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Local response to global uncertainty: Insights from experimental economics in small-scale fisheries

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ABSTRACT

Global change has systematically increased uncertainty for people balancing short-term needs with long-term resource sustainability. Here, we aim to understand how uncertainty drives changes in human behavior and the underlying mechanisms mediating use of behavioral strategies. We utilize a novel behavioral approach – dynamic common-pool resource economic experiments in the field – and apply it to small-scale fisheries as a system that is particularly vulnerable to global change. Contrary to previous research, we find that when faced with higher uncertainty, resource users are choosing to reduce harvest to compensate for potential future declines. Correlates of this behavior include the capacity for social learning, previous exposure to uncertainty, and strong local institutions. These findings have important implications for any local system facing increased uncertainty from global change. Given adequate access to resources and rights, local communities can be active agents of change, capable of addressing and mitigating impacts of processes generated by higher scales.

1. Introduction

1.1. Global change and common-pool resources

In an era of global change, local systems are becoming increasingly connected across scales, at times creating opportunities, other times exacerbating vulnerabilities (Adger, 2006). This phenomenon has systematically increased uncertainty for people balancing short-term needs with long-term resource sustainability. Small-scale fisheries are exemplar of local systems quickly becoming connected across scales vis-à-vis climate change, global markets, distant water fleets, migration, and international conservation and development policies (Adger et al., 2005; Armitage and Johnson, 2006; Berkes et al., 2006; Perry et al., 2011). Employing the vast majority of the world's fishers, and contributing roughly half of global fisheries production, healthy small-scale fisheries are critical for food security, livelihoods, and sustainability of marine systems (Berkes et al., 2001).

The ease of exhausting marine resources given technological advances, coupled with the difficulty in preventing others from harvesting what is left behind, make fisheries a text-book example of a common-pool resource. As such, resource users in fisheries face the same common-pool resource dilemma as in forests, pastures, and groundwater systems – how to balance the short-term, *individual* benefits of harvesting with the long-term, *shared* costs of overharvesting (Bromley et al., 1992; Ostrom, 1990; Ostrom et al., 2002).

Assuming that resource users are motivated by maximizing personal short-term profit, Garrett Hardin (Hardin, 1968) famously hypothesized that all common-pool resources will inevitably face their destiny as a tragedy of the commons. This seminal theory suggests that resource users, and fishers in particular (Gordon, 1954), are not capable of environmental or resource stewardship alone, and thus require some sort of external intervention. Decades later, empirical evidence has shown that this is not always the case, and collective action, cooperation, and stewardship behavior among resource users can emerge in the absence of external intervention (Bromley et al., 1992; Ostrom, 1990; Ostrom et al., 2002). However, as fishers and other resource users are now confronted with an increasing rate of change in environmental and socio-economic conditions, the fundamental unanswered question becomes, how does uncertainty and unpredictability change behavior?

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1.2. Behavioral change under high uncertainty

Early work suggests that when environmental uncertainty increases, harvesting pressure also increases, resulting in higher probabilities of resource depletion and poor collective outcomes (Budescu et al., 1995, 1992; Rapoport et al., 1993, 1992). Subsequent work suggests that the relationship between cooperation and uncertainty remains inconclusive (van Dijk et al., 1999). Individuals do not act similarly and as uncertainty increases, decisions are mediated by social value orientations (Roch and Samuelson, 1997). For example, non-cooperators are more likely to overharvest under conditions of uncertainty; but the reverse is true for cooperators – uncertainty will foster cooperation (Biel and Garlinc, 1995; Roch and Samuelson, 1997). In addition to social value orientation, behavior is also contingent on the type of uncertainty (i.e. environmental versus social) (Kocher et al., 2015; van Dijk et al., 1999; Wit and Wilke, 1998), and the degree of temporal discounting (i.e. intra- versus inter-generational) (Jacquet et al., 2013).

