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Overexploitation of renewable resources: The role of misperceptions

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Abstract

Numerous renewable resources have been exploited beyond limits for sustainable and economic development. At times over-exploitation has been observed even in cases where management regimes have been in place. Thus, it seems pertinent to search for explanations beyond the theory of the commons. An experiment is performed where subjects set reindeer quotas in a district where lichen has been severely depleted by preceding overgrazing. All subjects err on the side of over-exploitation. Behavior seems to be dominated by inappropriate, static mental models and inefficient heuristics. Hence, a subtle information problem is revealed. © 1998 Elsevier Science B.V. All rights reserved.

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1. Introduction

Numerous renewable resources have been exploited beyond limits for sustainability. Quite a few such resources have been more or less destroyed, for example, fish and whales, forests, soil, and ground water reservoirs. Open access to a resource, the commons problem, is known to cause overexploitation (Gordon, 1954; Hardin, 1968). However, it seems to be the rule rather than the exception that policies to limit access are put in place too late to prevent overexploitation. Could it be that policy makers misperceive the bioeconomics of renewable resources? Depletion of profitable renewable resources has even taken place when the commons problem has been absent in the first place, indicating that local mismanagement could also be a problem. The purpose of this paper is to investigate misperceptions of bioeconomics.

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Earlier it has been shown that misperceptions of bioeconomics could lead to overinvestment and overexploitation in the first place (Moxnes, 1998). In this paper, focus is on crisis management of a renewable resource, that is, management of a resource where a certain amount of overexploitation is already a fact. Our case is reindeer herding and over-grazing of lichen. Lichen is the crucial source of winter forage for the reindeer. While this is neither a familiar nor an important resource for most people, the underlying ecosystem is representative of a large class of renewable resources. The class is characterized by a *stock* nature of the resource (for example, water reservoirs, fish stocks, and perennial lichen). In this lies the value of an otherwise rare case. The stocks make this class different from *flow* resources (for example, river water and seasonal grass).

While there exist numerous examples of lichen depletion due to overgrazing, there are only a few accounts where the commons problem is not present. For this reason we rely on a laboratory experiment, where the commons problem and other competing hypotheses are ruled out by the experimental design. The experiment belongs to a class of experiments studying 'misperceptions of feedback' (Brehmer, 1992; Diehl and Sterman, 1995; Funke, 1991; Sterman, 1989a, b. Experimental studies in this category show, with few exceptions, considerable deviations from normative standards. Pitfalls are typically created by feedback and the stock nature of variables. Hence, we expect to observe mismanagement. However, at the outset it is difficult to predict the extent to which biases will occur, to what extent biases will differ between subjects, to predict what mental models and what heuristics will be applied, and to predict the effects of information treatments.

First we review some evidence of historical overexploitation of lichen. Next, we present the task, hypotheses, and experimental design. The ensuing results show that all of the 48 participants chose strategies that lead to stronger exploitation of lichen than what is optimal. The majority nearly extinguishes the resource base. Discussing behaviour, it seems that very few operate with a proper dynamic mental model of lichen stocks. Behaviour is largely consistent with static mental models and inappropriate heuristics.

2. Historical accounts of mismanagement

The experience at St. Paul Island in Alaska provides a very interesting case of mismanagement. According to Scheffer (1951), four bucks and 21 does were imported in 1911, "to provide the native residents with a sustained source of fresh meat." Scheffer quotes Hanna's predictions from 1922: "It would seem that here is the place to maintain model reindeer herds –." Contrary to the high hopes, development became 'disappointing' (Fig. 1). The population grew rapidly to about 2000 animals in 1938. Twelve years later, there were only eight animals left. By 1942 investigations showed that practically all the lichen was gone, the key source of energy for the reindeer during the winter. With hindsight Scheffer argues that "the reindeer population was at least three times the carrying capacity of the range."

The commons problem was not present. The local government seems to have made decisions on killings from the very beginning. It "made a serious effort in 1940 and 1941

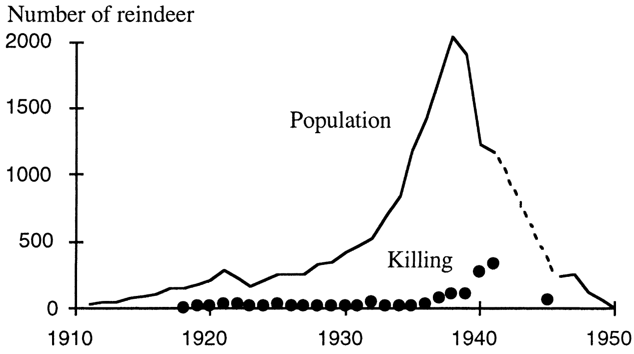

Fig. 1. Data from St. Paul Island, Alaska. Source: Scheffer (1951). Population data from 1942 through 1945 are lacking due to the evacuation of the 500 inhabitants during the war. Population data are accurate to within about 10 percent.

to reduce the size of the herd by doubling and tripling the annual kill." However, the reductions in the herd were far too small and came far too late to prevent the depletion of lichen. From Scheffer's article it seems that the islanders were not particularly ignorant about reindeer herding. At the outset they were instructed by an Inuit herder in the handling of reindeer. Hanna's evaluation of St. Paul was published in The Scientific Monthly, and it seems likely that the ideas from this article were known to the inhabitants.

According to the American Society of Mammalogists in 1950 (quoted by Scheffer), St. Paul Island was not an exception: "(The Society) urges that the Canadian Government not undertake the introduction of reindeer into Ungava. Before any introduction is seriously considered, those persons involved in any planning are urged to make a thorough study beforehand of the problems of integrating lichen ecology, reindeer biology, and native culture – serious problems that have not been solved to date on any workable scale on the North American continent." Numerous cases of over-grazing of lichen are also known from other parts of the world, for example, in the Nordic countries. Normally the commons problem is present.

