Perez, I., D. J. Yu, M. A. Janssen, and J. M. Anderies. 2015. Social roles and performance of social-ecological systems: evidence from behavioral lab experiments. *Ecology and Society* **20**(3): 23. http://dx.doi.org/10.5751/ES-07493-200323

Research, part of a Special Feature on Advancing the Understanding of Behavior in Social-Ecological Systems: Results from Lab and Field Experiments

Social roles and performance of social-ecological systems: evidence from behavioral lab experiments

Irene Perez [1], David J. Yu [1,2,3], Marco A. Janssen [1,4] and John M. Anderies [1,4,5]

ABSTRACT. Social roles are thought to play an important role in determining the capacity for collective action in a community regarding the use of shared resources. Here we report on the results of a study using a behavioral experimental approach regarding the relationship between social roles and the performance of social-ecological systems. The computer-based irrigation experiment that was the basis of this study mimics the decisions faced by farmers in small-scale irrigation systems. In each of 20 rounds, which are analogous to growing seasons, participants face a two-stage commons dilemma. First they must decide how much to invest in the public infrastructure, e.g., canals and water diversion structures. Second, they must decide how much to extract from the water made available by that public infrastructure. Each round begins with a 60-second communication period before the players make their investment and extraction decisions. By analyzing the chat messages exchanged among participants during the communication stage of the experiment, we coded up to three roles per participant using the scheme of seven roles known to be important in the literature: leader, knowledge generator, connector, follower, moralist, enforcer, and observer. Our study supports the importance of certain social roles (e.g., connector) previously highlighted by several case study analyses. However, using qualitative comparative analysis we found that none of the individual roles was sufficient for groups to succeed, i.e., to reach a certain level of group production. Instead, we found that a combination of at least five roles was necessary for success. In addition, in the context of upstream-downstream asymmetry, we observed a pattern in which social roles assumed by participants tended to differ by their positions. Although our work generated some interesting insights, further research is needed to determine how robust our findings are to different action situations, such as biophysical context, social network, and resource uncertainty.

Key Words: *behavioral experiments; communication; irrigation systems; lab experiments; qualitative comparative analysis; social-ecological networks; social-ecological systems; social roles*

INTRODUCTION

The presence of certain social roles is considered crucial for successful governance of common-pool resources. Over the last several years, scholars have studied how the presence and function of certain social roles, such as leaders and connectors, impact the performance of social-ecological systems. For example, work by Gutiérrez et al. (2011) suggests that the presence of strong leadership may be the most important factor to explain success in the context of comanagement of fisheries worldwide. Other roles such as followers, connectors, or sense-makers are considered by several authors as key for the governance of social-ecological systems, especially in terms of the capacity of the community to adapt to new conditions (Folke et al. 2003, 2005, Olsson et al. 2004). Despite the recognized importance of social roles in governing common-pool resources, challenges in data collection have made empirical evidence difficult to gather. In this paper, we contribute to this emerging literature by using behavioral laboratory experiments to study the linkages between social roles and collective action. Participants in a typical behavioral experiment face a social dilemma and must decide what their level of cooperation will be. We used communication among participants in a computer-based irrigation experiment to identify social roles that emerge during the course of experimental treatments and then identified those roles that might be necessary for successful collective action in governing a common-pool resource.

Following the Institutional Analysis and Development framework (Ostrom 2005), a behavioral experiment represents an action arena where the experimental design generates the action situation in which a randomly drawn group of participants are invited to make decisions. An action situation refers to the social space where participants interact, exchange information, and solve problems. Behavioral experiments enable researchers to replicate action situations by defining the choices and information available to the participants as well as the payoffs associated with different outcomes of participant decisions. Although the experiments discussed in this paper were performed with undergraduate students at a major university in the United States, the same experimental design, i.e., action situation, may be used with different types of participants, such as farmers or fishers in developing countries (Harrison and List 2004). Earlier irrigation experiments run with such diverse participant groups showed that differences in trust were a more important explanatory variable for differences in outcomes than was the type of user group, e.g. fishers, farmers, students, in the experiment (Janssen et al. 2012). In our research, the existence of different social roles in a community provided the motivation to test whether these social roles can help explain group dynamics in experimental studies. In the context of a multimethod research program, we used different methods to address various research questions regarding social-ecological systems (Poteete et al. 2010). As such, our study complements previous studies that used other methods such as case studies (e.g., Olsson et al. 2004) and meta-analysis (e.g., Gutiérrez et al. 2011)

The action situation in the computer-based experiment performed in this study represents a small-scale irrigation system

[1]Center for Behavior, Institutions and the Environment, Arizona State University, [2]Lyles School of Civil Engineering, Purdue University, [3]Department of Political Science, Purdue University, [4]School of Sustainability, Arizona State University, [5]School of Human Evolution and Social Change, Arizona State University

in which participants in different positions (from upstream to downstream locations) interact to maintain the irrigation infrastructure and share the water generated by that infrastructure to irrigate their fields. Participants faced two types of social dilemmas in our experiment (Ostrom and Gardner 1993). First, they had to collectively contribute enough investment into the public infrastructure to make water available: water diversion structures such as weirs had to be repaired and canals had to be cleaned each year. Secondly, they had to coordinate for fair distribution of water, which could be undermined by upstream-downstream asymmetry of participant positions. However, upstream participants could not adequately maintain the infrastructure without help from downstream participants. This interdependency thus deterred upstream participants from overappropriating water because downstream participants who did not get enough water could reduce their contributions to the infrastructure (Ostrom and Gardner 1993, Janssen et al. 2012). Previous studies using similar experimental settings have found that upstream participants invest and extract more than downstream participants and that the contributions to the public infrastructure can be explained by a combined effect of observed inequality in the previous round and asymmetric access privileges (Janssen et al. 2011*a*, 2001*b*, 2012, Pérez et al. 2013). Building on these results, we attempted to analyze whether social roles can help further explain differences in groups' performance in terms of water extraction.

Prior to the investment and extraction stages of the game, participants in our experiment could chat via text messages during the communication stage of the game to discuss whatever they wish before they made investment and extraction decisions. We recorded all of these text messages, which we then used to discern the social roles that participants in our experiment had naturally assumed. Although the underlying causal processes are still debated, it is well known that communication improves outcomes in social dilemmas (Ostrom et al. 1992, Sally 1995, Janssen et al. 2010). Previous studies have concluded that it is the option for and the amount of communication rather than the content of the communication that is necessary to improve outcomes (Pavitt et al. 2005, Janssen 2010, but see Pavitt 2011). We analyzed communication by linking the content of the communication among participants to social roles. Our goal was to investigate how social roles at the group level and roles assumed by different positions affected the performance of the groups. We were aware that a mismatch might occur between what players said they were going to do (i.e., the role that they seemed to assume) and what they really did during the game. Furthermore, there might be a difference between the social role we identified from chat data and what participants might have actually experienced. Note that most of the roles we distinguished from the chat data cannot be distinguished in the data on investment and appropriation decisions.

We considered seven types of roles: leader, knowledge generator, connector, follower, moralist, enforcer, and observer. (For a definition of each social role, see Table 1.) These roles are often thought to be essential functional groups of actors that are associated with adaptive governance of social-ecological systems (Ostrom 1990, Folke et al. 2005). Although these roles do not constitute an exhaustive list of all possible roles, they may sufficiently represent the spectrum of key roles in our irrigation experiment. A growing number of studies support the importance of these seven roles for successful collective action. For example, numerous studies suggest that certain individuals often act to provide leadership and knowledge in social problems (Olsson et al. 2004, Pavitt et al. 2007, Gutiérrez et al. 2011). These sources argue that the presence of leaders and their generation of knowledge may enhance the likelihood of individuals solving collective action problems. Studies also illustrate that the presence of connectors, individuals who link with other individuals within and beyond their social networks, may enhance the capacity of local communities to adapt to new conditions (Stubbs and Lemon 2001, Tompkins et al. 2002, Ernstson et al. 2010). It is argued that, by bringing in novel ideas and facilitating information exchange across networks, connectors help local communities find cooperative solutions more effectively. Some studies also support the importance of the role of moralists (Pavitt et al. 2005, Janssen 2010, Poteete et al. 2010). It is suggested that individuals caught in social dilemmas often voice norms of equity and continuously try to ensure their mutual commitment to such social norms. Finally, the roles of observer and enforcer are widely observed in field and behavioral studies (Ostrom et al. 1992, Fehr and Gachter 2000, Henrich et al. 2006, Rustagi et al. 2010). These functions reinforce norms and rule conformance and are considered crucial for the success of collective action (Ostrom 1990).

Instead of investigating the effect of a specific role, we focused more on discerning combinations of roles that increase the likelihood that users will self-organize and successfully solve the commons dilemmas they face. One example is the possible relationship between knowledge generators and connectors. Diffusion of knowledge will be hindered if knowledge generators are not linked to others via connectors. To address this question of how role combinations affect collective action, we used qualitative comparative analysis (QCA; Ragin 1987). Using QCA, researchers can determine combinations of conditions (in our case, adopted social roles) that are linked to certain outcomes (in our case, group success as measured by total group water extractions). We undertook QCA at the group (roles adopted by any of the players in a group) and positional (roles adopted by participants in the different positions [upstream, downstream] in each group) levels to analyze both how different combinations of roles (group level) and roles assumed by participants in different positions (positional level) affect group performance.

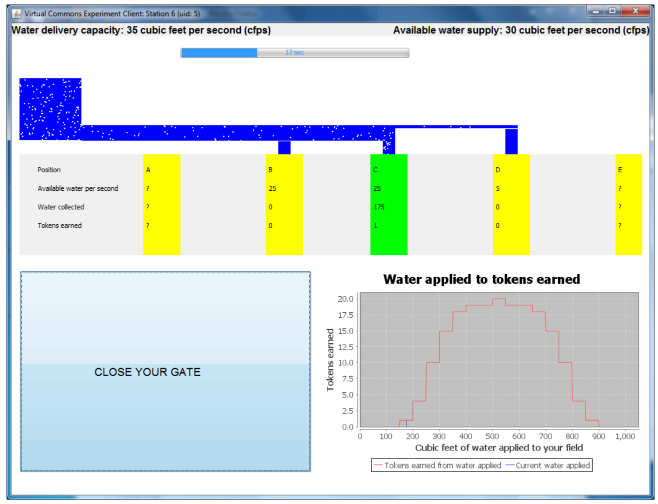
QCA at the group level allowed us to understand which role or combination of roles may be necessary for a group to succeed. For example, are observers necessary? Is it the combination of leaders and moralists that is critical? At the positional level, QCA allowed us to study where roles emerged in successful groups. For example, do groups with the leader role adopted by players in positions furthest upstream or furthest downstream (A and E in Fig. 1) do better than groups with the leader role adopted by a player in the middle position (C in Fig. 1)? Which combinations of roles are more likely to be adopted by the player in position A in successful groups? Our results suggest that it is not a specific role but rather a combination of a minimum of five roles that was necessary for success. For example, we found that at least one participant adopting the role of leader was necessary, but not sufficient, for success. In one of the role combinations present in successful groups, a leader was accompanied by at least one each of a follower, a knowledge generator, a connector, and a moralist.

At the positional level, we found heterogeneous combinations of roles related to participants' positions. For example, in successful groups, players in middle positions adopted the role of leader more frequently than upstream or downstream players.

Table 1. Definition of social roles and example of the type of messages used to code them.

Connector (C)	Definition: Transmit the decisions made by the leader or opinions of other players. Example of messages: B: "*hey C, tell D to only do 200*"; C: "*okay, D only do 200*"
Enforcer (E)	Definition: Punish the behavior of other players. Example of messages: "*Since ABC are not being fair we shouldn't invest any tokens*", "*I'm going on strike*"
Follower (F)	Definition: Follows a leader. Example of messages: "*okay A,*" "*I'll do the same,*" "*hey C, let's listen to A*"
Knowledge generator (K)	Definition: Shares information about the rules or status of the game. Example of messages: "*as long as we keep the efficiency above 66% we will be fine*"
Leader (L)	Definition: Proposes a strategy/rule about investment or harvesting and at least one other player follows it. Example of messages: "*we need to invest 15,*" "*B can you tell A to only take 300?*"
Moralist (M)	Definition: Shows concern about downstream players or looks for fair shares for the whole group. Example of messages: "*I feel bad for E,*" "*E is getting none :(*" "*ok, share water is good idea*"
Observer (O)	Definition: Shares info about the compliance of the rules or the behavior of other players, as well as the player who answers to another observer request about information about other players. Example of messages: "*hey ask B how much A has*"; "*A is at like 19,*" "*last round C took 470*"

Fig. 1. Screenshot of the experiment. The player's position is indicated in green (in the figure, position C) and the other players' positions are indicated in yellow. In this screenshot, player C's gate is open, and all other players' gates are closed. Participants located in positions A, B, C, D, and E need to make decisions whether to open or close their gate. The water is coming from the left of the screen.



