ICES CM 2010/P:02

This article is published in *Fish and Fisheries* DOI: 10.1111/j.1467-2979.2010.00372.x

Exploring the 'Public Goods Game' model to overcome the Tragedy of the Commons in fisheries management.

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Abstract

In situations of declining or depleted fish stocks, exploiters seem to have fallen prey to the Tragedy of the Commons, which occurs when the maximisation of short-term self-interest produces outcomes leaving all participants worse off than feasible alternatives would. Standard economic theory predicts that in social dilemmas, such as fishing from a common resource, individuals are not willing to cooperate and sacrifice catches in the short term, and that, consequently, the resource is overharvested. However, over the last decades, a multitude of research has shown that humans often achieve outcomes that are "better than rational" by building conditions where reciprocity, reputation, and trust help to overcome the temptations of short-term self-interest. The evolution of the natural human tendency to cooperate under certain conditions can be explained, and its neuro-physiological and genetic bases are being unravelled. Nevertheless, fisheries management still often deploys top-down regulation and economic incentives in its aim to regulate fisher behaviour, and under-utilizes the potential for spontaneous responsible fisher behaviour through setting conditions that enhance natural cooperative tendencies. Here I introduce this body of knowledge on how to overcome the Tragedy of the Commons to the audience of fisheries scientists, hoping to open up novel ways of thinking in this field. I do this through a series of thought experiments, based on actual published experiments, exploring under what conditions responsible and cooperative fisher behaviour can be expected. Keys include reputation-building and indirect reciprocity, face-to-face communication, knowledge on the state of the resource, and self-decision on rules and sanctions.

Solon (c. 638 BC–558 BC), drawing up his laws, was laughed at for supposing that his countrymen's greed could be kept within bounds by means of laws. He replied that he was framing his laws in such a way as to make it clear that it would be to everybody's advantage to keep rather than to break them.

Key words: Cooperation, Fisheries Management, Governance, Indirect Reciprocity, Public Goods Experiments, Tragedy of the Commons

Introduction

One of the objectives for fisheries management is to ensure that the fish resource is exploited to the level that produces the highest socioeconomic returns while at the same time considering conservation of the ecosystem. A task for fisheries scientists is therefore to estimate what that level of exploitation should be, based on research on the biology of the system and the impacts of the fishing activities. Although science has not been able to provide the ultimate answer to the question of optimal fishing activity levels, it is clear that in many fisheries contemporary levels are too high. Across the globe, a large number of important fish stocks are currently thought to be overexploited or depleted (Pauly *et al.* 2002, Christensen *et al.* 2003, Myers and Worm 2003). In these cases, there is no conflict between the objectives of economic profitability and nature conservation because both require the reduction of contemporary levels of fishing. The problem, however, is that although it is clear that in the long term the reduction of fishing activity is beneficial in all possible ways, in the short term socioeconomic losses will be suffered. The question is how to distribute these losses. The dynamics of the rational exploitation of fish stocks can be studied by game theory (Munro 1979, Clark 1985); an excellent review of the application of game theory to fisheries over the last three decades is given by Bailey *et al.* (2010).

Fisheries seem to be stuck in the 'Tragedy of the Commons'. This phrase was coined by Hardin (1968), who gave the following description:

> "*Picture a pasture open to all. It is to be expected that each herdsman will try to keep as many cattle as possible on the commons […] to maximize his gain. […] This utility has one negative and one positive component. The positive component is a function of the increment of one animal. Since the herdsman receives all the proceeds from the sale of the additional animal, the positive utility is nearly +1. The negative component is a function of the additional overgrazing created by one more animal. Since, however, the effects of overgrazing are shared by all the herdsmen, the negative utility for any particular decision-making herdsman is only a fraction of -1. Adding together the component partial utilities, the rational herdsman concludes that the only sensible course for him to pursue is to add another animal to his herd. And another; and another... But this is the conclusion reached by each and every rational herdsman sharing a commons. Therein is the tragedy. Each man is locked into a system that compels him to increase his herd without limit – in a world that is limited. Ruin is the destination toward which all men rush, each pursuing his own best interest in a society that believes in the freedom of the commons. Freedom in a commons brings ruin to all.*" (Hardin 1968).

Fishers, using an open-access common-pool resource face a similar dilemma: while they could jointly harvest at a rate that maximises sustainable economic returns to the group, they experience incentives that lead to an equilibrium of overharvesting. Phrased differently (Hart 1998), if individual fishers agree to limit their catch today in the expectation of continued future catches, they can never be sure that the catch they have just given up will not be immediately snapped up by competing fishers ('dynamic externality', Levhari and Mirman 1980). In addition, every caught fish not only constitutes the removal of that fish from the population, but also of all the potential future offspring that fish could have generated (Richter and van Soest in press, 2010).

The instruments available to fisheries managers to limit the removals of fish include Total Allowable Catches (TACs), fishing effort restrictions, prescriptions for gear characteristics, (temporal) closures of areas to fishing, etc. Fisheries management is in many cases a top-down bureaucratic exercise with centralized control (Daw and Gray 2005). However, recently it is becoming apparent that central intervention from authorities often directly undermines existing willingness to cooperate and obey these rules and diminishes any stewardship motives (Bowles 2008, Richter and van Soest in press, 2010). Thus, a reduced sense of 'ownership' among fishers towards the problem and towards the management regulations may partly explain the reduced level of compliance to the regulations that is experienced (Kuperan and Sutinen 1998, Hatcher *et al.* 2000, Raakjær Nielsen 2003, Raakjær Nielsen and Mathiesen 2003). The regulations are viewed by the fishers as opposing rather than supporting their interests and this manifests itself as a reduced compliance to 'the letter' as well as 'the spirit' of the regulations. Non-compliance 'to the letter' refers to illegal fishing activities, such as illegal landings or the use of illegal gear or mesh sizes, whereas non-compliance 'to the spirit' refers to attempting to find loopholes in the regulations that allow continuation of business as usual without reducing catches (if the reduction of fishing mortality was the objective of the regulation in question, as is often the case). One of the challenges of contemporary fisheries management is to redesign the management institutions such that they rebuild the 'social capital' among the stakeholders: the sense of stewardship and the natural willingness to cooperate (an excellent overview on this is given by Richter and van Soest in press, 2010).

