Fisheries and the Prisoner's Dilemma Game: Conditions for the Evolution of Cooperation among Users of Common Property Resources

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Abstract

Recent studies using a Prisoner's Dilemma framework have led to a theory of cooperation based on repeated encounters and the development of reciprocity. The theory is applicable to a diversity of disciplines and has implications for the use of common property resources such as fisheries, i.e., what are the conditions under which the users of a fishery resource will cooperate to avoid, what some consider, the inevitable "tragedy of the commons"? The Prisoner's Dilemma approach helps formalize some of the recent theoretical developments on conditions of successful common property resource use. In particular, it offers insights regarding the importance of probability of encounter among users, development of reciprocal relations among them, the number of users in an area and the degree of crowding, heterogeneity of user-groups, the importance of local residency, and the supply-demand characteristics of the resource.

Much empirical material has recently been compiled on the use of common property resources such as fish and wildlife, forests, grazing lands and irrigation waters.[1] These case studies indicate that different groups of people have developed over the years an impressive array of resource management practices, many of them well suited to address the special management problems of common property resources. Thus, many of these resources are communally controlled and may be characterized as _res communes_, to use the terminology of Ciriacy-Wantrup and Bishop,[2] rather than as _res nullius_, unowned and subject to a free-for-all. This is not to say that all fish, forests, grazing lands and waters are _res communes_; they are not. The point here is that while the commons problem (or the "tragedy of the commons" of Hardin[3]) does exist with many resources it is by no means the universal condition. This issue has been explored, among others, by Cox with respect to grazing lands, and by Berkes for fisheries. A fundamental problem of research and management, therefore, is the investigation of conditions under which the commons problem may be solved. To do this, however, it is necessary to start to develop some general principles which may be formalized.

The availability of an increasing number of case studies with different resource types has stimulated the development of common property theory. Recent contributions include those on conditions and success criteria, research strategies and methodology, reciprocity, the nature [9] of user-group organizations, and the typology of management regimes. However, the complexity of variables has so far precluded the development of formal models. It should be noted that there is no lack of mathematical models on overexploitation of resources, as for example in the case of fisheries.[11] Lacking are models on development of cooperation among resource users, conditions for the sustainable use of resources,[12] and the determinants of viability of common property institutions.

The objective of our paper is to contribute towards a theory of common property resources by applying the game-theoretic model known as Prisoner's Dilemma to the question of cooperation among users of common property resources. This requires an initial assessment of some of the variables that would lend themselves to this kind of analysis. It is assumed that the Prisoner's Dilemma approach is likely to be useful with only a limited set of the relevant variables. Thus, we seek to explore both the potential and the limitations of such an application. We claim no new contribution to game theory itself; the basic theorems of Prisoner's Dilemma have already been worked out by others. We only seek to apply and adapt these theorems to common property resources, using illustrations from the field of fisheries.

FACTORS AFFECTING COMMON PROPERTY INSTITUTIONS

There is a spectrum of possible relationships among users of common property resources such as fish. Fishermen may have neutral attitudes towards one other, they may be competing or cooperating. Assuming that we are dealing with relatively small-scale coastal marine or freshwater fisheries, a few generalizations are possible with respect to a "life cycle" of resource development. Initially, the resource would be used by relatively few fishermen. This may be a traditional fishery or simply a commercial fishery in early stages of development. Assuming the latter, initially the resource is superabundant relative to the effort applied to it. The activity of one fisherman is not likely to affect that of another; there is plenty of fish to go around.

According to the current bioeconomic theory of fisheries, such a state of affairs is not likely to last for long. The profitability of the fishery will attract new entrants until fishing effort expands to the point at which costs have risen and revenues declined so much that all resource rents are dissipated or competed away.[13] In the absence of regulations, the model assumes that the level of effort will not stay at a level which would maximize yields or profits. Rather, such an open-access fishery will gravitate towards a higher level of effort, an equilibrium (sometimes called bionomic equilibrium) in which the cost of fishing for the fleet as a whole equals the revenue as a whole, discouraging any new entrants.