METHODS

We used the chat messages exchanged among participants during the communication stage of the computer-based irrigation experiment to code social roles that participants adopted. Identified social roles were used as the conditions in a QCA to obtain the combinations of social roles that might have led to higher group performance. We did not code the actual behavior of the players but rather the social roles that players seemed to assume based on their messages during the communication stage of the game. Figure 2 graphically summarizes the methods and main results obtained through QCA.

Irrigation lab experiments

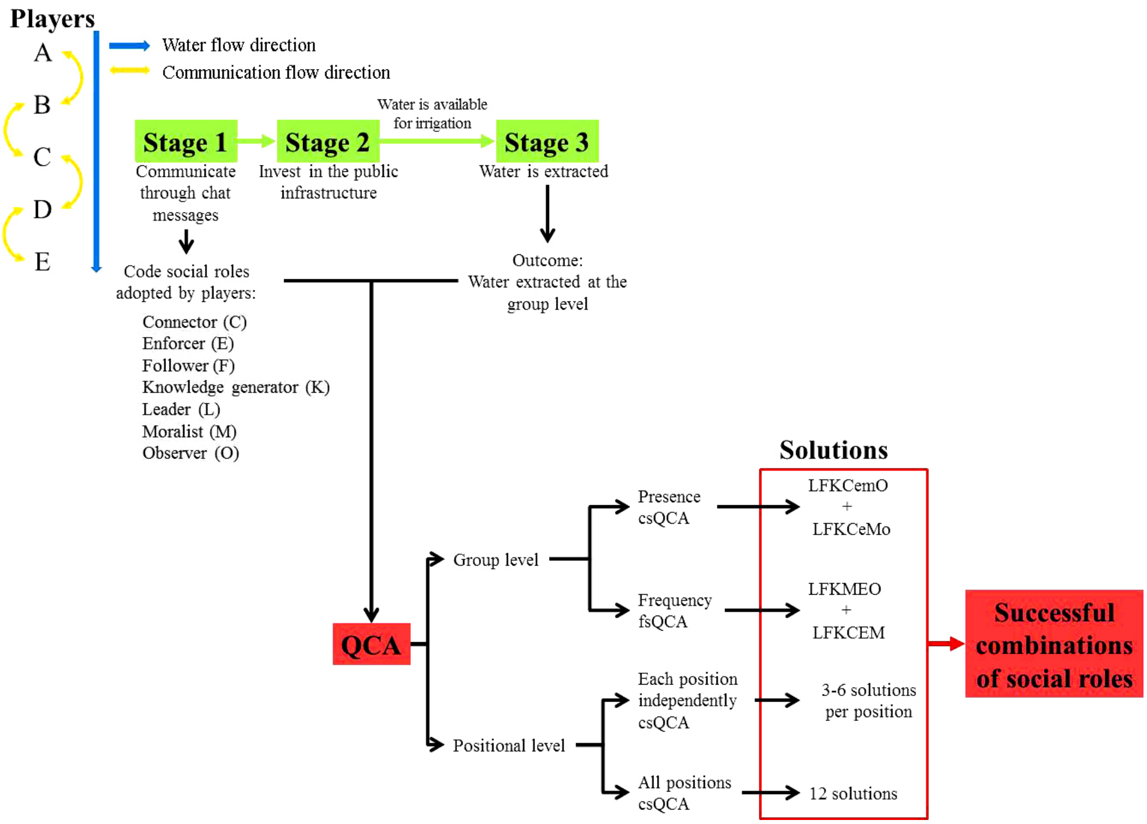
The experiment took the form of a five-player irrigation game. The participants occupied different positions, A, B, C, D, and E, related to their position along the irrigation canal (A was the head end, E was the tail end).

The entire experimental treatment, which takes about 75 minutes, consists of 2 training rounds prior to the start of the real experiment, followed by 20 actual rounds. Each round proceeds in the following sequence: communication, investment, and appropriation stages.

Communication stage

At the beginning of each round, participants are allowed to communicate via text messages using a chat interface for 60 seconds. Participants are allowed to discuss anything they wish with the usual caveats, such as proper language, no threats, and no promises of side payments.

Fig. 2. Graphical summary of methods and results. Following qualitative comparative analysis (QCA) notation, in the solution box an uppercase letter means that the condition is present, and a lowercase letter means that the condition is absent. csQCA = crisp-set QCA, fsQCA = fuzzy-set QCA.



Investment stage

Participants must make a decision concerning how much to invest to provide public infrastructure, such as canals and water diversion structures. At the beginning of each round, participants are endowed with 10 tokens. Participants can then invest all, zero, or a portion of their endowment into maintaining public infrastructure. Each token is worth \$0.05. The production of public infrastructure depends linearly on the total investment made by the group: each token invested increases the infrastructure stock by one unit. However, after each round, the infrastructure stock depreciates by a constant percentage. The relationship between water delivery capacity and infrastructure stock exhibits a nonlinear, S-shaped relationship. Below a certain threshold, infrastructure generates no output, i.e., water. Once this threshold is crossed, additional investment generates increasing marginal returns on water delivery capacity. Beyond a certain stock level, additional investment generates diminishing marginal returns. In the experiments, we chose a scaling that made it impossible for one person to create sufficient infrastructure stock to deliver water without the help of others. For example, unless a sufficiently large group of farmers worked together at the same time to repair headgate structures and canals each year, the system became dysfunctional and delivered little to no water. Hence cooperation was required to generate an adequate level of public infrastructure.

The rate of water delivery as a function of infrastructure efficiency is shown in Table 2. The maximum supply of water is 30 cubic feet per second (cf/s) in the default case. In the investment stage of each round, participants are shown a screen that displayed Table 2. Participants are reminded what the infrastructure stock in the previous round was and are told that it has decreased by a certain amount. They are then asked to make their investment decision. For example, if the infrastructure stock in the previous round was 75 and has decreased by 25, the players are told that the infrastructure stock at the beginning of the round was 50 (75 - 25 = 50). Suppose that each player invests 7 tokens (7 x 5 = 35 total investment). Then the infrastructure stock is 50 + 35 = 85. Based on Table 2, the system is capable of delivering a maximum of 40 cf/s during the appropriation stage. After participants make their investment decisions, they are shown a screen that summarizes the following information: how much their neighbors invested, the level of infrastructure efficiency, the water delivery capacity, and the supply of water to the irrigation system. Because the infrastructure stock depreciates by 25 units in each round, each participant needs to invest on average five tokens to keep the infrastructure at the same level.

Table 2. Production function of water delivery as a function of infrastructure efficiency.

Infrastructure efficiency (%)	Water delivery (cf/s)
< 45	0
46-51	5
52-55	10
56-58	15
59-61	20
62-65	25
66-70	30
71-80	35
81-100	40

Appropriation stage

Participants make decisions regarding opening and closing their irrigation gates over a 50-second period as they attempted to divert water to their field and grow a crop. Participants are presented with the dashboard shown in Figure 1. Participants are shown the water delivery capacity (top left), how much water was available in the river (top right), and how much time was left in the round (top center). Participants see water flowing (movement of white dots to simulate water flow) and their gates opening and closing in real time. The real-time interaction was purposely chosen to include the need for real-time coordination to solve the asymmetric commons problem. That is, participants execute the strategy (if any) they worked out in the communication stage of a round. As participants open their gates, they accumulate water in their fields. Table 3 shows the earnings generated by a crop as a function of the total water delivered to the participants' fields. If less than 150 cf of water is diverted to their field, the participant earns no tokens. The maximum number of tokens is earned when a total of 500 to 549 cf of water was delivered to a field. Applying more than 549 cf is detrimental to crop production (water logging) and the earnings go down accordingly.

Table 3. Earnings resulting from amount of water applied to the field.

Water units received (cf)	Tokens earned
< 150	0
150-199	1
200-249	4
250-299	10
300-349	15
350-399	18
400-499	19
500-549	20
550-649	19
650-699	18
700-749	15
750-799	10
800-849	4
850-899	1
> 899	0

The maximum capacity of each player's gate is 25 cf/s. If a participant opened his/her gate and 25 cf/s is available in the main canal, it takes 20 s to reach the maximum earnings possible. With 5 participants attempting to maximize their earnings, there is a demand of 5 x 500 = 2500 cf. Because the maximum supply of water is 30 cf/s x 50s = 1500 cf of water, there is a situation of resource scarcity. If participants stopp at 300 cf, each can generate earnings of 15 tokens. However, if the upstream participants who had first access to water maximize their earnings, the two downstream participants will not receive enough water to generate any earnings from growing a crop. For example, participant A could open her gate for the first 20 seconds, participant B for the first 36 seconds, and participants C, D, and E for the entire period, generating earnings of 20 (500 cf) tokens each for participants A and B, 19 (430 cf) for participant C, 0 (70 cf) for participant D, and 0 (0 cf) for participant E. This payoff structure sets up our asymmetric commons dilemma.

This experiment is a modification of the treatment reported by Anderies et al. (2013). In the study by Anderies et al., participants had full information about the other participants' behavior and could communicate with all participants in their group. In the experiment reported here, we limited communication by imposing a linearly connected network in which participants could only communicate with their immediate neighbors. Using this network structure, we attempted to mimic the challenges of communication, monitoring, and sanctioning that farmers in small-scale irrigation systems may face. Each participant's view of the action arena (dashboard) is shown in Figure 1. The participant saw her own field in green. The structure of the social network in this experiment was designed such that participants could only communicate with and observe the actions of their immediate neighbors; for example, participant B could only communicate with and observe the investment and extraction of participants A and C. Notice that in Figure 1, player C can see that player B and player D both have their gates closed, but cannot observe players A and E. Likewise, player B can see that player C's gate is open and player A's gate is closed, but cannot observe players D and E.

Every group starts round 1 of the experiment with an initial infrastructure stock of 75 (75% efficiency), and the infrastructure depreciation rate is 25 for the first 10 rounds of the experiment. In the first 10 rounds, the infrastructure depreciation rate and the amount of water supply from rivers remain constant. After round 10, however, these two conditions begin to fluctuate. For the purposes of this study, we considered the first 10 rounds in which uncertainty about the water supply and the infrastructure depreciation rate was not present. Further information about the experimental setting as well as the effects of variability on group performance can be found in Anderies et al. (2013).

The Nash and social equilibria for this experimental design can be calculated by assuming that participants have zero reaction time and attempt in the opening and closing of gates to maximize their number of tokens. In the first round there is no need to invest in the public infrastructure because the delivery capacity (35 cf/s) is already higher than the supply (30 cf/s) of water. Anderies et al. (2013) showed that the Nash equilibrium for selfish rational actors led to investments only during the first three rounds by the upstream participants. If there was a positive water delivery capacity (infrastructure stock was above 45) and a participant had not reached 500 cf of water, the participant kept their gate open. Participants only invested in the public infrastructure if they could rely on a positive return on investment. Participants A, B, and C invested modest levels in round 2 to reach the infrastructure level of 66. In round 3 only participant A invested. After round 3 the infrastructure had deteriorated to a level that did not support water delivery. In this noncooperative equilibrium, the participants earned 575 tokens as a group in the first 10 rounds. In contrast, participants who followed a cooperative strategy kept the infrastructure stock at 66 (delivery capacity = 30 cf/s) and invested 25 tokens every round in the infrastructure to maintain it at that level. The cooperative strategy led to 978 tokens for the group in 10 rounds. An example of one of the possible cooperative strategies was to have four participants, A-D, investing six tokens, and one participant, E, investing only one token. If the participants coordinated their gates, growing a crop could generate 15 tokens for participants A to D and 10 tokens for E. Hence, a cooperative strategy could lead to an outcome in which each participant earned 19 tokens per round.

