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RESEARCH ARTICLE

Avoiding catastrophic collapse in small-scale fisheries through inefficient cooperation: evidence from a framed field experiment

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Abstract

Small-scale fisheries (SSFs) are significant for poverty alleviation, but are threatened by over-exploitation and climate change effects such as drastic drops in regrowth rates. How will fishers adapt? To shed light on this, we ran a common-pool resource experiment with SSF fishers in Thailand. Our results show that groups confronted with a potential abrupt drop in the regrowth rate are more likely to form cooperative agreements compared to groups not confronted with such a drop, which theory cannot predict. However, groups that form cooperative agreements do not necessarily manage the resource efficiently; many groups under-exploit. Over-exploitation is driven by individual characteristics, e.g., if individuals can diversify income, and if they are born outside the village. We conclude that more systematic exploration of the role of socio-economic factors, and how these factors interact with ecological conditions facing fishers, are needed. Our work can be seen as one step in this direction.

Keywords: abrupt ecosystem changes; collective action; common-pool resources; ecological regime shifts; framed field experiments; small-scale fisheries

JEL classification: Q22; Q54; Q56

1. Introduction

Small-scale fisheries (SSFs) account for about 90 per cent of the world's 40 million capture fishers, and together provide about half of total global fish catch (Béné *et al.*, 2007). In many low income countries, SSFs are significant contributors to poverty alleviation and food security, accounting for more than 50 per cent of total animal protein intake (Hall *et al.*, 2013; FAO, 2016).

Many SSFs, however, are threatened by unsustainable over-exploitation stemming from open access regimes and governance failures. Moreover, climate change will increasingly change the quantity and variability of fish stocks across the globe. In certain regions of the world, abrupt and potentially persistent changes to stock levels and regrowth rates are to be expected due to a combination of overfishing, changes in water temperature, and frequency of hypoxia (Cheung *et al*., 2016). Such abrupt and potentially persistent ecosystem changes, often referred to as *regime shifts* (Scheffer *et al*., 2001; Scheffer and Carpenter, 2003; Biggs *et al*., 2012), have become increasingly common and have already occurred in many types of ecosystems, including fisheries (Rocha *et al*., 2015). Expected large, negative (maybe even catastrophic) changes to human welfare are at stake in these SSFs. Because overfishing in combination with external pressures makes an important interacting driver of these abrupt changes, it is important to study how fishers respond to such latent abrupt changes, which are triggered through their own actions.

Many of these SSFs are unregulated and in such a context it is only if resource users manage to collectively reach a sustainable exploitation level that they can overcome a tragedy of the commons (Hardin, 1968). However, numerous studies highlight how sustainable self-organized collective management is not easy to obtain (see e.g., Ostrom *et al*., 2002). This is also true also for SSFs (Camargo *et al*., 2008; Béné *et al*., 2009; Gelcich *et al*., 2013; Gelcich, 2014). Nevertheless, the ability to avoid regime shifts and potential resource collapses will crucially depend on whether fishers are able to adapt to them. We want to understand how fishers, sharing a common fishing ground, make extraction decisions in such a context. In particular, we aim to answer the following research questions: Should we expect an increase or a decrease in the frequencies of over-exploitation when fishers are confronted with potential regime shifts? Will fishers be able avoid catastrophic resource collapses?

To answer our research questions we performed a framed lab-in-the-field-experiment with small-scale fishers and compared two treatments. In both treatments the fishers played a dynamic common-pool resource (CPR) game, but whereas some groups faced resource dynamics entailing a potential negative drop in the regrowth rate (a regime shift), triggered by their own exploitation behavior, other groups faced resource dynamics without such a drastic shift. The experiment was performed with fishers from a village situated in the Phuket province, the biggest island of Thailand, located in the Andaman Sea. Most fishers in this village make their living from fishing and harvesting sea products, e.g., diving and plunging for sea cucumbers, oysters, pearls, and shell fish. Their income depends heavily on what they are able to catch from the sea, and their catches, in turn, rely on the abundance of sea animals in the area.

Our experimental results show that groups of fishers facing a latent regime shift are more likely to form cooperative agreements compared to groups facing smooth resource dynamics without such a shift, something our theoretical derived hypotheses cannot predict. However, groups that form cooperative agreements do not necessarily manage the resource efficiently. Instead, most of them under-exploit the resource, which for fishers facing a latent regime shift, means that they are able to avoid the regime shift.

These experimental results complement theoretical work on CPR management in the face of ecosystem regime shifts. For example, they contrast theoretical findings suggesting that latent regime shifts can magnify the externality associated with non-cooperation (Mäler *et al*., 2003; Kossioris *et al*., 2008) in a CPR system. Instead, our results support theoretical findings by Crépin and Lindahl (2009), demonstrating that cooperative resource users can under-exploit a resource with a latent regime shift. It is important to keep in mind though, that these theoretical results hinge on an assumption that resource users either cooperate (and exploit optimally), or not. They say nothing about when we should expect cooperation to emerge, or not. Our results demonstrate that the resource dynamics itself can trigger cooperation in a CPR setting (see also Lindahl *et al.* (2016*a*) for similar experimental results). In this respect, our results can directly inform theory.