As a solution to this damaging open-access condition, most fishery managers have focused on government regulations. As MacKenzie summarizes them, government intervention takes the form of measures (a) to control the quantity harvested by instituting quotas, (b) to regulate fishing effort by restricting the type and size of vessels and gear, and ultimately the number of licenses, and (c) to provide financial support for those adversely affected by regulation.[14] With increasing recognition that government regulation is only one of the several possibilities to solve the problem,[15] some economists have started to focus on the various mechanisms by which groups of fisherman can limit their own efforts or the number of entrants into the fishery.[16] It is this class of responses which is of particular interest for this paper.

Analysing the "life cycle" of such fishery resource development with respect to the question of cooperation among the fishermen, a classification of a sort summarized in Table 1 is obtained. If the resource is superabundant relative to the effort applied to it, the relations among fishermen may be expected to be neutral; they have no incentive to affect one another adversely, nor do they have any incentive to cooperate. But as new entrants join the fishery, in accordance with the bioeconomic model, and there is less fish to go around, there would be increasing conflict among fishermen. Such conflict may take the form of competition over fish and over buyers, and may involve interference such as removing one another's fish traps and cutting nets.

In reality, direct interference occurs only under rare circumstances. In most cases, it does not take fishermen long to realize that an all-out war produces no winners. Perhaps the simplest form of cooperation is the development of mutual respect for one another's livelihood, a "live-and-let-live" philosophy. Not surprisingly, even in fishing communities in which there is no evidence of cooperation, mutual respect among fellow competitors is a well established practice.[17]

The next step beyond simple conflict management is the development of mutually acceptable rules, user-group organizations such as fishermen's associations, and what may be generally called common property institutions. According to Bromley, common property involves a set of "institutional arrangements concerning who may make use of a resource, who may not make use of a resource, and the rules governing how the accepted users shall conduct themselves." The presence of common property institutions, by definition, means that the resource in question is res communes and not res nuilius; the resource is no longer open-access.

Bromley's set of three types of rules probably represents the minimum for a viable common property institution, and it is possible to elaborate on these rules by specifying partitioning rules, rules of entry and exit and so on, as Oakerson has done.[19] In some case studies, such as those on Japanese common lands,[20] Japanese coastal fisheries,[21] and Cree Indian hunting, fishing and trapping in the Canadian eastern subarctic,[22] it is clear that the groups in question have much more than just the minimum rules for a viable common property institution. These are societies in which the historical and cultural context of the common property institution is important. As with the Cree Indian case, the relevant institution has changed over time but has persisted in one form or another over the centuries. These people have a hunting culture, and institutions such as those regulating the trapping of beaver are intertwined with rules regarding the sharing of resources in general. In such "traditional societies", the common property institution may be said to be imbedded in the culture of the group. This is probably true also with a number of Pacific Island societies.[23]

The availability of a large number of case studies in the 1980s has permitted the development of an evolutionary view on common property institutions. There are case studies with rudimentary rules of resource use, others with substantial rules or with elaborate common property institutions. There are also many case studies of tragedies of the commons. In some of these, the tragedy may have occurred in the absence of any common property institution; this is generally the case with open-ocean fisheries which are ownerless resources (res nullius).

In other cases, the tragedy occurs because of the breakdown of existing common property institutions or user cooperation in general. The best examples of these come from traditional societies which have been invaded by outside economic interests or which have suffered from rapid and disruptive changes. Berkes has identified, with examples, four classes of such external factors leading to the commons problem: (a) rapid population growth, (b) rapid technology change, (c) rapid commercialization of the resource, and (d) the creation of open-access conditions by outside forces, as a colonization.[24]

It must be added in reference to Table 1 that the breakdown of common property institutions is not seen as the final phase of some deterministic sequence of events. The breakdown may come after stage 3, 4 or 5 or it may not occur at all. If it does occur, the common property institution may well recover later at some point. There is, in fact, a case study in which common property institutions seem to have collapsed and recovered probably three times.[25]

In addition to such external forces creating a commons problem, Ostrom has recognized a number of factors determining whether a user-group organization will originate, and if it does, whether it will survive.[26] On the basis of some of this analysis and generalities emerging from the literature, the following four classes of factors are identified as conditions limiting the emergence of common property institutions or leading to their breakdown:

1. Probability of encounters and of reciprocity *very* low,
2. The number of users too large; too crowded an area ,
3. Users are heterogeneous; two or more user-groups present,
4. Condition of resource scarcity or superabundance relative to number

of users and demand for resource.