Experiment participation

The experiments were performed at Arizona State University in the spring semester of 2012. The participants were randomly recruited from a database of undergraduate students from all majors who had indicated that they were willing to participate in our human-subject experiment. Invitations were sent out to a random sample of the whole population when a session of our experiment was scheduled. Based on exit surveys, of the 115 students (23 groups of 5 players) that participated in the experiments reported in this paper, 49% were female and the average age was 20 years. Average earnings were $22, including a show-up bonus of $5 plus payments for their play (made in private) for experiments with an average duration of 75 minutes. The individual minimum and maximum earnings were $12.20 and $34.70, respectively. The final earnings, the total investment, and extraction by each group are shown in Appendix 1.

Coding different roles

In accord with the literature, we defined seven social roles that participants in the irrigation experiment could adopt: connector (C), enforcer (E), follower (F), knowledge generator (K), leader (L), moralist (M), and observer (O). See Table 1 for definitions. Participants can adopt more than one role at a time (e.g., leaders can be moralists, enforcers can observe other's actions at the same time, and so forth). We coded up to three roles per participant in each of two time slices: rounds 1-5 and 6-10. We considered two groups of rounds because more than one round was needed to detect the role or roles that each participant was adopting, and at the same time, assumed roles by participants change as the game progresses. The number of roles held by a participant varied; some players assumed only one role (e.g., an obedient follower), whereas others took on multiple roles. On average, participants assumed two roles in each of the two time slices. We limited the number of coded roles per participant to three to consider the most important roles assumed by each player and because in most of the cases players assumed fewer than four roles at a time. In the few cases in which more than three rolls were identified, coders selected the more relevant roles by counting the number of chat messages representative of each role. After round 10, environmental uncertainty is introduced into the experiment. We did not include these later rounds (11-20) in our current coding because our aim was to study the effect of social roles on the performance of social-ecological systems in a stable environment. Future studies will analyze how social roles adopted by participants in the irrigation experiment are affected by environmental uncertainty as well as how social roles may evolve during the game.

Coding was based on the text messages that the participants exchanged during the communication stage (Table 1) and not the actual behavior of the players. Roles were coded independently by two of the authors (Pérez and Yu). Each coder used cues from the phrases and words found in the text messages to identify the most fitting roles as defined by our guidelines (Table 1). For example, if a participant sent messages that raised concerns about unequal appropriation of water, that participant was coded as moralist. We did not attempt to uncover the actual mechanisms that might link group composition to outcomes. Further, we recognize the potential importance of the relationship between social roles and real actions during the game (Cardenas 2003). These issues are beyond the scope of this paper and will be the focus of future research. Having said that, the work we report on here looking only at correlations between group composition detected thought chat messages and outcomes is a first step and already has generated several interesting insights.

After both coders completed their coding, results were compared for mismatches. The two coders arrived at their final coding decisions by discussing these mismatched roles until a consensus was reached. To assess intercoder reliability, we used the simplest measure available: percent agreement between the two coders. We chose percent agreement over more sophisticated measures (e.g., Cohen's Kappa coefficient and Krippendorff's alpha) that account for coding agreements occurring by chance. The reason is that our coding scheme had 64 possibilities of role-combination per player (i.e., coding up to 3 roles per player from 7 possible roles and no role). With such a large number of coding possibilities, the probability that coding agreements occurred by chance was very low in our study. Percent agreement was derived in the following way. For each case (each time slice per participant), the numbers of identified roles and blank spaces (no role) matched by the two coders were counted and then divided by three, because three roles were possible per player. This number represents the degree of agreement per case. This number was then summed for the entire set of cases and divided by the total number of cases to derive the measure of percent agreement. The resulting percent agreement was 76%. A minimum threshold for an acceptable level of intercoder reliability for exploratory studies is often regarded to be around 70% (Lombard et al. 2002, Riffe et al. 2005). Based on this figure and the exploratory nature of our work, we suggest that our coding work exhibits reasonable intercode reliability.

Qualitative comparative analysis

We undertook QCAs (Ragin 1987, 2000) to examine different combinations of conditions, i.e., social roles, that are associated with improved group performance. QCA is an approach to analysis of data sets with small sample sizes that relies on Boolean algebra for cross-case comparisons to reduce causal complexity into a minimal set of conditions necessary for an outcome (Ragin 1987). QCA establishes conditions of necessity and sufficiency. A condition is necessary if it must be present for a certain outcome to occur. A condition is sufficient if, by itself, it can produce a certain outcome (Ragin 1987). A condition is both necessary and sufficient if it is the only cause for the outcome. If various conditions can produce the outcome by themselves, these are sufficient but not necessary causes. Finally, if a cause only appears in a subset of combinations that produce the outcome, then this causal condition is neither necessary nor sufficient. The results of the sufficiency test are summarized in the so-called truth table, which lists all possible combinations of the conditions and outcomes, and shows how often they appear in the set of cases considered, i.e., consistency. The higher the value of consistency, the more cases or membership scores in the row have the same outcome. Results of the truth table are simplified by means of the Quine-McCluskey algorithm commonly used in QCA (Quine 1955, McCluskey 1956). For example, if some expressions differ in only one causal condition to produce the same outcome, then that causal condition can be considered irrelevant and can be removed to create a simpler, combined expression (Ragin 1987). Further information regarding the QCA methodology can be found in Ragin (1987 and 2000), or by visiting the COMPASS website (http://www.compasss.org).

Figure 2 graphically summarizes the process by which QCA was used in this study. At the group level, our conditions related to whether roles were present or absent in the different groups. In this case, we were not concerned with whether a particular role occured at position A, B, C, etc. At the positional level, on the other hand, our conditions related to the roles each participant assumed in each group. In this case, we were concerned about where roles occur; QCA at the positional level helped us to understand if the position (i.e., position A, B, C, D, or E) of a player who assumed a given role was relevant to explaining group success.

Group-level analysis
The two main QCA variants, crisp-set QCA (csQCA) for dichotomized variables and fuzzy-set QCA (fsQCA) for values between zero and one, were conducted at the group level. In the csQCA our conditions were the presence or absence of roles in the different groups. In the fsQCA, we used the frequencies of each role in the groups as conditions for the emergence of group success. Our motivation was the idea that the frequency of roles better explains group success than whether a certain role is present or not. QCA results at the group level using csQCA and fsQCA can give us complementary information about the relationships between social roles and collective action.

For the csQCA, the condition, i.e., presence of social role, was considered 0 if the role was absent and 1 if present during any of the 2 snapshots (i.e., rounds 1-5 and 6-10) in each group. For example, if one player assumed the role of leader during one snapshot it was coded as 1. For the fsQCA, our raw data included values from 0 (none of the players assumed the role during any of the snapshots) up to 5 (the role was present during both snapshots in more than one player). For example, if the role of leader was absent it was given a value of 0, if it was assumed by one player during one snapshot, it was given a 0.6 value, and if the role of leader was kept during the two snapshots, even if it was assumed by different players, a value of 1 was given. Notice that 0.5 in fsQCA is the crossover point in the assessment of whether a case is more "in" than "out of" a set; scores less than 0.5 but greater than 0 indicate that the objects are more out of than in a set and scores close to 1 indicate strong membership. When players assumed more than one social role at the same time, we considered those social roles as independent observations.

Position-level analysis
We analyzed two cases at the positional level using csQCA: each position independently and all the positions and roles together. In the first case, our aim was to analyze the combinations of roles adopted by each position for success. For example, which roles were adopted by position A in successful groups? In the second case, we identified the combinations of roles adopted in each group by each position. That is, did groups with leaders in position A and E did better than groups with leaders in position C? Is it important that the knowledge generator was in position A while the moralist was in position C? Just as in the group-level analysis, the condition, i.e., presence of social role, was considered zero if the role was absent and one if present during any of the two snapshots in each position.

Measure of group performance
We selected the total group water extractions (*Ext*) as the indicator of group performance. The amount of water extracted in one round does not affect the water available for the next round, and this amount only depends on the levels of cooperation. Water extractions were highly correlated (Spearman's correlation = 0.6) with other important indicators: investments in the public infrastructure, earnings, and efficiency of the public infrastructure, as well as the gini coefficients of investments and extractions among the members of each group (Table 4). For example, if inequality in extractions increased, players extracting less water usually reacted by decreasing their investments in the public infrastructure. This situation caused the water level to drop and with it, the level of water extraction. In fact, we could view the amount of the total water extracted as an indicator of group production. As such, increases in water extraction were correlated with increases in cooperation in this experiment. Appendix 2 shows QCA results using the percentage of the maximum earning as the indicator of group performance.

For the csQCA, a group was considered successful if the group extraction was above the median of the extractions of all groups. Using the median as a threshold for group success was considered adequate because the mode of group extraction coincided with the median, and the median was the only threshold in our data (Fig. 3). For the outcome in the fsQCA, we considered breaks in the extraction level between groups to define thresholds values (Fig. 3). Appendix 1 shows the experimental results and Table A3.1 in Appendix 3 shows the raw data used in the csQCA and fsQCA.

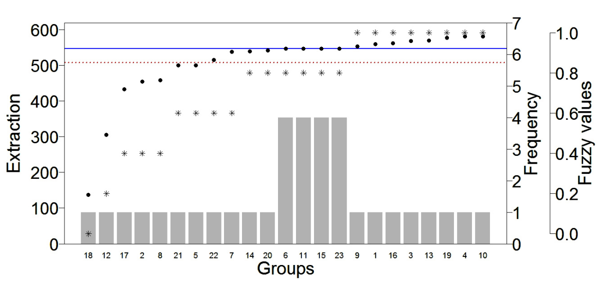
All analyses were conducted using the R Project for Statistical Computing package (R Development Core Team 2008), particularly applying the package QCA (Thiem and Dusa 2013). In the Results section we present a comprehensive description of the QCA results. More detailed results, i.e., truth tables and necessity tests, can be found in Appendix 3.

Table 4. csQCA results of each position independently (truth table is shown in Appendix 3).

Position	Role							Cases
	L	K	C	F	M	E	O	Group number
A	-	0		1	0	0	1	15; 16
	0	-		1	1	0	1	6,11
	0	1		0	0	0	0	1
B	-	1	0	1	0	0	0	4; 9
	0	0	0	1	1	0	1	1
	0	0	1	1	1	0	0	3
	1	1	1	1	1	0	1	15
C	0	-	1	1	0	0	1	11; 6
	1	-	1	1	0	0	0	16; 9
	0	0	0	1	1	0	1	10
	1	0	0	0	1	0	1	1, 4
D	-	1	0	1	0	0	1	13,16; 9
	0	0	1	1	1	1	1	15
	0	1	1	0	0	0	0	6
	1	0	0	0	0	1	0	10
	1	0	0	0	1	0	1	11
	1	0	1	0	1	0	0	3
E	0	0		1	0	0	0	1,11,23
	0	1		0	1	0	0	6
	1	1		0	0	0	0	3

The numeral 1 means that the condition is present; 0, that the condition is absent. During minimization, if some configurations differ in only one causal condition in producing the same outcome, then that causal condition is considered irrelevant. The causal condition that distinguished several expressions is represented with a dash (—) in the table. Cases from the same configuration are separated by a comma. Cases from different configurations are separated by a semicolon. L = leader, K = knowledge generator, C = connector, F = follower, M = moralist, E = enforcer, O = observer, csQCA = crisp-set qualitative comparative analysis.

Fig. 3. Selection of successful (above the median of extractions) and unsuccessful (below the median of extractions) groups and fuzzy values to run qualitative comparative analysis. The amount of water extracted, the number of group that extracted each amount, and the fuzzy values assigned are represented for each group. Circular dots represent groups' resource extraction levels, stars represent fuzzy values, and bars mark the frequency of groups extracting at the same level as the given group (e.g., groups 6,11,15, and 23 extracted the same amount of water; thus, the frequency is 4. For all other groups, their extraction level is unique (i.e., their frequency is 1), numbers represent group number, the blue line represents the median of extractions, and the dotted red line represents average extractions



RESULTS

As Figure 2 shows, using QCA at the group level, we found that group success emerged in four combinations of roles. All of them included the roles of leader, follower, and knowledge generator. Using csQCA, one resulting combination included the roles of connector and observer, and the other combination included the roles of connector and moralist. Using fsQCA, one combination included the roles of moralist, enforcer, and observer, and the other one included the roles of connector, enforcer, and moralist. At the positional level, we found that some participants in some positions were more likely to assume certain social roles. Considering each position independently, we obtained from 3-6 solutions per position and 12 solutions when we analyzed all positions together (Fig. 2).

