

Individual Restraint and Group Efficiency in Commons Dilemmas: The Effects of Two Types of Environmental Uncertainty¹

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In most real-world commons, the exact resource quantity is rarely known, and the rate at which the resource regenerates is not always predictable. Annual salmon runs, for example, are based on breeding rates and many other factors; those fishing never know exactly how many fish will be available for next year's season. The present study employed a computerized commons dilemma simulation to investigate the impact of uncertainty in pool size and regeneration rate on individuals harvest choice and the efficiency with which groups managed the resource pool. Both types of uncertainty produced significant declines in individual restraint and group efficiency, although the group-level effects tended to be stronger than those at the individual level. Implications for the management of real-world commons are discussed.

Many environmental problems (e.g., biodiversity loss, overfishing, water pollution, etc.) share important features of what psychologists and sociologists call social dilemmas. Social dilemmas involve a conflict between individual and group interests, and are characterized by two general properties: (a) Each individual in a group receives a higher payoff for self-interest actions (i.e., defection) than for public-interest actions (i.e., cooperation) regardless of how others act, and (b) the total payoffs associated with universal defection are lower than for universal cooperation (Dawes, 1980).

Social dilemmas that involve the management of a limited shared resource are known as commons dilemmas. The word "commons" originally

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referred to jointly owned pastures on which herdsmen grazed their cattle (Hardin, 1968; Lloyd, 1837/1968). The term is used more broadly today, referring to any desirable resource held jointly by a group of individuals (Gifford, 1987).

To date, most psychological research on commons dilemmas has focused on factors, both personal and situational, that foster or hinder cooperation and resource management efficiency in the commons. Much of this research involves computer simulations of real-world dilemmas (e.g., Fusco, Bell, Jorgensen, & Smith, 1991; Gifford & Wells, 1991; Parker et al., 1983; Summers, *in press*). In a typical simulation, a small group of participants shares a limited resource pool. Participants are instructed to maximize personal profits, but also to avoid extinguishing the resource. The simulation usually lasts for a limited number of rounds or until the resource is extinguished. The resource typically replenishes itself following every round at a rate predetermined by the experimenter. Feedback about the number of resource units remaining in the pool and the number of units harvested by other group members generally is provided after each trial.

Two main types of feedback are employed. In some studies, bogus feedback is provided about other group members choices and the state of the resource pool (e.g., Messick et al., 1983; Samuelson, Messick, Rutte, & Wilke, 1984). This enables the experimenter to control the rate at which the resource declines and the variability in other group members harvests. Other studies employ live feedback; harvesters participate in real groups and receive feedback about others actual choices and the actual number of points remaining in the pool (e.g., Bell, Petersen, & Hautaluoma, 1989; Cass & Edney, 1978).

Many different types of dependent measures have been employed in commons dilemma research, but most fall into two general classes: measures of individual harvest restraint, and measures of group resource management efficiency. Individual restraint is generally operationalized as the number of resource units harvested by each individual during each trial. Taking few points from the pool is considered cooperative, whereas taking many points reflects self-interest or defection.

Group efficiency measures focus on how well the group as a whole manages the resource pool. Standard measures include total resource units harvested (efficient groups may take less in the short term, but maximize their long-term outcomes), number of trials completed (efficient groups maintain the pool longer than inefficient groups), and points replenished to the pool (over the course of the simulation, efficient groups have more points replenished to the pool than inefficient groups). Group efficiency measures are often highly intercorrelated, and in some instances are aggregated to form an overall efficiency index (e.g., Gifford, 1982).

Uncertainty in Commons Dilemmas

Messick, Allison, and Samuelson (1988) identified two types of uncertainty present in commons dilemmas. The first type, social uncertainty, refers to uncertainty about the harvest strategies that others in one's group will adopt. Will others adopt a cooperative strategy and act in the best interests of the group, or will they act in their own self-interest and attempt to maximize personal outcomes at the expense of the resource and their fellow group members? The second type of uncertainty, and the primary focus of the present study, is environmental uncertainty, which can refer to uncertainty about the amount of a resource that is available for harvesting or uncertainty about the rate at which a resource will replenish itself.

