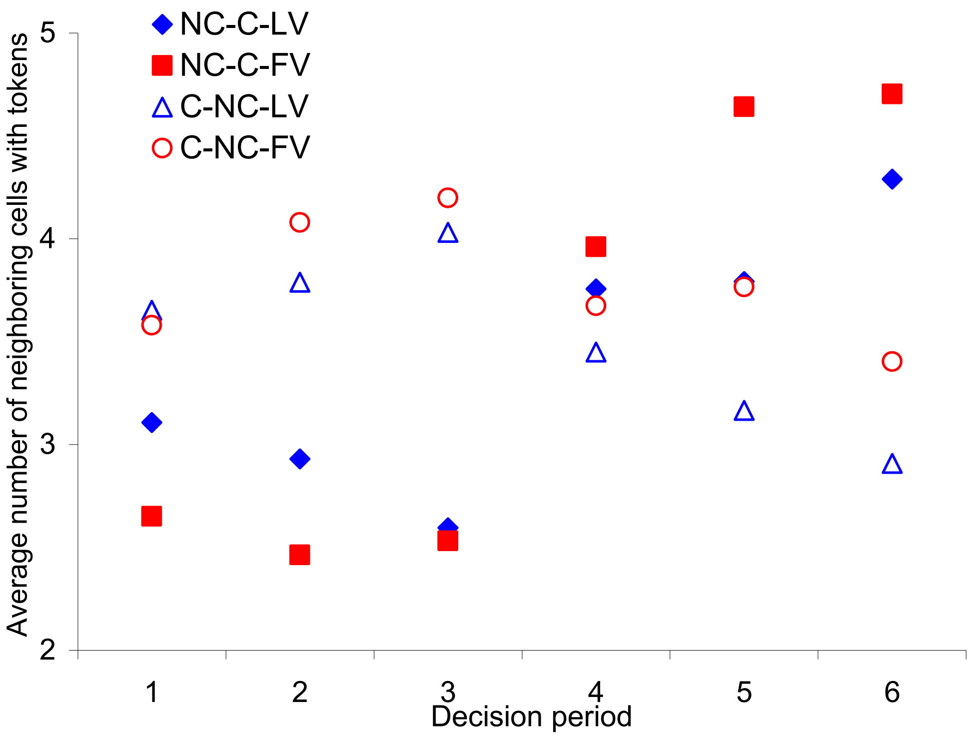




When we look at the treatments with limited vision we see a similar pattern, however, with one interesting difference. In experiments with limited vision we observe a sharp decline if the experiment started with communication rounds (Figure 4). In fact, the distribution of the number of tokens on the neighboring cells in round 6 (C-NC) becomes similar to the distribution of the first round in experiments that start without communication (NC-C) (p-value is 0.05 using the Kolmogorov-Smirnov test). This is not the case for the full vision experiments. The hypothesis that both distributions (round 1 of NC-C-FV and round 6 of C-NC-FV) are the same is rejected using the Kolmogorov-Smirnov test (p-value is 0.19).

