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Contents

Results from behavioural experiments: assessing resource users' behavioural response to change

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Global climate change is expected to have exceptionally dramatic impacts in the Arctic, including effects on the fishery sector and fishermen. For these stakeholders substantial welfare impacts could be at stake. The magnitude and direction of these transformations will depend on, among other things, how fishermen respond to future changes as well as how they respond to anticipation of certain changes. This report summarizes the results of a series of laboratory experiments performed to analyse and detect some potential responses. The experiments were complemented with a small survey among arctic fishermen. Our results suggest that long-term collective action among fishermen should be promoted since it is likely to prevent abrupt changes and enables a more sustainable resource management. Our results however also suggest that users respond *heavily* to uncertainties related to potential future negative changes (in the resource stock), in the form of more aggressive exploitation strategies and less potential for collective action. We want to highlight that these results are based primarily on laboratory experiments and should be interpreted with caution. Nevertheless, in a world where fishermen experience many uncertainties it could be crucial to provide them with coordination devices, such as for example a total allowable catch representing a safe minimum standard. Moreover, when providing fishermen with such information one may need to consider carefully the presentation, e.g. how to visualize potential future effects.

1 Introduction

Global climate change is expected to have exceptionally dramatic impacts in the Arctic. In particular, the Arctic Ocean is predicted to transform from a year-round frozen sea to a sea with open waters in summer and a layer of annual ice in winter. Such dramatic change is likely to have considerable impacts on marine ecosystems, economic activities, governance, and indigenous and local peoples in the Arctic. (D5.91)

Local and indigenous peoples of the Arctic are particularly dependent on natural resources for their livelihood. Arctic fisheries and aquaculture is one of the most important industries in the Arctic constituting relatively large shares of GDP in some countries (Greenland 15 %, Iceland 10 %). For local communities fishing, fish processing and/or fish farming can be even more important, and historically, in many cases, fisheries have been the main reason for settlement in rural areas in the Arctic. The share of world marine catches caught in Arctic waters in 2012 was 6 per cent (4,5 mill tonnes) - with 96 per cent of the total mass caught in the Northeast Atlantic. (D3.11, D3.21 and D3.31)

Predictions based on the SINMOD model and the IPCC A1B scenario of possible future climate development show that primary and secondary production is likely to decrease slightly in the Arctic waters in the next 40-100 years. Coupling these results with catch and survey data for Northeast Arctic cod -- the most important Arctic fish stock -- shows a somewhat changed distribution of the biomass and a probable 10 per cent increase for the coming 45 years (D3.11).

However, substantial uncertainties prevail regarding ecosystem responses to climate change and their global economic impacts. In particular it is difficult to guess how different Arctic species will reorganize in response to climate warming, possible ocean acidification and increase in stocks of invasive species. Multiple scenarios with very different outcomes could arise (D5.71). One possible consequence of climate change, which may not necessarily be the most common one (D3.11) is that fish stocks may change substantially, in for example growth rates or migration patterns. Climate change may also influence other factors, such as policies (e.g. increase in price of fuel/transportation, or changing quotas) and changing market conditions (e.g. demand shocks) (D3.31), which may indirectly affect fish stocks and fishermen. Expected changes in the welfare of these local stakeholders (and beyond) could be substantial.

An additional source of uncertainty concerns resource users' response to change. Policy discussions often assume people will react in a rational way, following the standard assumptions around the so-called *Homo economicus* (people are rational, care only about maximizing their own gains and have perfect will-power). Such assumptions will influence the kind of instruments put in place to correct particular environmental problems or generally improve management. However, people do not necessarily behave according to such rationality assumptions. Rather, decision-making is influences by such factors as cognitive limitations, as well as other-regarding preferences and the use of certain heuristics, which may be biased in various ways (Shogren and Taylor, 2008).

All these deviations from the assumptions of *Homo economicus* may have significant influence on how people (in our case resource users) react to changes in fish stock dynamics, to policy instruments and to changing market conditions. Hence, it is important to study how resource users may react to, and deal with the potential of such changes that could be endogenously driven, i.e. triggered through their own actions. Furthermore, while people's response to marginal changes is easier to predict, it is much more challenging to assess how people behave when faced with more abrupt and substantial changes. The growing literature on the topic demonstrates that, in general, management can more easily deal with linear changes than with non-linear responses (Crepin et al., 2012). This literature also reveals that the management outcome of common resources (like a fishing ground) depends on how resource users, such as fishermen, respond to such non-linear changes in the stock as well as how resource users deal with the rivalry among themselves (Mäler et al., 2003; Crepín and Lindahl, 2009).

Our objective is thus to understand how fishermen (and other resource users), sharing a common resource, might go about taking decisions in a context where the resource stock could change abruptly, while simultaneously facing other types of changes, such as policy oriented or market based changes.

We rely on the experimental method to generate data, as it would be very challenging to collect empirical field data. Sufficient data (both ecological and economic) must contain precise information about the resource and management situation before and after an abrupt shift for the studied system. Such data is hardly available (Walker and Meyers, 2004). Furthermore, very little data is available on people's behaviour in the kind of situation we envision for the Arctic.

In order to test the reactions of groups of users to the kinds of change imagined we designed five different experimental settings. First we consider a potential abrupt change in the resource renewal rate, which may occur as a consequence of over-exploitation of a resource with complex dynamics, like Arctic fish (D3.11; D5.71) (section 3). Given the substantial uncertainty surrounding future resource stocks in the Arctic we also test how resource users may react to different levels of uncertainty regarding possible abrupt change (section 4). Since changes facing resource users like Arctic fishermen may be changes in policies and market prices, rather than direct consequences of climate change (D3.31), we investigate how different policies like a quota, information (see section 5) and changes in price (see section 6) in the context of potential abrupt change influence behaviour. A key feature of many ecosystems, including the Arctic Ocean, is the high degree of resource interdependencies (e.g. through food webs, D 5.71). Specifically, poor management of one resource will result in negative spill-over effects on the other resource(s). In order to test how resource users allowed to experiment (to some extent) with the resources they use cope with interdependent resources we developed an exploratory experiment (see section 7). This experiment also included the feature of asymmetric access (easier available to some groups that to others) to these resources. All our experiments were performed with a standard set of subjects (students) but with a real problem- and resource-description. We would have preferred and actually attempted to run the experiments with real fishermen but were not able to gather enough participants. To increase the external validity we therefore complemented our experimental studies with a small survey that we sent out to 74 fishermen in the Arctic and that we also report here (see section 8). After a general overview of the experimental method (see section 2) and the report of the results from the five different aspects mentioned above we discuss our results and conclude (see section 9).

2 Experimental design and procedures

This project relies heavily on behavioural experiments, complemented with post-experiment questionnaires. We performed a series of framed laboratory (lab) experiments (see Harrison and List, 2004) with a standard set of subjects (university students, recruited from Stockholm University Campus) and with a real problem- and resource-description. To complement the data obtained from the experiments, a post-experiment questionnaire was specifically designed to capture variables that can influence individual decisions and help explain the collective outcome. When designing the experiments there were some restrictions to consider. The experimental setting needed to be easy to understand while still encompassing complex resource dynamics involving thresholds and hysteresis or resource interdependencies and asymmetric access. Another requirement was that the experiment could be run smoothly.