Results at the group level

As Figure 4 shows, all 23 groups coded had at least 1 follower, 1 knowledge generator, and 1 leader. The remainder of the roles, connector, enforcer, moralist, and observer, were missing in some of the groups. We found that the most frequent role was the follower, followed by the knowledge generator, the moralist, the observer, the connector, and the enforcer (Fig. 4A).

Fig. 4. Emergent social roles at the group level. (A) Percentage of groups in which the role was present (left blue bars) and percentage of participants that take on each role (right purple bars). (B) Distribution of presence and absence of each role when the data in A are broken down into successful (blue bars in the lower half of the figure) and unsuccessful (red bars in the upper half of the figure) groups. Dark shades mean that the role is present; light shades mean that the role is absent. (C) Frequency of each role in successful (right blue bars) and unsuccessful (left red bars) groups. All groups had at least one leader, knowledge generator, and follower. The rest of the social roles did not emerge in all the groups. The most frequent role was the follower, followed by the knowledge generator, the moralist, the observer, the connector and the enforcer. L = leader, K = knowledge generator, C = connector, F = follower, M = moralist, E = enforcer, O = observer.

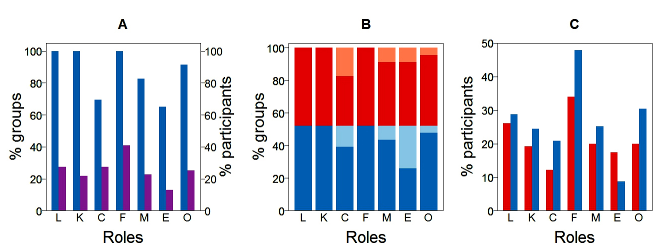


Figure 4B shows the distribution of roles by successful and unsuccessful groups. Using csQCA, we found that group success emerged in two combinations of roles. The combinations were connector and observer, and connector and moralist (Fig. 2). Note that in both combinations, a necessary condition for groups to be successful was to have at least one player adopting the role of connector. Interestingly, in neither case was it necessary to have a player adopting the role of enforcer. In addition to these conditions, successful groups also needed to have one player adopting the role of either moralist or observer. Note that because all groups had the roles of leader, follower, and knowledge generator, we did not include them in this analysis. Although all of the successful combinations of roles included at least one connector but no enforcers, 67% of the unsuccessful combinations of roles included one of these two roles. In addition, the roles of moralist and observer, found in 50% of the successful combinations, were also present in 83% of the unsuccessful combinations.

fsQCA for the frequency of each role during the two snapshots (Fig.4C) revealed two combinations of roles for successful groups. It was necessary for them to have a leader, knowledge generator, follower, moralist, and enforcer and to have either an observer or a connector. There were only two unsuccessful combinations of roles. One combination included all of the roles except moralist, and the other combination did not include the roles of enforcer and observer.

Results at the positional level

Our results show that the distribution of roles by positions was heterogeneous (Fig. 5). The role of leader was rarely assumed by players in position E, but was frequently assumed by players in position C. Players in position A were frequently knowledge generators, and connectors were often found in position D. The role of follower was frequently assumed by players in positions B and D and less frequently by players in position E. Players in position E were rarely moralists and frequently enforcers. Players in upstream and middle positions (A, B, and C) seldom assumed the role of an enforcer. The role of observer was frequently adopted by players in positions B, C, and D.

Fig. 5. Percentage of groups in which a role is present by position. This figure emphasizes that the role of follower was most prevalent, and most followers occupied position B. It also shows that enforcers seldom occupied positions A, B, or C. As one would expect, enforcers tended to emerge in position E. L = leader, K = knowledge generator, C = connector, F = follower, M = moralist, E = enforcer, O = observer.

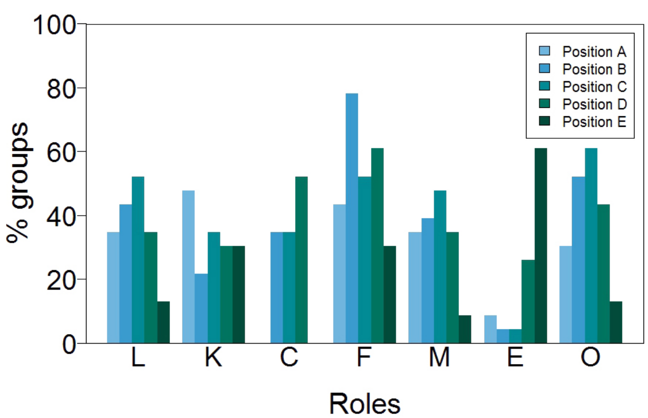


Figure 6 shows the distribution of roles by each position in successful and unsuccessful groups. Considering each position independently, csQCA generated up to six possible combinations of roles per position (Table 4). These combinations included from one to six social roles. Table 4 shows that in all combinations at least one player in the upstream or midstream positions (A, B, C) adopted the role of follower (for player B, all the successful combinations included the role of follower), whereas 50% and 60% of the combinations had players that adopted the same role for positions D and E, respectively. Interestingly, no players adopted the role of enforcer in any of the combinations except for two cases in which a player in position D adopted the role of enforcer. For positions C and D, 50% or more of the successful combinations included the role of leader; this proportion dropped up to 20% for the rest of the positions. The role of connector was found more often in position C in the successful combinations. The role of moralist was present in more than 30% of the successful combinations for all the positions. Finally, position E did not include the role of observer in the successful combinations, whereas more than half of the successful combinations included this role for positions A, C, and D.

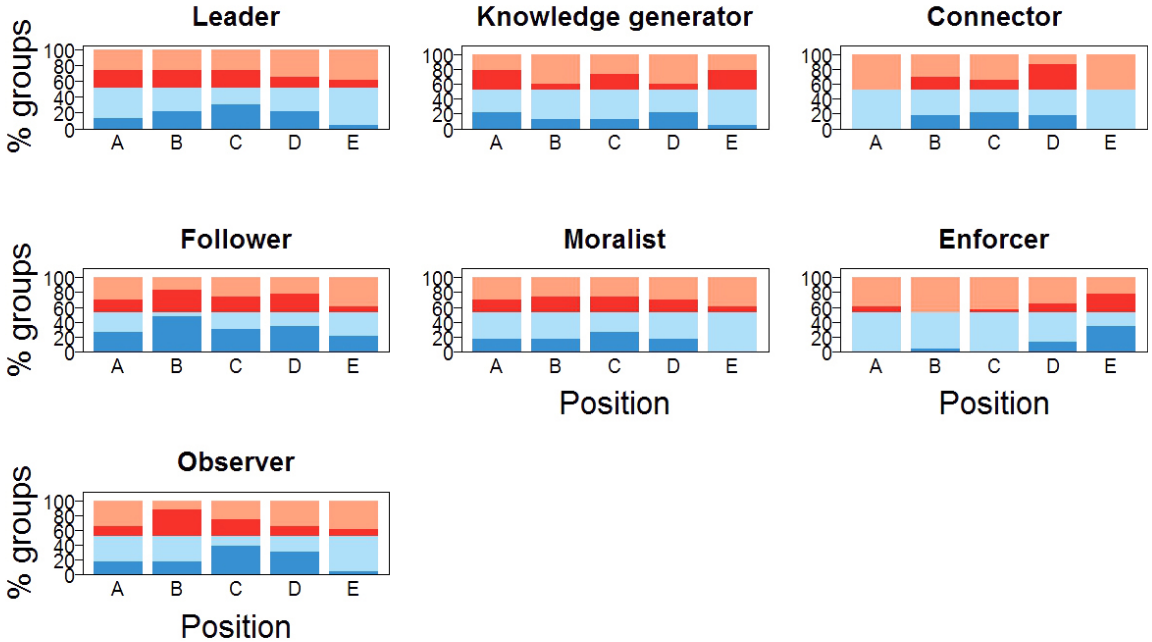
In addition, we performed a csQCA for all positions together. Because effective use of csQCA depends on the ratio of cases to causal conditions (meaning there should be the same or fewer conditions than cases), we selected the roles of leader, moralist, enforcer, and observer for the analysis of the combinations of roles and positions. In this analysis, we omitted the role of follower because it was correlated with the role of leader (i.e., if there was a follower, there was a leader and the other way around), the role of connector because only positions B, C, and D could have this role, and the role of knowledge generator because we considered that the presence of this role might improve the performance of the groups independently of which position was assuming this role. The csQCA led to 12 combinations of roles for successful groups (Table 5). Even though only one case, i.e., the successful group, was included in each specific combination of roles per position (Table 5), we highlight some interesting results that emerged from the frequency distribution of each role-position in the 12 successful combinations.

Table 5. csQCA results of roles by positions (truth table is shown in Appendix 3).

Position: A				B				C				D				E				Cases
Condition: L	M	E	O	L	M	E	O	L	M	E	O	L	M	E	O	L	M	E	O	Group number
0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	1	0	4
0	0	0	0	0	0	0	1	1	1	0	1	0	0	0	1	0	0	0	0	23
0	0	0	0	0	1	0	0	1	1	0	1	0	0	0	1	0	0	1	0	13
0	0	0	0	0	1	0	1	1	1	0	1	0	0	0	0	0	0	0	0	1
0	0	0	0	1	0	0	0	1	0	0	0	1	0	0	1	0	0	1	0	9
0	0	0	1	1	1	0	1	1	1	0	1	0	1	1	1	0	0	1	0	15
0	1	0	1	0	0	0	1	0	0	0	1	1	1	0	1	0	0	0	0	11
0	1	0	1	1	1	0	1	0	0	0	1	0	0	0	0	0	1	0	0	6
1	0	0	0	0	1	0	0	0	1	0	1	1	0	1	0	0	0	1	0	10
1	0	0	1	1	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	16
1	1	0	0	0	0	0	1	1	1	0	1	0	0	0	1	0	0	1	0	19
1	1	0	0	0	1	0	0	0	0	0	0	1	1	0	0	1	0	0	0	3

The numeral 1 means that the condition is present; 0, that the condition is absent. L = leader, M = moralist, E = enforcer, O = observer, csQCA = crisp-set qualitative comparative analysis.

Fig. 6. Distribution of the presence/absence of each role per position when the data shown in Figure 5 are broken down into successful (blue bars in the lower half of the figure) and unsuccessful (red bars in the upper half of the figure) groups. Dark shading means that the role is present; light shading means that the role is absent. Some social roles emerged more frequently in some of the positions.

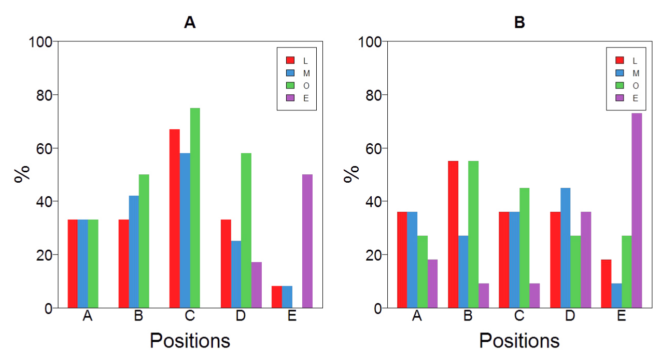


Positions with roles
In almost all of the successful combinations (92%), players in positions B and C assumed at least one role. After these positions, the most frequent position with a role in the successful groups was position D (75%) followed by position E (67%). Position A was the least frequent position with a role in the successful groups (58%). On the contrary, in the unsuccessful combinations, position C was the least frequent position with a role (55%), followed by positions A (64%), E (73%), and B and D (82%) (see Table A3.8 in Appendix 3).

Frequency of roles per position
Players in position C assumed the most roles in the resulting combinations (50% of the 48 possible; i.e., 48 means that 1 position has the 4 roles in the 12 csQCA combinations), followed by positions B and D (33%), A (25%), and E (17%). In the unsuccessful combinations, players in positions B and D assumed relatively more roles (36% of the 44 possible; i.e., 44 means that 1 position has the 4 roles in the 11 csQCA unsuccessful combinations), followed by positions C and E (32%), and A (30%).