Since we hypothesize the stock nature of lichen to cause misperceptions, evidence that the dynamic nature of lichen is clearly understood, would help reject the hypothesis. In scholarly papers, the stock nature of renewable resources has been acknowledged and analyzed at least since the formation of the Lotka–Volterra equations in the early 1930s. However, according to diffusion theory, Rogers (1995), there is no obvious and direct link between theory and practice. In fact, we find little evidence that the stock nature of lichen has been focused in discussions of overgrazing. Klein (1968) presents data for a dramatic overshoot on St. Matthew Island, north west of St. Paul. He mentions over-grazing of lichen as the first factor when explaining the rapid die-off of reindeer in 1964. However, when discussing natural mechanisms of population control, he argues that the lack of complexity in northern ecosystems could explain the overshooting tendency. When he comments on the apparent stabilization of reindeer in South Georgia, less severe winter conditions than those on St. Matthew are hypothesised to explain the difference. He does not discuss and compare the dynamics of lichen with the dynamics of Tussock grass which is the winter forage in South Georgia.

Based on a stock model for lichen pastures in Northern Norway, Moxnes et al. (1993) called for reductions in reindeer herds to rebuild lichen. With few exceptions, the ensuing debate did not recognize the stock nature of lichen to be an important topic. Rather the debate abounded with assertions about the importance of hunting, berry picking, tourism, pollution, use of snow scooters and motor bikes. While all these factors have negative impacts on lichen, none of them are likely to explain the depletion of lichen in recent years. Reactions ranged from agreement to full disagreement, indicating that there is no coherent view on total reindeer management within the sami community.

3. Experimental design

3.1. Task

The experiment is organized as a simulator. The task is to set yearly quotas for reindeer over a 12 year period. Each subject acts as a dictator; the commons problem is non-existent. Fig. 2 shows the computer screen. Each year, six different information cues are updated. In the results boxes, numbers do not appear before the experiment is finished. Details and instructions to the subjects are presented in Moxnes (1995).

3.2. Underlying model

The underlying simulation model can be described as a predator–prey model for reindeer and lichen, however somewhat more complicated than the Lotka–Volterra equations (Moxnes et al., 1993). The crucial assumption for this study is the stock nature of lichen, where lichen growth $g(L)$ depends on the amount of lichen L, (see Eq. (1) and Fig. 3). A similar model is used by biologists (see for example, Gaare and Skogland, 1980). Parameters were based on Lyftingsmo (1965). Andreyev (1977) and Igoshina

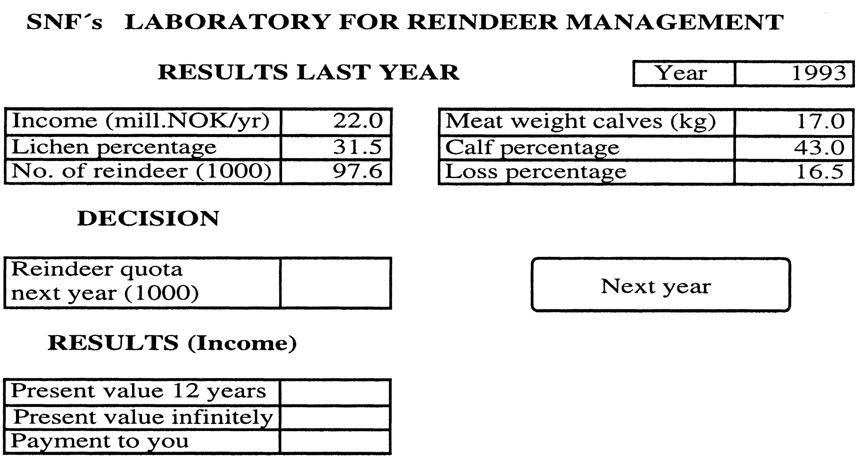

Fig. 2. Computer screen, with values for initial year.

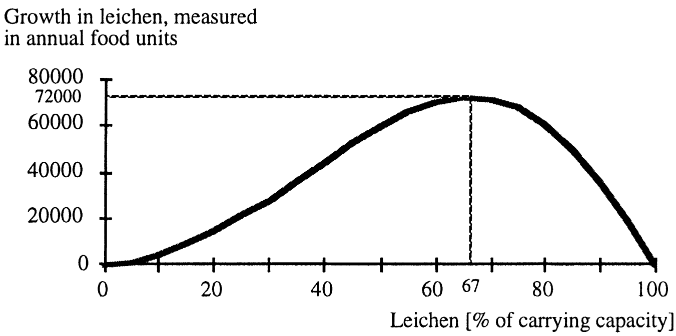

Fig. 3. Lichen growth as a function of lichen.

(1939) present similar data. The removal of lichen by grazing $h(L,N)$, depends on the number of reindeer N and the level of lichen (Holling, 1965). Grazing is not very sensitive to the amount of lichen except when lichen levels are low. A linearized version of this curve is used in the lichen model by Gaare and Skogland (1980).

$$\frac{dL}{dt} = g(L) - h(L,N) \tag{1}$$

Reindeer is described by a cohort model to capture the maturation delay. Slaughtering is determined by the quotas set by the subjects. The slaughtering strategy serves to maintain a near to optimal herd structure. Both recruitment and natural mortality depends on body weight (Lenvik and Aune, 1988; Eloranta and Nieminen, 1986). Body weight depends on the availability of lichen and is related to the assumptions about grazing h. The model assumes a constant availability of summer grass per animal.

3.3. Main hypothesis and benchmark to judge performance

The subjects are asked to maximize the present value of infinite horizon incomes PV. Optimal management is assumed beyond the 12 year time horizon of the experiment. The discount rate is 2 percent p.a. Since the subjects do not receive complete information about the underlying model, an exact optimal policy does not exist. However, it is fairly easy to establish a sufficiently precise benchmark to test our hypothesis about mismanagement.

All subjects learn that the pastures can sustain not more than 72 000 animals in the long run, and that the optimal situation is characterized by this number of reindeer and a lichen stock of 67 percent of the carrying capacity (Fig. 3). Hence, the maximization of PV can be transformed into a problem of reaching the optimal situation in an optimal manner. Since incomes are lost whenever the lichen stock deviates much from 67 percent, the adjustment should be as quick as possible, refer economic literature on optimal harvest.