In all our experiments a group of 3-4 subjects managed a common resource stock. Upon arrival, the subjects were seated around a table; they signed a consent form and were given the experiment instructions to read after which there was time for clarifying questions. The subjects were told that they each represented a fictive resource user (e.g. a fisherman) and that they together with the other participants in their group had access to a common resource stock. They were informed that they could harvest 'units' of this resource, where each harvested unit was translated to SEK (where SEK 1 ≈ 0,1 Euro, see also the specifics for each experiment for more details on payment). To approximate an infinite time horizon, our subjects did not know the exact number of rounds to be played, only that the experiment session would last a maximum of two hours in total. In each round each participant took an individual decision of how many units of the resource to harvest or in some case decided on how much effort (in hours) to put in. Unless communication was the particular treatment, subjects were allowed to communicate face-to-face right from the start of the game and at any moment. In these cases discussions were neither restricted in terms of time nor content. Subjects could disclose and/or discuss their individual decisions and agree upon a common exploitation strategy. In the post-experimental questionnaire we asked the subjects to state their age, gender, and educational background. We also enquired about their ability to understand the resource dynamics, whether they communicated, whether they were able to reach agreements, how well they cooperated, about the trust in the group, etc. To complement those self-reported variables collected through the questionnaires, the experimenters also took notes. For a more detailed description and motivation on the design see Lindahl et al. (2012, 2014, 2015c).

3 Experiment 1: Thresholds and behaviour (Based on Lindahl et al. 2012; 2014)

Our objective with the first experiment was to understand how resource users take decisions when there is a latent abrupt change in the resource growth rate (compared to a situation when there is no such abrupt change). More specifically, in a situation where there is a critical stock threshold, below which the resource growth rate drops substantially, how will such a shift influence individual exploitation and cooperation strategies and consequently the overall resource management? Should we for example expect an increase or a decrease in the frequency of over exploitation? To answer these questions we compared two experimental treatments. In both treatments subjects played a similar dynamic common pool resource game, but whereas some groups faced a simple (a logistic type of) resource dynamics, other groups faced a more complex resource dynamics with a potential endogenously driven abrupt change.

In the resource economics literature, the logistic growth function is often used to model resource growth (see e.g. Clark, 1990). This function was also our point of reference as it has the advantage that one can easily capture resource dynamics with a potential endogenous abrupt change by adding a sigmoid term (e.g. a Holling-type III predation term, see Ludwig et al., 1978). Such a non-concave growth function can simulate the dynamics of relatively complex ecosystems (Scheffer and Carpenter, 2003; Crépin, 2007; Grass 2012) and has already been used in the theoretical resource management literature (see e.g. Crépin and Lindahl, 2009; Crépin et al., 2011) to analyse the implications of such potential regime shifts for management.

To our experiment subjects, we presented the resource dynamics as discrete time versions. We used examples, figures and tables to illustrate the exact resource dynamics for the different treatments. The minimum resource stock size to allow for possible renewal was set to five units, and a maximum resource stock size to 50 units, a measure of the carrying capacity.

Figure 1 shows the resource dynamics of the logistic type model treatment (a) and the Ludwig et al. type model treatment (b) respectively. The maximum sustainable yield is nine resource stock units, and the resource growth rates change by steps of five units. For the resource dynamics involving a latent threshold in the renewal rate of the resource stock (Figure 1b) the following applies: if the resource stock size decreases below the threshold of 20 units, the regeneration drops dramatically (from a regeneration rate of seven to one resource stock unit). There is also a hysteresis effect: in order to recover a high regeneration rate (light grey bars in Figure 1b) once the resource stock size falls below 20 units, the resource stock must be rebuilt up to 25 units or more. In the experiment we set the initial stock to 50 units so that each groups started at the maximum resource stock level.

About 150 subjects participated in this experiment. Communication was allowed and in each round each subject took an individual decision about how many resource units to harvest. Each harvested unit was worth SEK 5.

In this experiment we expect fewer instances of over-exploitation in the threshold treatment (due to risk of crossing the threshold). However, if a group cooperates the threshold should not have a significant influence because the group will stay in the maximum sustainable region (a growth rate of 9 units).

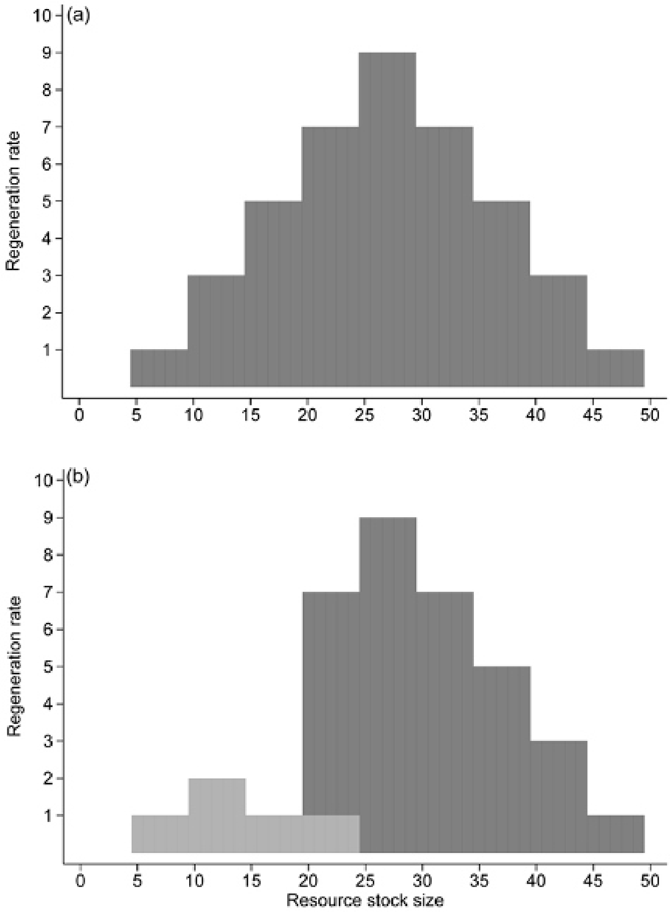

Figure 1: Graphical illustrations of the resource dynamics of scenario A (a) and B (b) as presented to the experiment subjects. (a) represents a discrete version of the logistic growth function (no threshold treatment), (b) shows a resource dynamics that entails a threshold, i.e. there is a drastic and persistent drop in the regeneration rate at a resource stock size of 20 units (threshold treatment).

Figure 2 illustrates the average amount of over- and under-exploitation in each period. From this figure, it is obvious that, on average, the threshold treatment implies less over-exploitation and less under-exploitation in each period compared to the no threshold treatment. Thus, the average efficiency in the no threshold treatment is significantly lower. These results thus suggest that resource users will manage the resource stock more efficiently (i.e. closer to the maximum sustainable yield) when confronted with a potential abrupt drop in availability (threshold treatment) compared to a resource that does not entail such a potential shift (no threshold treatment). This is very much in line with our predictions.