How fishers and other resource users anticipate and deal with change and uncertainty (termed adaptive capacity) (Smit and Wandel, 2006) involves difficult trade-offs and has direct implications for their immediate and long-term well-being and the ecological resilience of the environments they depend on (Cinner et al., 2011). Fishing less is an example of an adaptive strategy potentially dampening resource decline, while fishing more in response to uncertainty or perceived declines is an adaptive strategy capable of amplifying destructive feedbacks, and undermining long-term resilience (Cinner et al., 2011). Importantly, adaptive strategies are contingent on available opportunities and resources (Adger, 2006; Finkbeiner, 2015; Leach et al., 1999); not all fishers can afford to fish less and incur short-term costs when future declines are anticipated. The main objectives in this study are to understand how uncertainty drives changes in harvesting behavior of a common pool resource, and what mechanisms foster or constrain use of alternative adaptive strategies.

2. Methods

2.1. Field experimental economics

To test behavioral responses to uncertainty, we used a field experimental economics approach (Smith, 1982), and evaluated individual choices under a variety of circumstances and conditions (Cardenas and Carpenter, 2005). Relative to purely observational techniques, using an experimental approach in behavioral research reduces confounding effects, and allows for replication and direct comparison among different groups (Cardenas and Carpenter, 2005; Poteete et al., 2010). Experimental economics has recently been brought from the laboratory to the field, engaging actual stakeholders (Cardenas, 2000; Cardenas and Carpenter, 2005; Cárdenas, 2009), and thus increasing external validity of results (Gelcich et al., 2013). Used in conjunction with other techniques, such as surveys and interviews, experimental economics can address *why* behavior changes, in addition to *how* (Castillo et al., 2011).

2.2. Study system

The small-scale fisheries along the Pacific coast of the Baja Peninsula in Mexico (Fig. 1) were selected as a model system for this research due to the critical importance of fisheries and highly dynamic and uncertain conditions small-scale fishers in the region face (Brusca et al., 2004; Lluch-Cota et al., 2007). This system supports the production and harvest of highly lucrative fisheries products such as abalone (*Haliotis* spp.) and lobster (*Panulirus* spp.), exported directly to international markets. At the same time, seasonal and inter-annual upwelling-driven changes in nearshore physical and biological conditions result in high local exposure to change and disturbance (Collins et al., 2002; Pérez-Brunius et al., 2006). In recent years, high variability in oceanographic conditions, including high temperatures and hypoxia, has resulted in mass mortalities of abalone and other invertebrates, reducing local fished species' abundance by up to 75% (Micheli et al., 2012). Fishers in this region are generally organized into cooperatives at the community level with varying degrees of organization, collective action, and capacities of adapting to change (Finkbeiner and Basurto, 2015; McCay et al., 2014).

2.3. Experimental design

To understand how uncertainty drives changes in fishing behavior we used a dynamic common-pool resource game with realistic biological and economic parameters and real monetary incentives (Janssen, 2010) to simulate decisions fishers make in their abalone fishery, based on long-term oceanographic, biological, and socio-economic research in the region. We conducted 36 distinct sessions of economic games with a total of 180 fishers from six cooperatives (Fig. 1), testing the effects of six different treatments on fishing behavior (Table 1). In groups of five, fishers decided how many abalone they wished to individually harvest from a dynamic common-pool stock over the course of 15 rounds. For each abalone harvested, fishers would receive $15 Mexican Pesos, and could potentially make the equivalent of a normal day of fishing over the course of the game. The initial stock of the resource was 100 units. Each round was representative of a fishing season; as such, the stock grew 10% of its remaining population size in between each round. Fishers did not know how much other individual players were harvesting; only the total group capture was disclosed in each round. Individual fishers could never harvest over five abalone per round. Thus, no more than 25 abalone could be taken collectively in each round. Even so, if all fishers extracted the maximum allowable catch, the stock could be depleted by the fifth round effectively ending the game and the potential to make more money for the remaining 10 rounds.