It must be noted that this is by no means a comprehensive list of determinants of common property institutions; in particular, the set of factors identified by Ostrom on the origins and survival of user-group organizations (in effect, the common property institution itself) is more comprehensive.[27] We have chosen the above set of four factors for two reasons: (1) They are consistent with a large number of case studies and seem to represent an emerging consensus,-- and (2) they are suitable for the application of a game-theoretic framework. The latter criterion is not trivial; the beginnings of any theory has to start with the formalization of those hypotheses that lend themselves to testing.

THE BASICS OF THE PRISONER'S DILEMMA GAME

The Prisoner's Dilemma game provides a general framework to analyze the evolution of mutual cooperation between individuals in a wide variety of situations from bacteria to humans.[29] The application of Game Theory is appropriate in predicting the optimum behavior patterns when the results of particular acts by an individual depend on what others are doing.[30] The Prisoner's Dilemma exemplifies a situation in which two players can choose between cooperation and defection; and gains to each player depends on the opponent's choice. The payoff matrix for Prisoner's Dilemma is given in Figure 1, where P, R, S, T, represent the payoffs to player 1. The game is defined by the conditions,

$$(1) \quad T > R > P > S$$

$$(2) \quad 2R > T + S$$

When the other player chooses cooperation, the first player can either defect and get T (Temptation to defect) or cooperate and get R (Reward for mutual cooperation). If the other player chooses to defect, the first player can either defect and get P (Punishment for mutual defection) or cooperate and get S (Sucker's payoff). Since $T > R$ and $P > S$ by definition, one always gets a higher payoff by defecting no matter what the other player does. However, the paradox is that mutual cooperation pays more than mutual defection.

When the game between two players consist of a single round, the solution to the game is defection.[31] If, however, the game is repeated an indefinite number of times, cooperation between the players is possible. The problem then becomes to determine suitable conditions for cooperation. In an iterated game situation, players can decide on cooperationor defection at each move depending on the history of their previous interactions. A decision rule governing the acts of a player on each move is called a "strategy". The expected payoff for a player using strategy A against a player who uses strategy B in an iterated game is represented by V(A/B). If $V(A/B) > V(B/B)$, strategy A can invade a population of players using strategy B. If no strategy can invade the population of players using B, the strategy B is said to be an evolutionarily stable strategy (ESS).

The concept of ESS is based on viewing the success of different strategies from an evolutionary perspective. If we assume a population of players, in which individuals meet with each other randomly and each interaction results in payoffs determined by the strategies chosen by the players, a successful strategy would be expected to increase in the population if success (the total payoff) can be interpreted as Darwinian Fitness.[32] The expected payoff accruing to a player in an iterated game is computed by summing the weighted payoffs resulting from each interaction. The weighing reflects the value of future moves relative to current moves. If the probability that two players will meet the next time is w, the probability that they will meet for the nth time is w^{n-1}. The expected payoff for each of the players who always choose to cooperate, is then,

$$R + wR + w^2R + \ldots = R/(1-w)$$

This is also the total payoff for a player when both players assume a strategy called TIT FOR TAT (TFT). In this strategy, a player cooperates on the first move, and then does what the other player did on the proceeding move. If both players play TFT, they will always choose to cooperate.