Social dilemmas, such as the Tragedy of the Commons, occur whenever individuals face situations in which the maximisation of short-term self-interest yields outcomes leaving all participants worse off than feasible alternatives would. The dilemma exists because at least one possible outcome yields a greater advantage for all participants, and the tragedy occurs if that outcome is not achieved. Standard rational economic theory predicts that when faced with social dilemmas individuals find it costly to contribute to the public good and prefer others to pay instead; and that consequently, if everyone follows the equilibrium strategy, the good is not provided or only underprovided (resulting in tragedy). However, over the last few decades a multitude of research has shown – in agreement with common experience – that in actual fact humans often achieve outcomes that are "better than rational" by building conditions where reciprocity, reputation, and trust can help to overcome the strong temptations of short-term self-interest (Ostrom 1998, reviewed in a game-theoretical context by Sigmund 2010). Apparently, humans are not only motivated by purely immediate economic incentives, but also by social ones (Ostrom 1998); indeed the fear for loss of social status and avoidance of social conflicts are important drivers of human behaviour, and interpersonal conflicts have been shown to be more stressful than financial difficulties (Bolger *et al.* 1989). Studies have provided insight into why and how a psychological inclination towards trust and social justice could have evolved and become hardwired (Fehr and Rockenbach 2004, Nowak and Sigmund 2005, McNamara *et al.* 2009, Levin 2010); the evolutionary roots of human altruism are evident from the fact that chimpanzees display similar behaviour (Warneken *et al.* 2007). On an abstract level, Zahavi (1975, Zahavi and Zahavi 1997) has pioneered the *Handicap Principle*, explaining the evolution of characteristics that appear to reduce fitness because they are costly and thus honest signals of quality. The hardwiring itself, namely the physiological basis of trust, cooperation, and generosity, is being unravelled: the neuropeptide oxytocin appears to play a role (Zak *et al.* 2004, Kosfeld *et al.* 2005, Morhenn *et al.* 2008), and neural correlates in the brain have been uncovered (Rilling *et al.* 2002, Fehr and Rockenbach 2004, Zak 2004, Rilling *et al.* 2005, Rilling *et al.* 2008, Zak 2008), giving birth to the discipline *neuroeconomics* (Zak 2004). The satisfaction that humans derive from punishing norm violations has been shown to have a neural basis (De Quervain *et al.* 2004). Moreover, a genetic polymorphism in the gene AVPR1a RS3 has been found to correlate with individual variation in levels of trust, cooperation, and generosity (Knafo *et al.* 2008). Many experiments have shown that humans do cooperate when faced with social dilemmas and have investigated under what conditions levels of cooperation are enhanced (Ostrom 2001, Milinski *et al.* 2002b, Milinski *et al.* 2002a, Fehr and Fischbacher 2003, Kerr *et al.* 2004, Ouwerkerk *et al.* 2005, Milinski *et al.* 2006, Rockenbach and Milinski 2006, Milinski *et al.* 2008, Rockenbach and Milinski 2009). Conditions that increase cooperation include familiarity (Hart 1998, Hart 2003) and non-anonymity with the possibility of direct or indirect reciprocity and reputation building (Milinski *et al.* 2002b, Milinski *et al.* 2002a, Fehr and Fischbacher 2003, Fehr and Rockenbach 2004, Zak *et al.* 2004, Nowak and Sigmund 2005), face-to-face communication (Ostrom 2001) and physical contact (Morhenn *et al.* 2008), the threat of punishment (Fehr and Fischbacher 2003, Fehr and Rockenbach 2004, Zak *et al.* 2004, Rockenbach and Milinski 2006, Rockenbach and Milinski 2009) or social exclusion (Kerr *et al.* 2004, Ouwerkerk *et al.* 2005, Spiekermann 2009). In the case where the public good is an open-access common-pool resource, such as the ocean fisheries, an increase of the number of participants is negatively related to achieving cooperation (Weissing and Ostrom 1991, Ostrom 2001). A recent analysis of the economic and biological fundamentals that influence the success of coalition formation shows that the larger the number of fishing states that compete for the fish stock the higher would be the relative gains from full cooperation, but the lower is the likelihood of large regional fisheries management organizations being stable (Pintassilgo *et al.* 2008). Besides group size, variables such as heterogeneity of participants, their dependence on the benefits received, their discount rates, the information available to participants, and their background personality types, may affect the behaviour in social dilemmas (Ostrom 1998, Bailey *et al.* 2010).

Thus, the grim and gloomy predictions of earlier theories (Olson 1965, Hardin 1968) that humans are stuck within economic traps has been replaced by the more optimistic recognition that individuals in social dilemmas face the possibility of achieving results that avoid the most deficient outcomes (Ostrom 2001). Policies based on the assumption that humans can only be lifted out of the economic trap through externally imposed sanctions have been subject to major failure and have exacerbated the very problems they were intended to ameliorate (Ostrom 1998, Bowles 2008, Richter and van Soest in press, 2010). Field research has shown that individuals systematically engage in collective action to provide local public goods without an external authority to offer inducements or impose sanctions (Ostrom 1998). Thus, if cooperation is already hardwired in human nature, we just have to set the conditions in such a way that this aspect of our innate behaviour will be expressed. This should encourage us to investigate under exactly what conditions cooperative behaviour is enhanced (Sigmund 2010), and whether these conditions could be implemented in the context of fishery management.

This paper explores ways in which to incorporate such conditions in fisheries-management settings and to bring about cooperative behaviour. I follow a series of experimental studies (Milinski *et al.* 2002b, Milinski *et al.* 2006, Rockenbach and Milinski 2006) in which behavioural scientists and economists have formally explored which conditions boost cooperation among people caught in the dilemma, such as non-anonymity where behaviour is publically observable and the actors' reputation is at stake. I attempt to translate the experimental settings where increased levels of cooperation were demonstrated, into the setting of fisheries management, albeit in a crude way. I then discuss the feasibility of incorporating these conditions into fisheries management systems. I intend this paper as a thought experiment to encourage further investigations into the broad area of creating the best conditions for cooperative behaviour among fishers.