Insights from this study also contribute to the existing literature on commons management, and in particular to the experimental commons literature. Controlled experiments have been proven particularly useful for gathering data on drivers of human behavior in CPR systems (see, e.g., Kopelman *et al.*, 2002; Ostrom, 2006). In early experiments, the resource dilemma was usually formalized as a static game and the attention was directed towards understanding how individual strategies, social interactions, and group outcomes changed over time as participants got more information about the behavior of the others.[1] These experimental studies, however, did typically not contain relevant features of some of the challenges experienced by real resource users (Janssen *et al.*, 2015). In recent years, there has been an increased effort to address this issue with controlled experiments that incorporate ecological characteristics, such as spatial resource dynamics (Janssen, 2010; Janssen *et al.*, 2010), resource interdependencies (Lindahl *et al.*, 2015), and endogenously-driven resource dynamics (Cárdenas *et al.*, 2013). Osés-Eraso *et al.* (2008) compare, for example, behavior under exogenous and endogenously-driven (human-induced) resource scarcity; Moreno-Sánchez and Maldonado (2010) and Blanco *et al.* (2015) compare behavior under contrasting resource states (abundant versus scarce); Santis and Chaves (2015) investigate the role of quotas under contrasting resource states (abundant versus scarce); Kimbrough and Vostroknutov (2015) determine the effects of differing resource replenishment rates; and Hine and Gifford (1996) examine the effect of an uncertain resource growth rate, to name a few. We contribute to this strand of literature by introducing a request game[2] where the resource follows a logistic-type of resource dynamics, but where there is a latent regime shift – an endogenously-driven abrupt drop in the regrowth of the resource.

Even though the logistic growth model has been used extensively within resource economics, and is considered to be the canonical renewable resource model (Clark, 1990), it has received substantially less attention in the CPR experimental field. To our knowledge, there are only a handful of studies employing a similar design (see, e.g., Noussair *et al.*, 2015; Schill *et al.*, 2015; Lindahl *et al.*, 2016*a*, 2016*b*; Rocha *et al.*, 2020). Unlike Noussair and colleagues. we introduce and test the effect of a latent regime shift compared to when there is no such shift. Further, in our experiment, we allow the participants to communicate in an attempt to mimic the field as much as possible, where communication is neither forced, nor banned. The studies by Schill *et al.* (2015) and Rocha *et al.* (2020) are also centered on an abrupt change in the resource dynamics, but in their cases there is an externally imposed uncertainty about the latent regime shift and they analyze to what extent behavior is affected but this uncertainty. Higher uncertainty (both with

[1]From these early studies we learned, e.g., about the importance of communication (cheap talk), and about the ability to sanction free-riders (see Ostrom (2006) and Chaudhuri (2011) for overviews). These were factors that reduced social uncertainty by making it easier for conditional cooperators to identify other cooperators, etc.

[2]There are essentially two main types of CPR experiments used in the literature. One approach, which is more common, is to use an investment type of analogy (see Ostrom *et al.* (1992) for an early application). The other approach is to use a request/resource extraction type of analogy (see Jorgenson and Papciak (1981) for an early application). We use the resource extraction type of approach. For more details on these two approaches, see Lindahl *et al.* (2021).

respect to risk and ambiguity) is associated with more cautious exploitation behavior. Lindahl *et al.* (2016*b*) study the role of regulation in a context with regime shifts and find that regulation outperforms self-organization. Our study bears the most resemblance to the study by Lindahl *et al.* (2016*a*) who also compare outcomes of two treatments where one treatment entails resource dynamics with a regime shift and one does not. However, our study differ from theirs in how we construct the treatments (see section 2.1 for details) but perhaps most importantly because we run the experiment with resource users, whose livelihood crucially depends on the resource.

Lab experiments provide the researcher with a 'clean test tube' that enables control over contextual variables and facilitates causal inferences. Because they typically are conducted with students, they enable testing of complex designs, and are relatively easy and cheap to run. The potential drawback of lab experiments in a resource user context is precisely that they use student participants instead of real resource users (Cárdenas and Ostrom, 2004). To which extent experimental results can be generalized beyond the lab is an important question that has received much attention in the literature (see, e.g., Levitt and List, 2007; Falk and Heckman, 2009). Whereas previous results from the lab, such as significance of communication, have been confirmed in CPR field experiments (Cárdenas, 2000), some of these field experiments have also found that, depending on the social, cultural and ecological context, experimental outcomes can differ significantly (Henrich *et al.*, 2005; Castillo *et al.*, 2011; Prediger *et al.*, 2011; de Melo and Piaggio, 2015; Pfaff *et al.*, 2015; Gneezy *et al.*, 2016; Cárdenas *et al.*, 2017; Drury O'Neill *et al.*, 2019). Our study allows us to investigate to what extent exploitation behavior in a CPR game with a potential regime shift also depends on individual characteristics, and socio-economic conditions of the fishers. If we observe that fisher behavior deviates from the behavioral assumption of a rational decision-maker actor model, it is valuable, both for future research and for policy, to detect systematic patterns in these deviations. We argue that our work can be seen as one step in the direction of enhancing the understanding of behavioral responses of fishers to latent regime shifts.

2. Methodological approach

Our main method of choice is a framed lab-in-the-field experiment (see Harrison and List (2004) for a classification of experiments), complemented with interview and observational data.