In past commons dilemma studies, participants often have been provided with precise information about the resource size and regeneration rate. However, in real-world commons, these factors often are not precisely known (Budescu, Rapoport, & Suleiman, 1990; Messick et al., 1988; Rapoport, Budescu, Suleiman, & Weg, 1992; Suleiman & Rapoport, 1989). Annual salmon runs, for example, are based on breeding rates and many other factors; ocean harvesters never know exactly how many salmon will appear for next year's season, although fisheries experts are improving their prediction models (e.g., Schnute, Richards, & Cass, 1989).

To date there has been little research on the impact of environmental uncertainty in commons dilemmas on harvest behavior. We were able to identify only two studies on pool-size uncertainty (Budescu et al., 1990; Rapoport et al., 1992), and no studies on regeneration-rate uncertainty. Both of the pool-size uncertainty studies employed repeated single-trial games in which participants harvested points from pools that were randomly selected from a set of different uniform probability distributions. All of the distributions had the same mean pool size (500), however the range of possible values for each distribution varied. For example, in the Budescu et al. (1990) study, the range of possible pool-size values was 0 to 1,000 in the high uncertainty condition, 250 to 750 in the moderate uncertainty condition, and 500 to 500 (i.e., did not vary) in the no uncertainty condition.

Both studies reported a strong positive relationship between pool-size uncertainty and harvesting; participants took significantly more points from the common pool as pool-size uncertainty increased. A potential cognitive mediator was also identified. As pool-size uncertainty increased, so did harvesters' estimates of the number of points in the pool. When provided with imprecise pool-size feedback, people tended to overestimate the actual number of points in the pool and to harvest accordingly. This suggests that harvesters may overharvest when pool-size feedback is uncertain because they fool

themselves into believing that more of the resource is available than is actually the case.

The present study was designed to extend the research on environmental uncertainty in several new directions. Whereas Budescu et al. (1990) and Rapoport et al. (1992) both employed single-trial games with little environmental framing, the present study employs a new simulation, FISH, in which participants manage a fishery over several harvesting seasons. We believe that our simulation more accurately reflects the conditions under which resource-use decisions are made in the real world. Thus, one goal of this study is to determine whether findings from previous pool-size uncertainty studies can be replicated using a more ecologically valid simulation.

A second way in which the present study advances previous research is through the inclusion of a manipulation to investigate the impact of regeneration rate uncertainty on harvest behavior. Although this is the first study to focus on regeneration rate uncertainty, we expect it to operate in much the same way as pool-size uncertainty. Under conditions of uncertainty, we expect harvesters to develop overly optimistic estimates of upcoming regeneration rates and thus to increase their harvests relative to harvesters who are provided with more precise information about regeneration rates.

The inclusion of both regeneration-rate uncertainty and pool-size uncertainty in this study will also enable us to determine whether these two factors interact to influence harvest behavior. This issue has important implications for real-world commons dilemmas, in which both types of environmental uncertainty are usually present.

A final unique feature of the present study involves the comparison of environmental uncertainty effects at two distinct levels of analysis, the individual level and the group level. Both previous studies on environmental uncertainty used an individual level of analysis; they focused on the effect of pool-size uncertainty on individual harvesters resource-use decisions. To date, the impact of environmental uncertainty on group resource management efficiency has not been investigated; nor has the relationship between individual-level and group-level effects.

Why bother with two levels of analysis? Is it not a forgone conclusion that a significant increase in individual harvesting will result in a significant decrease in group resource management efficiency? The answer to this question is no. A variety of outcomes are in fact possible. For example, due to power differences, effects that are significant at the individual level may not reach significance at the group level. Conversely, it is also possible that weak effects at the individual level could combine to produce stronger effects at the group level. Effect-size comparisons of the effects produced at the two levels will be used to address this issue. Finally, given that group inefficiency

can arise from underharvesting (as well as overharvesting), it is possible for significant increases in harvesting at the individual level to result in increased efficiency at the group level, provided the original baseline of harvesting is low enough.

Method

The Simulation: FISH

FISH (Gifford & Wells, 1991) is a computer-based, real-time interactive commons dilemma simulation. In this simulation, many of the essential elements of any commons dilemma, such as the initial pool size, number of trials (seasons), probability of harvest (catching a fish), various income and cost variables, degree of certainty about the resource's actual quantity ("perhaps-real" fish may be displayed), spawning (regeneration) rate, length of time permitted for a cast, and amount of off-season time required for regeneration (spawning), may be varied.