Roles assumed by players in different positions
As for the roles occupied by players in different positions, Figure 7A shows that players in position C more frequently assumed the role of leader and players in position E rarely assumed this role in the successful combinations of roles. Enforcers were usually in downstream positions; observers were in positions B, C, and D; and moralists were in midstream and upstream positions (A, B, and C). In relation to the role of leader, another interesting pattern was that in the four combinations in which a leader existed in

Fig. 7. Frequency distribution of each role per position in the successful (A) and unsuccessful (B) combinations of social roles. This graphic suggests a pattern in which in successful groups, leaders, and moralists tend to emerge upstream, observers emerge midstream, and enforcers downstream. In unsuccessful groups, enforcers emerge in all positions, probably because of more conflict in the group. L = leader, M = moralist, O = observer, E = enforcer.



position A, there were also other leaders in different positions in the same group. This pattern did not occur when a player in position B, C, or D was the leader. In the unsuccessful combinations (Fig. 7B), players in positions B and E more frequently assumed the role of leader. In the unsuccessful combinations, the role of enforcer emerged in all the positions but more frequently in downstream positions. In addition, the roles of observer and moralist were more uniformly distributed in the unsuccessful combinations compared with the successful combinations, but more frequently in downstream positions (Fig. 7).

DISCUSSION

In this study, we used communication data in a behavioral lab experiment as a proxy to define participants' social roles and to discern combinations of roles that may have affected the performance of the groups. Our results support previous studies based on case study analysis, which argue that roles such as leader, knowledge generator, or connector are key to explaining success in the governance of social-ecological systems (e.g., Olsson et al. 2004). Of the seven roles considered in this study (leader, knowledge generator, connector, follower, moralist, enforcer, and observer), our results suggest that none were sufficient for improved group performance. Rather, a combination of at least five roles was necessary for improved outcomes. Because all groups had the role of leader, knowledge generator, and follower, these were necessary conditions, but not sufficient. In addition to these roles, successful groups also included one of these subsets: (1) a connector and observer, (2) a connector and moralist, (3) a moralist, enforcer, and observer, or (4) a moralist, connector, and enforcer. Our results also highlight the importance of positions and roles. The asymmetries and network structure introduced in our experiment caused players in some positions to be more likely to assume certain social roles. We did not consider the actual behavior of participants to code the social roles players were assuming. For example, a player was coded as a leader if he/she proposed a strategy/rule about investment or harvesting and at least one other player said he/she would follow the proposed strategy/rule but not if that player actually followed the proposed strategy. Similarly, a player was coded as a moralist if the player showed concern about downstream players or looked for fair shares for the whole group but not if the player actually took a fair amount of the resource. However, results already provide very interesting insight into understanding how social roles may influence governance of common-pool resources.

We attempt to further explain our results by relating some of the details of what happened in some of the groups to their emergent role combinations. Group 3 is considered to have a successful combination of roles by means of both csQCA and fsQCA (see Tables A3.2 and A3.4 in the Appendix 3). In this group, participants in positions B, C, and D were connectors, whereas participants in positions A and E were leaders. Owing to the connector role of B, C, and D, there was very active communication between downstream and upstream participants. In addition, players A and B took on the moralist role by showing sympathy toward downstream players and sharing the water with them. In response, the downstream players continued to invest in the infrastructure, which helps to maintain infrastructure efficiency and water availability at high levels. As a result, the group water extraction level stayed at a high level. In the worst-performing group (group 18, Fig. 3) upstream players (positions A and B) did not share water with downstream players (D and E). Players D and E attempted to warn upstream players with the threat of noninvesting, but player C barely communicated and did not connect upstream and downstream players. As a consequence, all players ended up not investing, and infrastructure efficiency and water availability subsequently dropped to low levels. In this group, we found enforcers in positions A, D, and E and observers in positions A, B, D, and E, but no moralists. A similar unfolding of events was observed in groups 2 and 9 (see Tables A3.2 and A3.4 in Appendix 3).

This sequence of events and combinations of roles show that the structure of the social network used in this study, in which participants could observe and communicate with their immediate neighbors, made the connector a necessary role in most of the combinations that led to the emergence of group success. This critical role of connectors highlights the importance of communication and monitoring for successful governance (Ostrom et al. 1992, Sally 1995, Janssen et al. 2010). Also, in the social network structure of our experiment, connectors were necessary for other roles to be effective contributors to group success. This finding highlights the importance of relaying information about others' behaviors throughout the network, and supports previous case study–based studies arguing that connectors are key to explaining success in the governance of social-ecological systems (e.g., Stubbs and Lemon 2001, Tompkins et al. 2002). However, in an experimental setting, the role of connector did not emerge when participants were organized in a fully connected network (*unpublished data*). Thus, the context of the action situation significantly influences which social roles likely emerge and become crucial for improved performance. When one of our successful combinations of roles did not include a connector, it included the role of observer. The observer role was necessary in half of the better-performing role combinations. This pattern highlights the importance of relaying the information about others' behaviors throughout the network and is consistent with the empirical evidence that monitoring of opportunistic behavior is crucial for robust governance of common-pool resources (Ostrom 1990, Cox et al. 2010).

The presence of an enforcer led to improved group performance if it was accompanied by either a connector (this role spreads the enforcer's threat throughout the social network) or an observer and a moralist (the former monitors others' actions and the latter responds to the enforcer's complaints). Our results also show that most of the unsuccessful combinations had the role of enforcer, a finding that does not conform to the suggested importance of graduated sanctions (Ostrom 1990, Cox et al. 2010) in the literature. In our experiment, the option of enforcement was available, but this role was usually activated when there was already much unfair distribution of water among participants. Thus, this pattern suggests that the emergence of an enforcer in a group might be an indication of little or no collective action. A similar pattern also occurred with the roles of observer and moralist in some of the groups.

The role of leader, considered as key for success (e.g., Gutiérrez et al. 2011), was present in all groups, both successful and unsuccessful. The performance of the group might be related to the location of the role of leader in the social network. Players in positions A and E rarely assumed the role of leader in the successful combinations, in contrast to players in position C, who assumed that role more frequently, whereas in the unsuccessful combinations the leader was more uniformly distributed. In addition, the role of leader was assigned based on the type of messages (i.e., proposing a strategy/rule about investment or harvesting) rather than the type of strategy/rule being proposed. It could be the case that a leader proposed a "wrong" strategy, causing underinvestment or overharvesting. In addition, because we coded players as leaders based on information found in the chat messages that at least one player said he/she was going to follow the proposed strategy/rule (i.e., without consideration of the actual behavior of the players), it was possible that no player actually followed the strategy/rule proposed by the coded leader. Also, the role of leader was accompanied by the role of moralist in half of the successful combinations. Thus, success may depend more on the type of leader that is present, e.g., a moralistic leader, than on the strategies that the leader is advocating, and on others recognizing that player as the leader rather than just the mere presence of a leader. Another point to consider is the dynamics of roles during the experiment. Kopelman et al. (2002) present some examples of leaders emerging when cooperative experiences fail. Future studies will determine if the role of leader changes as the outcomes of the strategies performed are evaluated.

The network structure of the experiment also led to a situation in which certain social roles occupied certain positions more frequently. In general, players in positions B, C, and D were more active in assuming roles compared with players in positions A and E. The reason for this pattern is that positions B, C, and D are more connected compared with positions A and E, and act as a link between the most and least privileged positions in terms of resource access. Downstream players, realizing the structural inequality that they are locked into, are more likely to accept unfair outcomes (Dayton-Johnson 2000). As a consequence, individuals in position E who did not get enough water and realized their structural disadvantage often did not complain (i.e., did not assume the enforcer or observer roles) or try to change the game strategy (i.e., assume the leader role). Because they have privileged access to water, players in position A did not need to assume many roles (e.g., enforcer) to obtain water.

CONCLUSIONS

This study contributes to our understanding of how social roles may influence governance of small-scale common-pool resource systems. In addition, our results suggest that coding social roles through the messages sent during the game can be useful in understanding the role that communication plays in improving outcomes of social dilemmas in behavioral experiments. An important question for future research is the possible mismatch between actions proposed through chat messages and actual behavior during the game. This study complements previous case-based studies on social roles using behavioral lab experiments. Our study supports the importance of certain social roles, e.g., connector, as highlighted by existing research. However, we found that it is not an individual role but certain combinations of social roles that make up the necessary conditions for explaining collective action in social-ecological systems. We also found that the combinations of roles we identified are highly constrained by the asymmetries in participants' resource access capabilities. How robust our findings are to different action situations (e.g., different biophysical and social contexts) is an open question. We suggest that this question poses an exciting and promising area of explorative research to better understand conditions for successful governance of common-pool resources.

Responses to this article can be read online at:
http://www.ecologyandsociety.org/issues/responses.php/7493

Acknowledgments:

We acknowledge financial support by the National Science Foundation, grant number GEO-1115054.

LITERATURE CITED

Anderies J. M., M. A. Janssen, A. Lee, and H. Wasserman. 2013. Environmental variability and collective action: experimental insights from an irrigation game. *Ecological Economics* 93:166-176. http://dx.doi.org/10.1016/j.ecolecon.2013.04.010

Cardenas, J.-C. 2003. Real wealth and experimental cooperation: experiments in the field lab. *Journal of Development Economics* 7:263-289. http://dx.doi.org/10.1016/S0304-3878(02)00098-6

Cox, M., G. Arnold, and S. Villamayor Tomás. 2010. A review of design principles for community-based natural resource management. *Ecology and Society* 15(4): 38. [online] URL: http://www.ecologyandsociety.org/vol15/iss4/art38/

Dayton-Johnson, J. 2000. Determinants of collective action on the local commons: a model with evidence from Mexico. *Journal of Development Economics* 62(1):181-208. http://dx.doi.org/10.1016/s0304-3878(00)00080-8

Ernstson, H., S. Barthel, E. Andersson, and S. T. Borgström. 2010. Scale-crossing brokers and network governance of urban ecosystem services: the case of Stockholm. *Ecology and Society* 15(4): 28. [online] URL: http://www.ecologyandsociety.org/vol15/iss4/art28/

Fehr, E., and S. Gachter. 2000. Cooperation and punishment in public goods experiments. *American Economic Review* 90:980-994. http://dx.doi.org/10.1257/aer.90.4.980

Folke, C., T. Hahn, P. Olsson, and J. Norberg. 2005. Adaptive governance of social-ecological systems. *Annual Review of Environment and Resources* 30:441-473. http://dx.doi.org/10.1146/annurev.energy.30.050504.144511

Gutiérrez, N. L., R. Hilborn, and O. Defeo. 2011. Leadership, social capital and incentives promote successful fisheries. *Nature* 470:386-389. http://dx.doi.org/10.1038/nature09689

Harrison, G. W., and J. A. List. 2004. Field experiments. *Journal of Economic Literature* 42:1009-1055. http://dx.doi.org/10.1257/0022051043004577

Henrich, J., R. McElreath, A. Barr, J. Ensminger, C. Barrett, A. Bolyanatz, J. C. Cardenas, M. Gurven, E. Gwako, N. Henrich, C. Lesorogol, F. Marlowe, D. Tracer, and J. Ziker. 2006. Costly punishment across human societies. *Science* 312:1767-1770. http://dx.doi.org/10.1126/science.1127333

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., J. M. Anderies, and J.-C. Cardenas. 2011*a*. Head-enders as stationary bandits in asymmetric commons: comparing irrigation experiments in the laboratory and the field. *Ecological Economics* 70:1590-1598. http://dx.doi.org/10.1016/j.ecolecon.2011.01.006

Janssen, M. A., J. M. Anderies, and S. R. Joshi. 2011*b*. Coordination and cooperation in asymmetric commons dilemmas. *Experimental Economics* 14:547-566. http://dx.doi.org/10.1007/s10683-011-9281-9

Janssen, M .A., F. Bousquet, J.-C. Cardenas, D. Castillo, and K. Worrapimphong. 2012. Field experiments on irrigation dilemmas. *Agricultural Systems* 109:65-75. http://dx.doi.org/10.1016/j.agsy.2012.03.004

Janssen, M. A., R. Holahan, A. Lee, and E. Ostrom. 2010. Lab experiments to study social-ecological systems. *Science* 328:613-617. http://dx.doi.org/10.1126/science.1183532

Kopelman, S., J. M. Weber, and D. M. Messick. 2002. Factors influencing cooperation in commons dilemmas: a review of experimental psychological research. Pages 113-156 *in* E. Ostrom, T. Dietz, N. Dolšak, P. C. Stern, S. Stonich, and E. U. Weber, editors. *The drama of the commons*. National Academy Press, Washington, D.C., USA.