As the game proceeded and the abalone stock declined, the total number of abalone each individual could harvest decreased (Supplemental material), just as catch per unit effort would decrease during resource scarcity in real fishery dynamics. Each game included two treatments with fifteen rounds of decision-making each. Participating fishers also completed a post-experiment survey to collect demographic information and to ascertain perceptions on different sources of uncertainty and risk they experience in real life (Supplemental material). The economic games concluded with an open discussion among all participants about their reactions and thoughts on the games and reflections about how this approximates decision-making in a fishery in real life.

2.4. Experimental treatments

The above dynamics describe the baseline treatment (Table 1, Treatment A1). During the subsequent treatment (communication) (Table 1, Treatment A2), participants were given permission to have face-to-face communication for three minutes in between each round. During this time, participants could talk about anything related to the game.

In the environmental uncertainty treatment (Table 1, Treatment B1), participants were told there was a 1/10 probability of a mass mortality event affecting 50% of the remaining abalone stock. To operationalize this, a ten-sided dice was thrown in between each round visible to all the participants. If the dice landed on a five, then 50% of the remaining abalone would be removed from the stock. If the dice landed on any other number, the next round would commence as usual. In the subsequent treatment (environmental uncertainty with communication) (Table 1, Treatment B2), the same rules apply as in the environmental uncertainty treatment – there is a 1/10 probability that a mass mortality will reduce the remaining stock by half in each round – however, participants are also allowed to communicate (the same rules as in the communication treatment apply).

