Group size in social-ecological systems

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Cooperation becomes more difficult as a group becomes larger, but it is unclear where it will break down. Here, we study group size within well-functioning social-ecological systems. We consider centuries-old evidence from hundreds of communities in the Alps that harvested common property resources. Results show that the average group size remained remarkably stable over about six centuries, in contrast to a general increase in the regional population. The population more than doubled, but although single groups experienced fluctuations over time, the average group size remained stable. Ecological factors, such as managing forest instead of pasture land, played a minor role in determining group size. The evidence instead indicates that factors related to social interactions had a significant role in determining group size. We discuss possible interpretations of the findings based on constraints in individual cognition and obstacles in collective decision making.

cooperation | group size | common property resources | transaction costs | social brain hypothesis

By sustaining high levels of cooperation, human societies can avoid the tragedies of excessive fishing, deforestation, and climate change and achieve successful management of social-ecological systems. A broad consensus exists that the ability to cooperate, and thus to avoid the tragedy of the commons, critically depends on group size (1–3). However, the exact association between group size and cooperation is a topic of ongoing debate in the empirical literature (4–7). We add insights on questions raised by this debate, including the following: (*i*) What is the size of human groups in well-functioning social-ecological systems, (*ii*) has such group size been historically stable, and (*iii*) are the determinants of group size social or ecological?

Cooperation is difficult to achieve in a group, in part, because each individual has an incentive to "free-ride" on others' efforts. From a theoretical perspective, the larger the group, the more likely it is for coordination and cooperation to fail (8). The empirical literature has considered this classic Olsonian hypothesis through a variety of field, behavioral and experimental data, but it has not clearly identified the relationship between group size and successful cooperation (9–11). A multiplicity of factors can affect cooperation, and these factors not only vary with group size but also affect it (12, 13). Prior research shows that two clusters of factors, ecological and social, can determine the observed group size (10, 13, 14). One of the ecological factors is production technology, which characterizes the group task. A group may be large because the payoffs from cooperation increase with scale to the extent that they offset, at least in part, the incentive to free-ride. Among the social factors, the literature has focused on group heterogeneity: Its role in the successful management of the commons has been found to be negative or positive depending on the type of heterogeneity and the specific task (15, 16). For instance, in attaining a group agreement, the existence of high diversity in economic interests may be an obstacle. However, some public goods could be provided through the contributions of just a few individuals in the group, and, in this case, their provision may be easier in a group that is heterogeneous in terms of prosociality than in a homogeneous group (17). This study integrates different streams of literature into a unified framework and marks a step forward in understanding group size and successful cooperation.

Here, we study the average size of groups, their stability, and the determinants by considering the management of common property resources in the Alps (18, 19). We follow hundreds of communities over a time span of about six centuries (13th–19th centuries). The overall population in the region more than doubled during this period, and we are interested in discovering how this increase influenced the size of groups. The cases considered represent instances of a general pattern of self-governance to avert the tragedy of the commons that has been documented worldwide by Ostrom (20) and others (21, 22). More specifically, our dataset contains observations on 248 groups in the Trentino region of Italy, each of which is a community owning pastures and forests in common (23). This dataset has three distinctive aspects. First, ecological conditions varied widely across groups, which allowed controlling for the role of production technology. Second, endogeneity exists in the selection of group size as resource users self-organized from the bottom up, and they were free to cluster within or across villages, largely autonomous from the central government. The endogeneity in group size allows the observation of how group size evolved over time in these alpine communities and identification of the presence of attraction points. Third, coverage throughout several centuries is provided by a reliable, homogeneous data source. Having such a notable long-term perspective enables the observation of resilient social-ecological systems. Through six centuries, the systems experienced a wide range of political, demographic, cultural, and climatic shocks. We perform a longitudinal analysis on group size, which nicely complements existing cross-sectional studies that compare different groups at a specific point in time (12, 24–26).