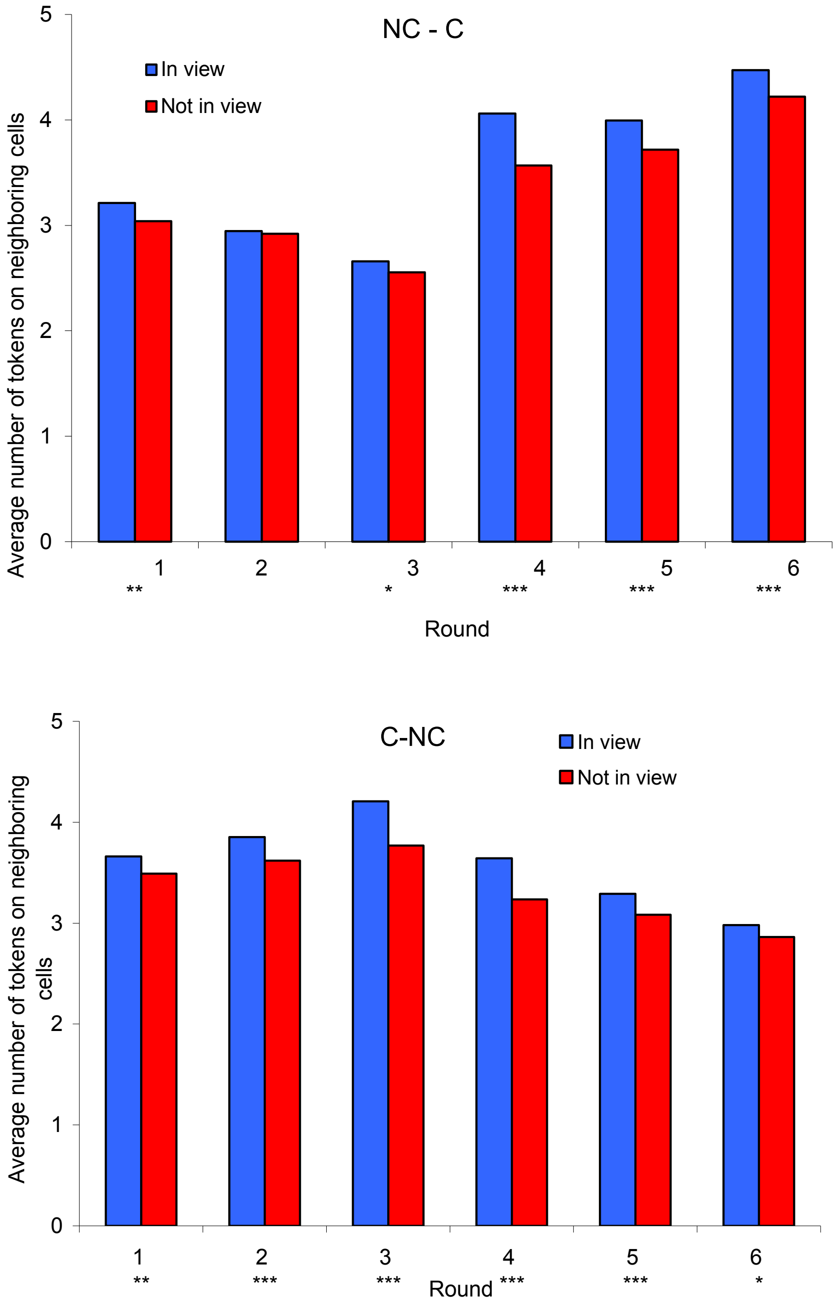
When we test the distributions of round 1 for the experiments that start without communication for limited vision and full vision, we find that the hypothesis that they are the same is rejected (p-value = 0.12, using the Kolmogorov-Smirnov test).

Figure 4: The average number of tokens in neighboring cells at the moment of harvesting is given for each treatment in each of the six rounds.



In the limited vision treatment, we can distinguish two different harvesting situations. One where the harvester can be seen by other participants who are within the vision radius, and one where the harvester has no other participant within the vision radius. We test whether the distributions are different of the harvesting events with other in the vision or not. Figure 5 shows the average number of tokens on neighboring cells. We see that the average number of tokens is lower when participants cannot be observed by others. This is especially significant in rounds with communication. This indicates that participants are more eager to harvest tokens when there are only a few tokens around if others cannot see the actions of the participant. We expect that communication will lead to a certain norm on when to harvest. But when they cannot be seen by others they are often tempted to harvest tokens with lower amount of neighboring tokens than in the norm.

Figure 5: 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 we provide the level of significance of the difference between the two distributions: * P < 0.1, ** P < 0.05, *** P < 0.001.