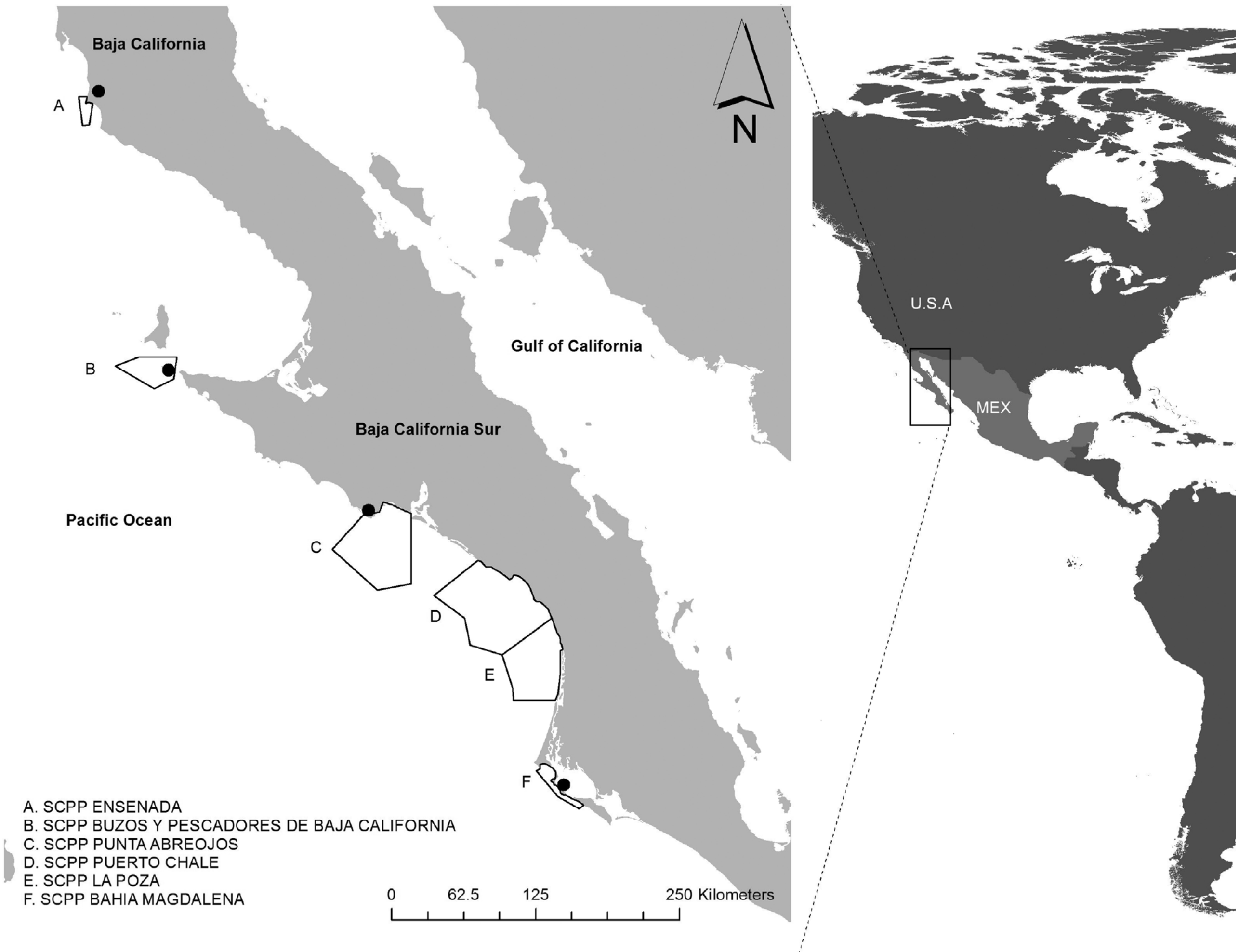

Fig. 1. Map of the study system – Baja Peninsula, México. Polygons represent the extent of each fishing concession granted to each cooperative in the study sample.

Table 1
Six treatments used in the common-pool resource game.

Treatment	Rules
Baseline (A1)	No communication allowed. Individual, private and confidential decisions
Communication (A2)	Face to face communication for three minutes allowed before each round; decision still made in private
Environmental uncertainty (B1)	1/10 probability of a mass mortality affecting 50% of the remaining abalone stock; determined by throwing a 10-sided dice before each round
Environmental uncertainty w/communication (B2)	Environmental uncertainty (see above) with communication (see above)
Exclusive rights (C1)	Participants informed they have exclusive rights to abalone stock and an informal rule to harvest no more than two abalone/player/round; no penalties for exceeding informal rule
Exclusive rights w/social uncertainty (C2)	Exclusive rights (see above) with the addition of a poacher whose harvest is determined by throwing a 10-sided dice each round; amount poached is not revealed to participants but added into total group capture

Treatments were replicated twice in each of the six communities for 15 rounds (unless resource was over-extracted before the end of the game) with distinct five person groups.

For the exclusive rights treatment (Table 1, Treatment C1), the hypothetical abalone fishing ground was reframed as a concession, or a territorial use right, for which the participating cooperative had exclusive access to, consistent with their abalone property rights arrangements in real life. During instructions, participants were also told that even though the government had granted them an individual quota of five abalone per round, their cooperative democratically and collectively voted to reduce individual quota to only two abalone per round, also consistent with decision-making autonomy that some fishing cooperatives exercise in the region. However, participants were told that during the experiments, if they individually decided to harvest more than the internal rule of two abalone/person/round (up to five), that decision would never be detected or punished. Thus, there were no material consequences for cheating behavior during the experiments.

Finally, during the subsequent treatment (exclusive rights and social uncertainty) (Table 1, Treatment C2), the same rules apply as in the exclusive rights treatment with the concession framing and informal cooperative harvest rule, with one additional condition. In each round, there was a probability that a hypothetical poacher would enter their concession and illegally harvest a portion of their stock. To simulate this, a ten-sided dice was thrown each round while fishers were also making their individual harvest decisions. This time, the dice was not visible to the fishers, and depending on the number landed (0–9), the poacher would take that number of abalone from the cooperative's concession. The poacher's harvest was then added on to the total group's harvest and announced to the participants, so that participants never knew what portion of the harvest was from the poacher or from each other. Participants were told, that due to limits on resources, personnel and funding, they did not have the enforcement to drive the poacher outside of their concession − a reality that they often face in their daily lives.