This study proposes an analytical framework for thinking about cooperation and group size, as well as a unique dataset of

Significance

What is the size of human groups for successful cooperation? Theoretically, the larger the group, the more difficult it is to sustain cooperation. We studied hundreds of villages in the Alps that harvested common property resources for almost six centuries. In the field, the average size of successful villages was around 176 individuals, although the variance was considerable. Overall, however, this average remained stable over time despite a doubling of the region's population. Multiple social and ecological factors could, in principle, drive group size. Here, we report the predominance of social factors, such as group heterogeneity, over ecological ones, such as managing forest instead of pasture land.

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groups that managed the commons for hundreds of years. We show that the mean size of groups remains stable over time at around 176 individuals, and that it is related more to how humans interact in society than to the specific ecological problem at hand. We discuss how these findings fit within two well-known perspectives on group size proposed by social scientists, the social brain hypothesis (SBH) (24–26) and the collective choice hypothesis (CCH) (27, 28), which state that in a well-functioning social-ecological system, group size is constrained by individual cognitive limits and collective decision making.

Communities in the Alps historically had leeway in managing group size for governing the common resources and shaping property rights. All household heads entitled to common property resources in the community were called to join the assembly at which decisions were undertaken face to face. Assemblies deliberated on management aspects and set rules for harvesting the resources and for organization building. The assembly enjoyed wide-ranging powers, including appointing community officers, regulating assembly participation, inflicting sanctions, alienating the common land, and regulating membership rights and inheritance rules (29). Besides crafting the resource governance rules, the community was also in charge of their local, day-to-day enforcement (19). Private property was widespread over vineyards and plow land but unusual over forests and mountain pastures because of the prohibitive costs of establishing private property rights in the absence of natural barriers, such as rivers or cliffs, that delimited the property. All regulations concerning the common property resources were recorded in formal documents called charters (*Carte di Regola*). These documents typically open with a list of the participants to the assembly and then describe what institutions were in place. Using these sources, we collected first-hand data on the size of groups and their social and ecological characteristics. Subsequently, we identified and coded all the known charters available in the regional archives, with the possible exception of any that may have been lost, damaged, or destroyed. The charter system emerged from the bottom up, upon a request from the peasants to the central political authority, which allowed for local self-governance. In this sense, the existence of a charter in a given community provides precise knowledge about the existence of a formal organization and the success in overcoming the hindrances of collective decision making. The first charters were drafted in the 13th century, and the charter system lasted until the beginning of the 19th century, when it was abruptly upended in the entire region by Napoleon (18, 30).

A Simple Model of Group Size

A simple model can help to frame the issue of group size in the presence or absence of an internal organization. Organized groups can cooperate more easily, but the organization entails costs. Consider n individuals engaged in harvesting a common property resource who can freely form one or more groups and can freely organize themselves (20). In an unorganized group, everyone makes harvesting decisions independently, and efficiency losses will likely increase along with group size (2). This relation is grounded in theoretical models of decentralized interactions (1) and in empirical evidence (31). Cooperation in larger groups may be easier when engaging in contributions toward a public good rather than in harvesting resources from a common pool, which we are considering here. Rivalry in benefits is absent from the former but present in the latter. For example, the aggregate benefits of one unit of effort in keeping the air clean increase with group size. In contrast, the benefits of limiting overfishing are constant, regardless of the group size; as the group grows, the individual shares of the aggregate benefit will be reduced (8, 29, 32). Both theoretical and empirical perspectives on common property resources suggest full efficiency with individual ownership and a rapid decline in efficiency already occurring when the groups reach eight members, with losses above 50% and approaching 100% for large sizes (19) (*Supporting Information*).

In our model, such efficiency losses can be entirely avoided by building an organization through a charter. While restoring full efficiency, the organization also involves transaction costs related to bargaining, monitoring, coordinating, solving conflicts, and so forth (18, 20). Fig. 1 illustrates the choice of groups between experiencing efficiency losses when unorganized (dashed line) and paying organizational costs (solid line). The organization entails fixed setup costs (FC) and variable running costs (VC) so that the total costs (TC) can be modeled as (18): $TC(n) = FC + VC(n)$. We assume running costs increase with group size, $VC' > 0$, and increase more than proportionally, $VC'' > 0$.