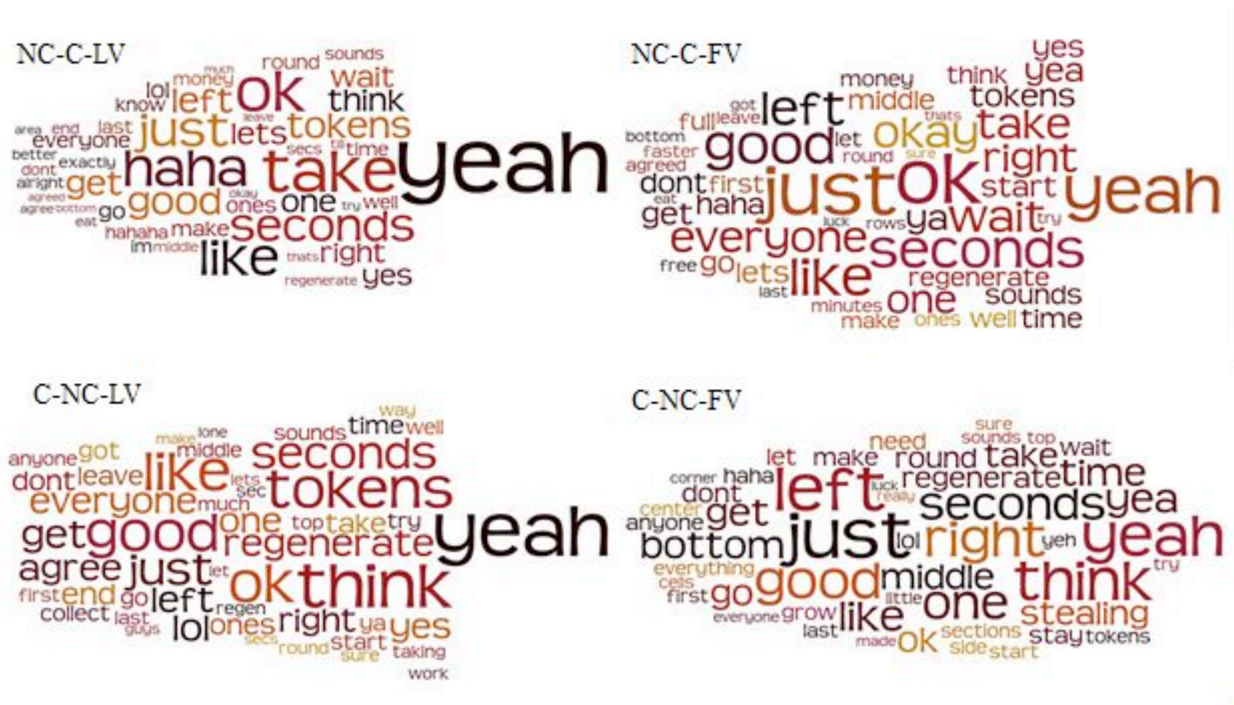


Communication analysis

All the chat messages were read and the type of communication is very similar to that found in earlier studies with this experimental environment (Janssen, 2010; Janssen et al., 2010). In most groups participants discuss not to "eat" single tokens in order to allow regeneration of the resource. Furthermore, they coordinate to divide up the resource in five equal parts, four corners and one in the middle. Some groups decide not to harvest at the beginning of the round to allow the resource to grow. Most groups agree 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 to the informal arrangements was lower in the experiments with limited vision.

Figure 6 shows the 50 most frequently used words in the chat rounds for each of the four treatments. The word clouds are very similar. The most frequently used word in the chat in all treatments is “yeah”. We see that participants coordinate temporal (“wait,” “seconds”), and spatial (“right,” “left,” “middle”) collection of the tokens. The words also indicate confirmation and agreement of the informal arrangements (“agreed,” “ok,” “sure,” “yes,” “everyone”). Finally, the communication is performed in a positive atmosphere (“haha,” “lol,” “yeah”).

Figure 6: Word clouds of the 50 most frequently used words in the chat rounds of the four different treatments. Wordle.net was used to generate the figures. The larger the size of the word the more frequently the word is used. The treatment is named in the upper left of each display.



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.

In this paper a series of lab experiments are discussed that show that information availability has a significant impact on outcomes. The results show that limited information affects the monitoring rate for informal institutional arrangements, but there are more effects. When experiments start without communication, we found a higher level of earnings when participants have 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 the majority of participants can be classified as conditional cooperators (Fischbacher et al., 2001) and this explains observed cooperation in social-ecological systems (Rustagi et al. 2010). If conditional cooperation depends on expectations for the behavior of others, such as compliance to social norms, the quality of information is a key component to explain the level of cooperation.