General description of the 'public goods game' as an experimental tool

The 'public goods game' is the experimental model commonly used to study social dilemmas. For example, four people are each given an endowment of €5. They are then told that they can each choose to invest some or all of their €5 in a group project by putting, without discussion, an amount between €0 and €5 in an envelope. The experimenter will collect the contributions, total them up, double the amount, and then divide this money among the players, irrespective of their contribution. If all contribute €1, everybody receives €2 (that is, a net gain of €1). If all players but one contribute, the defector has a net gain of €1.50 and the contributors of €0.50 each. The prediction from standard rational economic theory is that no one will ever contribute anything because each €1 contributed yields only €0.50 to its contributor in return (corresponding to a relative loss of €0.50), no matter what the others do. This is a public goods problem because the group would be best off (taking home €10 each) if all contributed €5. But individual self-interest is at odds with group interest. In these experimental settings, however, usually people cooperate more than is predicted by standard economic theory (findings which are critically discussed by Kümmerli *et al.* 2010); nevertheless, observed cooperation is heterogeneous, declines quickly over time, and is often suboptimal, especially in sparse institutional settings (Ostrom 1998).

Translation of the basic 'public goods game' into fisheries-management settings

In analogy to the above, four fishers each have a quota to catch 5 fish. They are then told that they can each choose to invest in the rebuilding of the fish stock by refraining from catching an amount between 0 and 5 fish. The total of spared fish will be doubled and then divided among the group.

Instead of considering up to 5 fish, it is of course more realistic to consider quantities in units of tonnes of fish. Or fishers can be asked to choose to refrain from catching a proportion of their individual quota share, or from using a proportion of their allocated effort.

In the experimental setting, the experimenter has a quasi unlimited amount of money available that can be used to artificially double the amount contributed into the common pool. It will not be possible to analogously double the amount of fish in the common pool. However, fortunately, fish double themselves. Any fish that is left in the pool for some period of time will have increased in biomass by the amount of growth minus the natural mortality over that period. Indeed, the dilemma of reducing fishing intensity to the level of maximum sustainable yield consists of fishers having to forego some yield in the short term while gaining more yield in the long term. For example, a typical catch of cod from the Irish Sea will have increased in weight by a factor 1.4 if left alone for one year [calculation based on natural mortality M = 0.2 and catch numbers and fish weights by age group averaged over 1998-2007 (ICES 2008)]. Furthermore, because large fish sell for a better price than small fish, these cod will have increased in value by a factor 1.6 if left alone for one year [based on grades by weight from Community Size Standards (Council Regulation [EC] No 2406/96) and average 2001-2007 prices in the Netherlands (Taal *et al.* 2008)]. Let us call this factor W (for 'wait'); W can have a value of around 1.5.

The game will thus prescribe that fishers choose an amount of their quota entitlement and postpone using it until, e.g. next year. The next year, the total amount of catch given up by all fishers multiplied by W and divided by the group size will be added to the fisher's ordinary quota entitlement for that year. With W = 1.5, if all four fishers sacrifice €1000 worth of catch, a year later they would all be allowed to add €1500 worth of catch to their quota; that is a net gain of €500 for each of them. If only one fisher gives up this year's catch worth €1000, each of the four fishers would be allowed to add €375 worth of catch to their quota next year; the cooperative fisher will suffer a net loss of €625 while the defectors each enjoy a net gain of €375. The time period can also be made shorter, such that fishers are asked to postpone catching for, e.g. half a year, and having the amount multiplied by 0.5 * W. However, quota are usually not all caught right at the start of the year but distributed over the year instead, which makes it hard to decide what counts as a postponement of catch. Note that when the TAC and quota for the next year are being calculated through standard stock assessment procedures, an assumption is being made about the current year's total catch. Our calculations above are valid as long as any catch sacrificed is not added ("returned") to the modelled stock size. This implies that the non-caught fish survive in excess of the expected stock size, and that they can indeed be allocated as extra quota entitlement in the next year to the respective fishers in the group under consideration.

I will later describe a variant of the game where the reward is not given (only) in terms of additional quota, but partly or wholly in terms of the general benefit of a progressively rebuilt stock.

In the calculations above I ignored the economic phenomenon 'discounting', which arises from the rational preference to receive benefits today rather than tomorrow: €100 today has higher value than €100 next year, and that is why borrowed money has to be paid back with interest. High uncertainty about the future results in high a discount rate, and this constitutes one of the fundamental problems in resource management. In our calculations, we could reduce the gain with a factor representing the discount rate – as long as its inverse is (much) smaller than W. With a discounting factor of 0.9 per year and W = 1.5, the perceived gain that drives the cooperation would be +0.35.

One more aspect that needs to be dealt with in the general description of the fishing game is the group size. The experimental setting of 4 people in a group may be very artificial. National quota are usually distributed over up to several 100 fishers. Whereas in the example with 4 players, a contributor would lose only €0.50 of each contributed €1 if the 3 others defect, the player would lose €0.99 (almost all of his contribution) if all others among 200 players defect. The gains if all players cooperate are not dependent on group size: they always double their starting amount. Thus, the rationality of cooperation decreases with group size. I therefore propose that the fishers be distributed over groups of about 4 to 6 players. Of course, if the fleet segment under consideration consists of only a limited number of enterprises, say <20, the game can perhaps be played in one group.

In any case, in the settings corresponding to the basic public goods game not much cooperative behaviour is to be expected, as the fishers are caught in the Tragedy of the Commons.

Exploring the game when reputation matters

Theorists have shown that cooperation through indirect reciprocity can evolve (Nowak and Sigmund 2005). Indirect reciprocity refers to the phenomenon that individuals who have helped others are given support, and that supporters as well as helpers build up a positive reputation or image score. Experimental studies have confirmed that human subjects preferentially help others who have a positive image score.