An implication is that small groups will be unorganized, which is in line with the available evidence (18). Organization will only benefit groups larger than $\underline{n}$, which is defined in Fig. 1 as the threshold that occurs at the intercept of the lines representing efficiency losses and organizational costs. Another implication is that large groups will be subject to fissions. An organized group will benefit from splitting into two separate entities when it passes a threshold $\tilde{n}$ in size because of savings in organizational costs. The definition of $\tilde{n}$ is given in Fig. 1 as the crossing point between the two organizational cost curves. If organizational costs increase proportional to group size, no reasons exist for fissions. Instead, if costs increase more than proportionally, as assumed in the model, group size will have an upper bound.

For simplicity, the model assumes constant, or declining, returns from cooperation in group size, at least beyond some point. Evidence from forest management shows increasing returns from cooperation at very small group sizes and then decreasing returns as the group size becomes larger (8). This evidence is based on exogenously imposed group sizes, and what we present next is instead based on groups that decide their size endogenously.

Average Group Size Has Been Stable for Centuries

The Trentino communities that successfully managed common resources remained remarkably similar in group size over time. The mean number of resource appropriators in organized groups stayed stable at around 176 over the very long run (Fig. 2). The time trend over about six centuries is flat (Table 1, column 1). The median number of resource appropriators is also stable, at around 140. When the time interval of 1249–1801 is divided into six subintervals with the same number of observations, the

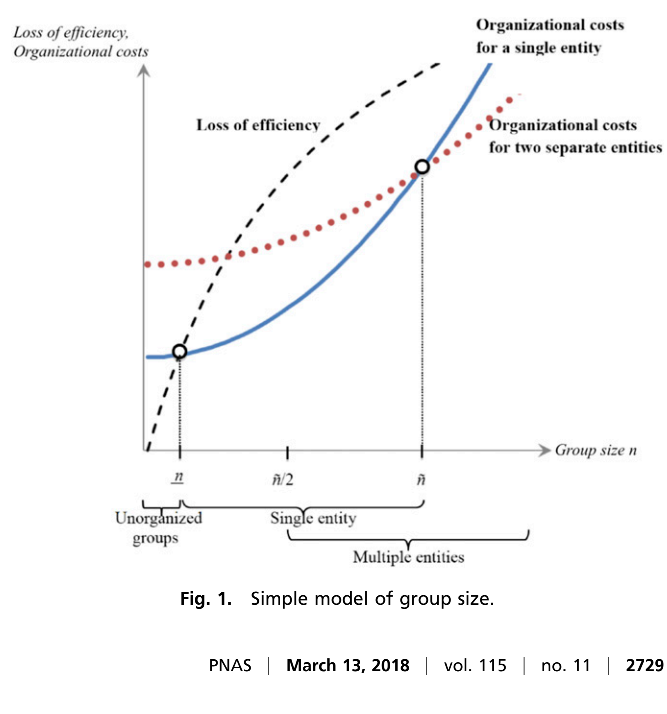

Fig. 1. Simple model of group size.

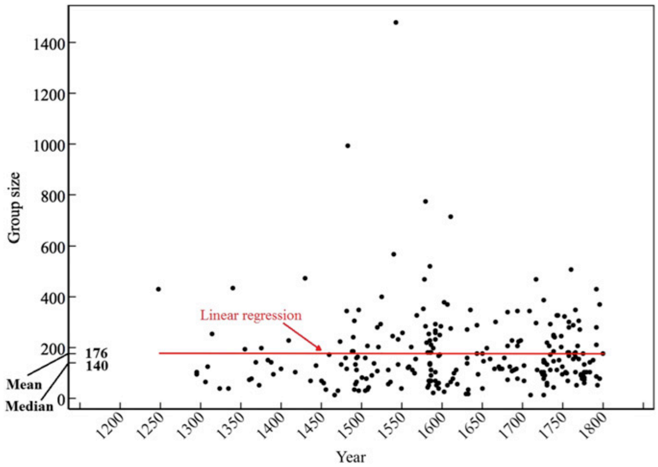

Fig. 2. Group size over six centuries. The analysis of 248 documents with listed assembly attendants shows that group size has a constant trend during 1249–1801. The trend estimation (red line) is shown in Table 1 (column 1). The observations refer to 156 different communities.