Although communication is found to be a key factor in increasing cooperation in social dilemma experiments, there are different possible explanations varying from improved understanding to belonging to a group. Communication also provides information that influences the expectations people have about each other. If participants have different expectations about each other, communication will have an effect. Future research could test the effect that the varieties of expectations have on communication.

The experiments show that limited information has an effect on the performance of groups, although we do not see participants crafting different informal regulations with different levels of information. More research is needed to replicate findings in the field where different levels of information lead to different institutional arrangements.

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.

References

Acheson, J.M. 2003. *Capturing the commons: Devising institutions to manage the Maine lobster industry.* Hanover, NH: University Press of New England.

Alaska Fisheries Science Center. 2011. *Fisheries monitoring and analysis*, http://www.afsc.noaa.gov/FMA/ website accessed November 26, 2011.

Bateson, M., D. Nettle and G. Roberts. 2006. Cues of being watched enhance cooperation in a real-world setting. *Biology Letters* 2: 412-414

Burnham, T.C. and B. Hare. 2007. Engineering human cooperation: Does involuntary neural activation increase public goods contributions? *Human Nature* 18:88–108.

Burns, R.D. 1993. Irrigated rice culture in monsoon Asia: The search for an effective water control technology. *World Development* 21(5): 771-789.

Cardenas, J-C. 2000. How do groups solve local commons dilemmas? Lessons from experimental economics in the field. *Environment, Development and Sustainability* 2(3-4): 305-322.

Castillo, D., F. Bousquet, M.A. Janssen, K. Worrapimphong, and J.-C. Cardenas. 2011. Context matters to explain field experiments: results from Thai and Colombian fishing villages. *Ecological Economics* 70(9): 1609-1620.

Chaudhuri, A., and T. Paichayontvijit. 2006. Conditional cooperation and voluntary contributions to a public good. *Economics Bulletin 3*(8): 1–14.

de Oleveira, A., R. Croson, C. Eckel. 2009. One bad apple: Uncertainty and heterogeneity in public good provision. Working paper. Amherst: Department of Resource Economics, University of Massachusetts-Amherst.

Fischbacher, U., S. Gächter and E. Fehr. 2001. Are people conditionally cooperative? Evidence from a public goods experiment. *Economics Letters* 71(3): 397-404.

Folke, C., L. Pritchard, F. Berkes, J. Colding, and U. Svedin. 2007. The problem of fit between ecosystems and institutions: Ten years later. *Ecology and Society* 12(1): 30. [online] URL: http://www.ecologyandsociety.org/vol12/iss1/art30/.

Frey, B.S., and S. Meier. 2004. Social comparisons and pro-social behavior: Testing "conditional cooperation" in a field experiment. *American Economic Review* 94(5): 1717-1722.

Janssen, M. A. 2010. Introducing ecological dynamics into common-pool resource experiments. *Ecology and Society* 15(2): 7 [online] URL: http://www.ecologyandsociety.org/vol15/iss2/art7/.

Janssen, M.A., F. Bousquet, J.C. Cardenas, D. Castillo, and K. Worrapimphong. Field experiments of irrigation dilemmas, in review

Janssen, M.A., R.L. Goldstone, F. Menczer and E. Ostrom. 2008. Effect of rule choice in dynamic interactive spatial commons. *International Journal of the Commons* 2(2): 288-312.

Janssen, M.A., R. Holahan, A. Lee and E. Ostrom. 2010. Lab experiments to study social-ecological systems. *Science* 328: 613-617.

Maass, A., and R.L. Anderson. 1986. *. . .and the desert shall rejoice: Conflict, growth and justice in arid environments.* Malabar, FL: R. E. Krieger.

Meinzen-Dick, R., 2007. Beyond panaceas in water institutions. *Proceedings of the National Academy of Sciences* 104(39): 15200-15205.