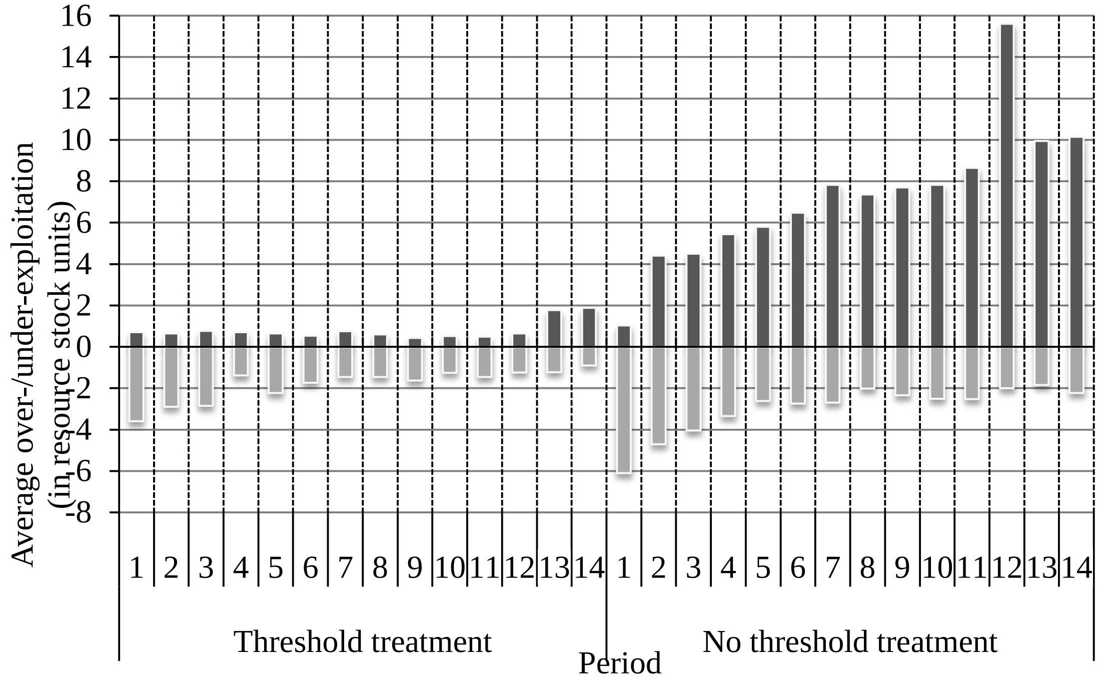

Figure 2: Average over- and under-exploitation (in resource stock units) for the threshold treatment and the no threshold treatment (logistic resource dynamics) for each experiment round.

We also look into the behaviour of cooperative groups. According to theory, a cooperative group (see Lindahl et al. 2015a for more details) should be operating at the maximum sustainable yield (regardless of treatment). We find however that there is a significant difference in behaviour between the two treatments. The average achieved efficiency for cooperative groups that participated in the threshold treatment is 0.831 (with a standard deviation of 0.223). For cooperative groups in the no threshold treatment the average efficiency is 0.682 (with a standard deviation of 0.277). A Mann-Whitney U test reveals that this difference is significant on the 1-percent level (p-value = 0.000).

Our analysis points to the following: the threat of reaching a critical tipping point, beyond which the growth rate will drop drastically, triggers more effective communication within the group, enabling stronger commitment for cooperation and more knowledge sharing, which together explains the results.

4 Experiment 2: Threshold uncertainty and behaviour (Based on Schill et al. 2015)

With this experiment, we wanted to extent the design in Lindahl et al. (2014, 2015a), highlight the role of uncertainty and address the following research question: How does the *risk* of a latent undesirable drop in the resource growth rate influence user group exploitation strategies (resource management) and collective action? To answer this research question we introduced three risk treatments (probability levels of 0.1, 0.5 and 0.9) and compared those with the threshold treatment (from experiment 1, see above). In all other respects the experimental design was identical.

We introduced the risk of a threshold as follows: We showed the subjects in the risk treatments the resource dynamics (using figures and tables) of two different scenarios – scenario A and B – (as shown in Figure 1a and Figure 1b above) and let them know that one of those scenarios was being played with a given probability. Subjects were also told that the experimenter decided upon the scenario ex-ante by doing a random. Subjects in the threshold treatment (probability of 1.0) were presented only with the resource dynamics of scenario B. In total, we recruited 307 subjects and again each harvested unit was worth SEK 5.

In this experiment we expect risk to be negatively correlated with over-exploitation. Again (as in experiment 1) if a group cooperates the treatment should not have a significant influence on exploitation strategies.

Figure 2 shows time series of the resource stock size (after group harvest, before growth) for each group by treatment (a-d). The overall harvest pattern in all four treatments is relatively similar: There are groups that, for some rounds or the entire game, under-exploit the resource (i.e. resource stock size is above 25 units), some groups that achieve a resource stock size between 25 and 29 units (where the regeneration rate is the highest) in every round of the game and a few groups which moderately over-exploit (i.e. resource stock sizes between 25 and 20 units).

The statistical analysis (see Schill et al. 2015 for details) show that whether or not people face such a latent shift with certainty or with different risk levels (low, medium, high) neither makes them more nor less likely to exploit the resource beyond its critical potential threshold. We find, however, that if the likelihood of the latent shift is certain or high and if there are more females in the group, groups are more prone to initially agree on a common exploitation strategy, which in turn increases the likelihood for averting the latent shift. Furthermore, we find that cooperative groups are equally unlikely to cross the potential threshold. The risk level also influences how efficient the groups are in managing the resource and whether or not groups cooperate. Cooperative groups that face a threshold with certainty or a 90% chance perform better; they generate higher payoffs, and manage the resource more sustainably.

Moreover, threshold certainty, as well as a 50/50 chance of being confronted with a threshold increases the likelihood for cooperation. We explain that this outcome (medium risk produces more cooperation than high risk) might result from different behavioural responses to the two ways used to present the probabilities in the game (lottery versus flipping a coin). Hence, risk influences individual as well as group behaviour in our CPR setting and triggers certain behaviours. Exactly which levels of risk trigger which behavioural response (group agreement in round one and cooperation) is ambiguous and needs further exploration.