When a player uses a strategy of always defecting (ALLD) against TFT, the payoff in the first round will be T, and P in the following rounds, since TFT will retaliate to defection by defecting from the second round on. Thus, expected payoff for ALLD playing against TFT is

$$\begin{aligned} V(ALLD/TFT) &= T + wP + w^2P + w^3P + \ldots \\ &= T + w\,P/(1-w) \end{aligned}$$

ALLD cannot invade TFT if

$$\begin{aligned} &V(TFT/TFT) \geq V(ALLD/TFT) \\ &\text{or } R/(1-w) \geq T + w\,P/(1-w) \end{aligned} \qquad (1)$$

If a player uses a strategy of alternating D and C against TFT, the expected payoff for this strategy is

$$V(ALTDC/TFT) = T + wS + w^2T + w^3S + \ldots$$
$$= (T + wS)/(1-w^2)$$

The strategy of alternating D and C against TFT can not invade TFT if

$$R/(1-w) \geq (T + wS)/(1-w^2) \qquad (2)$$

The inequalities (1) and (2) can also be expressed, respectively, as

$$w \geq (T-R)/(T-P) \text{ and} \qquad (3)$$

$$w \geq (T-R)/(R-S) \qquad (4)$$

Therefore, if w is larger than both of the ratios given above, neither ALLD nor ALTDC can invade TFT. Axelrod has shown that if neither ALLD nor ALTDC can not invade TFT, no other strategy can invade TFT. Therefore TFT is an evolutionarily stable strategy. More detailed treatment of the model and proofs may be found in Axelrod.[33]

APPLICATIONS OF PRISONER'S DILEMMA TO FISHERY MANAGEMENT

Having reviewed the basics of the Prisoner's Dilemma game, what are some of the predictions relevant to future management, and do these predictions agree with generalizations obtained from empirical studies?

Restating the four general principals reviewed earlier, this section will deal with each in turn with respect to predictions of the Prisoner's Dilemma game.

Principle 1: Cooperation is less likely if the probabilty of encounters among some users is relatively low.

On the basis of inequalities (3) and (4), both the value of the probability of encounter (w) and the values of the payoff matrix are important for this question. For example, given a fixed payoff schedule of R = 3, S = 0, T = 5, ;P = 1, probability of encounter, w = 0.67 is sufficient for the stability of the cooperative strategy, TIT FOR TAT. Here the values of the payoff matrix may represent the relative landed value of fish obtained by fishermen.

If the payoff matrix is altered in such a way that temptation pays less (assuming T = 4 with the rest unchanged) then w = 0.33 is sufficient for the stability of TIT FOR TAT. On the other hand, if temptation is relatively great (assuming T = 5.9), the critical value of the probability of encounter, w, is 0.97. If T is even greater, that is, the temptation not to cooperate very high, then the equality $2R > T + S$ does not hold, and Prisoner's Dilemma model would no longer be applicable.

In real life, many cases of cooperation among fishermen appear to satisfy the requirements of the Prisoner's Dilemma model, and a payoff schedule on the order of R=3, S=0, T=5, P=1 does not appear unreasonable even though there are no examples in the literature of an actual payoff schedule calculated from field data. The usefulness of the model is in the demonstration of the critical importance of the probability of encounter, given a payoff schedule of constant values.

In a community-based fishery, a probability of encounter of 0.67 is entirely feasible. On the basis of previous fieldwork with a diversity of fishing communities of mostly less than 100 fishing units, the probability of encounter may be estimated at close to 1.0 on an annual basis.[34] On a weekly basis, the probability of encounter would still be on the order of 0.6 - 0.8. In most of these cases, fishermen would not be encountering one other at sea. Rather, the encounters would be in the harbor, coffeehouse, the local pub, over the radio, and at the office of the local organization, be it a cooperative or an association or simply the fishmarket. Constant meetings among fishermen and endless talk about fishing appears to be a universal feature of fishing communities. The importance of this fact for our purposes is that cooperation is more likely to develop in such face-to-face communities than in larger settlements in which the opportunity is much reduced for fishermen to get together and discuss matters of common interest.

Corollary to Principle 1: Cooperation is less likely if there is little reciprocity among resource users.