Netting, R. Mc., 1981. *Balancing on an Alp.* Cambridge, MA: Cambridge University Press.

Nikiforakis, N. 2010. Feedback, punishment and cooperation in public good experiments. *Games and Economic Behavior* 68(2): 689-702

Ostrom, E., 1990. *Governing the commons: The evolution of institutions for collective action.* Cambridge, MA: Cambridge University Press.

Ostrom, E. 2005. *Understanding institutional diversity.* Princeton, NJ: Princeton University Press.

Ostrom, E. 2009. A general framework for analyzing sustainability of social-ecological systems. *Science* 325: 419-422.

Ostrom, E, R. Gardner and J. Walker 1994. *Rules, games and common-pool resources*. Ann Arbor: University of Michigan Press.

Poteete, A., M.A. Janssen, and E. Ostrom. 2010. *Working together: Collective action, the commons, and multiple methods in practice.* Princeton, NJ: Princeton University Press.

Prediger, S., B. Vollan, and M. Frölich. 2011. The impact of culture and ecology on cooperation in a common-pool resource experiment. *Ecological Economics* 70(9): 1599-1608.

Rustagi, D., S. Engel, and M. Kosfeld. 2010. Conditional cooperation and costly monitoring explain success in forest commons management. *Science* 330: 961-965.

Shivakoti, G, and E. Ostrom. 2002. *Improving irrigation governance and management in Nepal*. Oakland, CA: ICS Press.

Schlager, E. 1994. Fishers' institutional responses to common-pool resource dilemmas. *In* E. Ostrom, R. Gardner, and J. Walker, eds., *Rules, games, and common-pool resources.* Ann Arbor: University of Michigan Press, 247-266.

Stevenson, G.G., 1990. *The Swiss grazing commons: The economics of open access, private, and common property.* Cambridge, MA: Cambridge University Press.

Tang, S.Y., 1992. *Institutions and collective action: Self-governance in irrigation.* Oakland, CA: ICS Press.

Villena, M.G., and F. Zecchetto. 2010. Subject-specific performance information can worsen the tragedy of the commons: Experimental evidence. *Journal of Economic Psychology* 32: 330-347.

Vollan, B. 2008. Socio-ecological explanations for crowding-out effects from economic experiments in Southern Africa. *Ecological Economics* 67(4): 560-673.

Wilson, J. A., J. M. Acheson, M. Metcalfe, and P. Kleban. 1994. Chaos, complexity, and community management of fisheries. *Marine Policy* 18:291–305.

Wilson, J., L. Yan, and C. Wilson. 2007. The precursors of governance in the Maine lobster fishery. *Proceedings of the National Academy of Sciences* 104(39): 15212-15217.

Young, O. R. 2002. *The institutional dimensions of environmental change: fit, interplay, and scale.* Cambridge, MA: MIT Press.

Appendix: Instructions

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

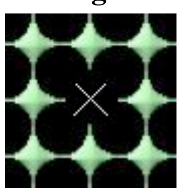
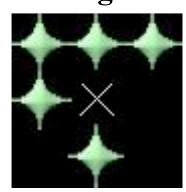


Image 2



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.