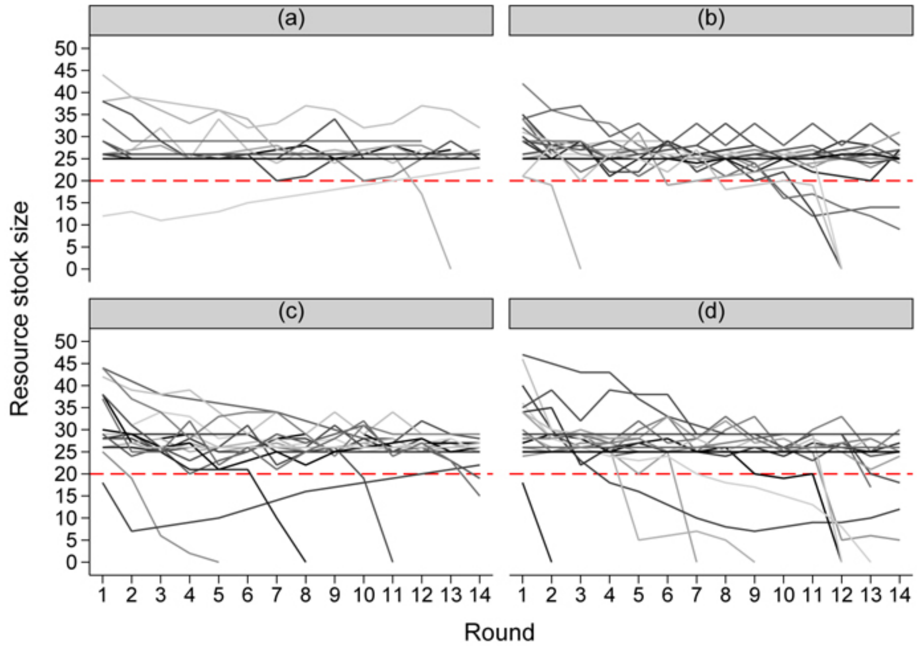

Figure 3. Time series of resource stock size after group harvest for each group of the threshold treatment (a), high risk treatment (b), medium risk treatment (c) and low risk treatment (d). Data points below the red dashed line (potential threshold) indicate severe over-exploitation, i.e. crossing of potential threshold.

5 Experiment 3: Thresholds, Policies and Behaviour (Based on Lindahl et al. 2015a, manuscript in prep).

In this experiment we analysed how a system regulated by a quantitative instrument, in the form of a quota, performs in comparison with two unregulated systems where the underlying resource dynamics entail a latent abrupt drop in the renewal rate. These two unregulated systems differ in the way the latent regime shift is presented to the users. To this end we modified the experimental design developed by Lindahl and colleagues (Lindahl et al. 2012; 2014, see also above). In total, 240 subjects participated in this experiment.

First we compared the *baseline threshold treatment*, the unregulated case (which was identical to the threshold treatment in experiment 1) with a regulated case in the form of a total allowable catch (TAC) at the threshold (see Figure 4 below).

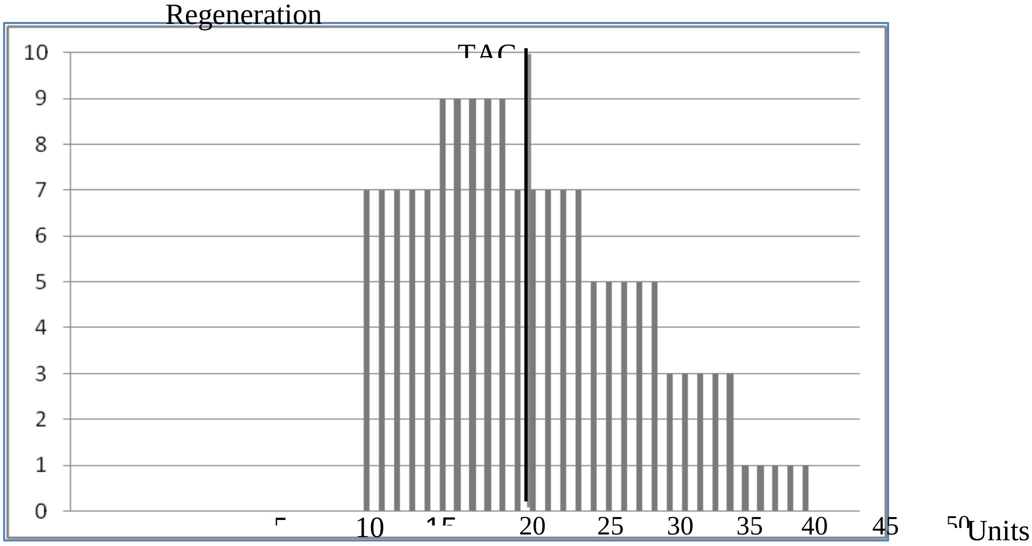

Figure 4: Illustration of resource dynamics as illustrated to the experimental participants in the quota treatment. If TAC (at 20 resource stock units) is not respected the stock will be put in a recovery zone, implying that the subjects have to wait for a specific number of periods (see Table 1 below).

Table 1: Punishment if breaking the quota

Resource stock size	**No fishing allowed for # periods**		**Resource stock size**	**No fishing allowed for # periods**		**Resource stock size**	**No fishing allowed for # periods**
19	7		12	12		5	18
18	8		11	13		4	Game ends
17	9		10	13		3	Game ends
16	10		9	14		2	Game ends
15	11		8	15		1	Game ends
14	11		7	16		0	Game ends
13	12		6	17			

For the regulated case and the unregulated baseline threshold case the ecosystem dynamics were communicated via the picture and an accompanying table. The system was regulated by a total allowable catch (TAC) at the threshold, which could be respected or not. If not, the subjects would be punished through a recovery phase where they could not harvest for a certain number of periods (see Table 1). This treatment was inspired by the **Common Fisheries Policy** (**CFP**) of the European Union (EU), which sets quotas for the quantity of each species that can be caught in a certain area. Each country is given a quota based on the total available (Total Allowable Catch, TAC), which is fixed annually by the Council of Ministers in consultation with scientific advisers. After quotas are fixed by the Council of Ministers, each EU member state is responsible for policing its own quota. Different countries distribute their quota among fishermen using different systems. Areas may be closed from fishing to allow stocks to recover.

A crucial feature in our experiment was that if the group followed the optimal management strategy of recovery or depletion, the payoff potential in the *quota treatment* mimicked the threshold treatment in this phase. Again, each resource unit harvested was worth SEK 5.

In this experiment we expect more under-exploitation in the quota treatment compared to the threshold treatment because the subjects are "forced" to let the resource recover.

We also compared the baseline threshold treatment with a similar unregulated case with a little modification. We modified the way in which the threshold was communicated to the subjects. In the hereafter referred to *lack of visualization treatment*, we presented the resource dynamics without the graph, using only a table to illustrate resource dynamics. Note that the payoff structure was *exactly* identical to baseline case.

Between these two treatments we hypothesize that there are no behavioural differences. For an overview of the treatments in this experiment see Table 2 below.

Table 2: Sketch of policy treatments

Baseline threshold treatment	**Quota treatment**	**Lack of visualization treatment**
Latent regime shift in the ecosystem dynamics	Latent regime shift in the ecosystem dynamics	Latent regime shift in the ecosystem dynamics
Unregulated	Regulated with a TAC	Unregulated
Dynamics communicated via a table and a figure	Dynamics Communicated via a table and a figure	Dynamics Communicated via a table

When comparing the baseline threshold treatment to the quota treatment we note that a resource regulated using a quota system will be associated with more under-exploitation (provided the quota is set at an efficient rate of harvest). This is in line with our predictions. The quota treatment is however also associated with more over-exploitation, although this effect is not as strong (see Figure 5 and Table 3 below).