Fifty percent of the subjects get to see Fig. 3 as an information treatment. Starting out with 31.5 percent of carrying capacity for lichen, the curve immediately reveals that a reduction to 30 000 reindeer is needed to stabilize lichen. The quota must be set lower than that to achieve regrowth in the lichen stock. Going only slightly below 30 000

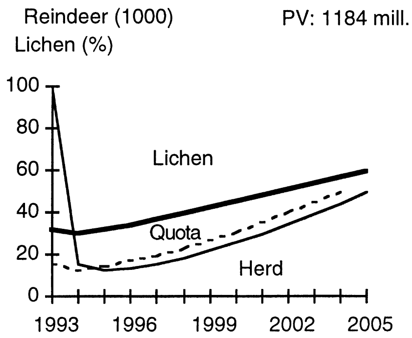

Fig. 4. Optimal quota policy, number of reindeer, and lichen percentage.

implies that the regrowth of lichen will be slow and future income potentials will be lost. Going very low with the reindeer quota, the future regrowth of the herd will be limited by its reproduction rate (import of livestock is not allowed). In this case, the flock will not be large enough to utilize a future abundance of lichen. After a closer comparison of growth rates based on available information only, we set the benchmark to 20 000 animals (Moxnes, 1995). Thus, subjects should set the first year quota below this limit. If a quota of 20 000 reindeer is set in the first year, outcome feedback would typically indicate a further reduction. Note that after a lower herd size has been reached, quotas can be set at any height as long as natural reproduction is limiting the herd growth.

To check the reasoning above, we find a near-optimal deterministic solution by trial and error. The following strategy is used: $Q=72^{*}(L/67)^{\alpha}$, where Q is the quota, L the lichen percentage and the optimal value of the parameter α is 2.1. The strategy resembles a target escapement policy. However, the herd is never reduced to zero because a minimum of reindeer is needed for future 'harvesting' of lichen. The solution is not very sensitive to the exact choice of a lower quota (α). The solution shown in Fig. 4 gives a PV of NOK 1184 million, and a present value over the 12 year horizon PV_{12} of NOK 163 million. The quota is 13 000 animals at the lowest, well below the benchmark.

The remaining 50 percent of the subjects do not get to see the growth curve for lichen. They have to infer the curve from available information and from outcome feedback. As mentioned before, the written information pinpoints the maximum of the growth curve. That the curve has to go through the origin is obvious. After receiving outcome feedback the curve should be fairly well established after a couple of years. Moxnes (1995) suggests a first year benchmark of 30 000 reindeer for this treatment. The written text explains that it took 10 years with an excess of about 30 000 animals to overgraze lichen towards 31.5 percent. Hence, a herd size about 30 000 below what can be fed by the current growth, should ensure a return to optimal conditions in about 10 years. Setting the first year benchmark at 30 000 animals, the herd could be increased to 72 000 animals in about 5 years by natural growth. Hence, the benchmark is likely to be sufficiently high to rule out virtually any risk that lichen should become excessive. After receiving outcome feedback, the quota should be reduced below 20 000 animals. Hence, we reduce the benchmark to 20 000 reindeer after 2 years.

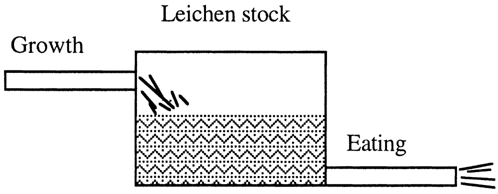

Fig. 5. Figure to illustrate the stock and flow relationship for lichen.

At first sight the optimal policy might seem extreme and unrealistic. However, in real life total bans on fishing and hunting have been practised for many species.

3.4. Minor hypotheses, pedagogical devices

Two information treatments are used to help reveal the nature of possible misperceptions. At the same time these two treatments are tests of two potential pedagogical devices. The first information treatment ('Stock') was designed to counteract the hypothesized misperceptions of lichen dynamics by attempting to improve on subjects' mental models of the stock nature of lichen (Eq. (1)). A positive effect on performance will indicate that subjects need help to construct a dynamic model *and* that they are able to use this information to improve their strategies. No effect should be expected if they already have a dynamic model in mind *or* if they do not know how to use this information to improve their strategies. Hence, a positive effect will yield the most useful information. The treatment consisted of Fig. 5 and the following text:

> "More about lichen: Note that lichen is perennial. The lichen stock (the lichen percentage) increases by yearly growth and is reduced by yearly eating by reindeer. To have a stable lichen stock, yearly eating must equal yearly growth. To get an increase in the lichen stock, yearly eating must be made lower than yearly growth. This point is illustrated by the water container below."

The second treatment ('Growth') also tries to improve on subjects' mental models of the stock nature of lichen by showing the growth curve for lichen shown in Fig. 3 and the text below. The growth curve is a frequently used model in economics and biology (Schaefer, 1954). In addition to the qualitative information, this treatment also provides exact numerical estimates for lichen growth measured in yearly reindeer rations. As for treatment one, it is a positive effect that provides the most useful information:

> "In particular note the following about the growth of lichen: Before you start, look carefully at the figure below (Fig. 3). It shows how much the lichen grows for different levels of lichen. When there is little lichen there is little growth, 'the seed' is lacking. When there is plenty of lichen, growth is also low because lichen is competing with itself about the space. If 67 percent of the lichen remains after reindeer eating, the growth is at its maximum. This growth is sufficient to feed 72 000 reindeer. If you are pleased with the current lichen stock, choose a total herd size that eats exactly the

growth. This stabilises lichen. If you want the amount of lichen to increase, choose a smaller herd size. If you prefer less lichen, choose a larger herd size.''