2.1 Experiment design

How can we transform a commons dilemma problem, involving not only strategic elements but also complex resource dynamics, into a comprehensive decision task for our resource users? We chose to modify an experimental design developed by Lindahl *et al.* (2016*a*). Like them, we depart from a logistic growth function as a representation of the resource dynamics, and with a 'Holling-type' III predation term (Ludwig *et al.*, 1978) to simulate a regime shift. In the model with a regime shift, there is a critical threshold at which the dynamics, in terms of regrowth, change dramatically (Biggs *et al.*, 2012).

To our experimental participants – the fishers – we presented the resource dynamics as discrete versions of the logistic growth function. In one of the two treatments, the resource dynamics entail a drastic latent abrupt drop in the regrowth beyond a critical threshold of the resource stock (henceforth we refer to this treatment as the 'regime shift treatment'). The other treatment does not entail such an abrupt shift (henceforth referred to as the 'no regime shift treatment').

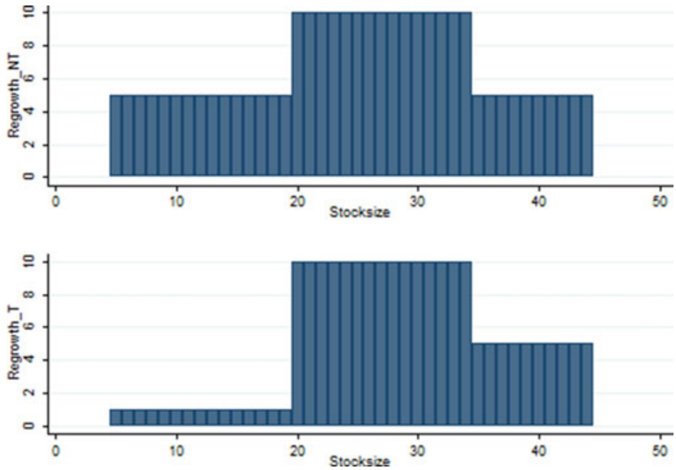

Figure 1. Resource dynamics. The upper panel illustrates resource dynamics for the no regime shift treatment, and the lower panel for the regime shift treatment.

Figure 1 is an illustration of the resource dynamics we used for the no regime shift treatment (upper panel), and the regime shift treatment (lower panel).

The following features hold for both treatments: the minimum resource stock size which allows for renewal is five units, while the maximum resource stock size is 45 units. The maximum sustainable yield (regrowth) is ten resource stock units, which occur between stock sizes 20 and 34. For stock sizes above 34 units, the regrowth is five units. Thus for stock sizes between 20 and 50, the resource dynamics is identical for the two treatments, but for stock sizes below 20 units, it differs; for the no regime shift treatment the regrowth is five units, but for the regime shift treatment, only one unit. This essentially means that, if the critical threshold has been crossed, in order to avoid a complete collapse of the fishery and for the stock to recover, fishers will have to refrain from fishing for a number of periods.

To account for illiteracy, practically everything had to be communicated verbally. For example, we instructed our participants verbally about the rules of the game, and used small fake fish as symbols that we lay out to explain the resource dynamics. Note that the graphs in figure 1 were not used in the actual experiment to explain the resource dynamics. Here we differ from Lindahl *et al.* (2016*a*). They used written instructions with figures and tables to explain the resource dynamics and the rules of the game. Because everything had to be explained verbally, we also needed to simplify the game, by changing the number of 'steps' of renewal rates for each treatment (using three instead of nine). In the beginning of the experiment we placed 50 pieces of the fake fish on a table, and adjusted the number depending on participants' extraction, and the stock regrowth. We also used a simple table to inform the participants about the resource dynamics (see table A1 in the online appendix; the instructions are also available in the online appendix). The institutional setting of this experiment was kept simple, i.e., rules and norms were self-imposed and not costly. To mimic the field as much as possible, we allowed for face-to-face communication during the entire experiment, but decisions were kept anonymous (see experimental procedure below).

2.2 Experimental procedure

The experiment was performed with fishers in a village[3] situated in the Phuket province, the biggest island of Thailand, located in the Andaman Sea. The total population of the village is estimated to be around 2,490 individuals, or just above 900 households. About 40 per cent of the population belongs to the so-called Mogans, referred to as 'Chao Leiï£¡ï£¡ï£¡ (sea people) by the Thais. Even though some villagers earn income by working in other sectors (as unskilled labor), for example in the tourism sector, the main source of income is still from fishery, and their incomes are realized on a daily basis. Most of them have low levels of education, and some are even illiterate. We recruited 96 fishers from the village. Appointments were arranged with the help of the headman's assistant, and the experiment was performed at the public meeting building in the village over four days.[4] The fishers were recruited with the help of a show-up fee of 200 Baht, and they also earned additionally on average 300 Baht. The average total earning, which corresponds approximately to a day's income from fishing, is equivalent to about 6.7 Euro (or US$7.8). Each session lasted approximately one and a half hours, and each fisher participated only once. Upon arrival, the fishers were informed about the experiment in general, the post-experimental interview, and payment procedures. They were also informed that their decisions in the experiment, and their interview responses would be kept anonymous, and that there would be a post-experiment information session on the last day of the experiment. After signing a consent form, they were randomly assigned to a group of four, and each group was seated around a table. The groups were kept separate, and could not see nor hear each other.