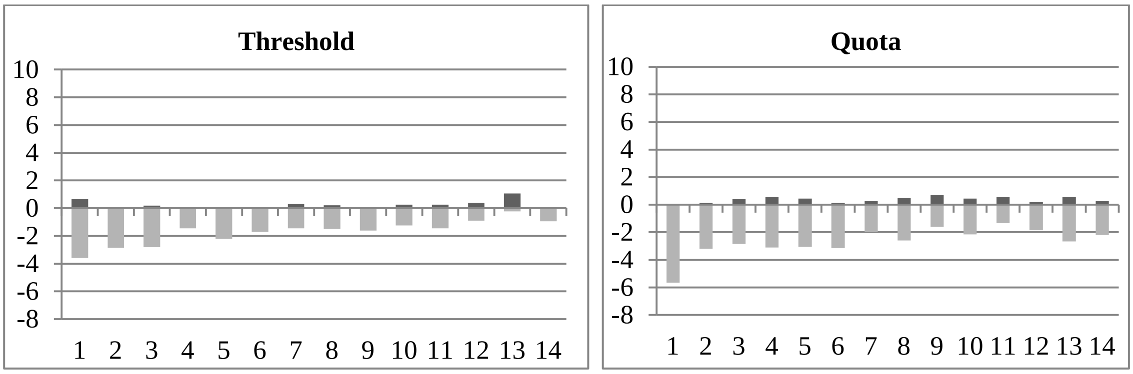

Figure 5: Average over- and under-exploitation in resource stock units for each experiment round for both treatments.

Table 3: Comparison between the quota treatment and the threshold treatment

	Threshold	Quota	p-values (Mann-W)
Average efficiency	0.837	0.745	0.0000
Average over-exploitation (in units)	0.2475	0.3714	0.0073
Average under-exploitation (in units)	-1.7080	-2.671	0.0050

The most striking difference is found when we compare the baseline threshold treatment with the lack of visualization treatment. As Figure 7 and Table 4 clearly illustrate, we find significantly less over-exploitation (and hence more efficient resource management, i.e. ability to come closer to the maximum possible sustainable yield) if the information regarding such an abrupt change is presented using a table *and* visualization compared to only using a table.

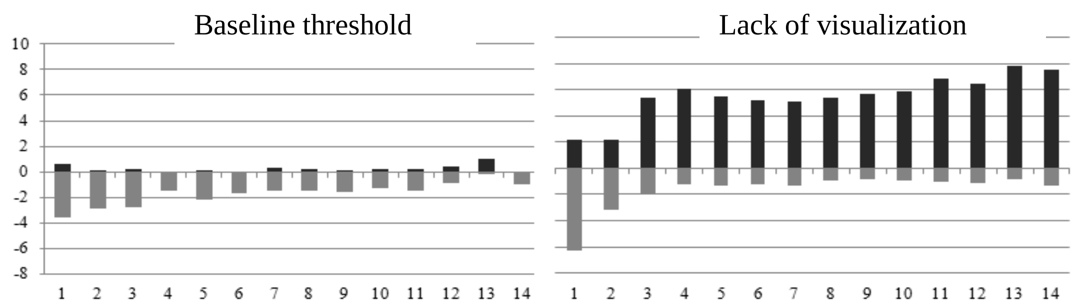

Figure 6: Average over- and under-exploitation in resource stock units for each experiment round for both treatments.

Table 4: Comparison between the baseline threshold treatment and the lack of visualization treatment

	Baseline threshold	Lack of visualization	p-value (Mann-W)
Average efficiency	0.837	0.645	0.0000
Average over exploitation	0,2476	5,497	0.0000
Average under exploitation	-1,708	-1,677	0,3488

6 Experiment 4: Thresholds and Price changes (Based on Lindahl et al. 2015b, manuscript in prep.)

What happens if there is a sudden demand increase, manifested for example in a price increase of fish? How will resource users react to such external surprises? Could cooperation erode or will we see more cooperation? Similarly, how will resource users respond to a sudden drop in profitability – in our case manifested through a price (decrease)? To explore these questions we extended the experimental design (the threshold treatment). We implemented this feature by telling our subjects that the experimental setting is not fixed, informing them that some variable(s) may change during the course of the game and that if something *did* change in the experimental setting, the experimental leader would immediately let them know about the change. For all our groups we introduced the price change after the fifth round. In both price treatments we started with a price of SEK 5 per harvested resource unit. In the price increase treatment the price increased to SEK 8 per unit, while decreasing to SEK 3 per unit in the price decrease treatment. In total 220 subjects participated in this experiment.

When resource users face this type of uncertainty it is challenging to make behavioural predictions, because behaviour will depend on resource users' expectations. We can however predict the following: We expect no behavioural differences between the two price treatments for the first 5 periods because up to this point the experimental setting is identical between these two treatments (there have been no realized changes and the instructions are identical). If we find a significant behavioural difference between the no change treatment (control) and the price treatments we know that just the anticipation of a change influenced behaviour. It will of course also be interesting to see how the different *realized* changes influence behaviour.

Below, in Figure 7 we see that there is a clear difference between the no price change treatment and the two price change treatments when we compare efficiency. This difference is also statistically significant (see Table 5)

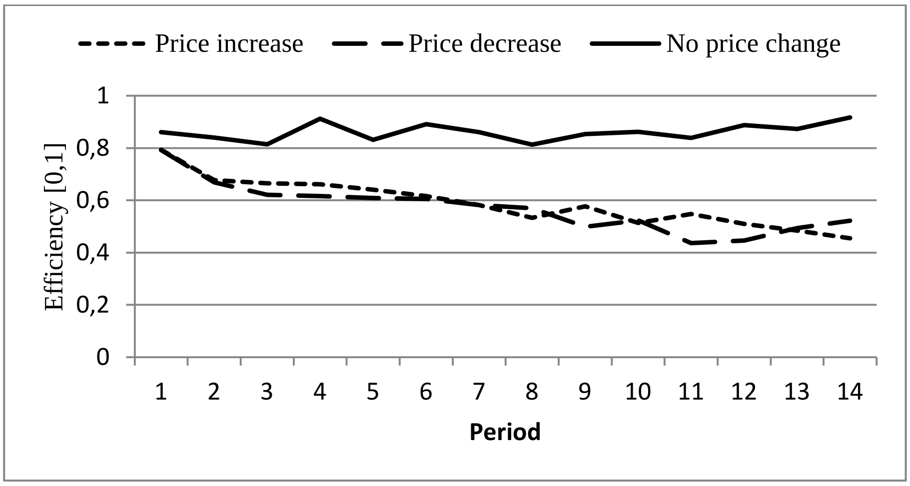

Figure 7: Average efficiency over time for the different treatments, measured as deviation from optimal claims, where an efficiency of 1 indicates optimal management

Most of this inefficiency stems from over-exploitation (see Lindahl et al. 2015c for details) Table 5 also reveals that there is no statistically significant difference between the two price change treatments when comparing average efficiency achieved, where efficiency is measured as the share of earnings of maximum possible.

Table 5: Comparing treatments with respect to average efficiency

Average efficiency	No change	Price increase	Price decrease	p-value (Mann-W)
Period 1-5	0.8515	0.6875		0.0009
Period 1-5	0.8515		0.6612	0.0011
Period 1-5		0.6875	0.6612	0.1528
Period 6-14	0.8663	0.5352		0.0000
Period 6-14	0.8663		0.5196	0.0000
Period 6-14		0.5352	0.5196	0.2793

It is interesting to see what type of change the subjects did anticipate – information which we collected in the post-experiment questionnaire. About half of the subjects stated that they did discuss different potential changes within the group during the experiment. Rather few, about 15 per cent, anticipated a price change. Most subjects, about 60 per cent, anticipated a stock decrease or a change in the growth rate. About 10 per cent anticipated a “no change” and about 10 per cent an early end of the game. With such expectations it is not surprising that the price change treatments differed from the no change treatment. The direction of the change, more aggressive exploitation, is also no surprise.