3.5. Details of the experimental design

An attempt has been made to rule out competing explanations of mismanagement by the experimental design:

1. As mentioned before the commons problem is ruled out by focusing on total quotas (Gordon, 1954; Hardin, 1968). That open access to limited resources leads to rent dissipation and possibly extinction, is demonstrated not only in theory, but also by experiments (see Plott, 1983; Walker and Gardner, 1992).
2. Crises might be affected by speculation and hoarding in the oil market (Mitchell, 1982) and in the food market (Sen, 1981). For instance, before the extinction of *Pinguinus impennis* in 1844, prices of birds and eggs rose to very high levels. In the experiment, reindeer meat prices are constant and convey no signs of demand side hoarding.
3. Crises might be prolonged and deepened by an inability to admit error by the individuals and organizations involved. Argyris (1990) describes organizational defences as follows: ''– any policy, practice, or action that prevents the people involved from being embarrassed or threatened, and at the same time, prevents them from learning how to reduce the causes of the embarrassment or threat.'' See Leibenstein and Maital (1994) for a game theoretic formulation of Argyris' idea. See also Bazerman (1986) on 'non-rational escalation of commitment', and Janis (1972) on 'groupthink'. Since the experiment does not involve interactions between people, other than some contact between experimenter and subject, there should be little need for defensive action.
4. If the natural rate of return for a renewable resource is lower than the discount rate, it will be profitable to extinct the resource (Clark, 1973). In the experiment this is not the case.
5. The subjects are told, via the criterion, to maximize infinite horizon incomes. However, it might still be that they are overly sympathetic and permissive towards those being inflicted by the quotas. In case they are, this would lead to higher early quotas or to delayed reductions in the quotas. To test if this role playing effect dominates the instructions, a third information treatment ('Pity') is used to reinforce the criterion. (With respect to role playing also note that there is no widespread controversy with respect to killing reindeer in Norway).

> ''More about the income goal: Note, in particular, that the goal is only to get as much income as possible. You are not supposed to take into consideration the problems that follow from rapid adjustments of the industry. In this respect, the experiment deviates from reality. Whatever weight you want to put on such problems, remember that the sole task here is to maximize incomes.''

Forty-eight subjects participated in the experiment. The three information treatments were used in a three-way factorial design. With 48 subjects, there were six replications in each of the eight cells. The participants were assigned randomly to the different treatments. One exception is eight participants with education in resource management who were assigned randomly, one to each of the eight different cells.

The majority of the participants had background in economics, some in geography, some in management and some in other areas. About half the participants had experience from research. The subjects had on average 6 years of education after finishing the 'gymnas' (at about 19 years of age). There were no significant differences in length of education between the treatments. Most of the participants were recruited from institutions in the Bergen area. None of the participants were familiar with the results in Moxnes et al. (1993).

None of the participants had any experience with reindeer management. The compelling reason for this choice was lack of funding and a long distance to the reindeer districts. The experiment remains interesting and relevant for the following reasons: First there is a chance that inexperienced subjects are representative of experienced ones,[1] as was found in the rather similar experiment by Moxnes (1998). If misperceptions of feedback are observed, this would be a good reason to replicate the study with experienced subjects. Secondly, the chosen subjects bear some resemblance to the politicians and bureaucrats involved in decision making concerning total resource management. Thirdly, if misperceptions are observed for highly educated outsiders to the industry, this result might reduce the need for defensive action within the industry.

While there are often compelling reasons to keep experiments simple to maintain experimental control, an explicit effort has been made to ensure a high degree of parallelism (Smith, 1982). It seems an economic approach to research in this area to start out exploring misperceptions in a realistic setting. If misperceptions are detected, further research should be used to test more specific theories. If misperceptions are not found, this would be a reason to reconsider the interpretation of the historical data presented earlier or to add realism to the experiment. One omission that could matter, is the omission of exogenous factors like traffic, pollution, and hydro power development. While we believe these factors to be of minor importance compared to overgrazing, experimental subjects, herders, and politicians might think otherwise.

The subjects were told that they would be paid a reward in accordance with the obtained PV. Hence, the experiment satisfies the precepts about non-satiation, saliency, and privacy proposed by Smith (1982). Whether the precept about dominance is fully satisfied is not so clear. The subjects were not told exactly what amounts of money to expect. Due to the lack of funding, the actual maximum payout per subject was NOK 9 or about USD 1.5. It is not clear from the literature what effect the ambiguity of the size of the financial incentive implies. The obvious effect of high rewards is to put more effort into the task. However, if high rewards lead to less experimentation and more conservative decisions, as found by Hogarth et al. (1991), performance could also deteriorate with higher expected rewards. With very few exceptions, the subjects seemed

[1] Bakken (1993) finds that context expertise "decreases performance if such expertise is at odds with the learning objectives of the experimental task". The daily challenge for fishermen is to be efficient at sea and in the markets. Similarly reindeer owners have to be clever at shepherding in common pastures and to deal efficiently in the markets. Thus, the expertise of both fishermen and reindeer owners could be at odds with the objective of total resource management.

highly motivated to do their best. The time spent varied from half an hour to nearly 2 hours.

Before reading the written material (see Moxnes, 1995) and the treatments above, the subjects were given a verbal introduction to the task and the computer screen. They were encouraged to ask questions. They were also encouraged to write down numbers during the experiment and to comment on decisions in a supplied form. The experiment was followed by a post-questionnaire. Pre- and post-tests and interviews with subjects did not reveal serious misperceptions of the instructions. Answers to the post-questionnaire also indicate that the task was not misperceived.

4. Results

The results of four representative subjects are shown in Fig. 6. The first case is characterized by passive management (non-binding quotas) after the first year. The future potential is nearly destroyed, leaving the infinite horizon present value of incomes PV only slightly above the present value of incomes over the 12 year period PV_{12}, NOK 43 versus 41 million. The second case is characterized by a gradual and slow reduction in quotas. Much of the future income potential is lost due to low levels of both reindeer and