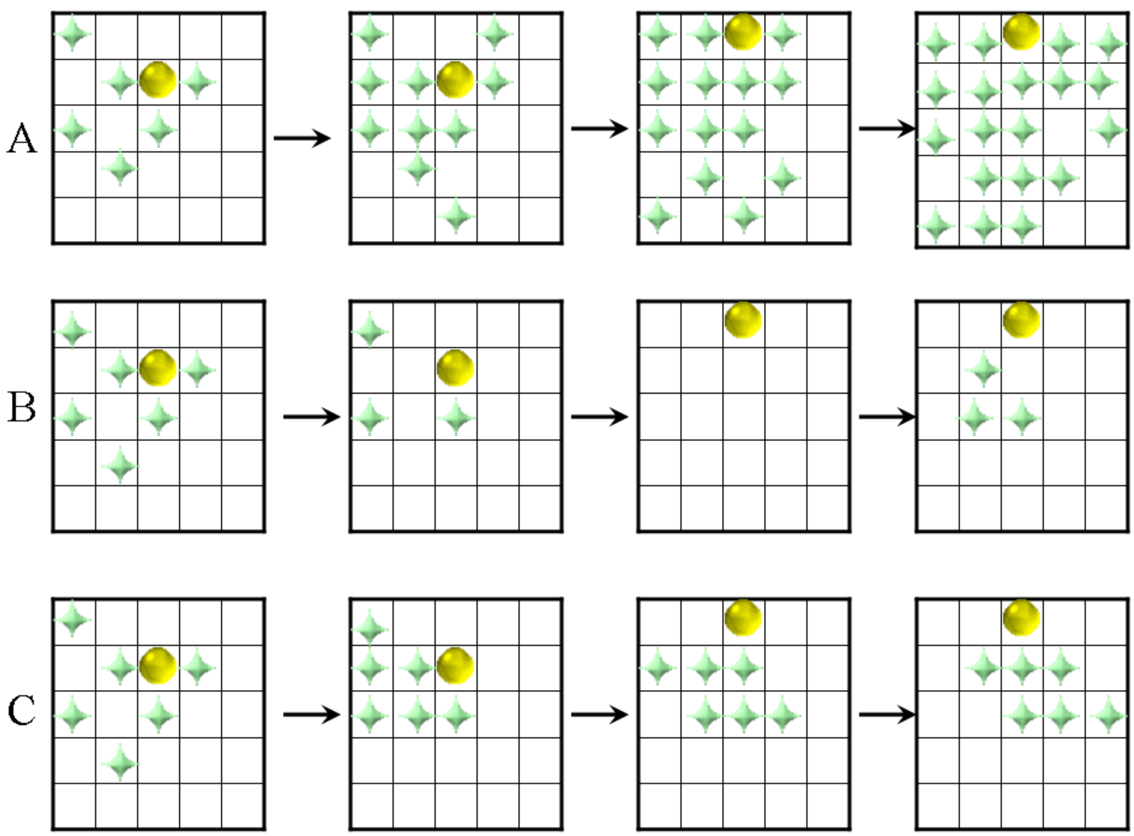
During this practice round, and **only during** this practice round, you are able to reset the tokens displayed on the screen by pressing the **R** key. When you press the **R** key you will reset the resource to its initial distribution, randomly filling half of the cells.

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.

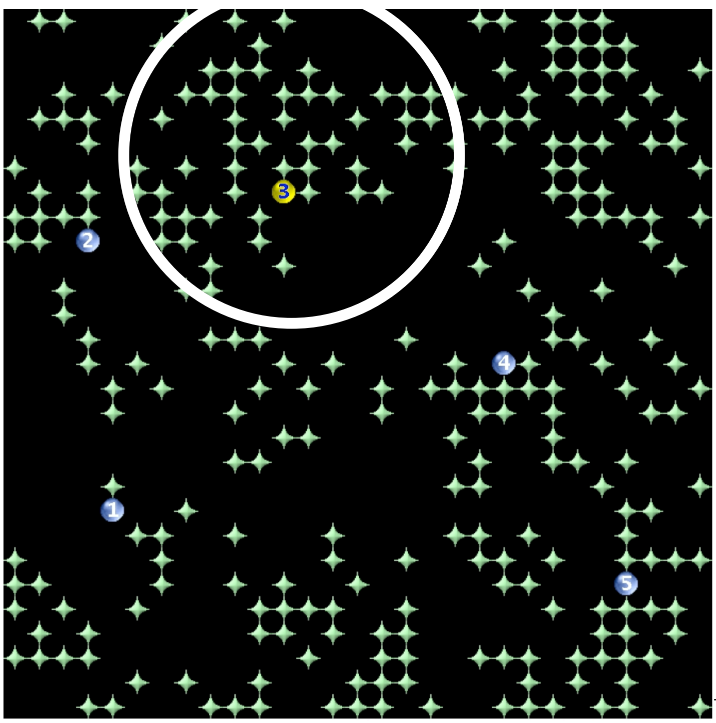
Round 1 instructions
This is the first round of the experiment. The length of the round is 4 minutes. Like in the practice round you can collect green tokens. This time you earn **two cents** for each token collected. This time you **cannot** reset the distribution of green tokens.