Lombard, M., J. Snyder-Duch, and C. C. Bracken. 2002. Content analysis in mass communication: assessment and reporting of intercoder reliability. *Human Communication Research* 28:587-604. http://dx.doi.org/10.1111/j.1468-2958.2002.tb00826.x

McCluskey, E. J. 1956. Minimization of boolean functions. *Bell System Technical Journa* 35(6):1417-1444. http://dx.doi.org/10.1002/j.1538-7305.1956.tb03835.x

Olsson, P., C. Folke, and T. Hahn. 2004. Social-ecological transformation for ecosystem management: the development of adaptive co-management of a wetland landscape in southern Sweden. *Ecology and Society* 9(4): 2. [online] URL: http://www.ecologyandsociety.org/vol9/iss4/art2/

Ostrom E. 1990. *Governing the commons: the evolution of institutions for collective action*. Cambridge University Press, Cambridge, Massachusetts, USA. http://dx.doi.org/10.1017/cbo9780511807763

Ostrom, E. 2005. *Understanding institutional diversity.* Princeton University Press, Princeton, New Jersey, USA.

Ostrom, E., and R. Gardner. 1993. Coping with asymmetries in the commons: self-governing irrigation systems can work. *Journal of Economic Perspectives* 7:93-112. http://dx.doi.org/10.1257/jep.7.4.93

Ostrom, E., J. Walker, and R. Gardner. 1992. Covenants with and without a sword: self-governance is possible. *American Political Science Review* 86:404-417. http://dx.doi.org/10.2307/1964229

Pavitt, C. 2011. Communication, performance, and perceptions in experimental simulations of resource dilemmas. *Small Group Research* 42(3):283-308. http://dx.doi.org/10.1177/1046496411399782

Pavitt, C., A. C. High, K. E. Tressler, and J. K. Winslow. 2007. Leadership communication during group resource dilemmas. *Small Group Research* 38(4):509-531. http://dx.doi.org/10.1177/1046496407304333

Pavitt, C., C. McFeeters, E. Towey, and V. Zingerman. 2005. Communication during resource dilemmas: 1. Effects of different replenishment rates. *Communication Monographs* 72(3):345-363. http://dx.doi.org/10.1080/03637750500206482

Pérez, I., J. A. Baggio, N. D. Rollins, and M. A. Janssen. 2013. *Cooperation in asymmetric commons dilemmas*. CSID Working Paper Series. CSID-2012-012. Center for the Study of Institutional Diversity, Arizona State University, Tempe, Arizona, USA.

Poteete, A. R., M. A. Janssen, and E. Ostrom. 2010. *Working together: collective action, the commons, and multiple methods in practice.* Princeton University Press, Princeton, New Jersey, USA. http://dx.doi.org/10.1515/9781400835157

Quine, W. V. 1955. A way to simplify truth functions. *American Mathematical Monthly* 62:627-631. http://dx.doi.org/10.2307/2307285

R Development Core Team. 2008. *R: a language and environment for statistical computing*. R Project for Statistical Computing, Vienna, Austria. [online] URL: http://www.R-project.org/

Ragin, C. C. 1987. *The comparative method: moving beyond qualitative and quantitative strategies*. University of California Press, Berkeley, California, USA.

Ragin, C. C. 2000. *Fuzzy-set social science*. University of Chicago Press, Chicago, Illinois, USA.

Riffe, D., S. Lacy, and F. G. Fico. 2005. *Analyzing media messages: using quantitative content analysis in research*. Erlbaum Associates, Mahwah, New Jersey, USA.

Rustagi, D., S. Engel, and M. Kosfeld. 2010. Conditional cooperation and costly monitoring explain success in forest commons management. *Science* 330(6006):961-965. http://dx.doi.org/10.1126/science.1193649

Sally, D. 1995. Conversation and cooperation in social dilemmas: a meta-analysis of experiments from 1958 to 1992. *Rationality and Society* 7:58-92. http://dx.doi.org/10.1177/1043463195007001004

Stubbs, M., and M. Lemon. 2001. Learning to network and networking to learn: facilitating the process of adaptive management in a local response to the UK's national air quality strategy. *Environmental Management* 27:321-334. http://dx.doi.org/10.1007/s002670010152

Thiem, A., and A. Dusa. 2013. *Qualitative comparative analysis with R: a user's guide*. SpringerBriefs in Political Science. Springer, New York, New York, USA. http://dx.doi.org/10.1007/978-1-4614-4584-5

Tompkins, E., W. N. Adger, and K. Brown. 2002. Institutional networks for inclusive coastal management in Trinidad and Tobago. *Environment and Planning A* 34:1095-1111. http://dx.doi.org/10.1068/a34213

Appendix 1. Experimental results.

Group	Total investment	Total extractions	Final earnings
1	263	560	827
2	251	455	732
3	245	569	853
4	259	581	842
5	263	501	758
6	242	547	822
7	229	538	821
8	274	459	696
9	275	554	805
10	266	582	839
11	269	547	812
12	198	306	623
13	258	570	831
14	291	540	773
15	271	547	801
16	320	563	762
17	251	434	705
18	133	137	532
19	230	577	858
20	246	542	812
21	269	500	746
22	244	516	786
23	247	547	826
TOTAL			
Mean	251.91	507.48	776.61
Median	258	547	805
SD	35.02	102.12	78.38
Max	320	582	858
Min	133	137	532
Gini	0.27	0.35	0.23

Appendix 2. Truth table of crisp-set qualitative comparative analysis (csQCA) at the group level using the percentage of the maximum earning as the indicator of group performance. Conditions are the social roles: L=Leader, K=Knowledge generator, C=Connector, F=Follower, M=Moralist, E=Enforcer, O=Observer.

Conditions							Outcome	Number	Consistency	Cases
L	**K**	**C**	**F**	**M**	**E**	**O**				**Group number**
1	1	0	1	1	0	1	1	2	1.000	1,7
1	1	1	1	1	0	0	1	1	1.000	3
1	1	0	1	1	1	1	0	5	0.800	10,13,14,20,22
1	1	1	1	1	0	1	0	4	0.750	5,6,11,23
1	1	1	1	1	1	1	0	6	0.500	4,8,12,15,19,21
1	1	1	1	0	1	1	0	3	0.333	2,9,18
1	1	1	1	0	0	1	0	1	0.000	16
1	1	1	1	1	1	0	0	1	0.000	17

Appendix 3. Detailed QCA results.

Qualitative comparative analysis (QCA) (Ragin 1987) was used to analyze the combination of social roles necessary for groups of five participants in a computer-based irrigation experiment to succeed, i.e., reach a certain amount of water extraction. We considered seven types of social roles: leader, knowledge-generator, connector, follower, moralist, enforcer, and observer. Crisp-set (csQCA) (Ragin 1987) and fuzzy-set (fsQCA) QCA (Ragin 2000) were used to analyze the presence and abundance of social roles in each group respectively. All analyses were conducted using the R Project (R Development Core Team, 2008) for Statistical Computing package, particularly applying the package QCA (Thiem and Dusa 2012).

Whereas fsQCA was applied to the abundance of each role in the groups, csQCA was applied to two levels of analysis: group and individual level. The conditions at the group level were the presence of each role in the groups. At the individual level we undertook two types of analyses using: i) the presence of each role in the different players' positions (positions A to E) and ii) each position independently. Table A3.1 shows the raw data used to perform the csQCA and fsQCA at the group level.

Table A3.1. Crisp- and fuzzy-values of all conditions and the outcome group extraction (EXT). Conditions are the social roles: L=Leader, K=Knowledge generator, C=Connector, F=Follower, M=Moralist, E=Enforcer, O=Observer.

Group	**Outcome**			**Abundance of roles**							**Fuzzy-values**						
	EXT	**cs-value**	**fs-value**	**L**	**K**	**C**	**F**	**M**	**E**	**O**	**L**	**K**	**C**	**F**	**M**	**E**	**0**
1	560	1	1	1	1	0	3	2	0	2	0.6	0.6	0	0.8	0.8	1	0.8
2	455	0	0.4	2	2	3	2	0	1	2	1	0.8	1	0.8	0	0.6	0.8
3	569	1	1	3	2	3	2	3	0	0	1	0.8	1	0.8	1	1	0
4	581	1	1	1	1	1	2	1	1	1	0.6	0.6	0.6	0.8	0.6	0.6	0.6
5	501	0	0.6	2	1	1	3	2	0	2	1	0.6	0.6	0.8	0.8	1	0.8
6	547	1	0.8	1	3	2	2	3	0	3	0.6	1	0.8	0.8	1	1	1
7	538	0	0.6	2	1	0	3	2	0	1	1	0.6	0	0.8	0.8	1	0.6
8	459	0	0.4	1	2	2	3	2	1	1	0.6	0.8	0.8	0.8	0.8	0.6	0.6
9	554	1	1	3	3	1	5	0	1	1	1	1	0.6	1	0	0.6	0.6
10	582	1	1	2	1	0	2	2	2	1	1	0.6	0	0.8	0.8	0.2	0.6
11	547	1	0.8	1	1	2	4	2	0	4	0.6	0.6	0.8	1	0.8	1	1
12	306	0	0.2	2	3	1	3	1	2	1	1	1	0.6	0.8	0.6	0.2	0.6
13	570	1	1	1	2	0	2	2	1	2	0.6	0.8	0	0.8	0.8	0.6	0.8
14	540	0	0.8	2	1	0	3	1	3	2	1	0.6	0	0.8	0.6	1	0.8
15	547	1	0.8	2	2	2	4	3	2	4	1	0.8	0.8	1	1	0.2	1
16	563	1	1	3	1	2	4	0	0	2	1	0.6	0.8	1	0	1	0.8
17	434	0	0.4	1	1	1	2	3	2	0	0.6	0.6	0.6	0.8	1	0.2	0
18	137	0	0	2	1	1	2	0	3	4	1	0.6	0.6	0.8	0	1	1
19	577	1	1	2	3	2	2	2	1	3	1	1	0.8	0.8	0.8	0.6	1
20	542	0	0.8	1	2	0	2	1	2	1	0.6	0.8	0	0.8	0.6	0.2	0.6
21	500	0	0.6	2	1	2	2	1	1	3	1	0.6	0.8	0.8	0.6	0.6	1
22	516	0	0.6	3	2	0	1	4	1	3	1	0.8	0	0.6	1	0.6	1
23	547	1	0.8	1	1	2	3	1	0	3	0.6	0.6	0.8	0.8	0.6	1	1

The core result of the QCA is the so-called truth-table. The truth-table list all possible combinations of the conditions and outcomes and shows how often they appear in the set of cases considered (i.e., consistency). The higher the value of consistency, the more cases or membership scores in the row agree in displaying the outcome. Tables A3.2, A3.4, A3.6 and A3.8 show the truth-table for the different QCA performed in this study: csQCA at the group level, fsQCA at the group level, csQCA for each position independently, and csQCA at the position level respectively. In addition to the sufficiency analysis that resulted in the truth-table, a necessity analysis was performed. Results of the sufficiency analysis are shown in Tables A3.3, A3.5, A3.7, and A3.9.

Crisp-set QCA at the group level

Table A3.2. Truth table of csQCA for the analysis of sufficiency for the group success. L=Leader, K=Knowledge generator, C=Connector, F=Follower, M=Moralist, E=Enforcer, O=Observer.