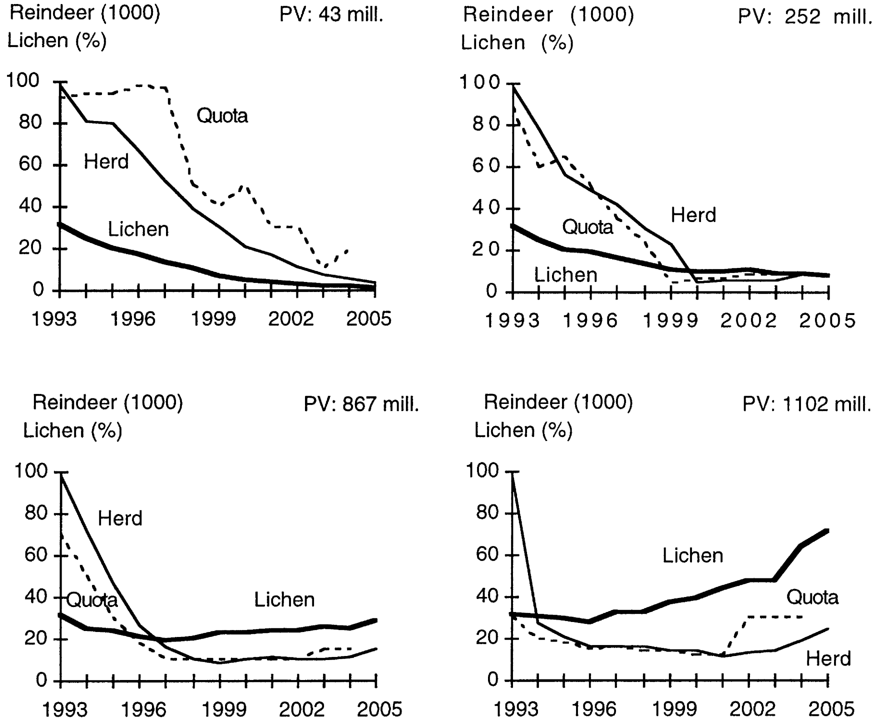

Fig. 6. Results of four subjects. PV_{12}s are NOK 41, 92, 119 and 136 mill, respectively.

Table 1
Percentage of subjects setting the quota below the benchmark

Year	1993	1994	1995	1996
Percent below benchmark	0	0	6	17

lichen. The third case is still characterized by a gradual decrease in quotas, however, the subject seems determined and persistent in his or her efforts. Note that the earlier response than in case two, is very important for the PV. Finally, in case four, the quota is cut drastically from the very beginning. However, it is still not below the benchmark for the first year, which was 20 000 animals with the 'Growth' treatment. The PV of NOK 1102 million is not much below NOK 1184 million obtained in the near-to-optimal case in Fig. 4. Quotas are increased too late to fully utilize the regrown lichen.

Table 1 shows that nobody got below the benchmark for the two first years, while 17 percent of the subjects got below the benchmark in the fourth year. Table 2 summarizes the results. All four indicators have a wide spread; ranging from close to zero to around the near-to-optimal values. All distributions are skewed as indicated by lower medians than means. The 'median subject' obtains the following results relative to the optimal values: 9 percent of PV, 49 percent of PV_{12}, 5 percent of the lichen stock and 12 percent of the herd size in the final year. The 'minimum' subject gets results close to what is obtained by not lowering the reindeer quota at all (PV of NOK 38 million).

Passive management, as shown in the upper-left panel of Fig. 6, is quite frequent. Of the 42 subjects that do not go below a quota of 30 000 animals in the second year, 13 fail to actively reduce the reindeer herd in any year after the second (quotas are always set higher than the current herd size), that is, 27 percent of all subjects act passively according to our definition. In the first year, all subjects set the quota below the herd size.

For those who manage to increase the stock of lichen, there seems to be a tendency that reindeer quotas are increased too slowly to avoid a period with excess lichen (overshooting the 67 percent level). Of the six subjects who end up with the highest lichen stocks, five are bound to overshoot while one subject can avoid it (see Moxnes, 1995).

Responses to the post-questionnaire are shown in Table 3. In accordance with the instructions, subjects were concerned about overgrazing of lichen. They were surprised and frustrated by the behaviour of the system and by lichen in particular. Only two of the five subjects that were not surprised, did well. With hindsight, a majority would have reduced quotas more quickly (those who were specific about reductions did not indicate sufficient revisions).

Table 2
Summary of results (Initial lichen, 31.5 percent, initial herd size 97 600)

Measure	St.dev.	Minimum	Median	Mean	Maximum	'Optimal'
PV (Mill.NOK)	377	40	107	342	1102	1184
PV_{12} (Mill.NOK)	34	39	80	87	148	163
Lichen in 2005 (percent)	18	1	3	13	71	59
Reindeer in 2005 (1000)	7	1	6	9	31	49

Table 3
Responses to the post-questionnaire

		Percentage
1. With hindsight, would you have managed differently? (Yes)		90
If yes, what? (open question)	Reduce quotas more quickly	77
	Do not know what to improve	12
	Would have increased quotas (all performed poorly)	12
	Would start to rebuild herd earlier (both performed well)	5
2. Were you surprised by the results? (Yes)		92
If yes, what? (open question)	Behaviour of lichen	62
	Size of quota reductions needed	15
	Rapid fall in income and/or the number of reindeer	12
	Nothing helped	12
3. Did you at any time feel pity for the reindeer owners? (Yes)		52
4. Did you weigh problems for reindeer owners caused by rapid slaughtering? (Yes)		35
5. Which of the following information cues did you put weight on? (Yes)		
(closed question)	Income	23
	Lichen percentage	92
	Number of reindeer	27
	Body weight	21
	Calving percentage	13
	Loss percentage	21

Fifty-two percent of the subjects felt pity for the reindeer owners (58 percent of those who received the treatment 'Pity'). Thirty-five percent of the subjects answered that they took account of problems caused by rapid slaughtering (29 percent with 'Pity'). However, we find no significant effect on the PV of admitting to have put weight on problems for reindeer owners. There is no effect of years of education or of education in resource management (8 subjects).[2] Due to the latter result, groups are ignored when comparing treatments.

Then we turn to the effect of treatments on PV.[3] The first columns in Table 4 show results for all subjects. The only treatment to have a significant direct effect is 'Growth'. With this treatment the average PV is NOK 509 million, without it is NOK 175 million. While the treatment is effective, the average subject still captures only 43 percent of the 'optimal' value. The signs of the two other treatments are as expected, however, the effects are small and insignificant. There is one significant interaction effect, the case when all treatments are present. The negative sign indicates that there is an information overflow problem.

[2] By using the SAS-platform in JMP, unequal sample sizes are correctly dealt with.
[3] Similar results are obtained when using the other three indicators in Table 2 as dependent variable.