The fishers were then told that, together with the other fishers in their group, they had access to a renewable fish stock from which they could fish, each fish unit being worth 20 Baht (corresponds to approximately 0.52 Euro or US$0.60), over a number of rounds. To keep the individual fishing decisions anonymous, in each round, each fisher indicated his (or her) individual decision (in whole numbers) on a protocol sheet (available in the online appendix), using numbers or markers. The protocol sheets were collected by the experiment leader after each round (and then returned to the fishers before the next round). The experiment leader calculated the sum of the units fished, as well as the new fish stock size, and communicated orally and with the fish symbols this new resource stock size to the group. Each group went through two practice rounds where we also asked participants control questions to make sure they understood the game.

Participants were told that the experiment would end if they depleted the resource stock,[5] or when the experiment leader decided to end the game. To avoid an end game effect, this end time was unknown. To ensure that the number of rounds was uncertain, we released the parallel groups (participating in the same session) at the same time (where some groups had played more rounds). We were slightly concerned about potential 'contamination effects', that participants in the experiment would tell other fishers

[3] To ensure anonymity, we refrain from naming the village.

[4] Before the field experiment a pretest was conducted with students at the Mahidol University in Nakorn Pathom province. After the experiment, we invited the participants to a meeting where we informed them about the purpose of the experiments. We also explained the two treatments we had used, and we invited them to ask questions, and give feedback about the experiment.

[5] If the group's total harvest was equal to or exceeded the number of available resource units in one round, the resource regrowth was zero, and the experiment ended for this group. The payment to the participant for that round was then based on her harvest in that round, as a share of the group's total harvest, in the same round.

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in the village about critical aspects of the game. Although we could not eliminate the risk completely we tried to minimize it, for example by asking fishers not to speak about the game. When doing so we also informed them that we ran different games (treatments). We also kept an intense time table to ensure we would not stay in the village too long. Finally, we cut the game shorter at times to vary the end of the game as we learned that this would be the piece of information that would be relatively easy to remember and that could significantly influence earnings (an end of game effect). After the experiment, we held interviews with each participant, after which they were paid privately, one by one.

2.3 Interviews and complementary data

The post-experiment interview was designed to extract individual and group attributes (see supplementary material). We asked, for example, for a number of socio-economic variables, such as age, gender, years of education, household income, size of household, expenditures and savings behavior, if they have a side income, how much of their catch they typically consume themselves vis-a-vis sell, and if they were born in the village.[6] During the experiment assistants were also taking notes on communication and cooperation behavior. For each group and round, a note was made if the group was able to reach an agreement (followed by communication), and if this agreement was being respected by all group members.

2.4 Formulating hypotheses

We want to know if we should expect an increase or a decrease in over-exploitation when fishers are confronted with the more challenging resource dynamics. We also want to know to what extent we can expect fishers to be able to avoid the latent regime shift and resource collapse. We will in this section formulize hypotheses around these research questions. We rely on methods from repeated game theory.

Our experimental participants receive a stock level update between the decisions. This means that they can condition their strategies on the current stock size, which allows us to assume Markov strategies (Maskin and Tirole, 2001). Because our time horizon is indefinite (Carmichael, 2005), the discount factor can represent the probability that the game will continue to the next period (Fudenberg and Tirole, 1998). To simplify the analysis we focus on pure strategies and consider equal sharing equilibrium outcomes (this is also pretty much consistent with observed behavior in the experiment).

So to answer the first research question we want to compare the outcome when fishers are confronted with a regime shift in the resource dynamics with the outcome when fishers are not confronted with such a shift. But what outcomes are possible and are some outcomes more or less likely to be observed depending on the treatment? We can first make the following observation.

Proposition 1. *For both treatments, each stock size X between 5 and 45 can be sustained as an equal sharing Markov Perfect Equilibrium in the first round,* $(t = 0)$*, if, for each player i, the expected discounted value of one resource unit,* $\delta_{i0,}$ *is large enough. That is, if*

[6]We also asked them about details of their fishing activities, about attitudes towards cooperative activities etc., and about their past experiences of abrupt changes in fish stocks. These variables did not show up as significant in any of our analyses so we refrain from providing more details about them.

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$\delta_{i0} \geq \hat{\delta}_{i0}$,

$$\text{where } \hat{\delta}_{i0} = \frac{50^2 4^2 - ((100 - X)4 - (50 - X))(50 - X)}{50^2 4^2 - ((100 - X)4 - (50 - X))(50 - X - H_X)}, \tag{1}$$

where H_X represents the regrowth at stock size X. For the subsequent rounds, $t \in [1, \infty]$, stock size X can be sustained if, for each player i, the discounted value of one resource unit, $\delta_{it,}$ is equal to or higher than $\hat{\delta}_{it}$,

$$\text{where } \hat{\delta}_{it} = \frac{(X + H_X)^2 4^2 - ((X + 2H_X)4 - H_X)H_X}{(X + H_X)^2 4^2}. \tag{2}$$

The proof of proposition 1 can be found in the online appendix. From equations (1) and (2), one can see that the value of the critical discount factor for a particular stock size, X, depends on the regrowth of the resource at that particular stock size, H_X. So even though all stock sizes can be sustained as a Markov Perfect Equilibrium, there may be some equilibria that are more or less likely to be sustained than others. For example, for stock sizes with a higher regrowth, the incentive to deviate from the equilibrium strategy and deplete the resource is lower. This is the case because the expected discounted value of the sum of future payoffs is also higher, and consequently, the critical value of the discount factor is lower. So for stock sizes where the regrowth differs between the treatments (is the same), the critical value of the discount factor will also differ (be the same).