Both text and VGA graphics support the metaphor of fishing. Introductory screens describe the simulation, so that FISH is essentially self-explanatory to participants. Multi-colored "real" fish are seen swimming in an ocean on the upper half of the screen and "perhaps-real" fish are displayed as outlines. Various items of information (e.g., fishers' current harvest totals and identities) are displayed (or not, depending on the scenario chosen by the experimenter) on the lower half of the screen.

Fishers may actively cast, drift without casting, or return to port to retire for the season. Regeneration occurs through the spawning of any fish that remain after a season of fishing. Payoffs can be arranged so that a relatively large, quick profit may be made (which tends to exhaust the resource), or a larger, albeit slower-growing profit may be made (when harvesters use restraint and allow the resource to regenerate).

FISH is local-area network-based; it allows fishers to harvest from the same stock at the same time. The program automatically collects and stores data on time spent fishing, number of casts, fish caught, costs, and profits for each fisher and fleet. It also incorporates economic factors. Fishers pay a start-up cost to leave port, which represents their capital costs (e.g., a loan payment on their boats) and operating costs (e.g., for labor and fuel). They receive payment for each fish caught (fish disappear from the screen when they are caught). Each fishing season ends when all fishers choose to return to port (i.e., have caught as many fish as they wish). FISH imposes no upper limit to the number of fish that can be harvested by each fisher during a season. Fishers, therefore, are able to exhaust the resource within one season.

Participants and Design

The participants were 168 undergraduate psychology students who participated in 56 three-person fishing groups, and received bonus course credit for participating. To increase ecological validity, each participant received one entry in a lottery in which the prize was the amount of money, in real funds, that he or she had earned during the simulation.

Each group was randomly assigned to one of four conditions created by the 2×2 (Pool-Size Uncertainty \times Regeneration-Rate Uncertainty) between-subject portion of the design; that is, there were 14 groups per cell. For the pool-size uncertainty manipulation, pool size was displayed either precisely or imprecisely throughout the session. All groups began with 12 actual fish, but in the uncertain pool-size condition, 4 of the fish were displayed as outlines, to indicate that they may or may not actually exist.³

For the other manipulation, resource regeneration rate was either known or unknown. Variable regeneration rates were used so that participants in the unknown-rate condition could not deduce the actual regeneration rate after a season or two of fishing experience. In the known-rate condition, participants were given the rates for the 10 coming seasons on a piece of paper. Only (a maximum of) five seasons were actually run; the additional information was given to prevent extra harvesting (end-of-game effects) during the fifth and final season. The average regeneration rate was 2 (which constitutes a doubling of the fish remaining in the pool), and it varied from 1.25 to 2.50. In the unknown-rate condition, identical regeneration rates were employed, although specific information about the magnitude of these rates was withheld from the participants. Regardless of the regeneration rate, in any given season the number of fish in the pool could never exceed 12, the initial stock size at the beginning of the simulation.

Except for the two uncertainty manipulations, all fishers participated in the same commons dilemma scenario, chosen from FISH's parameters. Each departure from port cost \$2, the operating cost was \$1 per min, casts were possible once in each 10-s period, the probability of catching a fish was set at .5 for each cast made, each catch was worth \$3, and 30 s elapsed between seasons for spawning to occur. Fishers were provided with feedback about pool size, their own harvests, and their own profits, but were not provided with

³Actual fish (i.e., those truly available for harvest) are displayed in FISH as filled-in fish, and "perhaps-real" fish (i.e., those that may or may not be available for harvest) are displayed as outlined fish. Fishers in the uncertain condition initially saw 9, 10, or 11 filled-in (i.e., certain) fish plus 4 outlined (i.e., uncertain) fish. To reinforce this visual image, their computer screen reported to them that the stock size was "9-13 fish," "10-14 fish," or "11-15 fish." As harvesting and spawning proceeded, apparent stock size varied, but 4 outlined fish were always visible (until the last actual fish was taken, if that happened).

feedback about others harvests and profits. All players were instructed to maximize their profits over the course of the simulation (i.e., over their multi-season careers). As in many other commons dilemma studies, communication among group members was not permitted during or between fishing seasons (cf. Allison & Messick, 1985; Bell et al., 1989).

Prior to the simulation, two practice seasons were run for each group to ensure that everyone understood the simulation.