Table 4
Effects of treatments

Selection	All subjects		Subj. with PV<200		Subj. with PV>200	
No. of subjects	48		29		19	
R^2	0.34		0.51		0.68	
p-value whole model	0.015		0.021		0.035	
Treatment	Estimate	*p*-value	Estimate	*p*-value	Estimate	*p*-value
Intercept	342	0	82	0	667	0
Pity	39	0.42	10	0.08	−13	0.81
Stock	17	0.73	−4	0.45	−66	0.26
Growth	167	0.001	12	0.038	165	0.012
Pity*Stock	53	0.27	10	0.081	−23	0.69
Pity*Growth	−3.8	0.94	5	0.38	−44	0.44
Stock*Growth	0.8	0.99	13	0.026	−67	0.24
Pity*Stock*Growth	−118	0.02	−14	0.018	−152	0.018

To test if there are different effects for those who do poorly and those who do better, the sample is split at a PV of NOK 200 million, with 29 subjects below and 19 above. The two significant effects from Table 2 reappear as significant in both cases. In addition there is a significant effect of 'Stock' combined with 'Growth' for those who do poorly.

5. Discussion of behaviour

When thinking about it, it seems natural that we have a repertoire of mental models and heuristics to tackle specific tasks (see Morris and Rouse, 1985). For some problems we have knowledge and heuristics to produce both rough answers and precise ones. For other, less familiar or more demanding tasks, we may have detailed system knowledge that we do not know how to use, and we may have heuristics available that we do not know whether they are appropriate or not. Given a task, it is not obvious what mental models and what heuristics subjects will use. However, the literature on decision making reveals a tendency towards relying on overly simplified mental models and heuristics, simplifications that do not always capture the essence of the decision problem. For instance, Kahneman and Tversky (1974) find that subjects assess the probability of belonging to a class by similarity, ignoring prior probabilities (the representativeness heuristic). Sterman (1989a) finds that subjects bias their decisions in the direction of what follows from static mental models, ignoring or adjusting insufficiently for the dynamic aspects of their tasks (misperceptions of feedback and stocks).

Inspired by Sterman, we investigate evidence of static and dynamic mental models. The static model represents the overly simplified one (see Fig. 7). It says: the more reindeer, the less lichen. Using this static mental model, a subject should expect the level of lichen to increase after a reduction in the herd from N_0 to N_1. However, what one sees after moderate initial reductions in the herd, is a reduction in lichen, indicated by the circle at N_1.

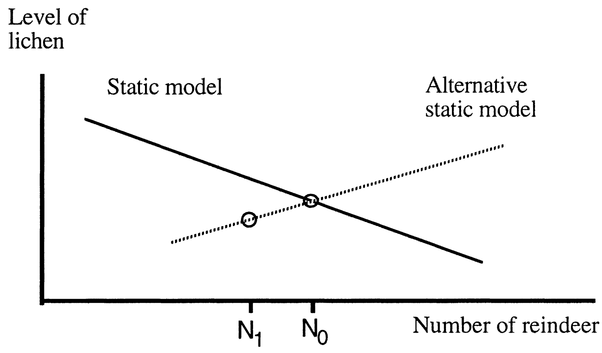

Fig. 7. A static model of the relationship between reindeer and lichen.

Fig. 8 shows a simplified dynamic model, which helps reveal the fallacy of the static model. In the dynamic model, it is the *rate of change* in lichen and not the *level* of lichen that is the dependent variable. The net rate of change is the difference between lichen growth and reindeer grazing. Growth in lichen is independent of the number of reindeer. Grazing increases with the number of reindeer. Whenever the number of reindeer is larger than the equilibrium level N_E, grazing is larger than growth, and the net growth is negative. Having this dynamic model in mind, one should not expect the level of lichen to increase after a reduction in the herd from N_0 to N_1. Rather one should expect the reduction in lichen to go on, only at a slower pace.

In the following, we discuss four cases where dynamic and static mental models are combined with analysis and heuristics.

1. *Dynamic model and an appropriate analysis*. None of the subjects belong to this class since nobody reduced the quota below the benchmark for the first 2 years.

However, a few subjects might have been able to perform the correct analysis. When they missed the benchmark, this could be because they acted on conspicuous problems rather focusing on the overall optimization (Dörner, 1990). The following sequence of subgoals seems plausible: First, a tendency to be concerned about yearly incomes due to

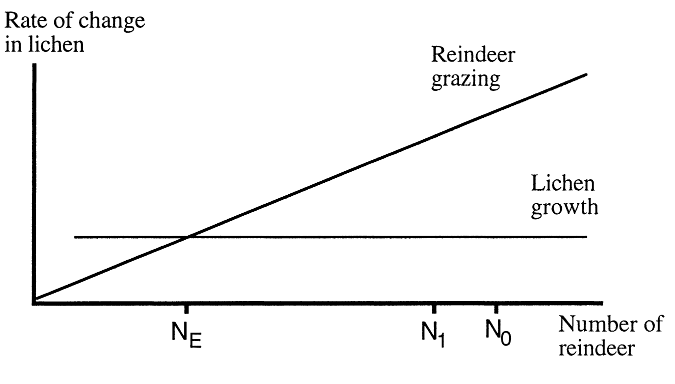

Fig. 8. A simplified dynamic model of the relationship between reindeer and lichen.

the need for quota reductions. In an additional test with six new subjects, who were interviewed while making decisions,[4] three out of the six expressed concern about yearly incomes in the beginning. In the questionnaire, 23 percent agreed to have put weight on the income cue. Second, the concern about incomes is replaced by a concern about lichen stabilization due to dwindling resource estimates. Third, after lichen is stabilized, the goal is shifted towards lichen regrowth, for a possible example see the lower right panel in Fig. 6. Fourth, as lichen starts to approach appropriate levels, focus is shifted towards the regrowth of reindeer (see Section 4). Typically, acting on conspicuous problems cause delays. While dealing with one problem, the next develops.

2. *Dynamic mental model and a trial-and-error heuristic*. The fact that many of the subjects continue to reduce quotas in spite of outcomes that are inconsistent with a static model, could be interpreted as evidence that they apply a dynamic model. Rather than using the dynamic model for analysis, they use it to motivate further trial-and-error reductions. Before such a conclusion is drawn, note that a competing hypothesis exists. A complete dynamic model is not needed. A conviction that quota reductions are the only sensible option to prevent lichen from dropping, would suffice. Therefore, it is difficult to indicate the size of this class except that it is limited by the large number of subjects that seems to belong to the class with static mental models (see the discussion in point 4).