Proposition 2. *Between stock sizes 5 and 19, Markov Perfect Equilibrium outcomes are less likely to be sustained in the regime shift treatment, compared to the no regime shift treatment. For other stock sizes, where resource growth of both treatments is identical, Markov Perfect Equilibrium outcomes are equally likely to be sustained.*

Proposition 2 follows from table A3 (online appendix) and given certain restrictions on the distributions of the discount factor (see proofs in the online appendix). From proposition 2 we know that in the region where we find over-exploitation (stock sizes between 5 and 19), Markov Perfect Equilibria are less likely to be sustained for the regime shift treatment. Thus, it is reasonable to expect fewer cases of over-exploitation in the regime shift treatment. This leads us to our first hypothesis.

Hypothesis 1. *The regime shift treatment is associated with less over-exploitation compared to the no regime shift treatment.*

So we expect less tragedies of the commons in the regime shift treatment. Please note that we define over-exploitation as exploitation above the optimal exploitation level, the maximum sustainable yield (MSY) (and vice versa for under-exploitation).

Moving to our second research question. In our experiment we allowed (but did not force) fishers to communicate. If fishers took the opportunity to communicate they could form explicit group agreements, and be able to avoid the regime shift. In fact they should be able to maximize joint earnings. A group of fishers maximizing their joint earnings (following the optimal strategy) should harvest 30 units in the first period, and then, in each subsequent period, harvest the MSY, 10 units, as long as they think the game will continue. If they think (with high enough probability) that the game will end, they should harvest the remaining stock units. This is true for both treatments (see table A2 in the online appendix for optimal claims for each stock size).[7] Because the regrowth for stock sizes between 20 and 34 is the same for the two treatments (see table A3 in the online appendix), the critical value of the discount factor will also be the same, meaning that the optimal exploitation path is equally likely to be sustained as a Markov Perfect Equilibrium in both treatments. But will groups that form cooperative agreements manage to exploit the resource optimally? This leads to our second hypothesis.

Hypothesis 2. *Groups that form cooperative agreements will follow the optimal path and be equally efficient in their management of the resource, regardless of treatment.*

Thus, we define such a cooperative group as one where the group is able to form explicit agreements for the entire duration of the experiment, and where these agreements are also being followed by all group members. Our second hypothesis is then formulated to test whether such a group will exploit optimally.

If groups that form cooperative agreements follow the optimal exploitation path, the overall outcome between treatments will then depend on the number of such groups we see in each of the treatment. But note that our derivations are based on assumptions about whether groups form cooperative agreements or not; they cannot inform us about when we should expect such agreements to emerge. Nevertheless we will investigate if we can say something about what makes a group more likely to form cooperative agreements.

Our hypotheses involve behavior and outcomes on the group level but what can we expect on the individual level? Will behavior depend on individual characteristics? The implicit assumption invoked in our theoretical exercise above is that users are homogeneous in how they reach decisions. Thus, we would not expect to see a difference in behavior between the treatments. But, our theoretical framework cannot guide our analysis further so we refrain from formulating a hypothesis around these variables. But we will investigate the potential influence of these variables.

3. Results

Descriptive statistics based on the interview data are presented in table 1 for each treatment separately. We have used non-parametric Mann-Whitney tests for continuous variables[8] and Pearson's χ^2 tests for proportions (all p-values are two-sided). There are 48 observations in each treatment. The average age of participants differs slightly between the two treatments; participants in the no regime shift treatment are on average five years older (48 compared to 43) on a five per cent significant level. We can, however, not find significant differences for the other socio-economic variables.[9]

[7] If, for some reason, the stock falls below 30 units, the optimal strategy is to let the resource recover until it reaches at least 30 units (most rapid approach) and then harvest 10 units for the subsequent periods.

[8] For all continuous variables in tables 1 and 2 we can reject normality on a 1 per cent level according to Shapiro-Wilks tests.

[9] The average income is about 14,000 Baht per month, they save a bit more than 3,500 Baht per month (which is about 25 per cent of their income), they consume about 30 per cent of their catches and the average household size is four members.

Table 1. Descriptive statistics of participants

	No regime shift (NRS)	Regime shift (RS)	
	Mean	Mean	*p*-value
Income per month (in Baht)	13,573 (9,803)	14,085 (12,803)	0.8775
Saving per month (in Baht)	3,775 (4,803)	3,492 (5,163)	0.7070
Size of household	4.271 (1.997)	3.833 (1.389)	0.3757
Percentage of catch consumed	27.313 (25.455)	29.042 (27.029)	0.9704
Age	48.81 (12.895)	43.35 (11.77)	0.0465
Years of education	4.083 (3.114)	4.333 (2.587)	0.4512
Gender (male = 1)	0.333 (0.476)	0.313 (0.468)	0.827
Born in the village (yes = 1)	0.292 (0.459)	0.229 (0.425)	0.485
Side income (yes = 1)	0.479 (0.505)	0.354 (0.483)	0.214

Note: Standard errors in parentheses.