2.5. Analysis

Wilcoxon-Mann-Whitney tests were used in the software package R to do pairwise comparisons of average group capture and average resource level across comparable treatments (Supplemental material). Group capture values were first standardized into proportions of group capture per total allowable capture given available resources in each respective round (Supplemental material), before statistics were calculated.

To understand the effects of experimental treatments and contextual data on average group capture decisions, we used Generalized Linear Models with cluster-robust standard error using R (Arai, 2015). This is a regression modeling technique that estimates the regression coefficients using an ordinary least squares approach (OLS), but adjusts the variance allowing for error correlation within groups (Cameron et al., 2006). The variable 'group' (each distinct five-person group participating in the experiments, $n = 36$) was used to adjust the variance using the cluster-robust standardized error approach. The response variable tested across all regression models was the average group capture standardized for maximum allowable catch (same as in the pairwise comparison approach). Across all models, treatments were included as fixed effects: communication, environmental uncertainty, exclusive rights, social uncertainty, and the interaction term for communication and environmental uncertainty. 'Round' (1–15) was also controlled for to account for serial autocorrelation in decisions across rounds.

3. Results

3.1. Comparison of treatment effects

Pooling results from the six cooperatives, across all treatments average group capture is reduced compared to the baseline treatment, resulting in sustained resource extraction over the course of 15 rounds (Fig. 2). In the baseline treatment, group capture starts very high and then drops precipitously as the resource level declines. When players are allowed to communicate, group capture is on average lower compared to the baseline, though not significantly so (Wilcoxon-Mann-Whitney, $p = 0.07$), and maintained at relatively stable levels until the last rounds, resulting in higher average resource levels (Wilcoxon-Mann-Whitney, $p < 0.0001$). When environmental uncertainty is introduced, through a 1/10 probability half of the abalone stock will be taken out by a mass mortality event, average group capture is slightly reduced compared to the baseline though not significantly. However, when communication is combined with environmental uncertainty, average group capture is significantly lower compared to the communication and environmental uncertainty treatments alone (Wilcoxon-Mann-Whitney, $p < 0.0001$ in both cases). When fishers are told they have exclusive collective rights to the hypothetical abalone stock, average group capture is significantly reduced (Wilcoxon-Mann-Whitney, $p = 0.002$), and average resource level is significantly higher (Wilcoxon-Mann-Whitney, $p < 0.0001$) compared to the baseline treatment. Finally, increasing social uncertainty through the introduction of a poacher further decreases average group capture compared to the exclusive rights treatment alone (Wilcoxon-Mann-Whitney, $p < 0.0001$).

3.2. Correlates of behavior change

Results from the pair-wise comparisons are consistent with results from the cluster robust standard error generalized linear regression model, estimating average group capture decisions as a function of experimental treatments and cooperative-level contextual data (Table 2); the interaction between communication and environmental uncertainty, exclusive rights, and social uncertainty all result in lower group catch. Treatment effects are consistent across all six cooperatives; however, there is a significant effect of cooperative with some harvesting less than others (Table 2, Model 1). Post-experiment surveys identify significant correlates of this cooperative effect (Supplemental material); cooperatives who perceive environmental change and poaching pressure as more severe in real life are likely to harvest fewer abalone during experiments (Table 2, Model 2). Survey results also