We proceed by testing a trial-and-error heuristic based on some conviction that quotas must be reduced, ΔQ_t, when lichen drops, ΔL_t . That lichen should be a part of this equation is suggested the problem description and by the 92 percent who pointed to lichen observations as their prime cue in the post-questionnaire.

$$\Delta Q_t = \alpha \Delta L_t + \beta \Delta L_{t-1} + \gamma + \varepsilon_t \tag{2}$$

Eq. (2) shows the proposed heuristic including a lagged version of ΔL_t. The implicit goal of the rule is a growth rate $\Delta L_t = \Delta L_{t-1} = -\gamma/(\alpha + \beta)$, for which the quota is not changed, $\Delta Q_t = 0$. We expect γ to be negative such that the implicit goal is positive growth. We expect $\alpha+\beta$ to be greater than zero. If the subjects tend to smooth information, both α and β should be positive. A negative β would indicate that subjects put more weight on the second derivative than on information smoothing. Moxnes (1998) finds that a similar rule explains experimental investments in fishing vessels, where the intended goal is profit maximization (zero growth). Diehl and Sterman (1995) explains production starts with a similar rule, where the intended goal is a given inventory level.

Table 5 shows average results from individual tests of all subject. First we consider those who obtain PVs above NOK 200 million. Row one shows averages of significant parameters only. Average values of α and γ have the expected signs. The implicit goal for growth in lichen is 1.2 percent points per year. The average value of β is positive and lower than α, indicating information smoothing. All average parameters are highly significant. The average R^2 is 0.73 for the subjects with at least one significant parameter, the median R^2 is 0.81. For subjects with no significant parameters (row two), the average

[4] This procedure was suggested by one of the anonymous referees. The method seems powerful both for pretesting and to gain understanding of behaviour.

Table 5
Tests of behavioral rule using OLS, d.f.=7. n_{R^2} is the number of cases with at least one sign. parameter, n_i is the number of cases where parameter i is sign

Selection	p-values	n_{R^2}	$\bar{R}^2$	n_α	$\bar{\alpha}$	$t_{\bar{\alpha}}$	n_β	$\bar{\beta}$	$t_{\bar{\beta}}$	n_γ	$\bar{\gamma}$	$t_{\bar{\gamma}}$
PV>200	p<0.1	10	0.73	9	2.1	8.1	6	1.3	5.3	5	−4.1	−7.6
	p>0.1	9	0.28	10	1.3	4.0	13	1.4	2.3	14	0.6	0.4
	all	19	0.52	19	1.7	7.4	19	1.3	3.3	19	−0.6	−0.5
PV<200	p<0.1	7	0.49	4	3.5	1.4	4	−1.2	−0.4	1	−7.6	–
	p>0.1	22	0.16	25	1.9	2.7	25	0.1	0.2	28	1.2	0.9
	all	29	0.24	29	2.1	3.1	29	−0.1	−0.1	29	0.9	0.7

R^2 is only 0.28. However, the average parameters α and β turn out to be significant and similar to the averages of significant parameters. The average constant γ is not significantly different from zero and the implicit growth target for this group is zero (the second conspicuous goal).

For those who obtain PVs below NOK 200 million, there are only a few significant parameters even though this group is the larger one, 29 versus 19 subjects. The most notable result is the average parameter for α (row six) which is significantly different from zero and similar in value to the result obtained for those who did better. Neither the average β nor the average γ are significantly different from zero. We conclude that among all 48 subjects, around ten seems to behave according to the proposed decision rule.

3. *Static model and consistent analysis*. Having the static model of Fig. 7 in mind, the consistent policy would be to move directly to 72 000 reindeer. Four subjects do so and another four move very close to this level in the first year. All eight keep the quota at this level for at least 3 years, on average they keep it for 4 years.

4. *Static model and a trial-and-error heuristic*. A first indication that there are members in this class is provided by two comments during the experiment: “Due to overgrazing I want a gradual reduction towards the sustainable herd”; and “To get down towards 72 000.” Both subjects seem to believe that it is possible to approach the long term goal from above, that is, in accordance with a static model. However, they choose a gradual approach rather than a direct move towards the goal.

A more comprehensive test to see if subjects reasoned according to a static model would have been to have them bet on the development of lichen. We did not do this. However, in the additional test with six new subjects, only two subjects indicated that lichen would continue to drop with a herd size above 72 000.

The perhaps strongest indication that a majority of the subjects reasoned according to a static model is provided by the post-questionnaire and the written comments. Ninety-two percent reported that they were surprised, with a clear majority pointing to the behaviour of lichen as the cause. Written comments express the same frustration: After the first year: “Do not quite understand the effect, try again”; and “Thought it helped to reduce quota, but it did not help.” After 3 to 6 years: “Do not know what is smart, everything gives loss of lichen percent and money”; “Experiment to reveal the mystical (when increasing the quota)”; “Since in spite of reductions, lichen continues to drop, try now to keep constant''; ''Do not understand why lichen drops – 'give up' and finish with 86 000''; ''Better for the animals, has lichen been permanently injured?''; ''Understand nothing, increase number of calves''; and ''Few reindeer eat much?'' These reactions are all consistent with a static mental model.

Note, however, that frustration could also follow from the failure of an intendedly rational heuristic. Having a static model in mind, and being ignorant or forgetful about the optimal solution (72 000 animals), a gradient search would seem appropriate. A gradient method could also be chosen with no static (or dynamic) model in mind. Using a gradient search, one would start out by making a rather small change in the quota to estimate the direction of ascent in lichen. Knowing the correct direction, one would continue changing the quota until the desired level of lichen had been reached. However, after an initial reduction of the quota, a drop in lichen suggests that the quota should be increased. After a subsequent increase in the quota, a further drop in lichen suggests that the optimum has been reached. Hence, a gradient rule could lead to passive management. However, as lichen would continue to drop, it would be tempting to blame some external factor (see the comments above and Dörner, 1987).

Are there evidence of a gradient search in the recorded data? All subjects decreased the quota to begin with, five subjects increased the quota in the second year, and another six subjects increased the quota in the third year. Of these, five ended up with a nearly constant quota throughout the experiment, while six did reduce the quota after having kept it nearly constant for on average 3.2 years after the first increase. The upper-right panel of Fig. 6 shows the earliest and most gradual reduction in this category. A regression on individual data over the first five data points does not give much support to the gradient heuristic.