In cooperative strategies such as TIT FOR TAT, reciprocity is essential. After cooperating on the first move, TIT FOR TAT simply reciprocates whatever the other player did on the previous move. As Axelrod has shown, this simple strategy is very robust; TIT FOR TAT has won against all other strategies in two successive computer tournaments organized by Axelrod.[35] The major characteristics of the strategy is that it is "nice" (cooperates on the first move), "provokable" (it defects immediately when the other player does so), and "forgiving" (returns to cooperation on the next move when the other player does so). The relationship between reciprocity and the probability of encounter (w) is that reciprocity depends on the opportunity of encounter; if w is *very* low, then TIT FOR TAT will have less opportunity to reciprocate.

The real life application of the corollary is similar to that of Principle 1. Fishermen have many ways in which they can reciprocate, including information sharing, assistance with the boat or with nets, and assistance in the face of adverse weather conditions. Among these, information exchange was found to be a universal mode of reciprocity in the subsistence fishery of a tightly knit Cree Indian community.[36] By contrast, Andersen found information exchange very limited (and deception and secrecy prevalent) among large-scale fishermen (trawlers).[37] In the case of small fishing communities, it must be noted, however, that negative reciprocal relations may also be prevalent. Perhaps one advantage of larger-scale fisheries is that captains are able to avoid, and thus maintain neutral relationships with, those whom they dislike.

Principle 2: Cooperation is less likely if the number of resource users is too large and the area too crowded.

The logic of this principle is similar to that of Principle 1. As the number of users (for example, numbers of fishermen or numbers of boats active in the area) increases, probability of interactions between pairs of users decreases. If individuals are selected randomly at each round of interaction, the probability that an individual will be matched by his/her previous opponent is 1/(N-1), where *H* is the number of individuals in the group. Assuming that the parameter, w, is proportional to 1/(N-1), it will become more and more difficult to satisfy inequalities (3) and (4) as the group size increases.

With low w, it follows that there will be less opportunity for reciprocal interactions. For example, in a community of only 100 fishermen, the probability of repeated interactions would be ten times as much as in a community with 1000 fishermen. This prediction of the model is consistent with the theories of Olson who postulated that "large" groups (as opposed to small and intermediate-sized ones) would have more difficulty instituting collective action. Another way of stating the general principle is that the group should be small enough to keep the costs of communication and decision-making relatively low.

In terms of real life examples, the Bay of Izmir fishery investigated by Berkes, with some 675 licensed fishing boats plus unknown numbers of unlicensed semi-professional and amateur fishermen, is a striking example. The area is so crowded that gillnet fishermen cannot leave their nets untended. While there are elements of cooperation among fishermen of at least one of the nine communities involved, there is so much interference from other fishermen in the area that would-be cooperators are constantly frustrated and tend to give up hopes of introducing order into the fishery.[39]

Principle 3: Cooperation is less likely if resource users in an area are heterogeneous; two or more user-groups are present.

The previous principles dealt with repeated interactions between individuals, whereas this principle deals with two or more groups with different interests, for example, coastal gillnetters vs. trawlers. In this case, the payoff matrix for the two (or more) groups is likely to be such that the values of R, S, T and P are no longer within the domain of the Prisoner's Dilemma game. For example, a trawler's payoff schedule in interactions with gillnetters is not likely to satisfy the conditions of the game; in many cases, the trawler has little to gain from cooperating with gillnetters. As Axelrod puts it, "the opportunity for mutual gain from cooperation comes into play when the gains from the other's cooperation are larger than the costs of one's own cooperation."[40]

A trawler may still cooperate with another trawler (although unlikely, subject to Corollary of Principle 1), and gillnetters may still cooperate with one another (subject to Principle 2). But if the payoff schedules for each of the two user-groups are such that one cannot gain from the other user-group's cooperation, then a "tragedy of the commons" situation is likely to result. The model is consistent with the observation that the most notable conflicts in the world of fisheries involve rival user-groups, rather than fishermen belonging to one user-group. These conflicts often pit large-scale industrial fisheries (such as trawlers) against small-scale or artisanai fisheries.[41]

It is not surprising that the two most conflict-ridden and unsuccessful fisheries in the area surveyed by Berkes involved two areas, Bay of Izmir and Bodrum, in which there were respectively, six and five distinct user-groups.[42] However, these two case studies also show that it may be *very* difficult to separate out the effects of crowding (Principle 2) from the effects of heterogeneity.