In the following experimental setting (Milinski *et al.* 2002b) the increase in cooperation under indirect reciprocity was measured. The description of the experiment and its sub-games below is taken from their article (Milinski *et al.* 2002b):

> General:
>
> "*The six subjects of each group could see a public screen on which instructions and the actual game were projected. They were told, first, that each person had a starting account of DM 20 (£10) and could gain or lose money dependent on his/her and the participants' decisions; second, that all decisions were anonymous and each player would be assigned a pseudoname (that is, a new identity) for the whole game; and last, that they would play in two different situations, an 'indirect reciprocity game' and a 'public goods game'.*"
>
> Indirect reciprocity game:
>
> "*Each person was assigned repeatedly as either a potential donor or a potential receiver. For example, a potential donor, say 'Telesto', was asked on the public screen whether he would give to 'Galatea'. If Telesto decided 'yes', he would lose DM2.50 from his account and Galatea would gain DM 4 on her account. Telesto's decision (yes or no) was displayed for 2 s on the public screen. Everybody knew about the contributions of all players, for example, whether Galatea had given in previous rounds when she had been playing as the potential donor or in rounds of the public goods game. The subjects also knew that there would be no direct reciprocity; if A was the potential donor of B, B would never be the potential donor of A. In each round of the indirect reciprocity game, each of the six players was once a potential donor and once a potential receiver.*"

Public goods game:

> "*For the public goods game, all six players were asked simultaneously whether they would contribute DM 2.50 to the public pool, the contents of which would then be doubled and redistributed evenly among all players irrespective of whether they had contributed. After all players had decided, each player's decision (yes or no), his/her contribution (that is, DM2.50 or 0), and his/her gain (for example, DM4.17 if all but one had contributed), was displayed below the pseudonames for 20 s.*"

As a result, cooperation (and consequently average individual payoff) in the public goods games was significantly increased when they were alternated with the indirect reciprocity game. Over eight rounds, the probability of cooperation in the pure public goods game fell down from 84% to 45%, but it remained around or above 84% when these were alternated with the indirect reciprocity game; the average individual payoff was 1.45 times higher in the latter situation than in the former.

Translation of the game when reputation matters into fisheries-management settings

The alternation between the two games can be translated in two fundamentally different ways. First, the setting of the experiment can be faithfully mimicked, such that fishers play in groups of, for example, six, remaining anonymous throughout the session through their assigned pseudonames. A session would then consist of, for example, 20 rounds of alternating indirect reciprocity and public goods games, where fishers are asked to donate part of their quota to another fisher or contribute to a common pool respectively. The amounts contributed to the common pool will be multiplied, as before, by *W*. Donated amounts could also be multiplied by *W*, if the game prescribes that received donations can only be fished one year later. After 20 rounds, the accounts will be tallied; for each fisher there will be a resulting quota for this year, and an amount that will be added to his quota next year.

Alternatively, the rounds of indirect reciprocity can be viewed as what happens in the real world as long as the public goods game is not played anonymously. The outcome of Milinski *et al*.'s (2002b) experiment indicates that people are more inclined to contribute to the common pool if their reputation is at stake and that people reward each other for their generosity. The experiment can be mimicked in a more fuzzy way, such that the public goods game is not interspersed with indirect reciprocity in the form of a game, but because of non-anonymity the indirect reciprocity is actually going on all the time in the real world. Because players are not anonymous here, it is expected that generous players will receive benefits in their local communities throughout the year and defectors may become social outcasts. And precisely this expectation (partly or wholly unconscious) of receiving favours versus becoming social outcasts operates as an incentive for them to contribute more generously in the public goods game. However, if only one 'round' of the public goods game is played per year (naturally interspersed by the rest of the year when the indirect reciprocity takes place) an individual will not be allowed quick adjustment of the level of cooperation in response to feedback from the effects of reputation. Perhaps multiple rounds per year will have to be played. Moreover, if this works at all, it may only work if a fishery is prosecuted by a relatively small local community where all fishers know each other personally and interact extensively year-round, in other words, where reputation is important. It may be an important prerequisite for this system to work that the outcomes of the public goods game are published, with participants' full names, for example in the local newspaper. It is not immediately clear whether the public goods game should be played in small groups or not, since the indirect reciprocity will be 'played' by all fishers in one inclusive group automatically, namely in their community.

In a similar experiment testing the effect of reputation and indirect reciprocity (Milinski *et al.* 2002a) it was found that persons donating in public to a well-known charity organization in turn received increased donations from the members of their group as well as enhanced political reputation (they were elected to represent the interests of their group). Apparently, the positive effect of generosity extends to political influence; moreover, it does not only work for generosity towards each other or a common pool of direct interest to the players, but also towards a charity from which only 'third parties' benefit. The implications of the latter are important, and feature in the next experiment.

When the 'public good' really is the public good

In a further experiment Milinski *et al*. (2006) have demonstrated that if, in contrast to the standard protocol where the common pool is divided among the participants, instead, it is promised that the pool will be invested to encourage people in the society at large to reduce their fossil fuel use (through an advertisement in a national newspaper), players can behave altruistically. The experimenters found a nonzero basic level of altruistic behaviour, which was enhanced if the players were provided with expert information describing the state of knowledge in climate research. Analogous to the previous experiment, personal investments in climate protection increased substantially if social reputation was at stake. This increase occurred because subjects rewarded other subjects – in indirect reciprocity rounds – who contributed to sustaining the climate, thus reinforcing their altruism. Therefore, altruism could convert to net personal benefit and to relaxing the dilemma if the gain in reputation was large enough. Their finding that people rewarded contributions of others to sustaining the climate is a surprising result and corroborates the result discussed above (Milinski *et al.* 2002a) where donations to charity were rewarded.

Translation of the game when the 'public good' really is the public good into fisheries-management settings

The finding that people are willing to invest in a public good that is not directly given back to them multiplied by some factor, is an important one for our case. This implies that fishers may be cooperative not only if their sacrificed quota is given back to them multiplied by W at a later stage, but also if the only gain to the individual fisher is the possible gain from a rebuilt or increased stock. This is important, because if this were not the case the stock would not necessarily benefit from such games; after all, the fish that was not taken out today would be taken out tomorrow (or rather, next year). However, if fishers can, under the right conditions, experience an incentive to invest in the rebuilding of the stock itself – a public good that is shared by all people, not just by their group of players – this can be used in fisheries management. In this case fishers would be willing to sacrifice catches for the sake of stock increase, from which they themselves and everybody else may benefit in an undetermined future and by an undetermined and uncertain amount.