7 Experiment 5: Interlinked resources (Based on Lindahl et al. 2015c)

In this experiment, we wanted to increase our understanding of if, and how, communication between resource users affects their joint ability to learn about and manage a complex resource system involving resource interdependencies. Resource interdependencies, a factor that is highly relevant for fisheries, can be associated with a particular management difficulty; if one of the resources is not managed optimally, there will be negative spill-over effects on the other resource(s). Consider for example coastal and offshore fisheries. These may be connected through migrating fish, through providing habitat for different life-stages of harvested species, or through food web linkages (for example, nutrient rich coastal ecosystem generating spawning larvae that is consumed by larger fish at sea). Management practices that degrade coastal system lead to undesirable effects also for the offshore fisheries, whereas sustainable harvesting can have a positive effect across systems (Berkström et al., 2012).

To capture this feature we developed a management situation suitable for laboratory experiments fulfilling three broad criteria: (1) respondents are reliant upon some level of experimentation to develop an understanding of non-trivial ecological dynamics (2) the ecological resources are interdependent, and thus extraction of one resource will affect the potential harvests that can be extracted from the other resource, and (3) access to the different but interdependent resources is asymmetric, meaning that actor groups are situated in more or less favourable positions in relations to others. The latter feature we felt necessary to include as access to ecosystem resources is rarely distributed evenly among user groups or potential beneficiaries. Furthermore, for such a management situation we wanted to be able to explicitly test the treatment of allowing or denying the actors the ability to communicate.

A configurational perspective, where an interdependent social-ecological systems (SES) is described in terms of parts and relations, (Bodin and Tengö, 2012), was applied when we designed the experiments. In other words, we selected specific patterns of mutual actors- and ecological resources interdependencies (SES configurations) that materialized into different virtual management situations resembling our three criteria. The simplest SES configuration that still fulfils all our criteria is presented in Figure 8 and involves two groups and two ecological resources.

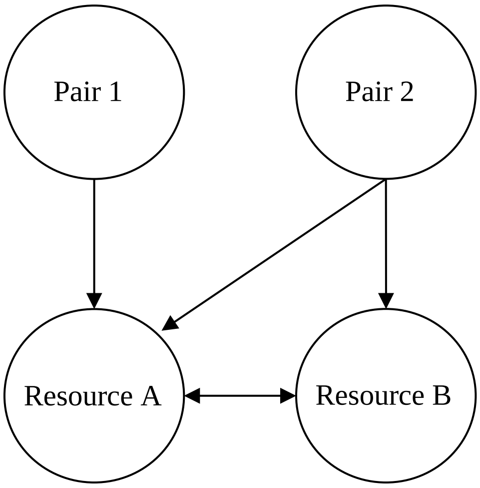

Figure 8: Basic configuration of the designed social-ecological system.

The top nodes represent two groups, while the bottom nodes represent two interdependent ecological resources. Resource A is shared between the two pairs, whereas resource B is only accessible to one of the pairs. Our treatment communication was accomplished by allowing the two pairs to communicate with each other, i.e. to add a social link between the two top nodes in Figure 8. Communication between the subjects within a given pair was allowed at all stages of the game in both treatments (they sat next to each other). In the communication treatment the two pairs could communicate with each other between each decision round (during the communication phase pairs were facing each other). The decisions taken by each pair were kept private. To enable private decisions we let each pair fill in a decision protocol while turning their back to the other pair.

In total, there were 72 students forming 18 groups of 4 subjects. The subjects were informed that the size of their harvest (in each decision round) from a resource depended on the total amount of hours spent harvesting from that resource (in that decision round). For each resource an optimal number of hours to spend on harvesting was assigned, which could generate a maximum harvest of 50 resource units. This optimal time was fixed and unknown to the subjects. An illustration of an approximate correlation between invested time and harvest was presented to the subjects (see Figure 9 below). The figure also illustrates that the two resources are interdependent. The maximum harvest of 50 units can only be obtained if resource B is harvested optimally and vice versa. If resource B is not harvested optimally, the harvest of resource A is described by a lower curve. After the experiment, the subjects were rewarded based on their performance, where the best performing pair received SEK 200. The performance was defined as their total accumulated harvests. In each session we ranked all the pairs with the same type of resource access. The amount of money received by a specific pair was then relative to the best performing pair with the same resource access in that specific experiment session. Thus, the potential rewards were the same irrespective of whether the pairs could access one or two resources.

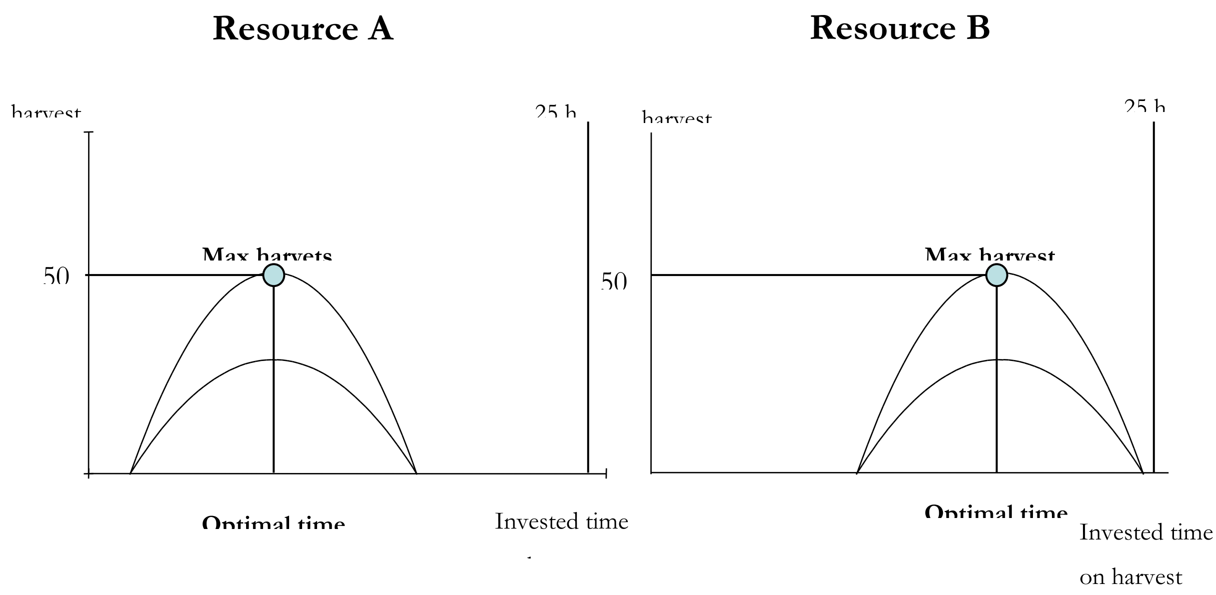

Figure 9: Resource dynamics and interdependence

Our results indicate that communication, through its interaction with experimental learning, is more multifaceted than what previous experimental studies on commons dilemmas suggest. We show for example that in communicating groups the likelihood of successful resource management increases, but this effect is mostly dominant in earlier periods, when resource dynamics are unknown. When groups can communicate there is a continuing trend of improved resource management over time. When groups cannot communicate the trend of increased performance stops at some specific break point, after which there is no increase in management efficiency (measured as deviation from optimal harvest) (see figure 10 below).