However, in certain situations, different user-groups seem to be able to get together and resolve their differences. The case in point is the fishery of northwestern Lake Erie in which gillnetters and trawlers tend to interfere with one another in the spring season when the two major species sought by the two gear types migrate into the same shallow waters. In the absence of cooperation, trawlers often damage gillnets unless they can manoeuvre around these stationary nets. By the time the spring fishery is over, gillnetters are claiming damage, accusations and counter-accusations are made, and both sides have lost valuable time and income. The solution, arrived at local association meetings and enforced by a captain who has the trust and respect of both sides, is to designate an exclusive trawling area marked with buoys. This way, trawlers operate inside this area only and the rest of the area is reserved for gillnetters.[43]

The ability for such cooperation in Lake Erie seems to be related to the fact that both kinds of fishermen belong to the same local associations and live in the same two communities, encountering one another quite frequently and communicating constantly over the radio. There are about 250 fishermen involved, operating a total of about 50 vessels. Many of the boats have the ability to switch operations from gill to trawl and back. In the parlance of the Prisoner's Dilemma game, the cooperation of two gear types in Lake Erie is explainable because the gains from the other's cooperation are larger than the costs of one's own cooperation, even though the payoff schedules for the two user-groups are somewhat different.

Corollary to Principle 3. Cooperation is less likely if some of the users do not live in the resource area.

This corollary is largely the consequence of the reduction in the probability of encounters (w) when the users reside in two or more communities. The problem may be partially solved if the users are able to communicate despite living in different areas, as in the case of northwest Lake Erie fishermen. Another example is the eastern Mediterranean lagoon fishery investigated by Berkes. Fishermen live in three neighboring villages,, but the institutional focus is the lagoon cooperative and all fishermen are in constant touch with one another.[44] Furthermore, there is a great deal of social exchange among the three villages. Most people have relatives in the other villages, and events such as marriages are often celebrated jointly. The survival of the user-group organization (the cooperative) is ensured by limiting membership to residents, justified under the Cooperatives Act in Turkey. Since the cooperative have exclusive fishing rights, monopoly is maintained over the resource.[45]

Many of the fishery conflicts through the southern seas of Turkey, as indeed through the world, involve non-residents fishing in areas previously controlled by fishermen residing in that area. When the demersal (bottom-dwelling) fish stocks of the southern Aegean were depleted in the late 1970s, the trawlers from that area moved to the relatively lightly fished Mediterranean coast, immediately creating conflicts with the resident inshore small-scale fisherman.[46] The general issue is that fishermen who use technology and gear which makes them mobile have little incentive to enter into cooperative relationships and little incentive to conserve stocks for long-term gain. Resident fishermen do have such incentives. However, in a situation of competition against those user-groups which are not likely to stay around (low w), and which have a low R and a high T in their payoff schedule, a "tragedy of the commons" is the likely result; "anything left for another day's effort may be freely taken by others."[47]

Principle 4. Cooperation is less likely if resource is very scarce or superabundant relative to the number of users and demand for the resource.

Few fishermen utilizing a superabundant resource do not usually cooperate (Table 1). This follows from empirical observations; as well, it is consistent with the predictions of the Prisoner's Dilemma game. In such a case, reward for mutual cooperation (R) and punishment for mutual noncooperation (P) would not be expected to be different. Thus, the condition $T > R > P > S$ leading to cooperation, is not applicable.