median group sizes show no statistically significant difference (Kruskal–Wallis rank test: $\chi^2 = 1.354$, df = 5, $P = 0.929$, $n = 248$). We note that this conclusion, and the following ones, are based on groups that succeeded in averting the tragedy of the commons. Owing to data limitations, we cannot observe cases of failed adaptation or collapse. Recall that the model does not define an optimal group size, even when all groups have an identical cost structure, but rather a range of possible values for organized groups. The data exhibit some dispersion with group size between 10 and 1,476, which may be compatible with the above prediction, especially when allowing for heterogeneity in bargaining, monitoring, and conflict resolution costs across communities (12, 18).

The observed long-term stability in the average group size of appropriators stands in sharp contrast to the patterns of population growth in Trentino. The regional population grew by about 275% from 1312 to 1810. During the same period, the general Italian population also exhibited similarly substantial growth (*Supporting Information*). Larger groups pose a greater challenge for cooperation and for reaching a durable consensus, as exemplified by anecdotal evidence regarding the citation from a charter highlighting the difficulties of face-to-face debates (*Supporting Information*). The documents from several communities show that groups enacted fissions along geographical lines (23, 33). One example is the community composed of Coredo, Smarano, and Sfruz, which jointly managed its commons in 1437. The community split into two in 1582 and subsequently into three in 1696. A fission usually divided both the common land and the group into two parts, with no apparent production specialization across subgroups. Fissions allowed maintaining a constant group size despite population growth.

Another piece of evidence comes from the following dynamic analysis of group size. We focus on a subset of observations with repeated recordings for the same community ($n = 92$). One can exploit the direction of change in group size (up or down) to identify an attraction point, which is an evolutionary stable point for the size of the group. Single groups experienced variations in size over time (the median absolute variation was of 61.5 appropriators over a 32.5-y interval) due to a variety of external shocks and internal population dynamics. One of the possible forces at play was also the need to maintain a group size suitable for the successful management of the commons. The evidence presented below is compatible with this factor having played a detectable role in shaping group size. To estimate this attraction point, we locate the threshold at which the direction of change reverses: Groups below the threshold tend to increase in size, while those above the threshold tend to decrease in size. First, we ordered groups from smallest to largest in terms of initial size, irrespective of their geographical location. We then computed the share of groups that remained constant or grew in size (Fig. 3). When the sample is split in half, this share is lower for large groups than for small ones (34% vs. 73%; χ^2 test, $z = 14.19$, $P < 0.001$, $n_1 = 46$, $n_2 = 46$). One can refine the analysis by constructing a moving average of groups that are the most similar in size. In fact, single groups are likely affected by both idiosyncratic and common random shocks. By averaging across groups, the idiosyncratic shocks will wash out, and thus cleaner evidence results.

The moving average tends to decline as group size increases (solid line in Fig. 3). Its crossing point at 50% estimates the location of the attraction point because it signals a balance between the groups that have grown in size and those that have become smaller. The estimated attraction point is 154. When performing a similar dynamic analysis, including the magnitude of the change in addition to its direction, we obtain an estimated attraction point of 150 (*Supporting Information*). These estimates are between the median and mean group size that we obtained from the cross-sectional analysis. Hence, the stability of the average group size over time is in line with evidence showing (*i*) the time invariance of mean and median sizes over the centuries, (*ii*) the active engagement in fissions to counterbalance internal population growth, and (*iii*) the existence of an attraction point in the evolution of group sizes.