Consider the experimental setup as described by Milinski *et al*. (2006) in which the public goods game is alternated with an indirect reciprocity game in a total of 20 rounds with anonymous players using pseudonames. Instead of the promise to publish a press advertisement warning about climate change (as in Milinski et al, 2006), in the fisheries context the benefit would be the likely increase of the stock. To illustrate, for the Celtic Sea cod stock (ICES Division VIIe-k) a TAC of 2600 t was advised for 2009, which was predicted to bring the spawning stock biomass in the next year to 8800 t (ICES 2008). If 10% of that TAC would be given up completely, these fish would grow and be subject to natural mortality and thereby increase in biomass by a factor W = 1.4 to 363 t resulting in an increase in predicted stock biomass of 4%. Alternatively, if the 10% was not given up but only postponed for one year, then the 260 t would be added to the TAC for the next year, and only a net gain of 103 t would be added to the stock biomass. This would mean there had only been a 1% increase in the predicted stock biomass.

One could envisage establishing a mixture of rewarding the fishers with some extra quota for next year combined with the more abstract reward of stock growth. Then the fishers' incentive to postpone some of this year's catch is partially a 'direct' gain (a known increase in quota, albeit postponed to next year) and partially an 'indirect' gain through stock growth. The net gain of the 103 t could, for example, be 'split' between extra quota and the stock in a ratio of 1 to 9; in this case fishers would experience a quota increase of 4% (discount rate ignored) and the stock biomass prediction would still benefit from a 1% increase. Note that even an only 1% benefit is probably more than the reduction in society's fossil fuel use one can expect to result from a newspaper advertisement as in the experiment (Milinski *et al.* 2006). Nevertheless, future states of fish stocks as well as catches are notoriously difficult to predict, and such uncertainty results in a high perceived discount rate. One of the (many) reasons fishers do not favour conservation plans, even if their long term benefits appear to increase, is that stock/catch predictions are often wrong. So even if it is predicted that by taking less today all fishers will benefit tomorrow, fishers know this will not necessarily happen.

An interesting result of the experiment by Milinski *et al.* (2006) is furthermore, that altruistic behaviour was enhanced if the players were provided with expert information describing the state of knowledge in climate research. This can be translated in various ways. First, it may be important to inform the fishers on their expected gains from projected stock growth (as in the calculations given above). But going a bit further, it may be important to inform the fishers about the ecosystem impact of fishing or even expose them to a movie documentary about global overfishing, such as the film *The End of the Line* by Rupert Murray that was released in 2009 (after the book with the same title, Clover 2006).

The interaction of indirect reciprocity and costly punishment

Various public goods studies have investigated the effect of the possibility of punishment on the level of cooperation (e.g., Fehr and Gächter 2002). For example, when players are allowed to punish defectors by reducing the defector's income at their own cost—let's say, by investing €1 to reduce another player's income by €3—defectors have been found to typically increase their contributions in future rounds, even with new partners. Such altruistic but costly punishment leads to a large increase in cooperation, but induces another type of dilemma, namely, that it considerably destroys monetary gains: both the punisher and the punished lose money. Especially in the early rounds, when punishment is heavily used, realized payoff is lower than in the absence of the punishment option. Not until cooperation has been established on a stable level is a significantly higher general payoff achieved under altruistic punishment. Thus, the group would be better off if contributions to the public good could be induced by a less destructive means. And in fact, the withholding of support in the indirect reciprocity game can be seen as such a less destructive form of 'punishment'. Withholding donations does not cost anything but the 'punisher' actually saves money or resources by not donating to a defector (who does not lose his money either; instead, he does not receive additional gains).

In a complicated experimental design, however, Rockenbach and Milinski (2006) found that, although subjects could choose a punishment-free environment where reputation building alone would allow for high levels of cooperation, the great majority chose the environment where a costly punishment option was available in addition to reputation building. In the experiment, 20 rounds were played that each consisted of a public goods game, followed by the option of costly punishment if that environment was chosen, followed by an indirect reciprocity game (or not, in a control treatment). Not only did the participants prefer to have the option of costly punishment available despite the fact that cheap reputation building alone could 'do the job', but they also reached very high levels of persistent cooperation as well as very high net payoff in that situation. Compared to the control treatment of only punishment without indirect reciprocity, the number of punishment acts was greatly reduced (thus saving costs to everybody and largely removing the added dilemma of costly punishment) while at the same time the less numerous free-riders were punished more heavily. Free-riders were effectively hit twice: they were punished directly by the removal of money from their account and they were damaged indirectly by being withheld donations. These strong incentives to cooperate induced not only the majority of subjects but even the worst free-riders to be more cooperative when punishment was combined with reputation building. The interaction between punishment and reputation building thus boosted cooperative efficiency.

Translation of the game where indirect reciprocity and costly punishment interact into fisheries-management settings

Apparently, groups of human beings prefer to have the option available to punish members who violate the social norm, not only by withholding social favours but also through direct costly punishment. If, as before, fishers would be allowed to monitor each others' contributions the option to punish defectors could be added. Until now, I translated the money contributions of the experimental game into sacrificed or postponed quota shares. The exchange of donations in the indirect reciprocity game was equated either, quite artificially, to the exchange of quota shares between fishers known by pseudonames, or to the exchange of social favours in the local communities where the fishers live. In a strict analogy to the current experiment, a punisher would give up some quota and the punished would have to reduce his quota by a larger amount, in rounds played under pseudonames. Although such settings may be stretching the analogy a bit too far, the concept that punishment is not a monetary fine but instead a reduction of the individual quota of the defector is worthwhile consideration. Groups of fishers could be envisaged who meet and negotiate to reach a voluntary and mutual agreement about individual quota allocations with the collective aim to postpone and/or sacrifice part of their quota for the sake of rebuilding the stock. In these negotiations, fishers would meet non-anonymously and they would be able to punish non-cooperative members by allocating smaller quota shares to them; in addition, these non-cooperative members would experience more subtle social damage in their local community. However, unless the game is artificially mimicked, it is hard to see how punishment, either by monetary fines or by reductions of quota, can be set up to be costly for the individual punisher, because the administrative costs of punishment would more logically be shared by the group or the society at large (resulting in a different type of 'game'). In the experiments, costly punishment is meant to reflect the fact that punishment is usually costly to the individual punisher: it demands time and energy, and often entails some risk (Sigmund 2010).