Conditions				Outcome	Number	Consistency	Cases
C	**M**	**E**	**O**	**EXT**			**Group number**
1	0	0	1	1	1	1.00	16
1	1	0	0	1	1	1.00	3
1	1	0	1	0	4	0.75	5,6,11,23
1	1	1	1	0	6	0.50	4,8,12,15,19,21
0	1	0	1	0	2	0.50	1,7
0	1	1	1	0	5	0.40	10,13,14,20,22
1	0	1	1	0	3	0.33	2,9,18
1	1	1	0	0	1	0.33	17

Table A3.3. Results of the csQCA for the analysis of necessity for the group success. L=Leader, K=Knowledge generator, C=Connector, F=Follower, M=Moralist, E=Enforcer, O=Observer.

	Consistency	Coverage
O	0.917	0.524
M+e	0.917	0.550
C+E	0.917	0.524
C+M	1.000	0.522

Fuzzy-set QCA at the group level

Table A3.4. Truth table of fsQCA for the analysis of sufficiency for the group success. L=Leader, K=Knowledge generator, C=Connector, F=Follower, M=Moralist, E=Enforcer, O=Observer.

Conditions							Outcome	Number	Consistency	Cases
L	**K**	**C**	**F**	**M**	**E**	**O**	**EXT**			**Group number**
1	1	0	1	1	1	1	1	5	1.00	1,7,13,14,22
1	1	1	1	1	1	0	1	1	1.00	3
1	1	1	1	1	1	1	1	8	0.96	4,5,6,8,11,19,21,23
1	1	0	1	1	0	1	1	2	0.94	10,20

1	1	1	1	1	0	1	1	2	0.87	12,15
1	1	1	1	0	1	1	0	4	0.83	2,9,16,18
1	1	1	1	1	0	-	0	1	0.78	17

Table A3.5. Results of the fsQCA for the analysis of necessity for the group success. L=Leader, K=Knowledge generator, C=Connector, F=Follower, M=Moralist, E=Enforcer, O=Observer.

	Consistency	**Coverage**		**Consistency**	**Coverage**
F	0.928	0.811	c+E+O	0.952	0.767
M+E	0.904	0.758	c+m+O	0.916	0.760
K+O	0.904	0.765	c+m+E	0.916	0.784
K+E	0.940	0.772	c+M+O	0.940	0.743
K+c	0.916	0.800	C+e+O	0.904	0.758
L+O	0.940	0.743	C+E+O	0.904	0.743
L+E	0.940	0.743	C+m+O	0.916	0.776
L+M	0.928	0.733	k+E+O	0.904	0.765
L+c	0.940	0.757	K+C+e	0.904	0.815
L+C	0.916	0.752	K+C+m	0.904	0.806
L+K	0.916	0.745	K+C+M	0.916	0.776
m+E+O	0.916	0.760	l+E+O	0.904	0.765
M+e+O	0.904	0.750			

Crisp-set QCA for each position independently

Table A3.6. Truth table of csQCA for the analysis of sufficiency for the group success at each position. L=Leader, K=Knowledge generator, C=Connector, F=Follower, M=Moralist, E=Enforcer, O=Observer.

Position A										
Conditions							**Outcome**	**Number**	**Consistency**	**Cases**
L	**K**	**C**	**F**	**M**	**E**	**O**	**EXT**			**Group number**
0	0		1	0	0	1	1	1	1.000	15
0	0		1	1	0	1	1	1	1.000	6
0	1		0	0	0	0	1	1	1.000	1
0	1		1	1	0	1	1	1	1.000	11
1	0		1	0	0	1	1	1	1.000	16
0	0		0	0	0	0	0	4	0.750	4,13,22,23
1	1		0	1	0	0	0	3	0.667	3,17,19
1	1		0	0	0	0	0	2	0.500	10,12
0	0		1	0	0	0	0	4	0.250	5,7,9,20
0	0		1	1	0	0	0	1	0.000	14
0	1		0	1	0	0	0	1	0.000	8
0	1		1	0	1	1	0	1	0.000	18
1	1		0	0	1	1	0	1	0.000	2
1	1		0	1	0	1	0	1	0.000	21
Position B										
Conditions							**Outcome**	**Number**	**Consistency**	**Cases**

L	K	C	F	M	E	O	EXT			Group number
0	0	0	1	1	0	1	1	1	1.000	1
0	0	1	1	1	0	0	1	1	1.000	3
0	1	0	1	0	0	0	1	1	1.000	4
1	1	0	1	0	0	0	1	1	1.000	9
1	1	1	1	1	0	1	1	1	1.000	15
0	0	1	1	0	0	1	0	4	0.750	2,11,19,23
0	0	0	1	1	0	0	0	3	0.667	10,13,17
1	0	0	0	1	0	1	0	2	0.500	6,22
1	0	1	1	0	0	0	0	2	0.500	5,16
0	0	0	1	0	0	0	0	2	0.000	8,21
0	1	0	1	0	0	1	0	1	0.000	12
1	0	0	0	0	0	1	0	1	0.000	18
1	0	0	0	0	1	1	0	1	0.000	14
1	0	0	1	1	0	0	0	1	0.000	7
1	1	0	0	0	0	1	0	1	0.000	20

Position C

Conditions							Outcome	Number	Consistency	Cases
L	K	C	F	M	E	O	EXT			Group number
1	0	0	0	1	0	1	1	2	1.000	1,4
0	0	0	1	1	0	1	1	1	1.000	10
0	0	1	1	0	0	1	1	1	1.000	11
0	1	1	1	0	0	1	1	1	1.000	6
1	0	1	1	0	0	0	1	1	1.000	16
1	1	1	1	0	0	0	1	1	1.000	9
1	1	0	0	1	0	1	0	5	0.600	5,7,13,19,23
1	0	0	1	1	0	1	0	2	0.500	15,22
0	0	1	1	0	0	0	0	3	0.333	2,3,8
0	0	0	0	0	0	0	0	2	0.000	17,18
0	0	0	1	0	0	0	0	1	0.000	20
0	0	0	1	0	0	1	0	1	0.000	14
0	0	1	0	0	0	1	0	1	0.000	21
1	1	0	0	1	1	0	0	1	0.000	12

Position D

Conditions							Outcome	Number	Consistency	Cases
L	K	C	F	M	E	O	EXT			Group number
0	1	0	1	0	0	1	1	2	1.000	13,16
0	0	1	1	1	1	1	1	1	1.000	15
0	1	1	0	0	0	0	1	1	1.000	6
1	0	0	0	0	1	0	1	1	1.000	10
1	0	0	0	1	0	1	1	1	1.000	11
1	0	1	0	1	0	0	1	1	1.000	3
1	1	0	1	0	0	1	1	1	1.000	9
0	0	1	1	0	0	1	0	3	0.667	19,21,23
0	0	0	1	0	0	0	0	2	0.500	1,7

0	0	1	1	0	0	0	0	2	0.500	4,12
0	0	0	0	1	1	0	0	1	0.000	20
0	0	0	1	1	0	1	0	1	0.000	5
0	0	1	1	0	1	1	0	1	0.000	15
0	0	1	1	1	1	0	0	1	0.000	17
1	0	1	0	0	0	0	0	1	0.000	2
1	1	0	0	0	1	0	0	1	0.000	14
1	1	0	0	1	0	0	0	1	0.000	22
1	1	1	0	1	0	0	0	1	0.000	8
Position E										
Conditions							**Outcome**	**Number**	**Consistency**	**Cases**
L	**K**	**C**	**F**	**M**	**E**	**O**	**EXT**			**Group number**
0	0		1	0	0	0	1	3	1.000	1,11,23
0	1		0	1	0	0	1	1	1.000	6
1	1		0	0	0	0	1	1	1.000	3
0	0		0	0	1	0	0	4	0.750	4,10,13,17
0	1		0	0	1	0	0	3	0.667	15,19,20
0	0		0	0	0	0	0	3	0.333	5,7,16
0	0		1	0	1	0	0	3	0.333	9,12,14
0	0		1	0	1	1	0	1	0.000	8
0	1		0	0	0	0	0	1	0.000	2
0	1		0	1	1	1	0	1	0.000	22
1	0		0	0	1	0	0	1	0.000	21
1	0		0	0	1	1	0	1	0.000	18

Table A3.7. Results of the csQCA for the analysis of necessity for the group success. L=Leader, K=Knowledge generator, C=Connector, F=Follower, M=Moralist, E=Enforcer, O=Observer.

Position A					
	Consistency	**Coverage**		**Consistency**	**Coverage**
A.e	1.000	0.571	**A.l+A.k+A.M**	0.917	0.550
A.f+A.O	0.917	0.611	**A.l+A.K+A.O**	1.000	0.522
A.F+A.o	1.000	0.571	**A.l+A.K+A.F**	1.000	0.522
A.k+A.o	0.917	0.579	**A.L+A.m+A.O**	1.000	0.571
A.k+A.f	0.917	0.524	**A.L+A.M+A.o**	0.917	0.524
A.K+A.m	0.917	0.524	**A.L+A.F+A.m**	1.000	0.545
A.l+A.o	0.917	0.550	**A.L+A.k+A.O**	0.917	0.524
A.l+A.M+A.O	0.917	0.524	**A.L+A.k+A.m**	0.917	0.524
A.l+A.f+A.m	1.000	0.522	**A.L+A.k+A.M**	0.917	0.524
A.l+A.F+A.M	0.917	0.550	**A.L+A.k+A.F**	0.917	0.524
Position B					
	Consistency	**Coverage**		**Consistency**	**Coverage**
B.e	1.000	0.545	**B.l+B.C+B.o**	0.917	0.611
B.F	0.917	0.611	**B.l+B.C+B.O**	0.917	0.524
B.F*B.e	0.917	0.611	**B.l+B.C+B.m**	0.917	0.550
B.k+B.o	0.917	0.550	**B.l+B.C+B.M**	0.917	0.579

B.L+B.k	0.917	0.524	**B.l+B.C+B.f**	0.917	0.524
B.c+B.M+B.O	0.917	0.524	**B.l+B.k+B.M**	0.917	0.524
B.C+B.M+B.o	1.000	0.632	**B.l+B.k+B.C**	0.917	0.524
B.C+B.f+B.o	0.917	0.524	**B.l+B.K+B.o**	0.917	0.579
B.k+B.m+B.O	1.000	0.522	**B.l+B.K+B.O**	0.917	0.550
B.k+B.c+B.O	1.000	0.522	**B.l+B.K+B.m**	0.917	0.550
B.k+B.c+B.M	1.000	0.522	**B.l+B.K+B.M**	0.917	0.579
B.k+B.C+B.m	1.000	0.522	**B.l+B.K+B.f**	0.917	0.550
B.K+B.M+B.O	0.917	0.579	**B.l+B.K+B.c**	0.917	0.524
B.K+B.C+B.M	1.000	0.632	**B.l+B.K+B.C**	0.917	0.611
B.l+B.m+B.O	1.000	0.545	**B.L+B.M+B.O**	0.917	0.550
B.l+B.M+B.o	1.000	0.600	**B.L+B.C+B.o**	0.917	0.524
B.l+B.f+B.m	0.917	0.524	**B.L+B.C+B.M**	0.917	0.579
B.l+B.c+B.O	0.917	0.524	**B.K+B.c+B.m+B.o**	1.000	0.522
B.l+B.c+B.M	0.917	0.524	**B.L+B.c+B.m+B.o**	1.000	0.522
Position C					
	Consistency	**Coverage**		**Consistency**	**Coverage**
C.e	1.000	0.545	**C.L+C.C.**	0.917	0.611
C.m+C.O	1.000	0.545	**C.k+C.f+C.m**	1.000	0.522
C.F+C.O	1.000	0.600	**C.k+C.C+C.f**	1.000	0.522
C.F+C.M	1.000	0.600	**C.K+C.M+C.o**	0.917	0.550
C.c.+C.m	1.000	0.522	**C.k+C.c+C.o**	0.917	0.524
C.c.+C.F	1.000	0.545	**C.l+C.M+C.o**	1.000	0.522
C.C.+C.O	1.000	0.632	**C.l+C.f+C.o**	0.917	0.524
C.C.+C.M	1.000	0.632	**C.l+C.f+C.m**	0.917	0.524
C.k+C.O	0.917	0.524	**C.l+C.c.+C.o**	1.000	0.522
C.L+C.O	0.917	0.647	**C.l+C.C.+C.f**	0.917	0.524
C.L+C.F	1.000	0.600	**C.L+C.k+C.m**	1.000	0.522
Position D					
	Consistency	**Coverage**		**Consistency**	**Coverage**
D.e+D.o	0.917	0.524	**D.c+D.F+D.o**	1.000	0.522
D.e+D.O	0.917	0.579	**D.c+D.F+D.m**	0.917	0.524
D.m+D.O	0.917	0.611	**D.c+D.F+D.M**	0.917	0.524
D.m+D.e	0.917	0.550	**D.C+D.E+D.O**	0.917	0.550
D.M+D.e	0.917	0.550	**D.C+D.f+D.O**	0.917	0.524
D.f+D.e	0.917	0.550	**D.C+D.F+D.O**	0.917	0.579
D.f+D.m	0.917	0.550	**D.C+D.F+D.E**	0.917	0.524
D.F+D.e	0.917	0.550	**D.C+D.F+D.M**	0.917	0.524
D.c+D.e	0.917	0.550	**D.K+D.F+D.M**	0.917	0.524
D.C+D.e	0.917	0.550	**D.K+D.c+D.F**	0.917	0.524
D.C+D.m	0.917	0.579	**D.K+D.C+D.o**	0.917	0.524
D.k+D.O	0.917	0.579	**D.K+D.C+D.f**	0.917	0.550
D.k+D.e	1.000	0.545	**D.l+D.E+D.O**	0.917	0.579
D.k+D.m	1.000	0.571	**D.l+D.M+D.O**	0.917	0.550
D.k+D.F	0.917	0.579	**D.l+D.M+D.E**	0.917	0.524
D.k+D.c	0.917	0.524	**D.l+D.f+D.O**	1.000	0.522
D.l+D.e	0.917	0.524	**D.l+D.F+D.M**	0.917	0.550