Ecological Versus Social Determinants

A central question is whether the forces shaping group size are ecological or social (34). The observed size could depend on the specific type of natural resource under management, or it could

Table 1. Stability of average group size

Dependent variable: Group size	(1)	(2)	(3)
Year (time trend)	−0.003 (0.066)	−0.001 (0.066)	0.002 (0.061)
Resource endowment is forest-rich (yes/no)		0.110 (26.23)	−9.617 (22.11)
Resource endowment is pasture-rich (yes/no)		−4.695 (23.99)	−3.160 (20.08)
Altitude greater than 750 m above sea level (yes/no)		−24.69 (18.66)	−20.75 (15.79)
Surname diversity within the group			791.3*** (164.8)
Constant	182.0 (111.2)	187.6 (115.6)	181.8 (107.2)
N	248	248	236
R^2	0.000	0.006	0.205

Panel generalized least squares regression with random effects and robust SEs clustered at the community level. The variable "surname diversity within the group" is mean-centered. Land use data are time-invariant (*Supporting Information*). Column 3 represents a smaller sample because of missing values for surname diversity; 1 SD in surname diversity corresponds to a group that is 37% larger (+67 individuals); the correlation may imply that larger groups are necessarily more diverse, or vice versa, that surname diversity determines group size. Statistical significance level: ***$P < 0.001$.

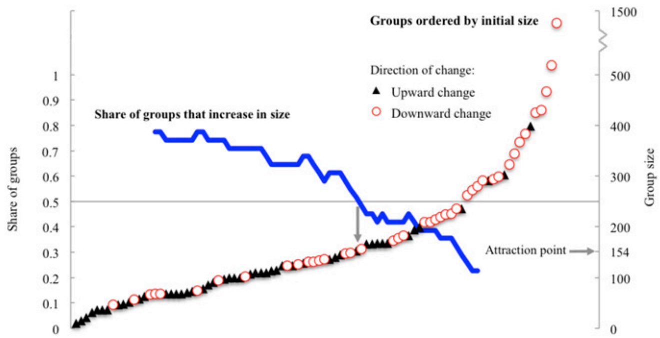

Fig. 3. Attraction point in group size. Each mark (red circle or black triangle) represents a group that we observe repeatedly over time ($n = 92$). The type of mark denotes the direction of change in group size: downward (red circle) or upward/unchanged (black triangle), respectively. The solid line builds upon the sequence of circles and triangles and indicates the share of triangles; more specifically, it computes the moving average of 31 adjacent observations (left axis). The balance between groups declining and growing in size at 0.5 determines the attraction point of 154.

be a feature of how humans generally interact in groups. We exploited variability across communities to disentangle the two forces. Direct and indirect evidence shows the predominance of social factors over ecological factors in determining group size.

Common resource endowments varied considerably across communities: Some had a prevalence of forest ($n = 95$), others were mainly endowed with pasture ($n = 81$), while others had limited or mixed common resources ($n = 72$) (*Supporting Information*). Forestland can differ substantially from pastureland in terms of yields, monitoring costs, timing of harvest, and optimal scale. Trees can take several decades to mature, while grass takes only a few months. In Trentino, the most valuable tree (red fir) reaches its maximum productivity between 60 and 90 y of age (35). Our results show that group size is not significantly affected by the diversity in resource endowment (Mann–Whitney test on forest-rich vs. pasture-rich communities: $z = -0.111$, $P = 0.914$, $n_1 = 95$, $n_2 = 81$). Panel data regression analyses offer similar results (Table 1, column 2), which are robust to other measures of resource endowment, such as the ratio of forest over pasture land (*Supporting Information*).