After having set high quotas and received frustrating feedback for a few years, different lessons seems to have been learnt. Some subjects continue a gradual reduction in quotas with repeated comments saying ''have to reduce more.'' The frustration and the few observations of radical changes in policies, indicate that very few realized the importance of the stock nature of lichen. Rather, the most likely motivation for ongoing quota reductions seems to be a conviction that this is the only sensible direction in which to move. Even when a few subjects made radical cuts in quotas, we cannot tell whether these were motivated by sudden realizations of the stock nature of lichen or by a felt need to do something drastic.

Twenty-seven percent of the subjects ended up as passive managers, doing nothing to actively reduce the number of reindeer after the second year. These subjects seem to give up a prior static mental model or a gradient heuristic without being able to replace it with an alternative. The comment ''give up'' illustrates the permanent frustration felt by many in this group. The lack of creativity could be explained by the strength of the prior mental model (Bazerman, 1986).

A few subjects seem to have accepted the alternative static model that more reindeer lead to more lichen (see the dotted line in Fig. 7). Four subjects increased quotas above 100 000 during the first 6 years. According to the post-questionnaire, five subjects, who performed poorly, would have increased quotas with hindsight. The alternative static hypothesis does not seem logical from a biological point of view. However, the following comment made after 3 years makes it sound plausible: ''Things were better before when the number of reindeer was higher.'' The subject then tried to reverse development, which would seem possible within a static framework. Note that for those who did poorly, the statistics were extremely favourable to the alternative static hypothesis. Fig. 6 shows that lichen and herd size is highly correlated for this group.

Finally, we comment on two of the information treatments. We found no effect of the 'Stock' treatment. By itself, this result is of limited value since it cannot be used to distinguish between the two possible explanations: no need for information about the stock nature *and* inability to use this information to improve strategies. However, the observed tendency of the majority to operate with a static mental model, point in the direction of inability to use the information. Two of the six subjects who were interviewed, were availed with the 'Stock' treatment. One of the two did well and did not aid our search for explanations. The second of the two moved directly to 72 000 animals and stayed close to 72 000 for 3 years. To begin with this person seemed to be satisfied with having chosen the equilibrium herd size and commented that now growth would be equal to eating. As lichen dropped, the subject started to focus on the need to increase the level of lichen. When asked, the subject was not clear about the size of the stock, indicating that the stock contained only one or a few years of accumulated growth. Hence, no radical cuts in quotas seemed to be needed to rebuild lichen. The information about the preceding 10 years of overgrazing by 100 000 animals to bring the lichen stock to 31.5 percent, was not used to get a good sense of the size of stock and the 'undergrazing' needed to rebuild lichen. This might explain the lacking effect of 'Stock'.

The positive effect of 'Growth' indicates that subjects both needed this information *and* that they were able to utilize it. We cannot say for sure whether it was the qualitative or the quantitative aspect of the curve that made the difference. Logically, the exact data should be of little importance once a subject has been presented with the qualitative aspects of the curve, recall the minor difference between the benchmarks for the cases with and without 'Growth'. However, we cannot rule out the possibility that the quantitative information played an important role. For instance, those who obtained a limited effect of the treatment, might have been anchored to a static mental model while adjusting insufficiently towards the herd sizes implied by the numbers on the growth curve (Kahneman and Tversky, 1974).

Table 4 shows that those who obtained less than NOK 200 million had very little help of the 'Growth' treatment. Why was the effect so small when the need for information was clearly there? Did they misread the curve? Some insight on this possibility is provided by four of the six subjects who were interviewed, and who were availed with the growth curve. Three of the four clearly understood what variables the curve related. However, all three treated the curve as if it represented an equilibrium model, that is, a static model. Instead of entering the diagram with the current level of lichen, they all entered it with their desired number or reindeer (72 000 food rations), and read out the resulting level of lichen (67 percent). When using the curve, they ignored that lichen changes slowly over time through accumulation of net growth. After having stressed to these three subjects that they could not escape the current level of lichen, they all proposed radical cuts in quotas. This seems an important point when using the growth curve as a pedagogical devise.

6. Concluding remarks

An experiment has been performed where 48 subjects, one by one, were faced with the challenge of setting quotas for the reindeer herds in a district where lichen was acknowledged to be severely depleted by preceding overgrazing. The commons problem was ruled out by the design of the experiment. Most of the subjects were highly educated. None had experience with reindeer herding. We find that all subjects err on the side of overexploitation. The median subject captures only 9 percent of the potential infinite horizon present value of incomes. For many subjects, both lichen and herds were nearly depleted by the end of the experiment. Similar behaviour has been observed in real reindeer herding, even in cases where the commons problem has been absent. As in reality, we find considerable differences between subjects.

Previous studies have shown that decision makers often rely on overly simplified and inappropriate mental models or heuristics when complex problems are attacked. Of particular relevance for the management of renewable stock resources is misperceptions of feedback in Sterman's terminology. None of the subjects combined an appropriate dynamic mental model with an appropriate analysis. We cannot rule out the possibility that perhaps one fourth of the subjects had or developed a dynamic mental model during the experiment. Much evidence points to the existence of static mental model and towards the use of inefficient and inappropriate heuristics for the remaining subjects. There are strong indications of limited learning during the experiment. More than 27 percent end up as passive managers.

No or moderate effects of information treatments indicate that one is faced with a considerable information problem. The challenge for further studies is to identify effective information policies, policies that will have an effect in competition with alternative policy suggestions. For privately owned and managed renewable resources, appropriate information policies could help speed up the diffusion of pertinent management strategies. Dynamic lichen models could, for instance, help actors understand the practical experiences made by others. For common property resources under democratic control, a minimum of individuals (a majority) must benefit from an information policy for it to be efficient. For global renewable resources, for which practical experience is still lacking, effective information policies are of a particular importance. For such resources it is the first trial that matters. The climate problem is a prime example with its stocks of greenhouse gases.

Concerning further research, experiments could be used to examine the effects of role playing and of small and ambiguous incentives, to investigate mental models and heuristics for simplified stock models, to test pedagogical instruments, and to investigate the effects of experience by running the experiment with public policy makers and reindeer herders, and with repeated trials to study learning. Finally, it seems important to study how the commons problem interfere with the management problem (Moxnes, 1998).

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