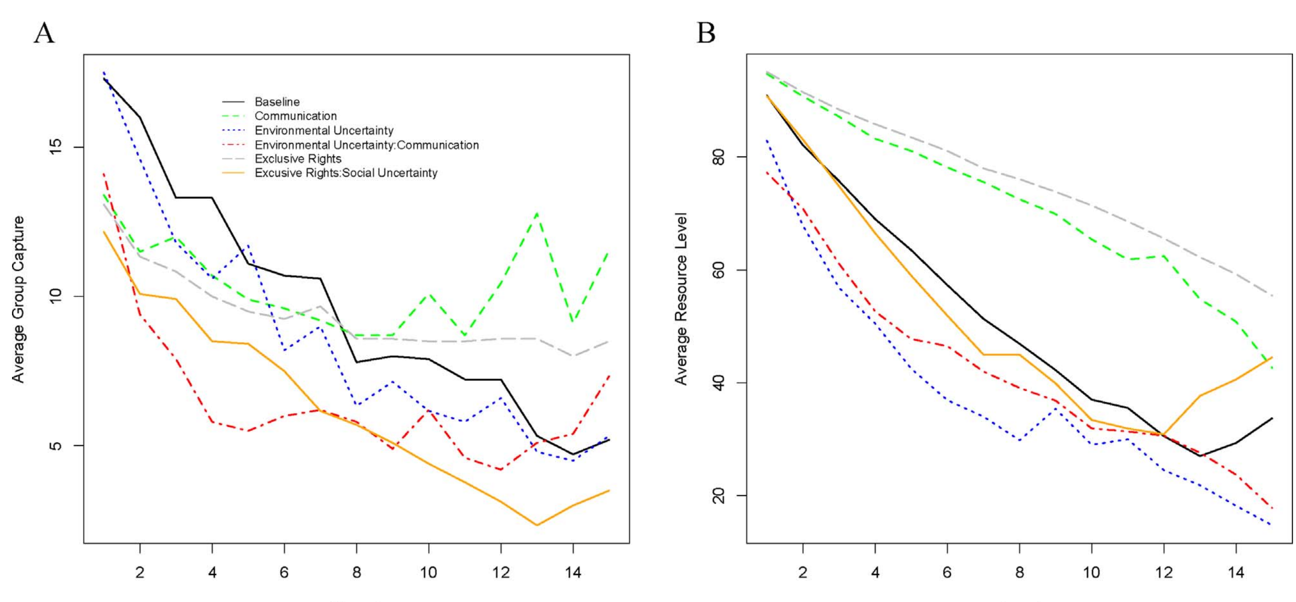

Fig. 2. (A) Average group capture levels for six treatment groups across 15 rounds. (B) Average resource level for six treatment groups across 15 rounds. Average resource levels are not directly comparable across treatment groups with uncertainty (blue, red, orange lines), as declines from average group catch decisions are confounded by declines from mass mortality and poaching events. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 2
Effects of experimental treatments and contextual data on average group catch decisions.

Dependent variable: Average group catch as fraction of maximum possible catch	Model 1	Model 2	Model 3
Intercept	0.519***	1.980***	0.659***
Communication	−0.023	−0.022	−0.023
Environmental uncertainty	−0.016	−0.016	−0.016
Comm: Env. uncertainty	−0.106**	−0.106**	−0.106**
Exclusive rights	−0.056***	−0.054***	−0.055***
Social uncertainty	−0.097***	−0.099***	−0.097***
Round	−0.012***	−0.012***	−0.012***
Cooperative X	0.014	–	–
Cooperative X	−0.051*	–	–
Cooperative X	0.015	–	–
Cooperative X	0.073**	–	–
Cooperative X	0.043*	–	–
Perceived severity environmental change	–	−0.154*	–
Per. severity poaching	–	−0.092*	–
Per. importance internal rules	–	−0.072	–
Per. effectiveness communication	–	−0.096*	–
Distance from port	–	–	0.0003***
Number of species	–	–	−0.015***
Enforcement capacity	–	–	−0.092***
AIC	−629	−613	−634