Dependent Measures

Three measures of group harvest efficiency were used in the present study: the number of seasons played without extinguishing the resource pool (Seasons), the number of fish replenished to the pool over the course of the simulation (Fish Replenished), and the number of fish remaining in the resource pool after the final season (Final Stock). Overall group harvest, a group efficiency measure used in several previous studies, was not employed in this study. Given that the simulation was preprogrammed to last only five seasons, groups that prematurely extinguished the pool could acquire more fish than groups who managed the resource in a more sustainable manner. Thus, overall group harvest was not a good indicator of efficiency for this study.

A single measure of individual harvest behavior was employed: the proportion of available fish harvested per individual per trial averaged over trials. A proportional measure of individual harvesting was employed instead of an absolute measure (e.g., number of fish harvested per player per trial) because the range of proportional measures is unaffected by the number of fish remaining in the pool. For example, if there were 12 fish available in the pool, participants scores on an absolute measure theoretically could range from 0 to 12, whereas if there were only 2 fish available the range of possible scores would be between 0 and 2. In both cases above, the theoretical range for a proportional measure would be between 0 (*takes nothing*) and 1 (*takes all the fish in the pool*). Given that the simulation used in this study (a) placed no upper limit on the number of fish that each participant could harvest per season, and (b) the number of fish available for harvesting varied across seasons and groups, a proportional measure was deemed more suitable than an absolute measure.

Results

Descriptive Statistics

On average, groups began almost four (3.83) out of the possible five seasons ($SD = 1.47$). Almost half of the groups (43%) extinguished the resource

pool before the end of the fifth season. The mean number of fish harvested by the groups over the course of the simulation was 17.63 ($SD = 3.90$). The number of fish replenished to the pool per group ranged from 0 to 21, with a mean of 8.39 ($SD = 6.16$). The number of fish remaining in the pool after the final round ranged from 0 to 21, with the mean being 2.73 ($SD = 3.40$). On average, participants harvested 23% ($SD = 13.50$) of the fish remaining in the pool during each season (range = 0% to 83%). A breakdown of dependent variable means and standard deviations by experimental condition is presented in Table 1.

Correlations among the three group efficiency measures were very high (Table 2). Given the conceptual and empirical redundancy of these measures, they were standardized and averaged to form a combined group efficiency index. The internal consistency of the combined index was high (Cronbach's $\alpha = .90$), suggesting that all three measures assessed the same latent construct.

Manipulation Checks

Two questions on the postexperimental questionnaire assessed the effectiveness of the uncertainty manipulations. The first question asked participants to rate, on a 10-point scale, their degree of certainty about the exact number of fish in the ocean during the simulation. Participants who received precise feedback about the number of fish in the pool were significantly more certain about stock size ($M = 7.16$) than were participants who received uncertain feedback ($M = 5.69$), $F(1, 166) = 23.38, p < .001$. The second question asked participants to rate, also on a 10-point scale, how predictable they found the regeneration rates used in the study. Participants who were told the upcoming regeneration rates found the rates to be significantly more predictable ($M = 5.86$) than those who were not told ($M = 4.90$), $F(1, 164) = 7.71, p < .01$. Both manipulation check analyses were also significant at the group level of analysis ($ps < .05$).

Environmental Uncertainty and Individuals Harvest Choices

In small groups, interactions among group members may or may not significantly influence or be influenced by the actions of other group members. If individuals' actions are affected by group membership, the statistical assumption of independent observations is violated, and it may be inappropriate to proceed with individual-level analyses. Kenny and La Voie (1985) have argued that statistical nonindependence is an empirical issue that can be addressed through intraclass correlation techniques. If individual scores are found to be independent of group influence, the analysis of individual-level

Table 1

Means (and Standard Deviations) of the Group Efficiency and Individual Restraint Measures by Experimental Condition

	Pool size certain	Pool size uncertain
Regeneration rate certain		
Seasons	4.71 (1.07)	3.71 (1.44)
Fish replenished	11.64 (4.80)	8.79 (6.93)
Final stock	4.93 (3.45)	2.07 (3.41)
Group efficiency index	1.75 (2.18)	-0.23 (2.86)
Individual restraint	0.18 (0.12)	0.24 (0.13)
Regeneration rate uncertain		
Seasons	3.71 (1.68)	3.29 (1.44)
Fish replenished	7.79 (6.23)	5.63 (5.37)
Final stock	2.36 (2.41)	1.57 (3.50)
Group efficiency index	-0.31 (2.70)	-1.22 (2.60)
Individual restraint	0.23 (0.11)	0.26 (0.16)

effects is justifiable. If, on the other hand, nonindependence is found, two options are available: Conduct group-level analysis or conduct individual-level analyses effects with group influence partialled out.