By contrast, social factors are strongly linked with group size. We measured group diversity in terms of the surnames of assembly participants. Larger group sizes are empirically associated with wider surname diversity (Table 1, column 3). Because this result is somewhat expected due to statistical laws, we also present other types of empirical analysis. The origin of surnames is largely independent from the objective of this study, and hence provides a useful indication of partitioning within a group. A classification of surnames cited in Trentino documents over four centuries (1156–1595) refers to occupation (17%); bodily parts/qualities; moral values; objects, such as weapons, clothes, or instruments; places; animals; plants; food; women-related; and others (*Supporting Information*). Surnames have been used in anthropology, biology, and genetics to study, among other variables, migrations, genetic isolation, and distances between populations (36, 37). Our surname diversity index $h = 1 - \Sigma_j(N_j/N)^2$ is analogous to the Herfindahl index and refers to an assembly of N individuals in which N_j is the number of people with a given surname j (38). It measures the probability that two randomly selected individuals from an assembly come from different "surname groups." The index h ranges from 0, when all surnames are equal, to $1 - 1/N$, when they are all different.

Indirect evidence about ecological and social factors comes from the study of institutions (39). Group organization may become increasingly unmanageable as a group encounters more obstacles to the ability to function. One may expect larger communities to be more complex, which may eventually trigger a fission or lead to the collapse of cooperation. We focus on institutional complexity, which is proxied using the number of institutional roles, and employ the stated qualifications of assembly attendees, such as consul, guard, or controller, to understand the governance structure of the community. Our proxy of institutional complexity positively correlates with group size (Table 2). Social factors also play a significant role in shaping institutional complexity, but ecological factors do not. Communities with high surname diversity, those above the median of the fractionalization index, are more complex than those with low diversity (Mann–Whitney test: $z = -3.699$, $P = 0.0003$, $n = 236$). Regression analyses of panel data also provide a similar result after controlling for group size (Table 2). In regressions, both group size and surname diversity compete with one another in explaining institutional complexity, which is reassuring, given their known correlation (Table 1, column 3). In contrast, the effect of the type of natural resources on the number of institutional roles is not statistically significant (Mann–Whitney test: $z = -0.700$, $P = 0.4840$, $n_1 = 90$, $n_2 = 77$). We also performed a robustness check using charter length as a proxy of institutional complexity and obtained similar results (*Supporting Information*).

In summary, our finding is that social factors shape group size and institutions more than ecological factors. A caveat applies to this conclusion. The dataset is a sample of communities that span altitudes between 76 and 1,579 m above sea level. Some communities grow olive trees, others grow vineyards, while others border perennial glaciers. Some are in remote locations, while others are along main trading routes. Only a few rely on lakes and rivers for their activities.

Nevertheless, we are aware that common property resources around the world encompass a much wider variety than is described here. For this reason, we looked for evidence on group sizes in common property resources that cover a broader range of societies and resources types. Elinor Ostrom and her collaborators developed a database, currently maintained by the Center for Behavior, Institutions and the Environment at Arizona State University, with cases from 27 different countries and comprising social-ecological systems, such as common forests, fisheries, and irrigation systems ($n = 84$). Data on the mean ($\mu = 235$), median ($M = 109$), and empirical distribution of group sizes of appropriators are in line with the evidence from Trentino showing a prevalence of small group sizes (*Supporting Information*).

The SBH and CCH

Human societies often solve ecological problems socially through bargaining and explicit agreements, but social interactions can present obstacles that limit the size of groups. Here, we focus on two existing views of social-ecological systems, the SBH and the CCH, as tentative interpretations of our empirical evidence. Although other interpretations are possible, these perspectives have been extensively debated in the literature and resonate with some key patterns observed in Trentino. Both hypotheses refer to factors that can shape the size of well-functioning groups, which are social rather than ecological.

The SBH, which was developed within the fields of neuroscience and anthropology, states that biological limitations in human cognition impose a ceiling on group size owing to constraints on memory and social skills for managing relationships (24–26). This limitation refers to "the largest group of people who know everyone in the group as individuals at the level of personal relationships" (26). It also applies to the number of users that harvest a common property resource with whom one can easily relate and keep track of. This restriction could interfere with peer monitoring and sanctioning of resource users and could hamper the ability to sustain cooperation (18, 20). The SBH assumes that humans exhibit limits in communication, strategic thinking, and social bonding that raise the transaction costs of social and economic exchanges and may restrict group size.