Regression outputs using cluster-robust standard error (accounting for distinct 5-person groups). Response variable is the average group capture standardized for maximum allowable catch. Across all models, treatments are included as fixed effects: communication, environmental uncertainty, exclusive rights, social uncertainty, and the interaction term for communication and environmental uncertainty. Round (1–15) is also controlled for to account for serial autocorrelation in decisions across rounds. Model 1 includes distinct cooperatives without names to protect anonymity. Model 2 includes perception indices derived from post-experiment surveys averaged within each community: perceived severity of environmental change, perceived severity of poaching pressure, perceived importance of cooperative internal rules, and perceived effectiveness of communication. Model 3 includes cooperative/community-level indicators of cooperation and collective action selected from longer list of variables (Supplemental material) by using stepAIC: distance of cooperative from major port, number of species authorized, and internal enforcement capacity. Akaike Information Criterion (AIC) values are reported for each model. Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1.

suggest that cooperatives who perceive their communication as more effective for solving problems in the fishery are likely to harvest fewer resources under uncertainty. Further analysis of cooperative-level characteristics suggests that cooperatives with higher internal enforcement capacity, and rights to fish a high number of different species groups are also deciding to harvest less during the common-pool resource experiments (Table 2, Model 3). Consistent with the effect of perceived severity of poaching pressure, cooperatives that are geographically closer to major ports are deciding to harvest fewer resources during the experiments, possibly because poaching pressure tends to be higher near major ports (Table 2, Model 3).

4. Discussion

4.1. Contextualizing the treatment effects of uncertainty

Our results show that when faced with increased uncertainty in their fishery, fishers are choosing to harvest fewer resources in common-pool resource experiments. During these experiments, despite declines in average resource levels over the course of fifteen rounds, stocks never hit zero, even given the occurrence of mass mortality events reducing the population by half (Fig. 2). If participants were following an optimization strategy of maximizing short-term monetary earnings, the abalone stock would be completely depleted by the fifth round. Our results, despite resource declines over the course of the experiment, run contrary to similar dynamic common-pool resources experiments, where resource *overharvest* was common (Janssen et al., 2012). Furthermore, during our experiments increased uncertainty leads fishers to harvest even less to compensate for potential or actual resource declines (Fig. 2), especially if allowed to communicate among themselves. These results suggest high levels of trust (Fischbacher and Gachter, 2010; Kocher et al., 2015) and pro-social behaviors (Roch and Samuelson, 1997) among the participants, in addition to a strong sense of autonomy, power, and capacity to influence their own resilience through local action (Berkes and Ross, 2013; Davidson, 2010; Magis, 2010).

4.2. Understanding correlates of behavior change

It is important to contextualize the external validity of these findings, as fishers in different contexts and geographies may respond differently to the same treatments (Gelcich et al., 2013). For this reason, we applied the experiments over a purposive selection of fishing cooperatives, with some having higher institutional and organizational capacity than others. We were then able to test the differences in experimental performance across cooperatives to understand enabling conditions of collective action under uncertainty. The following sections explore three enabling conditions we found to be important predictors of this behavior, and of its expected transferability to other systems.

4.2.1. Communication and social learning

The ability to communicate with other players was key in the reduction of group harvest under resource uncertainty, consistent with theoretical predictions and empirical evidence (Cardenas et al., 2004; Wit and Wilke, 1998). Likewise, post-experiment surveys suggest that cooperatives who perceive communication as effective at resolving problems within their fishery harvest less during the experiments, suggesting high external validity of experimental results. This highlights the importance of social learning before, during, and after exposure to environmental change. Social learning, or interaction and deliberation in social environments (Pahl-Wostl et al., 2007), is important for solving collective problems under environmental uncertainty and disturbance (Wilson, 2002) and can increase adaptive capacity in the face of change (Adger et al., 2005; Berkes et al., 2003). The fishers participating in this research have a history of social learning through their organization into cooperatives, their use of democratic decision-making during cooperative assemblies, and their role in co-management of their fishery resources with the Mexican government (McCay et al., 2014). In this context, knowledge generation through social processes may minimize future discounting during times of uncertainty through the generation of trust, social cohesion, legitimacy, and accountability.