To determine whether individuals' harvest scores were independent of group influence, an intraclass correlation was computed using Kenny's (1991) LEVEL II software. The intraclass correlation was marginally significant ($r = -.14$), $F(55, 112) = 0.63$, $p = .06$, indicating the presence of within-group dependencies in the individual harvest scores.⁴ The negative value of the intraclass correlation indicates that harvest scores tended to be more dissimilar within groups than across groups; there was a tendency for heavier harvesting by some members to be associated with more restrained harvesting by other group members. This is consistent with previous findings which show that harvesters reduce their harvests in response to feedback that others in their group are overharvesting (e.g., Samuelson et al., 1984).

⁴When testing for dependencies, liberal criteria for statistical significance typically are adopted (Kenny & La Voie, 1985).

Table 2

Correlations Among Group Efficiency Measures

	Seasons	Final stock	Fish replenished
Seasons	1.00		
Final stock	.63	1.00	
Fish replenished	.84	.82	1.00
Group efficiency index	.90	.89	.96

Note. $n = 56$ groups. All correlations significant $p < .001$ (Bonferroni-adjusted).

For all of the individual-level analyses, set correlation (Cohen, 1982), a variant of multivariate multiple regression that facilitates the analysis of partialled variable sets, was used to control within-group dependencies. Although the set correlation analysis is reported in a multiple regression format, it is conceptually equivalent to a factorial ANOVA in which the independent variables were pool-size uncertainty and regeneration-rate uncertainty, and the dependent variable was harvest behavior averaged over seasons and corrected for within-group dependencies.

Consistent with previous findings (Budescu et al., 1990; Rapoport et al., 1992), harvesters took a greater proportion of the resource for themselves when pool size was uncertain than when it was certain, $t(163) = -2.82, p < .01$.⁵ The effect size for this difference, reported as a correlation coefficient (Rosenthal, 1990), was .21. The same pattern was repeated for regeneration-rate uncertainty; harvesters displayed significantly less restraint when regeneration rate was uncertain as opposed to certain, $t(163) = -2.19, p < .05, r = .16$. The interaction between pool-size uncertainty and regeneration-rate uncertainty was not significant ($p > .25$).

Environmental Uncertainty and Group Resource Management Efficiency

As predicted, groups in the certain pool-size condition managed the resource more efficiently ($M = 0.72$, as measured by the combined group efficiency index) than groups in the uncertain pool-size condition ($M = -0.72$),

⁵Each harvester's mean harvest score was corrected by partialing out the variance attributable to the harvest scores of the other members of his or her group. Without correcting for dependencies, the result is still statistically significant, but slightly weaker in effect size terms ($r = .15$).

$F(1, 52) = 4.36, p < .05, r = .27$. The hypothesized link between regeneration rate uncertainty and group efficiency was also confirmed, $F(1, 52) = 4.84, p < .05, r = .28$; groups in the certain regeneration-rate condition were significantly more efficient ($M = -0.76$) than those in the uncertain regeneration-rate condition ($M = 0.76$). As was the case at the individual level, the interaction between pool-size uncertainty and regeneration-rate uncertainty was not significant at the group level ($p > .20$).

Discussion

The present study investigated the impact of pool-size uncertainty and regeneration-rate uncertainty on harvest behavior at two levels of analysis. Both types of uncertainty resulted in increased harvesting at the individual level and reduced resource management efficiency at the group level.

Individual Harvest Behavior

The results of this study are consistent with previous findings on the effects of pool-size uncertainty on individual harvest behavior in commons dilemmas (Budescu et al., 1990; Rapoport et al., 1992). All three studies agree that when pool size is uncertain participants display less restraint than when pool size is certain.⁶

The present replication is notable because it demonstrates that the pool-size uncertainty effect generalizes to a more complex, and realistic, decision context than those used in previous studies. Recall that Budescu et al. (1990) and Rapoport et al. (1992) both employed iterative single-trial games with no environmental framing. Harvesters simply harvested points from a nonreplenishable pool, the size of which was either known or uncertain. If the groups total request exceeded the number of points in the pool, each group