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

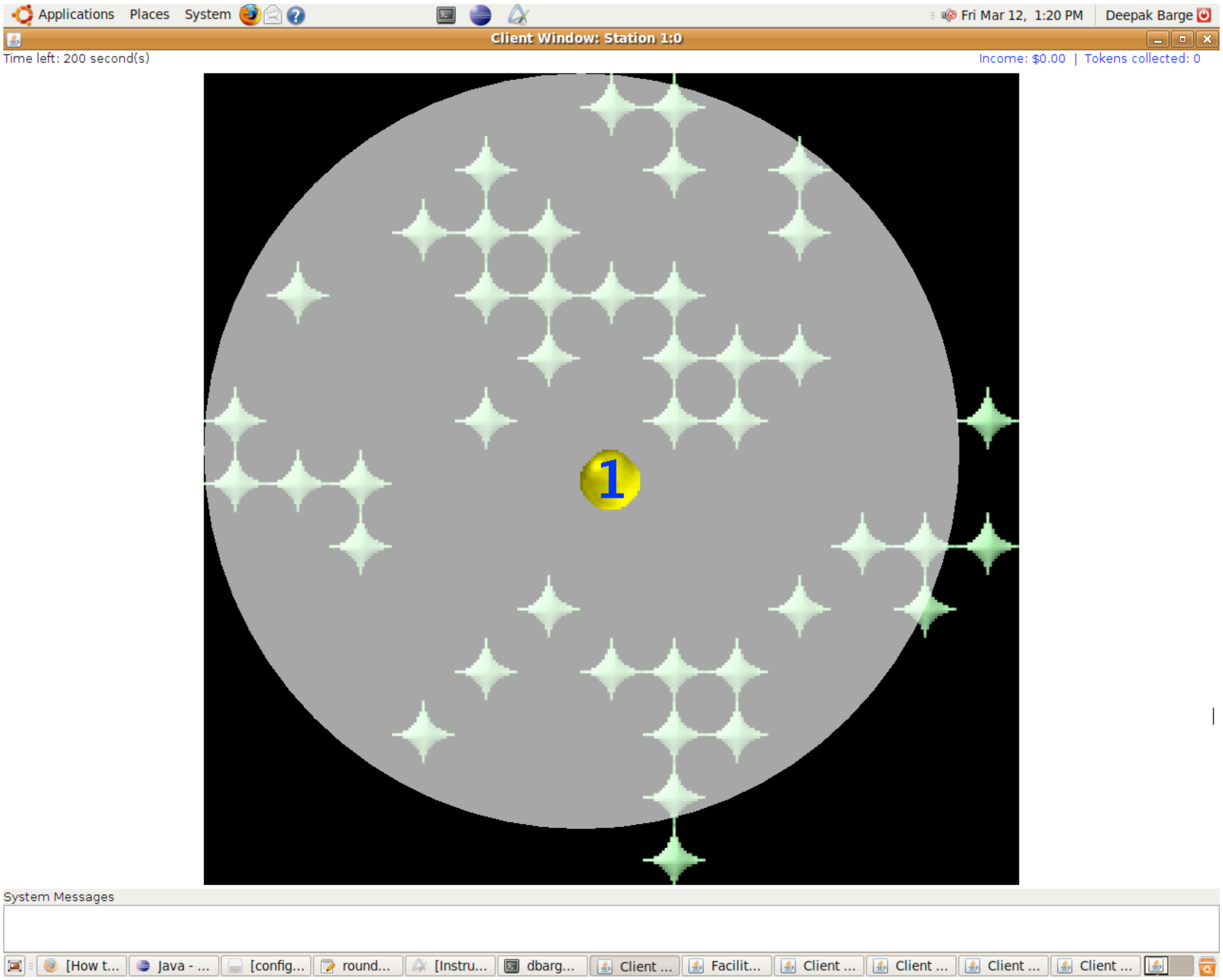
- You are moving too fast

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