4.2.2. Past experience with disturbance and uncertainty

Social processes can further create learning opportunities from exposure to past disturbance. Contrary to other experiments where resource scarcity led to increases in harvest (Blanco et al., 2015; Prediger et al., 2014) fishers in this study significantly reduce their harvest after experiencing the first mass mortality event, as compared to only anticipating a mass mortality event (Supplemental material). External validity of this behavioral difference between conditions of uncertainty versus actual exposure is confirmed by the analysis of cooperative perception indices (Table 2, Model 2; Supplemental material) and other cooperative-level characteristics (Table 2, Model 3; Supplemental material). Cooperatives who perceive environmental change and poaching pressure as more severe in their region, and with more exposure to poaching pressure due to proximity to ports, harvest less (controlling for cooperative enforcement capacity and access to fishing rights). A history of exposure is expected to build resilience in ecological systems (Gallopín, 2006), and may contribute to adaptive capacity through social learning processes as suggested by our results.

4.2.3. Strong institutional organization and capacity for collective action

In addition to the importance of social learning and past exposure, strong institutions play a critical role in explaining the use of adaptive strategies with a dampening effect on resource decline during the experiments (Prediger et al., 2011). For example, despite the high potential for free riding behavior after the introduction of poaching pressure during the social uncertainty treatment, fishers decide to compensate for overharvesting instead of becoming complicit with illegal behavior. How humans respond in the face of adversity is likely influenced by the resources and rights available to cope with exposure, and the institutions that mediate resource use and coping strategies (Adger, 2006; Finkbeiner, 2015; Leach et al., 1999). Fishers in the study sample are organized into community cooperatives, each with exclusive collective rights to their most lucrative benthic fishery resources (i.e. abalone, lobster), similar to the exclusive rights treatment in the experiment. These place-based rights provide an opportunity for fishers to invest in the future of their resources, and in turn, have helped to strengthen local institutional capacity for fisheries co-management and for anticipating and adapting to change (McCay et al., 2014; Micheli et al., 2012). However, there is considerable variation in performance across cooperatives in the region given differences in social and ecological realities (Finkbeiner, 2015; McCay et al., 2014). Across the cooperatives in the sample, those with greater access to a diversity of species and higher internal enforcement capacity are making more conservative catch decisions during the experiments (Table 2, Model 3). Both these attributes are indicative of strong institutional organization and capacity for collective action.

5. Conclusion

Global change is systematically increasing uncertainty for resource users like small-scale fishers. How human behavior changes as a function of environmental and social uncertainty has major implications for ecosystems and the human communities dependent on them. This study represents a novel effort to study cooperation and adaptive capacity under conditions of uncertainty using dynamic common-pool resource field experiments with small-scale fishers. This experimental approach has rarely been applied outside of the laboratory. These findings have important implications beyond fisheries for any common-pool resource system or community facing increased uncertainty from climate change, market drivers, governance transformations, or demographic shifts; our work provides a strong example of how resource users can take local action to respond to external drivers of uncertainty and change without undermining long-term resilience. Anticipating increasing uncertainties can be key when providing support to local communities to address their collective action dilemmas. Thus, coastal communities, and resource users in general, are not always passive victims of global change, but have the capacity to influence their resilience, contingent on social learning through institutional support and experience with previous exposures. Importantly, there are short-term socio-economic costs inherent in some adaptive strategies (e.g., loss of income from fishing less) that must be addressed as to not further marginalize already vulnerable populations. These findings therefore, may not be generalizable for all fisheries and all systems, particularly those without the resources, rights, and agency necessary for making decisions in dire circumstances to preserve environmental sustainability. But with adequate institutional, social, economic, and ecological support, empowered communities and individuals can be proactive to create opportunities out of potential catastrophic events.

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