⁶Following the completion of this study, we became aware of two additional (unpublished) studies that investigated pool-size uncertainty and individual restraint (Samuelson, 1990; Samuelson & Hannula, 1992). Both of these studies produced null results, with effect sizes near zero. A critical difference in the manner in which pool-size uncertainty was manipulated may account for these null findings. In our study and in the Budescu et al. (1990) study, participants were told that all possible values within the pool-size range were equally likely to be the actual pool size; that is, the range of possible pool sizes was a uniform (rectangular) probability distribution. In the Samuelson studies, the range of possible pool sizes was presented as a normal (bell-shaped) distribution. Using a normal distribution, as opposed to a uniform distribution, substantially weakens the uncertainty manipulation. With a uniform distribution, all values in the range have an equal likelihood of occurring. But with a normal distribution, values near the middle of the distribution are far more likely to be the actual pool size than values near the extremes of the distribution.

member received nothing for that trial. If the total request did not exceed the pool size, group members received their request. This decontextualized approach constitutes commons dilemma decision making stripped to its bare essentials.

Our approach was different. We employed a new simulation, FISH, designed to more closely model the context in which individuals make resource-use decisions in the real world. Rather than simply harvest points from a pool, participants were required to manage a fishery over several harvest seasons. Unlike in the Budescu and Rapoport studies in which pool size was unaffected by past choices, in the present study pool size was tied directly to the group's harvest decisions on previous seasons. Thus, much like the real world, if harvesters mismanaged the resource during the early stages of the simulation, there was less available during the later stages.

Another important difference relates to the complexity of the decision task used in the two sets of studies. In the decontextualized task employed in the Budescu and Rapoport studies, participants only had to take into account two main factors when making their harvest decisions: pool size and others possible choices. In our study, participants had to deal with several additional factors, including port charges, capital expenses, and operating costs, all of which had a bearing on the number of fish that needed to be caught to make a profit.

A second significant contribution of the present study was the finding that regeneration-rate uncertainty has a similar effect to pool-size uncertainty on individual harvest choice; harvesters took a greater proportion of the remaining resource for themselves when the upcoming regeneration rate was uncertain as opposed to certain. Interestingly, the two types of environmental uncertainty did not interact with each other to affect harvest choice. Alone, either pool-size uncertainty or regeneration-rate uncertainty is sufficient to increase consumption in the commons, but together they do not combine to produce more than an additive effect on harvest choice.

Why do individuals increase their harvests in response to environmental uncertainty? Budescu et al. (1990) and Rapoport et al.'s (1992) results suggest that a cognitive mechanism may mediate the effect. They found that when pool size was uncertain, harvesters tended to overestimate the number of number of points available for harvesting. Although we did not explicitly look at estimates in this study, it seems reasonable that a similar process operates for regeneration rate uncertainty; when regeneration rate is uncertain, harvesters may overestimate upcoming rates and, thus, leave fewer points in the pool to replenish.

The factors that underlie this overestimation bias are not well understood and require further investigation. However, Rapoport et al. (1992) offer two

speculative explanations. First, they note that the bias may reflect peoples tendency to perceive a positive association between variability and central tendency.

As the mean and variance are often positively correlated in real-life applications, this perception may simply reflect generalization from experience. In the present task, the increase in the range of the random resource might have been associated with an upward shift in its estimated mean and consequently, a higher probability of sampling relatively high values. (p. 54)

Alternatively, they propose that harvesters construct pool-size estimates by taking a weighted average of the two endpoints of the range. The positive estimation bias may arise simply from placing greater weight on the more desirable upper endpoint.

Another possibility is that the overestimation bias is not a critical mediator of the uncertainty effect, but is rather used as a post-hoc explanation used to justify noncooperative responses.⁷ For example, if harvesters are told that there are somewhere between 2 and 10 fish available for harvesting, this uncertainty provides them with a convenient excuse for taking many fish. "Sorry, I had a hunch that the real number of fish in the pool was nearer to the higher end than the lower end." This allows harvesters to explain away their noncooperative behavior in terms of being "unlucky" or a "bad guesser," rather than in more self-incriminatory terms like "I'm greedy" or "I'm not a team player." From this perspective, environmental uncertainty may lead to increased consumption because it provides a context in which individuals can act in their own self-interest, yet fool themselves, others, or both into believing that they were trying to act in the best interests of the group.