Table 2. Institutional complexity

Dependent variable: No. of assembly roles	(1)	(2)
Group size	0.261*** (0.0581)	0.156* (0.071)
Surname diversity within the group		4.852*** (0.872)
Resource endowment is forest-rich (yes/no)		−0.274 (0.238)
Resource endowment is pasture-rich (yes/no)		−0.101 (0.225)
Year (time trend)		0.005*** (0.001)
Altitude greater than 750 m above sea level (yes/no)		0.316 (0.189)
Constant	3.172*** (0.141)	−5.117*** (0.982)
Observations	236	236
Overall R^2	0.065	0.358

Panel generalized least squares regression with random effects and robust SEs clustered at the community level. The variable "surname diversity within the group" is mean-centered, and "group size" was divided by 100. Statistical significance levels: $*P < 0.05$; $***P < 0.001$.

The CCH instead refers to obstacles to the coherent functioning of the group in terms of decision making. When preferences over outcomes are heterogeneous, merging individual wants and needs into a collective will can be problematic (27). If unanimity is required, a diverse group may be incapable of coming to an agreement, for instance, in approving a new charter. If a simple majority is required, the collective decision making could be volatile and subject to endless revisions because of repeated reversals in voting outcomes (28). Already in 1785, Condorcet (40) showed that incoherencies in majority voting could emerge even within groups as small as three members. These results are consolidated within economics and political science, although no agreed-upon quantitative predictions about group size have emerged.

According to this line of interpretation, to function well, the Trentino groups should respect size limitations originating from both the SBH and CCH. Our evidence on group size from Trentino offers partial support for the SBH. The 95% confidence interval of our mean group size estimate for the users of collective pasture and forest is 157–196 individuals ($n = 248$). Dunbar (41) estimates a range of 100.2–231.1 individuals, and Killworth and coworkers (25) estimate a mean of 291. Large shares of the Trentino groups are below these levels: 76% and 85%, respectively. Groups also actively engage in fissions, which is a typical strategy within the SBH, aiming to maintain group size within a manageable cognitive load (23, 33). Some groups appear to be too large to be compatible with the SBH. We will later discuss the possible role of institutional strategies in these large groups.

However, a careful examination of the data reveals the explanatory power of the CCH, which focuses on the number of people with voting rights and on their similarity in interests and preferences. On the one hand, the CCH redefines what constitutes a group in terms of the assembly participants instead of the resource users. On the other hand, it highlights heterogeneity, which the SBH does not explicitly mention.

Two pieces of evidence specifically point toward a role for the CCH: the empirical relevance of group heterogeneity and the type of organizational strategies adopted. As already noted, larger groups are more heterogeneous than smaller ones. However, after controlling for group size, we find that higher heterogeneity in terms of surnames consistently correlates with more complex institutions (Table 2). Moreover, under a nominal unity, some groups adopted organizational strategies other than fission to cope with the challenges of increasing group size: a multiple-tiers or group-clustering strategy.

Under a multiple-tiers strategy, resource appropriators met face to face in smaller subgroups. In those meetings, they selected representatives, who would later meet with representatives of other subgroups. For instance, in the year 1544, Comun Comunale, a community with 1,476 appropriators, approved new regulations in a plenary assembly (Fig. 1). In 1611, appropriators structured themselves into four subgroups and sent only representatives to the general assembly.

Large communities could also follow a group-clustering strategy, which entailed partitioning the common land into multiple commons. Each individual appropriator was assigned to only one of the commons. For instance, in 1480, the community of Fiemme organized into four clusters. These institutional changes attempted to reduce the size of the group that interacted face to face and to account for the presence of groups that persistently remained nominally large.

Although both strategies make sense under the CCH, only group clustering is in line with the SBH. A multiple-tiers strategy reduces the assembly size but not the number of resource users.