The conclusion from this experiment for our purposes seems to be that people prefer a setting where punishment of non-cooperative peers is possible, perhaps satisfying a deeply rooted sense of fairness. In combination with non-anonymity and reputation building, this will increase the incentives to responsibly restrain fishing activity.

Discussion

I do not pretend to have solutions that prescribe in detail how fisheries management should incorporate the ideas developed here. A single best management instrument does not exist (Degnbol *et al.* 2006, Ostrom *et al.* 2007). The experiments that I discussed were of course not meant to prescribe policy, but rather to investigate incentives for human cooperation. Likewise, I do not intend to prescribe settings in fisheries management according to the 'translations' of these experiments. My contribution is therefore not so much the presentation of a new and magic policy strategy, but an introduction of existing knowledge to a different audience in a playful and thought-provoking way. The knowledge I presented has until now not been widely discussed and commonly shared in the community of fisheries scientists and fisheries managers (but see Eikeset *et al.* in press, 2010), although game theoretical analyses have a long history in fisheries science (Bailey *et al.* 2010). I hope to contribute to closing that gap in a complementary way and open up this field of knowledge to that community and encourage debate, inspire research in new directions, and offer novel perspectives on policy design for fisheries management (Degnbol *et al.* 2006).

The artificial experimental settings of the laboratory studies discussed here may raise some concerns. For example, volunteers were recruited from among students. First of all, if the variation in pro-social behaviour – be it genetic (Knafo *et al.* 2008) or caused by variation in social background – is not randomly distributed, it may not necessarily be the case that fishers reach the same level of cooperation as students do. The subset of volunteering students may also be a biased sample regarding pro-social tendencies; after all, to volunteer in an experiment constitutes the provisioning to a common good. Furthermore, although the student participants can take home real money, the amounts are small and the experiment may be perceived as 'only a game'; and in any case the participants were not asked to sacrifice their own money but instead they were asked to invest money that they were given by the experimenter. It can be argued that fishers will be much more reluctant to put their actual catches, their livelihood, at stake. Moreover, the fishers will differ in their assets, resources, stakes, and benefits, and it has not been addressed here how that would affect the outcomes (the influence of such differences has been discussed in Ostrom 2001). Another concern is that the experiments were artificial in how they treated 'non-anonymity'. Even in 'non-anonymous' rounds, the participants' real identity was never revealed to the other participants; only the pseudonames were known, and these played a role only within the game but not in the 'real world'. It may be questioned whether levels of pro-social behaviour would be different if the real identities of those involved would be public. Although these are valid concerns, I need to point out that the merit of such experiments is not that they measure actual levels of pro-social behaviour, but rather investigate what factors affect those levels in a relative sense. The underlying assumption is then that these factors influence human behaviour at a basic psychological or even biological level and that this would hold true under more realistic conditions. This assumption would be affected only if these factors interacted in a major way with factors that play a role in real-life situations.

I did not discuss any experiments that tested the effect of face-to-face communication between rounds, enabling participants to discuss what they all should do and build norms to encourage conformance (Nash 1953, Ostrom 1998, Ostrom 2001, Ostrom 2007). According to Ostrom's (1998) review the effect is large; in fact, no other variable has as large and consistent an effect on results as face-to-face communication. A strong recommendation for the design of governance based on industry involvement is therefore that the communication should actually happen in physical meetings with face-to-face interaction. At the psychology level, the reasons for this effect include communication of mutual commitment, increasing trust, creating and reinforcing norms, and developing a group identity. The face-to-face situation probably also adds additional values to the subjective payoff structure, as the opportunity for reputation-building may be more strongly felt. The effect of face-to-face communication is quite likely deeply rooted and hardwired in our biology; in experiments monetary sacrifice among strangers has been found to be mediated by endogenous oxytocin release after physical contact (Morhenn *et al.* 2008). A reluctance to betray trust and behave selfishly when being watched may be hardwired in humans as well (Milinski and Rockenbach 2007). Apparently, human beings take into account sophisticated signs of others watching: "don't lose your reputation" (Fehr 2004) is an unconscious imperative that guides social behaviour.

When stating that pro-social behaviour is hardwired, I do not mean that particular rules for reciprocity or trust are hardwired in our brains and inherited as such; the situation is more subtle. It is our emotional sensitivity towards social rewards and penalties as well as justness and fairness that is inherited and has evolved because it has the potential to elevate the likelihood of cooperation, which in turn enhances biological fitness (Sigmund 2010). For example, the satisfaction that humans derive from punishing norm violations has been shown to have a neural basis (De Quervain *et al.* 2004). A reputation for being trustworthy, or for using retribution against those who do not keep their agreements or keep up their fair share, becomes a valuable asset. In an evolutionary context, it increases fitness in an environment in which others also use reciprocity norms (McNamara *et al.* 2009, Sigmund 2010). Similarly, developing trust in an environment in which others are trustworthy is an asset. Hence, our sensitivity for learning social norms that increase our own long-term benefits when confronting social dilemmas with others who have learned similar norms, has evolved and become hardwired. Similarly, our language instinct is hardwired, notwithstanding the fact that no grammar rules or vocabulary of any particular language are transmitted through our genes (Pinker 1995). Similar to the case of language, given our innate sensitivity for social behaviour, we need to be socialized by parents, peers, teachers, business partners, and society at large for the appropriate behaviour to develop and be expressed. There is no contradiction between asserting that pro-social behaviour is innate and that it is learned. The genetic variation as well as variation in social background leads to variable expression of pro-social behaviour. In turn, variation may play a role in the evolution of the personality differences observed (McNamara *et al.* 2009, Sigmund 2010).