D.l+D.c	0.917	0.550	**D.l+D.C+D.O**	0.917	0.550
D.l+D.k	0.917	0.579	**D.l+D.K+D.M**	0.917	0.524
D.L+D.e	0.917	0.579	**D.l+D.K+D.f**	1.000	0.522
D.L+D.m	0.917	0.579	**D.L+D.C+D.O**	0.917	0.550
D.L+D.F	0.917	0.524	**D.L+D.K+D.C**	0.917	0.579
D.m+D.E+D.o	0.917	0.524	**D.K+D.F+D.E+D.O**	0.917	0.524
D.F+D.M+D.o	1.000	0.522	**D.K+D.c+D.M+D.O**	0.917	0.550
D.F+D.M+D.E	0.917	0.524	**D.K+D.C+D.M+D.E**	0.917	0.524
D.c+D.m+D.E	0.917	0.524	**D.L+D.K+D.c+D.O**	0.917	0.550
D.c+D.f+D.O	0.917	0.550			
Position E					
	Consistency	**Coverage**		**Consistency**	**Coverage**
E.o	1.000	0.600	**E.k+E.f**	1.000	0.522
E.m	0.917	0.524	**E.k+E.M+E.E**	0.917	0.524
E.l	0.917	0.550	**E.K+E.F+E.E**	0.917	0.550
E.m*E.o	0.917	0.579	**E.L+E.K+E.E**	0.917	0.524
E.l*E.o	0.917	0.611	**E.L+E.F+E.M+E.E**	0.917	0.579
E.f+E.e	0.917	0.579			

Crisp-set QCA at the position level

Table A3.8. Truth table of csQCA for the analysis of sufficiency for the group success. Out=Outcome, n=Number of cases, Const=Consistency, L=Leader, K=Knowledge generator, C=Connector, F=Follower, M=Moralist, E=Enforcer, O=Observer.

Position																				**Out**	**n**	**Cons.**	**Cases**
A				**B**				**C**				**D**				**E**							
Condition																				**EXT**			**Group number**
L	M	E	O	L	M	E	O	L	M	E	O	L	M	E	O	L	M	E	O				
0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	1	0	1	1	1	4
0	0	0	0	0	0	0	1	1	1	0	1	0	0	0	1	0	0	0	0	1	1	1	23
0	0	0	0	0	1	0	0	1	1	0	1	0	0	0	1	0	0	1	0	1	1	1	13
0	0	0	0	0	1	0	1	1	1	0	1	0	0	0	0	0	0	0	0	1	1	1	1
0	0	0	0	1	0	0	0	1	0	0	0	1	0	0	1	0	0	1	0	1	1	1	9
0	0	0	1	1	1	0	1	1	1	0	1	0	1	1	1	0	0	1	0	1	1	1	15
0	1	0	1	0	0	0	1	0	0	0	1	1	1	0	1	0	0	0	0	1	1	1	11
0	1	0	1	1	1	0	1	0	0	0	1	0	0	0	0	0	1	0	0	1	1	1	6
1	0	0	0	0	1	0	0	0	1	0	1	1	0	1	0	0	0	1	0	1	1	1	10
1	0	0	1	1	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	1	1	1	16
1	1	0	0	0	0	0	1	1	1	0	1	0	0	0	1	0	0	1	0	1	1	1	19
1	1	0	0	0	1	0	0	0	0	0	0	1	1	0	0	1	0	0	0	1	1	1	3
0	0	0	0	1	0	0	0	1	1	0	1	0	1	0	1	0	0	0	0	0	1	0	5
0	0	0	0	1	0	0	1	0	0	0	0	0	1	1	0	0	0	1	0	0	1	0	20

0	0	0	0	1	1	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	1	0	7
0	0	0	0	1	1	0	1	1	1	0	1	1	1	0	0	0	1	1	1	0	1	0	22
0	0	1	1	1	0	0	1	0	0	0	0	0	0	1	1	1	0	1	1	0	1	0	18
0	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	1	1	0	1	0	8
0	1	0	0	1	0	1	1	0	0	0	1	1	0	1	0	0	0	1	0	0	1	0	14
1	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	0	0	1	0	12
1	0	1	1	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	2
1	1	0	0	0	1	0	0	0	0	0	0	0	1	1	0	0	0	1	0	0	1	0	17
1	1	0	1	0	0	0	0	0	0	0	1	0	0	0	1	1	0	1	0	0	1	0	21

Table A3.9. Results of the csQCA for the analysis of necessity for the group success. To simplfy the table, the role of observer and the role of enforcer in positions A, B, and C were not included. Cons.=Consistency, Cov.=Coverage, L=Leader, K=Knowledge generator, C=Connector, F=Follower, M=Moralist, E=Enforcer, O=Observer, A.=Player in position A, B.=Player in position B, C.=Player in position C, D.=Player in position D, E.=Player in position E.

	Cons.	Cov.		Cons.	Cov.		Cons.	Cov.
E.m	0.917	0.524	B.l+C.L	0.917	0.579	A.l+C.L+D.M	0.917	0.55
E.l	0.917	0.55	B.L+D.E	0.917	0.524	A.l+B.l+E.E	1	0.522
C.E	1	0.545	A.l+D.E	0.917	0.524	A.l+B.L+E.E	0.917	0.524
B.E	1	0.545	A.l+D.m	0.917	0.524	A.l+B.L+D.L	0.917	0.579
A.E	1	0.571	A.L+D.E	0.917	0.579	A.l+B.L+C.l	0.917	0.524
C.E*E.m	0.917	0.55	D.m+E.L+E.E	0.917	0.524	A.L+D.m+E.E	0.917	0.524
C.E*E.l	0.917	0.579	D.m+D.E+E.L	0.917	0.579	A.L+D.m+D.E	0.917	0.579
B.E*E.m	0.917	0.55	D.l+E.L+E.E	0.917	0.524	A.L+D.l+E.E	0.917	0.579
B.E*E.l	0.917	0.579	D.l+D.E+E.E	0.917	0.55	A.L+D.l+D.m	0.917	0.55
B.E*C.E	1	0.571	D.l+D.m+E.L	0.917	0.55	A.L+D.l+D.M	0.917	0.524
A.E*E.m	0.917	0.579	D.l+D.M+E.E	1	0.545	A.L+C.L+E.M	0.917	0.611
A.E*E.l	0.917	0.579	D.l+D.M+D.E	0.917	0.524	A.L+C.L+D.m	0.917	0.55
A.E*C.E	1	0.6	C.L+D.m+E.L	0.917	0.579	A.L+C.L+D.M	0.917	0.55
A.E*B.E	1	0.6	C.L+D.M+E.E	0.917	0.524	A.L+C.L+D.l	0.917	0.55
B.E*C.E*E.m	0.917	0.579	C.L+D.M+E.M	0.917	0.611	A.L+B.l+E.E	0.917	0.55
B.E*C.E*E.l	0.917	0.611	C.L+D.M+D.E	0.917	0.55	A.L+B.L+D.m	0.917	0.524
A.E*C.E*E.m	0.917	0.611	C.L+D.l+D.M	0.917	0.55	A.L+B.L+D.l	0.917	0.524
A.E*C.E*E.l	0.917	0.611	B.l+EM+E.E	0.917	0.55	A.L+B.L+C.L	0.917	0.524
A.E*B.E*E.m	0.917	0.611	B.l+D.E+E.E	0.917	0.524	C.L+E.L+E.M+E.E	0.917	0.524
A.E*B.E*E.l	0.917	0.611	B.l+D.M+E.E	0.917	0.55	C.L+D.E+E.L+E.M	0.917	0.55
A.E*B.E*C.E	1	0.632	B.l+D.L+E.E	0.917	0.55	C.L+D.l+D.E+E.L	0.917	0.55
A.E*B.E*C.E*E.m	0.917	0.647	B.l+C.l+E.E	0.917	0.55	B.l+D.L+D.E+E.M	0.917	0.55
A.E*B.E*C.E*E.l	0.917	0.647	B.L+D.m+E.L	0.917	0.55	B.l+D.L+D.M+E.M	0.917	0.55
D.E+E.E	1	0.522	B.L+D.l+E.E	0.917	0.524	B.l+C.l+D.L+D.E	0.917	0.55
D.m+E.E	0.917	0.611	B.L+D.l+D.M	0.917	0.524	B.l+C.l+D.L+D.M	0.917	0.524
D.m+D.E	0.917	0.55	B.L+C.L+D.M	0.917	0.55	B.L+D.l+D.E+E.L	0.917	0.55
D.M+D.E	0.917	0.55	A.l+EL+E.E	0.917	0.524	B.L+C.L+E.L+E.E	0.917	0.524
D.l+D.E	0.917	0.524	A.l+D.E+E.E	0.917	0.55	B.L+C.L+D.E+E.L	0.917	0.55
D.L+D.E	0.917	0.579	A.l+D.M+E.E	0.917	0.524	A.l+B.L+D.E+E.L	0.917	0.55
D.L+D.m	0.917	0.579	A.l+D.l+E.E	0.917	0.524	A.l+B.L+D.M+D.E	0.917	0.579
C.l+D.m	0.917	0.55	A.l+D.l+E.L	0.917	0.524	A.L+B.l+D.E+E.M	0.917	0.55

C.l+D.l	0.917	0.524	A.l+D.l+D.E	0.917	0.524	A.L+B.l+D.M+E.M	0.917	0.579
C.L+E.E	0.917	0.688	A.l+D.l+D.M	0.917	0.524	A.L+B.l+D.L+E.M	0.917	0.611
C.L+D.E	0.917	0.611	A.l+D.L+E.E	0.917	0.579	A.L+B.l+D.L+D.E	0.917	0.55
C.L+D.L	0.917	0.611	A.l+C.l+E.E	0.917	0.524	A.L+B.l+D.L+D.M	0.917	0.55
B.l+D.E	0.917	0.579	A.l+C.L+E.E	0.917	0.524	A.L+B.l+C.l+D.E	0.917	0.579
B.l+D.m	0.917	0.579	A.l+C.L+E.L	0.917	0.55	A.L+B.l+C.l+D.M	0.917	0.524
B.l+D.l	0.917	0.55	A.l+C.L+D.E	0.917	0.55	A.L+B.l+C.l+D.L	0.917	0.55

LITERATURE CITED

Ragin, C.C. 1987. The comparative method: moving beyond qualitative and quantitative strategies.University of California Press, Berkeley, California, USA.

Ragin, C.C. 2000. Fuzzy-set social science. University of Chicago Press, Chicago, Illinois, USA.

R Development Core Team. 2008. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org.

Thiem A., and A. Dusa. 2012. Qualitative comparative analysis with R: a user’s guide. Springer, New York, USA.