More women than men showed up to participate in the experiment, but the gender distribution between the two treatments does not differ significantly.[10]

We now proceed to analyze the experimental outcome. To test hypothesis 1 we first look at over-exploitation and we include all groups. Figure 2 shows average over-exploitation over time, separated by treatment. Average over-exploitation for the no regime shifts groups is 2.695 units per round (standard deviation is 4.735). For the regime shifts groups the average over-exploitation is 1.676 units per round (standard deviation is 3.987), which is lower. However this difference is not significant according to our two-sided Mann-Whitney test (p-value equals 0.3419).

Result 1. *We can reject our first hypothesis. The regime shift treatment is not associated with less over-exploitation compared to the no regime shift treatment.*

Next we zoom in on groups that form cooperative agreements (these groups have made explicit agreements about exploitation levels for each round, and in each round,

[10]We decided not to exclude anyone based on gender. When advertising the experiment we asked for fishers, which by our definition includes a person (male or female) participating in a fishing activity. An individual who takes part in fishing conducted from a fishing vessel, a floating or fixed platform, or from shore. Although women are underrepresented when it comes to high sea fishing, they still play a critical role in small-scale fisheries. In some regions of the world, women account for 56 per cent of small-scale catches. They are often even more dominant in other links of the value chain (processing, marketing, preparing nets, boats, capturing bait and fry) (Harper *et al.*, 2013). We revisit the issue of gender in the discussion and conclusion sections.

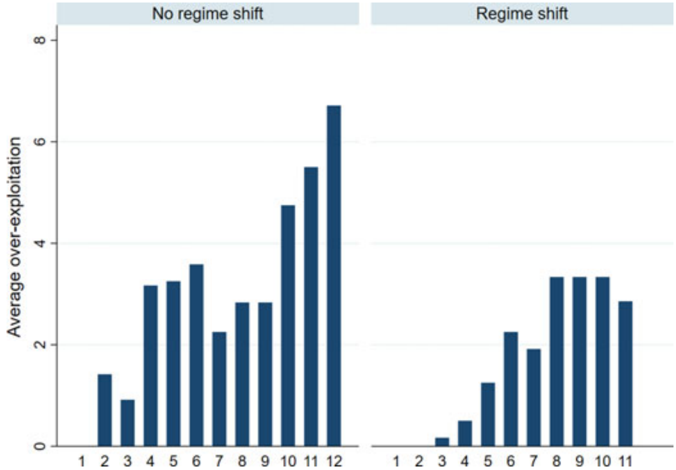

Figure 2. The left panel shows over-exploitation over time for the no regime shift treatment and the right panel shows over-exploitation over time for the regime shift treatment. Note that the end period differ for the two treatments, reflecting that no group in the regime shift treatment played for 12 rounds.

these agreements are also followed by all group members). This criterion was met by eight equal sharing groups in the regime shift treatment, and four in the no regime shift treatment. Our theoretical derivation in section 2 is based on equal sharing equilibrium outcomes but our definition of a cooperative group can actually include groups that form explicit agreements about non-equal sharing. In the theoretical section we already hinted that most groups shared the resource pretty much equally. But we still want to test if the assumption holds for our cooperative groups. To this end, we calculated the Gini coefficient for each group, and we can conclude that our sample of cooperative groups (groups that form cooperative agreements) only include groups with a Gini coefficient below 0.01.[11]

To test hypothesis 2, we need to figure out whether all these groups that formed cooperative agreements exploit optimally, or if exploitation behavior of these cooperative groups that played the regime shift treatment differ from exploitation behavior of cooperative groups playing the no regime shift treatment. Figure 3 shows that groups that formed cooperative agreements do not manage the resource optimally, average efficiency is well below 1, and this holds for both treatments. Most of these groups actually keep an average stock size (after regrowth) above 30 (which is the optimal after regrowth stock size), and thus under-exploit the resource. Further, two-sided Mann-Whitney tests reveal that there are no significant differences between the no regime shift (NRS) treatment and the regime shift (RS) treatment with respect to efficiency ($Mean_{RS} = 0.577$, $Std_{RS} = 0.174$; $Mean_{NRS} = 0.615$, $Std_{NRS} = 0.197$; $p = 0.8651$), or with respect to stock size ($Mean_{RS} = 34.640$, $Std_{RS} = 9.098$; $\mathrm{Mean}_{\mathrm{NRS}} = 31.722$, $\mathrm{Std}_{\mathrm{NRS}} = 6.486$; $p = 0.6104$) for these cooperative groups between the two treatments.

[11]Some groups kept a rotating scheme to be sure to maximize joint earnings. At the end of the experiment, a few members of those groups could therefore end up with one more resource unit than the other(s) in that group, resulting in a Gini coefficient above zero (but still below 0.01).