Yet another possibility is that environmental uncertainty operates at the level of social norms. In many group settings, there is normative pressure to cooperate or to act in the best interests of the group. Environmental uncertainty undermines this normative pressure in commons dilemmas by making it less clear what constitutes a cooperative response. From this perspective, uncertainty leads to overharvesting by obstructing the translation of an abstract goal (cooperation) into a concrete behavior (harvesting fewer fish). Although everyone in a group may agree that cooperation is desirable, there may be some

⁷In the study by Rapoport et al. (1992), participants were asked to provide pool-size estimates after they made their harvest requests, giving credence to this alternative explanation. In the Budescu et al. (1990) study, it is unclear whether estimates were made before or after participants made their harvest choices.

confusion about how cooperation should be operationalized. Without a concrete behavioral referent, the norm may become ineffectual.

In sum, the present study and past research have clearly demonstrated that harvesters take more of a shared resource for themselves when pool size, regeneration rate or both are uncertain as opposed to certain. However, it remains unclear what psychological mechanisms underlie this effect. Future research should be directed to resolving this issue.

Group Resource Management Efficiency

Both pool-size uncertainty and regeneration-rate uncertainty produced significant reductions in group resource management efficiency. Thus, the effects at the group level mirrored those at the individual level; reduced restraint at the individual level resulted in reduced efficiency at the group level. Although this finding is hardly revolutionary, it is important to note, as we did in the introduction, that other patterns of outcomes were in fact possible.

Of perhaps greater interest is the finding that environmental uncertainty produced stronger effects for group efficiency than for individual restraint. This difference in magnitude across levels of analysis is likely attributable to at least two factors. First, group efficiency was probably measured more reliably than individual restraint. The group efficiency index was formed by aggregating three efficiency measures, whereas individual restraint was based on a single behavioral indicator. Single-indicator measures are inherently less reliable than multiple-indicator measures and are therefore more likely to produce error-attenuated effects. Thus, all else being equal, the group efficiency index (the more reliable of the two dependent measures) should have produced the larger effect. This is exactly what happened.

Second, relatively small effects at the individual level, when aggregated, may turn into moderate or even large effects at the group level. For example, if each member of a group increases his or her harvest only slightly, the impact at the group level (i.e., in terms of number of fish replenished, seasons played, etc.) may be substantial. This would be especially true for large groups, in which more individual actions are aggregated to determine the group outcome. Researchers may wish to keep this potential amplification effect in mind when interpreting ostensibly weak results from individual-level studies.

Implications for Future Research and Real-World Commons Dilemmas

The present findings have important implications both for experimental commons dilemma research and for the management of real-world commons. In past commons dilemma studies, a common practice has been to provide

harvesters with precise information about pool size and regeneration rate. However, pool size and regeneration rate are at least somewhat uncertain in most real-world commons. This suggests that when the results of past studies are generalized to the real world, estimates of cooperation among harvesters may be too sanguine. Potential interactions between manipulated variables and environmental uncertainty may also limit generalizability to the real-world context. Although we recognize that ecological validity is not a fundamental goal in all research (e.g., Mook, 1983), we believe that it should play in a central role in applied commons dilemma research. One way that commons dilemma researchers could make their resource management simulations more ecologically valid would be to include uncertain feedback about pool size and regeneration rate.

The results of this study also have important implications for the management of real-world commons. If environmental uncertainty causes overharvesting, as our results suggest, then one way straightforward way to increase conservation behavior would be to improve upon the procedures and technologies used to estimate stock sizes and replenishment rates. It is important to emphasize, however, that providing accurate feedback to harvesters is not in itself a panacea to the commons problem. For example, even if regulatory agencies or industry scientists can generate precise estimates, memories of past mismanagement may prevent harvesters from treating these estimates as credible. One can almost hear cod fishermen in Newfoundland saying "We listened to you last time and look what happened. Why should we believe your numbers now?" Furthermore, even if scientific estimates are perceived to be credible, this does nothing to address the fundamental conflict between individual and group rationality that lies at the heart of all commons dilemmas. Regardless of information accuracy and credibility, harvesters still must decide whether they wish to maximize their own personal outcomes or to make a personal sacrifice for the good of the group.

Finally, we would note that the results of the present study may only apply to commons dilemmas in which communication among harvesters is not permitted and detailed feedback about the specific harvest decisions of others is not provided; conditions which are common, but by no means universal in commons dilemmas. Further research is required to determine whether these findings generalize to other situations.

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