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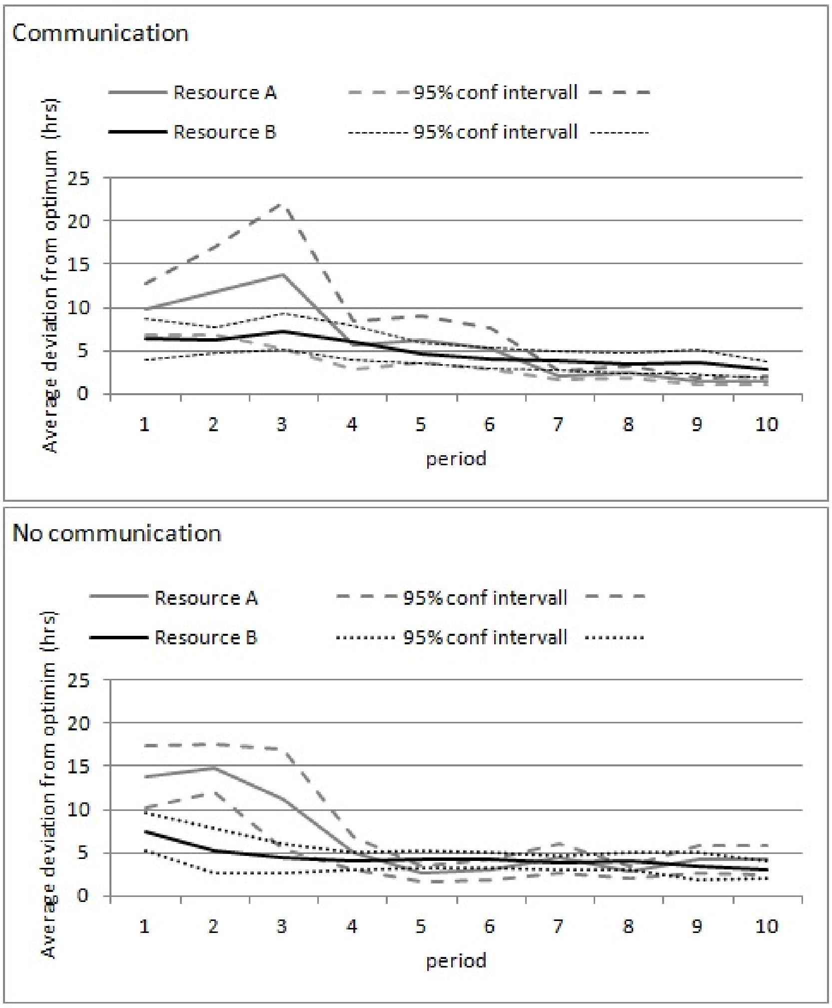

Figure 10: Average deviation from optimum in hours for both treatments and resources.

Experiments are generally employed to test hypotheses in a structured manner by using random assignment into treatment and control conditions (List and Price, 2013). This was also the approach we adopted for experiments 1-4 presented above. In this experiment we introduce ecological- *as well as* social complexity (resource access is asymmetrical), meaning that the focus of the experiment inevitably shifts from testing hypotheses to instead allowing for a more exploratory approach, where we generate new hypotheses.

Based on our results we hypothesize for example, that communication stimulates continual improvements by fine-tuning of management through experimental learning and coordinated resource extraction. Moreover, users of interdependent common and private property resources may devote more attention to the shared resource and neglect feasible improvements regarding the use of privately held resources. Furthermore, we hypothesize that in communicating groups, the need to quickly gain a basic understanding of the dynamics overshadows not only the devotion to improve management of the private resource but also the potential tensions brought by the asymmetry in resource access.

8 Results from a small survey of fishermen

8.1 Sample characteristics

The survey was sent out to 74 Norwegian professional fishermen with a response rate of 11% (n=8). The survey consisted of statements with response options on a five-level numeral Likert scale measuring strength of agreement from 'disagree' to 'agree' (Likert, 1932), as well as an option to comment on each statement. The analysed sample consists of eight respondents between the ages of 32 and 68 years (m=45, mdn=46). All respondents work full-time as fishermen and have a fishing experience ranging from 15 to 48 years (m=25, mdn=21). Fishing grounds range from the Helgeland coast in mid-Norway to the Norwegian-Russian border in the northeast, with seasonal geographic variations. The techniques used include net fishing, seine fishing and trap/pot fishing.

The targeted species depend on the season but include Atlantic cod (*Gadus morhua*), Atlantic herring (*Clupea harengus)*, Atlantic mackerel (*Scomber scombrus*), Atlantic halibut (*Hippoglossus hippoglossus*), Greenland halibut (*Reinhardtius hippoglossoides*), anglerfish (*Lophius piscatorius)*, haddock *(Melanogrammus aeglefinus)*, pollock (*Pollachius virens*), ling (*Molva molva*), rose fish (*Sebastes norvegicus*) and crab (unspecified).

8.2 Results

All respondents (n=8) stated that they are aware of the fact that today's resource use affects future resource availability (Fig. 1a). Only one out of eight, however, believes that his fishing has an impact on the resource to any significant extent (Fig. 1b). A reason for this is the small quotas assigned to the small size fleet. Compared to the Norwegian coastal and offshore fleets, and the Russian fleet, the small-size boat fleet has little impact on the resource availability, according to the surveyed fishermen. All respondents stated that it is common practice for fishing boats to communicate with each other about – among other things – fish stocks and weather conditions (Fig. 1h).

When it comes to unexpected fluctuations in resource populations, six out of eight respondents report having experienced abrupt changes in catch or resource availability, believed to stem from dramatic population reduction (Fig. 1c). Examples of species with sudden population decrease include Atlantic cod and Atlantic herring. Only one respondent thinks that such changes will become more prevalent in the future (Fig. 1d).

While half of the respondents think that politicians lack a good understanding of the resource (Fig. 1e), seven out of eight fishermen consider current resource management to be sustainable (Fig. 1f). All respondents further believe that they will be able to live just as well off their resource ten years from now (Fig. 1g).

The respondents appear to view the system as linear without any latent abrupt changes (c.f. experiment 1 in this report), i.e. a traditional system with which they are familiar. The attitude towards the resource is that there is no, or a low, risk of abrupt change and that things will remain as they are for at least ten years (fig. 1d, g). This perspective may explain why respondents view current management as sustainable, since existing management would appear appropriate from an experience-based perspective.

The alleged minor impact of small-scale fishing on resource availability is possibly a result of asymmetrical resource access and smaller benefits reaped by the small-boat fleet, in relation to large-scale fishing fleets (c.f. experiment 5). The assumption of having little impact may also be reinforced by the belief that traditional management is efficient, with one possible consequence being low incentives for changes in attitude and behaviour.