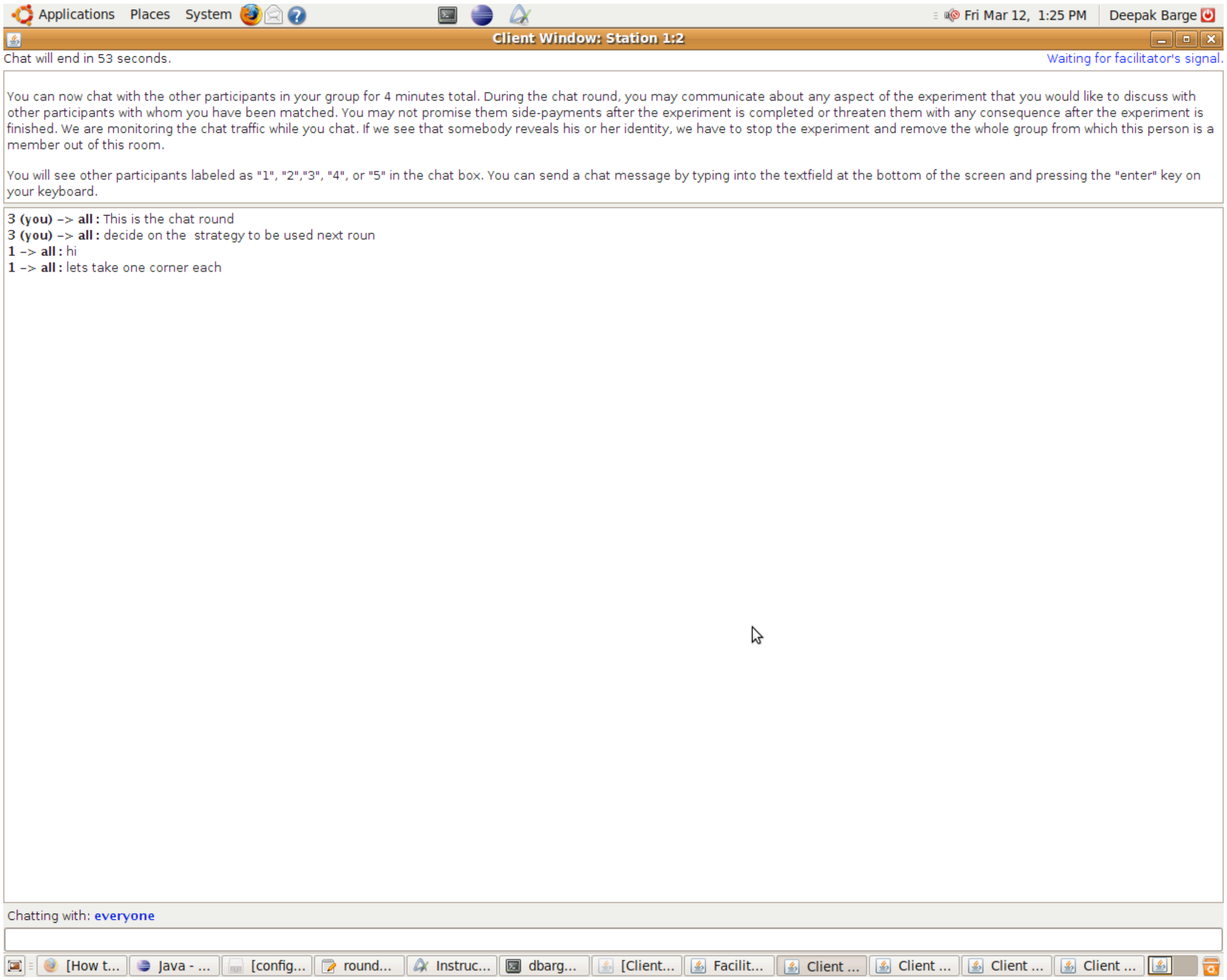
[Rounds 5 and 6 are the same as round 4]

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.