I focussed on very artificial experimental settings revealing conditions that enhance pro-social behaviour under controlled environments. However, in addition, extensive empirical field studies have found that the users of natural resources sometimes, but not always, invest in designing and implementing governance systems in order to increase the likelihood of sustaining them. Ostrom (2009) has reviewed these studies and provides an analysis of factors conducive to collective action in real-world examples. Ostrom's results have already been used for analyses of existing fisheries management systems (Eikeset *et al.* in press, 2010). That was not my aim; I chose to look at factors that promote pro-social behaviour at the most basic level of human expression. From the experiments I reviewed it is possible to distil basic properties of human nature under controlled conditions, bared from the complexities of multi-level interactions of factors in real-world case studies. Nevertheless, some results from Ostrom's (2009) analysis that are worth mentioning here are that, on the down-side, the large resource-size of high-sea fisheries, the large uncertainty in knowledge of the state of the resource, and the mobility of fish, are all non-conducive to pro-social collective action; and these variables are unfortunately not under our control. On the positive side, when users share common knowledge of the system and how their actions affect each other, and when users have full autonomy at the collective-choice level to craft and enforce some of their own rules, and when users are dependent on the resource for a substantial portion of their livelihoods, pro-social collective action is more likely.

An illustrative example of self-organized fishing rules is given by Hart (Hart 1998, Hart 2003) in his description of the mixed fishery for crabs and demersal fish off south Devon, UK. Edible crab (*Cancer pagurus*, Cancridae) are caught with pots that are set in strings of about 60 pots each and left on the bottom year round. Each crab fisher has a defined territory where up to 600 pots are set. Demersal fish are caught by trawls, which can cause expensive damage to crab pots if the two should become entangled. In the late 1970s, conflict between crabbers and trawlers caused by gear interference had escalated.

It led to the partitioning of the fishing ground, within the national 6-mile limit, into crabbing-only areas and areas where both crabbing and trawling could take place for all or some of the year. The partitioning was based on a voluntary agreement between the parties and has remained in force and working since its inception. The agreement is most threatened by large-beam trawlers (~30 m) and scallop dredgers originating from outside the group that exploit the inshore area. Hart (2003) analysed why this voluntary agreement works, so that the system might serve as a model for rulemaking where similar conflicts of interest exist. The participants in the fishery are either related or know each other well. Many live together in the same small communities, and most come from families for whom fishing has been a livelihood for centuries (see references in Hart 1998). In addition to achieving the goal of keeping conflicting gears apart, the system has resulted in a conservation effect for organisms that are damaged by towed gear, because some areas have been closed to trawling for more than 20 years.

Central intervention from authorities often directly undermines existing pro-social behaviour (Bowles 2008, Richter and van Soest in press, 2010). It should be carefully considered whether or not financial sanctions are implemented. The human tendency to cooperate may actually decline under an institutional regime of economic incentives for cooperation, for example because these incentives remove the possibility for people to signal their good behaviour to their social peers and build a good reputation (Bowles 2008, Richter and van Soest in press, 2010). Another reason for a decline of cooperation under an institutional regime of economic incentives may be that people feel they can ‘buy the right’ to be non-cooperative through paying the fine or fee (Bowles 2008, Richter and van Soest in press, 2010); they buy the right to overexploit the common resource. Similarly, the market for carbon-emission permits might be perceived as a trade in the rights to pollute the world. In experiments and in the field it has been found that sometimes financial incentives induced more self-interested behaviour, even after they were withdrawn (Bowles 2008). An example where formal rules destroyed informal norms is provided by Cardenas *et al*. (2000). In this study experiments were run with people in rural Colombia who are confronted with a common pool problem in their daily life. In the experiment subjects were asked to decide how much timber to extract from a forest. The scenario presented was that harvesting had an adverse effect on water quality (as is actually the case in the study region), posing a cost on everyone in the group. The game was played first without any regulations in place, while at a later stage an extraction norm was introduced that was enforced by a mild probabilistic fine. Cardenas *et al*. (2000) found that subjects reduced their extraction level immediately after the regulation was introduced, but started extracting more aggressively after realizing that consequences were rather mild. Strikingly, in the last rounds, extraction levels were higher with the regulation than without. As a result, payoffs were significantly lower when individuals were confronted with a formal rule than in its absence; the weak official rule interacted with the internal norms of the subjects and destroyed their intrinsic motivation to cooperate. However, from such results it cannot simply be concluded that regulations should be abolished. The loss of social capital may, to a high extent, be irreversible (Bowles 2008, Richter and van Soest in press, 2010).

Also too much monitoring may have the counterintuitive result that individuals feel they are not trusted and thus become less trustworthy; they may assume that formal organizations are charged with the responsibility of taking care of joint needs and that reciprocity is no longer needed (Ostrom 1998). Importantly, while economic incentives, such as fines, tend to diminish any existing social capital when they are imposed externally, the opposite seems to be the case when they are imposed from within, by peers (Bowles 2008). This also became apparent from the experiment discussed above (Rockenbach and Milinski 2006), where peer punishment combined with reputation building was the preferred setting and proved to be a very effective incentive for cooperation. Furthermore, experiments have revealed that if the participants are given the opportunity to vote whether the institution is allowed to keep the fine revenues, cooperation is enhanced (Vyrastekova and van Soest 2008, Richter and van Soest in press, 2010). The authors believe that the casting of votes served as a means of communication between the participants as to their views on the urgency of conserving the common resource and their willingness to cooperate towards that aim. Translated to the fisheries management context that would imply that even if managers believe it is desirable to keep institutional sanctioning, it may be important to involve the stakeholders in decision-making, for example on the level of sanctioning. Or the stakeholders themselves could institutionalize financial sanctions from within through their Producer Organisations. Most robust and long-lasting common-pool regimes involve clear mechanisms for monitoring and graduated sanctions for enforcing compliance, and few self-organized regimes rely entirely on communication alone to sustain cooperation in situations that generate strong temptations to break mutual commitments (Ostrom 1998). Monitors – who may be participants themselves – do not use strong sanctions for individuals who rarely break rules. Modest sanctions indicate to rule breakers that their lack of conformance has been observed by others. By paying a modest fine, they rejoin the community in good standing and learn that rule infractions are observed and sanctioned. Repeated rule breakers are more severely sanctioned and eventually excluded from the group. Rules meeting these design principles reinforce contingent commitments and enhance the trust participants have that others are also keeping their commitments (Ostrom 1998).