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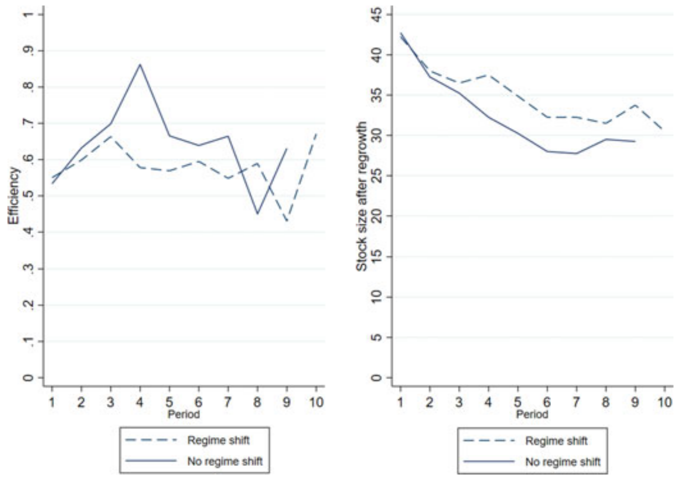

Figure 3. The left panel shows average efficiency over time for cooperative groups separated by treatment. The right panel shows average stock sizes (at the end of the period after regrowth) over time for cooperative groups, separated by treatment. Note that the end period differs across groups

Result 2. *We can partly reject our second hypothesis. We cannot detect any significant behavioral differences between the two treatments for groups that formed cooperative agreements. Also these cooperative groups do manage to avoid the regime shift. But they do not manage the resource optimally but under-exploit the resource.*

Can we say something about what makes a group form a cooperative agreement or not? Will for example the share of such groups differ between the treatments? We find that the share of groups that form cooperative agreements is higher in the regime shift (RS) treatment ($\text{Mean}_{\text{RS}} = 0.677$, $\text{Std}_{\text{RS}} = 0.041$; $\text{Mean}_{\text{NRS}} = 0.470$ $\text{Std}_{\text{NRS}} = 0.043$; $p = 0.0007$). We also complement our analysis with a logistic regression with cooperation as dependent variable (groups that formed cooperative agreements). The best model, evaluated based on the Aikaike criterion, is presented in table 2.[12]

Table 2 reveals that cooperative agreements are more likely to form when the group is confronted with the regime shift treatment.

Result 3. *The treatment is a significant predictor for the number of groups that form cooperative agreements.*

Efficiency is often used as a measure of how successful groups are at managing the resource, and efficiency means here that the group manages to stay at the MSY. Inefficient behavior means that users fail to maximize their joint earnings, and arises either because users over-exploit the resource, or because they under-exploit the resource. We see both types of behavior in our experiment. Can we say something about these

[12]Please note that we also tested for other socio-economic variables such as gender, monthly average income (per household member), savings behavior (as a percentage of income), if they had a side income, how much of their catch they kept for consumption, years of education, and if they were born in the village. These variables were not significant however and based on the AIC excluded from the model.

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Table 2. Logistic regression with cooperation (forming cooperative group agreements) as dependent variable

	Odds ratio	*p*-value
Constant	0.000 (0.000)	0.064
Treatment (regime shift = 1)	12.803 (15.870)	0.040
Age (group average)	1.176 (0.108)	0.078
LR χ^2	6.58	0.037
AIC	32.695	
N	24	

Note: Standard errors in parentheses.

individuals, can we detect some type of patterns among them? To answer this question we need to zoom in on individual exploitation behavior.

Over-exploitation (or under-exploitation in absolute values) of an individual in a specific period is calculated as the distance between the equal-sharing optimal individual claim and the actual individual exploitation. So in each period, a person can either over-exploit, under-exploit, or exploit optimally. However, we cannot use regression analysis to analyze per period behavior, as it would violate the assumption of independence. For this reason, we need to analyze average exploitation behavior, which means we have only one observation per individual. Again, on average, a person can either be an under-exploiter, an over-exploiter, or someone who exploits optimally.

Here we are especially interested in getting a better understanding of potential drivers of over-exploiters, when compared to optimal exploiters or under-exploiters. This is because over-exploiters run the risk of driving the resource stock to depletion.

To analyze individual exploitation behavior we run a tobit regression with the average individual over-exploitation as the dependent variable.[13] We cluster at the group level to control for group effects. In addition, besides controlling for the treatment, we also control for age, gender, average monthly household income, household size, if they have a side income – e.g., from tourism (which means that they can diversify their income), how much of their catch they keep for consumption vis-à-vis sell, and if they were born in the village. Our analysis reveals that some of these fisher characteristics, and socio-economic factors, do influence behavior in the game. The best model, evaluated based on the Aikaike criterion, is presented in table 3.

Result 4. *We find that over-exploitation is mainly associated with fishers born outside of the village, and with fishers with a side income. Age is also significant but the magnitude of this effect is comparably much lower. Interestingly, the treatment does not seem to have an effect on these fishers (the over-exploiters).*

[13]If the person on average exploited optimally or under-exploited the resource, that observation has a zero, which means we focus on comparing the over-exploiters to both these types.

Table 3. Tobit regression of individual over-exploitation

	Average individual over-exploitation	
	Coefficient	*p*-value
Constant	−19.855 (6.757)	0.004
Age	0.337 (0.122)	0.007
Treatment (Regime Shift = 1)	−8.827 (6.114)	0.152
Born in village (yes = 1)	−7.469 (2.989)	0.014
Side income (yes = 1)	6.832 (3.079)	0.029
F	4.86	0.001
AIC	289.210	
N	96	

Notes: Standard errors in parentheses. Individual average over-exploitation as dependent variable, ML estimates, robust standard errors clustered at the group level.

4. Discussion and conclusions

With this experiment we wanted to increase our understanding about how fishers sharing a common fishing ground will react to an endogenously-driven regime shift (manifested as an abrupt drop in the regrowth) in the fish stock. For example, we wanted to know if they will be able to avoid the shift, by collectively keeping their total exploitation low enough, or if they will ignore the potential shift, or even worse – increase their exploitation.