It is possible that there is an on-going discussion within the small-boat fleet regarding increased risk of regime shifts, poorly reflected in the small sample here. However, given that boats communicate with each other, the respondents' standpoint is likely based on community reports as well as personal experience, thus indicating that it might be a widespread belief. To what extent poor communication from authorities regarding increased risk of regime shifts is a contributing factor is however unclear and should be investigated further as it has proven to be a key factor in efficient management.

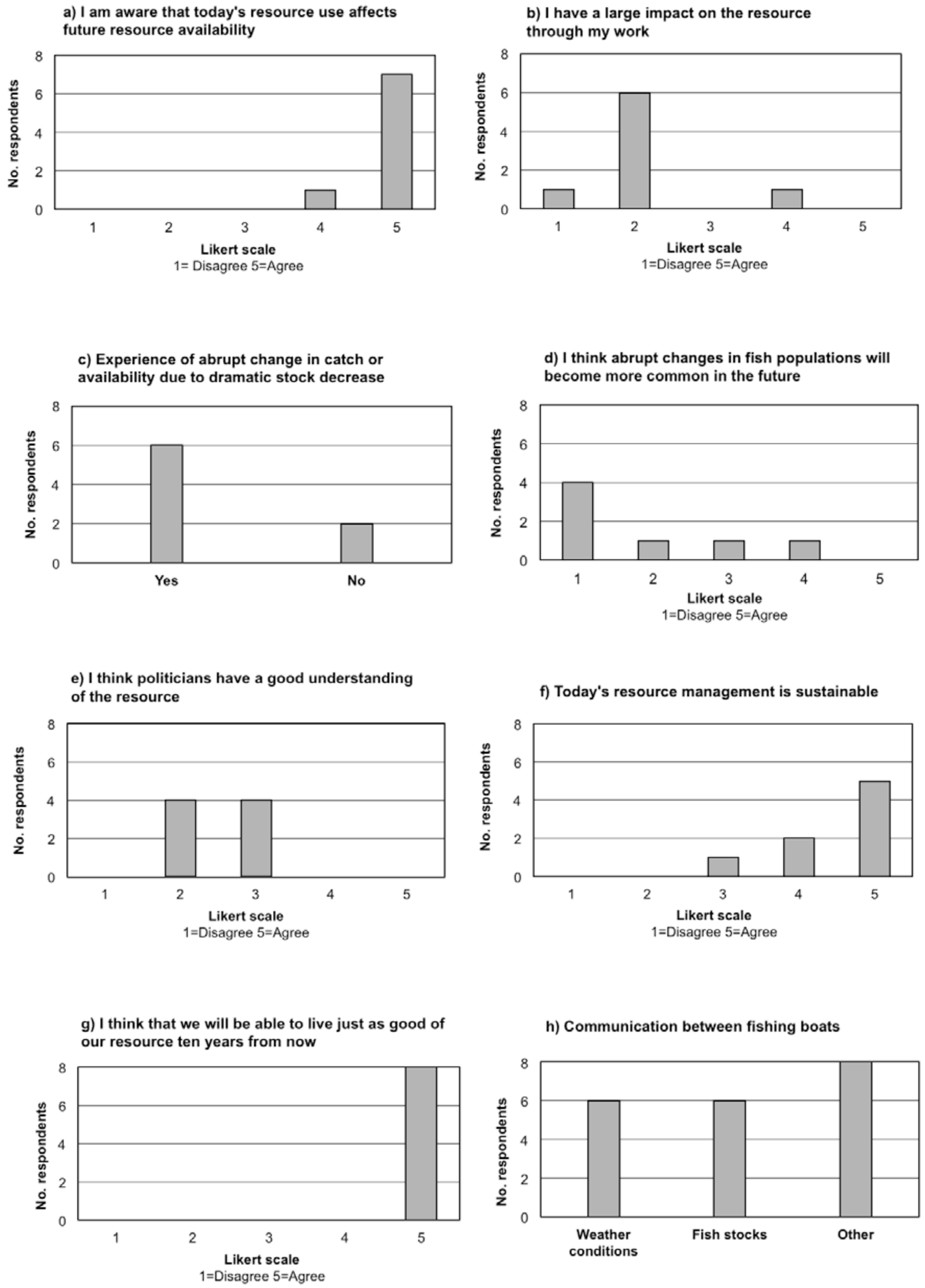

Figure 11: Results from a small survey of professional Norwegian fishermen (n=8).

9 Summary and conclusions

This report can help us provide some recommendations on how to support decision-making for populations facing potential abrupt changes negatively affecting the basis for their livelihoods. Our results suggest that long-term collective action among fishermen should be promoted as it is likely to prevent abrupt changes and as it enables a more sustainable resource management.

Policy recommendations for successful commons management often centre on how to enhance and support arenas for communication and conflict resolutions (Ostrom et al., 2002). Our results suggest that the actual problem faced by a group of resource (how it is perceived) also matters for the success of management. Thus, from a policy perspective it is also clear that one should consider carefully the best way to communicate potential future changes. For example, rather than assessing accurate risk levels, one should think clearly about *how* to communicate risks. Our results show that people may have difficulties grasping probabilities other than a 50/50 chance to which they can easily relate (e.g. flipping a coin). Moreover, our results suggest that graphical images can be particularly powerful. Recall that an unregulated system performed equally well as a regulated system (in the form of a TAC complemented by a recovery phase). However, this result was heavily dependent on the graphical image. If not present, users tend to over-exploit the resource substantially, thus increasing the likelihood of an abrupt shift.

A realized price change did not have any substantial influence on behaviour and we found no significant differences between the two price treatments. Our results suggest however, that users may respond *heavily* to uncertainties about potential future changes. In our experiment (c.f. experiment 4) they knew that something in the experimental setting could change but they did not know what. Many anticipated a sudden drop in resource availability, which triggered more over exploitation. This is in contrast to our first and second experiments, where risks of abrupt changes stimulate more cooperative outcomes. However, in all the risk treatments (c. f experiment 1 and 2) the "location" (the critical resource stock) of the potential threshold where a shift may occur was always known. Thus it was easier to coordinate strategies to avoid a shift. In our price change experiment this was not possible. In a world where fishermen experience many uncertainties it could be crucial to provide them with coordination devices, like for example a total allowable catch representing some safe minimum standard (Ciriacy-Wantrup 1952). Nevertheless, when providing resource users with this instrument, we still need to think carefully how we present them with it.

Policy implications from this effort thus depend heavily on likely future scenarios concerning abundance of fish species, their reproduction dynamics, market condition (e.g. market prices) and regulations, as well as the resource users' capacity and willingness to communicate with each. Most importantly perhaps they depend on how resource users perceive these future scenarios. We want to highlight though that these results are based on laboratory experiments performed with students and as such they should be interpreted and generalized with caution.

Our small survey indicates that Arctic fishermen *do* communicate with each other, about fish stock, among other things, which shows that they are likely to cooperate and coordinate with regard to fishing activities. It also shows that they do not typically foresee any abrupt and potentially persistent changes in the resource stock dynamics, at least not for the time being. Seeing as this is the case, we cannot really tell if they are also likely to coordinate well in light of potential negative changes. Moreover, the response rate of this survey was very low. To increase the external validity of our results we therefore suggest that more research be conducted in this area.

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