Discussion

Group size is a critical feature of social-ecological systems whose performance largely depends on the ability to cooperate (11, 20, 42). This article documents the analysis of a unique dataset spanning almost six centuries and including hundreds of communities that managed their common resources (18, 23, 29). We report a considerable stability of average group size. Estimates from multiple perspectives converge on similar figures at around 140–176 members per group, or in a larger range between 109 and 215 when performing a sensitivity analysis (*Supporting Information*).

The evidence from Trentino and other parts of the world suggests that successful cooperation takes place in rather small groups. In these systems, institutions can serve as a powerful technology to overcome social dilemmas by lowering the transaction costs of social interaction and by facilitating collective decision making (43). However, the extension of our findings to other social dilemmas requires important qualifications.

The ability to generalize these findings to other situations relies on understanding some overriding features of the Trentino settings. Our study is about what one could call "operational" groups, in which members were simultaneously resource appropriators and rule makers, and in both harvesting and voting activities, the interaction took place face to face. As appropriators, group members engaged in peer monitoring and sanctioning, which were instrumental activities to enforce the social and legal norms in place to prevent the tragedy of the commons. If an individual was unable to recognize whether another resource appropriator was an insider or outsider, or failed to recall his or her individual history or reputation, the group had potentially become dysfunctional. For this reason, large groups may experience steep increases in transaction costs in monitoring and sanctioning.

As rule makers, group members voted to identify solutions to controversies and to craft shared rules for the appropriation of the resource. A successful mechanism for group decision making should merge individual preferences into adaptive and coherent group choices. Failures can result in collective choices that prevent the group from adjusting to a novel situation or in the inability to enact durable rules because internal conflicts lead to frequent and contradictory changes. For this reason, diversity among members could be disruptive for the functioning of a group.

As a consequence, our findings about group size are qualitatively different from situations in which groups lack either collective decision making or a role for peer monitoring and sanctioning. An instance of the former is social networks of acquaintances, in which there may be increasing transaction costs to keep track of others and to recognize everyone but no constraints arise from frictions in collective decision making. One may conjecture that groups needing collective decision making will, on average, be smaller, or at least not larger, than social networks. This conjecture would explain, for instance, why the estimates of Dunbar (26) and Dunbar and Shultz (24), which are based on both neurobiological and field evidence from all sorts of groups, are smaller than those of Killworth and coworkers (25), which are essentially based on observational studies of network size. Other situations, such as state administration of a common resource, may involve collective decision making on the rules but no role for group members in enforcement. Under this regime, a form of indirect democracy, together with centralized rule enforcement, could sustain considerably larger group sizes than in the Trentino cases.

Understanding what lessons can be learned requires further qualifications. Although the average size of a successful group appears rather small, it applies to operational groups, as defined above. Conversely, a "nominal" group works as an umbrella organization that encompasses two or more operational groups. Each operational group would be largely autonomous in appropriation and conflict resolution, and would send representatives to coordinate with the other operational groups. Our findings mostly apply to the working of operational rather than nominal groups. Purely nominal groups can be much larger, as illustrated by those communities that engaged in group clustering. Once each operational group received its portion of the commons, its use would be exclusive for that group and the face-to-face social dynamics would be largely self-contained within the operational group. The nominal group resembles a modular organization that can scale up its activities by adding another module. Hence, a large nominal group could prosper as an organization in which members both cooperate within their operational module and coordinate across modules.

Materials and Methods

To compute group size, we start from counting assembly participants who met face to face to govern the common property resources. Given that some people with the right to access the commons may have been absent from the meeting, we rescaled this number using an assembly validity quorum to obtain the total number of households. To calculate the number of potential appropriators involved in harvesting the commons, we multiplied the number of households by the average household size (*Supporting Information*). While migration may have altered group sizes in principle, this channel was heavily restricted in practice. An immigrant could access the common land only if he or she became a formal member of the community, either by purchase or inheritance (18). Over time, inheritance rules evolved toward a patrilineal system that effectively stopped any net immigration into a community (29). A more detailed description of data and methods is available in *Supporting Information*.

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