Many fisheries industries in Western states have experienced a shift from government to governance over the last decade (van Hoof 2010), characterised by a trend towards decentralised, flexible and consensual styles of governance, at the expense of top-down, centralised, hierarchical, command-and-control regulation. In the European Union for example, The Common Fisheries Policy reform in 2002 had already started a process of strengthened participation in fisheries governance; and the recently released Green Paper on the CFP (Anonymous 2009) further explores avenues to increase participatory decision-making. According to this Green Paper, the general framework for fisheries policy would be set on the basis of a Commission proposal, but detailed implementation decisions could be taken at a regional level through a process of stakeholder interaction. It also foresees requests to industry to develop their own fisheries plans. Apparently, governments and the sector increasingly recognised that a fishing industry cannot be managed effectively without the cooperation and participation of fishers to formulate policy and to implement and enforce laws and regulations.

The institutional characteristics that would likely maintain existing social capital (Kuperan and Sutinen 1998, Hatcher *et al.* 2000, Raakjær Nielsen 2003, Raakjær Nielsen and Mathiesen 2003, van Hoof 2010, Richter and van Soest in press, 2010) include the extent to which the external intervention is perceived to be legitimate and adequate (or proportional), as well as the extent to which the institution is perceived to be supportive (rather than restrictive). When an institution is perceived to be legitimate and fair, participants are much more inclined to obey the rules. A study among Danish fishers (Raakjær Nielsen and Mathiesen 2003) reported that they "feel they are taken hostage by an illegitimate management system, and thus feel it is morally correct not to comply". One way to achieve legitimacy is involving stakeholders in the process of designing formal institutions (Hatcher *et al*. 2000, Dankel 2009, Eikeset *et al*. in press, 2010). An active dialogue between stakeholders and decision makers can also help identify and overcome potentially conflicting objectives from different stakeholders (Dankel 2009). A larger involvement of fishers in the decision-making process should also include the transmission of knowledge to the fishers concerning the status of the stocks (Raakjær Nielsen and Mathiesen 2003); this agrees with the findings that participants in common pool experiments tend to contribute more when information on the common-pool problem is provided (Milinski *et al.* 2006). It has also been found that biological characteristics of the stock, such as intrinsic growth rate and stock size, can have important influence on the fishers' cooperation (Trisak 2005). However, users' discount rates can also affect the outcome (Munro 1979). Compliance with fisheries regulations has been found to depend not only on economic incentives and the perceived meaningfulness of the regulation, but also on ethical views and mutual trust among the fishers to comply (Kuperan and Sutinen 1998, Hatcher *et al.* 2000, Raakjær Nielsen and Mathiesen 2003). Fishers may build a good local reputation when their behaviour signals responsible fishing. However, under certain conditions, non-compliance may become the social norm (Raakjær Nielsen and Mathiesen 2003, Kerr *et al.* 2004).

The Dutch system of individual transferable quota (ITQ) has been described as a change to partial co-management to show how this increased compliance and reduced costs to society (van Hoof 2010). Since almost two decades Dutch beam-trawl fishers are members of local quota-management groups. Within these groups, fishers pool their individual quota, enabling them to buy, sell, or lease quota, increasing their short-term flexibility. The introduction of this system clearly played a role in bringing back legitimacy to the system and in increasing compliance with quota management. Official landings have been within the set TACs and the costs of the inspection service and registered infringements have been greatly reduced (van Hoof 2010). Also there was a shift in the driver for compliance, from an economic rationale (based on the economic gain obtained from violating the regulation relative to the likelihood of detection and the severity of the sanction) towards social control, peer pressure, and a social normative rationale (van Hoof 2010). Nevertheless, the groups are reluctant to police their operations among themselves and they still look at the government as an agent to fulfil a role in enforcement (van Hoof 2010).

It appears that approaches based on the social sciences to achieve specific behavioural goals for a social good are being used to tackle real problems of fisheries management. A recent project ("Project 50%", A. Revill, personal communication, http://www.cefas.co.uk/data/fishing-gear-technology-at-cefas.aspx), aimed at reducing discards (non-landed catch) of fish in the English beam-trawl fishery in the Western Channel, successfully produced a desirable behavioural change of the fishermen. Fishers participating on a voluntary basis (without financial compensation) were asked to design a selective trawl which they believed would reduce discards, without any further prescription. The study would pay for the designed trawls to be produced. Newsletters were distributed to raise public awareness of the trials and the positive steps the fishers were taking to reduce discards; the participating skippers are non-anonymous. When the experimental beam trawlers fished with a standard trawl on one side and the modified trawl of the fishers' own design on the other side of the vessel, most designs indeed resulted in reduced discards and catches. More importantly, the fishers are willing to use these trawls in the future, despite the fact that catches are likely lower. Essential for the resulting behavioural change is that the fishers were given the freedom to use their own expert judgement on the characteristics of the trawl in order to reach the preset objective.

Conclusions and outlook/recommendations

The most important conclusion from this study is that small differences in institutional design may lead to very different outcomes in terms of cooperative fisher behaviour to overcome the Tragedy of the Commons. Human nature displays both self-interest and altruism, depending on external conditions, which can be manipulated. Thus, self-interested cynical people may become responsible moral agents under the right conditions. Settings that enhance these desirable outcomes include (i) non-anonymity – fishers' individual choices should be publicly known among them and/or in their wider social community; (ii) provision of knowledge to fishers on the state of the resource and the urgency and impact of their responsible behaviour; (iii) fishers' self-decision on rules and (levels of) economic sanctions; (iv) face-to-face communication among fishers and between fishers and managers and other stakeholders.

One dogma that may have to be abolished is that fisheries data at the individual vessel level are often strictly confidential. This suggestion follows from the findings that in order to maintain high levels of cooperation, it appears to be important to avail of the opportunity to acquire information on each other's intentions and to monitor each other's actual contributions, because this is required for reputation building and for the (social) rewarding or punishing of each other's behaviour. In the current situation, where individual vessel-based fisheries data are confidential, one such opportunity for monitoring each other's level of pro-social behaviour is absent.

Acknowledgements

This work is funded through a Fellowship (Grant-Aid Agreement No. PDOC/FS/07/002) funded by the Sea Change strategy with the support of the Marine Institute and the Marine Research Sub-programme of the National Development Plan 2007 – 2013, Ireland. I acknowledge Paul Hart and Manfred Milinski, from both of whom I learned about cooperation in social dilemmas while officially I was studying stickleback behaviour with them. I thank two anonymous reviewers who contributed to improving the manuscript.

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