Our theoretical derivations suggested that groups that form cooperative agreements would follow an optimal exploitation path regardless of treatment (thus avoiding a shift in the regime shift treatment), but we could not make any predictions on the number of groups that form cooperative agreements in the two treatments. We also predicted that groups in the regime shifts treatment would on average be more cautious compared to groups in the no regime shift treatment. Based only on these theoretical derivations we would thus have some hope that a regime shift could be avoided.

Our experimental results show that, indeed, when confronted with a potential regime shift, fishers may be able to 'stay on the safe side', thus avoiding a resource collapse, but do so by under-exploiting the resource. Moreover, we found more cooperative agreements in the regime shift treatment (which theory could not predict). All but one of these cooperative groups facing the regime shift managed to avoid the shift.

Although the experimental designs are not identical, and our experimental participants are fishers (instead of students), it is relevant to compare our results to the results found by Lindahl *et al.* (2016*a*), who analyzed behavioral responses (of students) to an endogenously driven regime shift in a CPR setting. Our finding that a potential regime shift can lead to more cooperative agreements corroborates what they found in the lab. However, there are also some contrasting results. For example, in our field experiment, groups that form cooperative agreements do not manage the resource equally efficiently as their students did in the lab. Lindahl *et al.* (2016*a*) found that cooperative groups

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(of students) stayed close to the optimum. There may be several reasons for this discrepancy. For example, we cannot rule out that differences in education and literacy play a role. Another potential explanation is the difference between designs. In our case the drop in the growth rate is more 'severe' than the drop used by Lindahl *et al.* (2016*a*) (see section 2.1 on experimental design for details), which could explain the more cautious behavior, leading to more under-exploitation in the field. Yet another plausible explanation is that other contextual variables, beside literacy and level of education, matter.

In the commons literature there is an increasing recognition of the role of contextual factors for the emergence and dynamics of cooperation (Anderies *et al*., 2011; Prediger *et al*., 2011; Gneezy *et al*., 2016) and a recognition that we need to organize how these different factors affect resulting outcomes (Ostrom, 2007, 2009). Our experiment design contributes to this literature by directly testing how fishers respond to potential regime shifts, and if this behavior also depends on fishers' individual characteristics, and current socio-economic conditions. Although most fishers under-exploit the resource in our experiment, we find that there are some over-exploiters, and that these fishers are equally likely to be found in both treatments. Our analysis reveals that an individual is more likely to be an over-exploiter if he (or she) is born outside the village, and if he (or she) can diversify his (or her) income. This over-exploitation could be the result of a direct link but also the result of an indirect link, where over-exploitation is driven by an expectation of the behavior of others that in turn is linked to these characteristics.

Being able to diversify income implies that the livelihood is less dependent on the local fish stock. So, this contrast results from studies arguing that over-exploitation can be driven by more resource dependency (see, e.g., Cinner *et al*., 2012). These studies emphasize solutions that center on making these fisheries more economically efficient, while at the same time incentivizing fishermen to leave the sector. We argue that such strategies may fail to fully recognize the different potentials and limitations fishers face, such as geographical immobility, and restricted opportunities for livelihood diversification, which characterize many SSF communities. We also find that people born outside of the village are more likely to be over-exploiters, which is in line with studies showing how place-attachment (which has both a functional and an identity component), can lead to more environmentally responsible behaviors (Vaske and Kobrin, 2001; Junot *et al*., 2018).

Based on these results we therefore suggest that another potential solution would instead be to turn to one of Ostrom's design principles for successful commons management, the importance of facilitating arenas for conflict resolution. Such an arena could be equally important for strengthening community ties, for building social relationships, and for knowledge sharing (about ecological conditions), which we think can be essential in these vulnerable communities, especially under geographic mobility restrictions.

To strengthen our conclusions, however, additional studies, e.g., in different field settings, would need to confirm our findings. For one thing, it would be beneficial to increase the sample size in order to gain sufficient power to draw stronger inferences. For another, it would be interesting to take the design to other locations, both within Thailand (keeping ethnicity and culture constant), but also to locations that differ with respect to socio-economic conditions. It would also be interesting to test variations in the ecosystem dynamics (e.g., with respect to the severity of the shift, and to uncertainties around a shift) and to investigate if individual characteristics can be linked to perceptions of behavior of others.

It would also be interesting to explicitly test the potential role of gender. The commonly-used term 'fisherman' implies that fishing is performed by men, but this is not an accurate picture. While certain fishing activities are more commonly undertaken by men, others are dominated by women. This is especially true for small-scale fisheries (Harper *et al*., 2013), where in some regions women account for 56 per cent of small-scale catches. Women's roles and contributions to the fisheries sector have been invisible and undervalued for a long time, resulting in women remaining in a marginalized position and excluded from policy-making mechanisms. In recent times, more literature has been directed to better understanding the role women play in SSFs. We did not find any significant gender effect in exploitation behavior, but we have to acknowledge that this could also be the result of a small sample size.

Although we cannot derive solid policy conclusions about how we should support SSFs facing these increasingly challenging resource conditions based on this one study, our work can nevertheless be seen as a first step, as one piece of a larger puzzle, where future pieces are yet to be discovered.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S1355770X22000171.

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