If the resource is *very* scarce relative to demand, two possibilities exist, neither of them consistent with the preconditions of cooperation. First, the resource may be so low in abundance that it is not worth anyone's effort to harvest it, that is, payoff values approach $T=R=S=P=Q$. The second possibility is that the resource may be low in abundance but very valuable for the few who are lucky enough to harvest it. In such situations, there is little incentive to conserve, and a runaway positive feedback effect (depletion followed by even higher prices, followed by further depletion...) will bring about a tragedy of the commons.[48] In the context of the Prisoner's Dilemma game, the situation may be explained in terms of a *very* high value of T which would make cooperative strategies such as TIT FOR TAT unstable.

DISCUSSION AND POLICY IMPLICATIONS

Predictions of the Prisoner's Dilemma game are basically consistent with empirical evidence and with common sense principles of fishery resource use. This game-theoretic framework appears to be a promising tool to begin to formalize a theory of common property resources. While this paper deals only with fisheries, the theory so generated may be equally applicable to other common property resources such as forestry, range lands and irrigation water. Prisoner's Dilemma model yet remains to be tested against case study material involving these other resource types.

Regarding complex and dynamic external factors affecting the use of common property resources (rapid population growth and technology change, commercialization, and creation of open-access conditions), the application of the Game Theory approach is somewhat simplistic because of the interaction of factors. In theory, it should be possible to introduce the effects of these complex external factors into the model by varying w and/or payoffs as a function of these factors.

In this respect, one of the most important limitations of the model is the problem of expressing the payoff schedules in some form of currency.[49] The model does not require the payoffs to the two players to be in comparable units. Thus, they need not be measured on an absolute scale. Payoffs to different players can be expressed relative to each other. Nevertheless, even for the same player, it is not an easy task to find a utility function which takes into account all the factors influencing payoffs in different situations. For example, some fishermen may be more cash-oriented than others. Some may attach relatively more value to fishing as a way of life and to the maintenance of harmonious relationship with their fellows.

The emphasis in seeking solutions to Prisoner's Dilemma has been evolutionary stability or persistence of cooperation. The problem of the emergence of cooperation (as opposed to its persistence) has been dealt by Axelrod and colleagues.[50] They have shown that the strategy leading to cooperation (TIT FOR TAT) can gain a foothold and spread in a population of selfish individuals (ALL D strategists) if a small group of individuals playing TIT FOR TAT comes in a cluster to keep interactions initially among themselves.[51]

The concept of evolutionarily stable strategies (ESS) concerns itself with the persistence of a strategy in a population in the face of threat of invasion by other strategies. A strategy is considered to be ESS if no other strategy can invade it. In our case, cooperation among the fishermen would be considered stable if it pays more to cooperate than not to cooperate. In its biological applications, the ESS approach replaces the criterion of "rationality" with evolutionary stability, and "self-interest" with Darwinian fitness.

The evolutionary approach to optimization of behavior patterns assumes that alternative forms of behavior have some heritable component. The heritability of a given behavioral trait, however, can be in the form of learning and cultural transmission. In human societies, transmission of behavior patterns by learning is the sole mechanism for transmission of information. Therefore, the evolutionary approach in our case is appropriate; the Prisoner's Dilemma model explicitly recognizes the importance of learning. As Axelrod puts it, "with intelligent players a successful strategy can appear more often in the future because other players convert to it."[52] Note that this is essentially the same as the following statement in evolutionary context: A successful trait will appear more often in the future because it will leave more descendents than will others.

In terms of policy implications, the Prisoner's Dilemma model provides a number of insights into the limitations of the "tragedy of the commons" model, arguably the dominant mental model in the management of fisheries in the industrialized world. The overexploitation of fish stocks is largely the result of the open-access condition of the resource. Fishermen tend to deplete the resource by unrestrained harvesting since whatever they leave behind today may be taken by others. If, however, the open-access condition is removed, the payoff schedules in the Prisoner's Dilemma context change completely. In this case, there is no reason for defection leading to over-exploitation, since fish left for tomorrow will not be taken by others from outside the community -- others who are not part of the network of cooperation and reciprocity. As summarized by Axelrod, for cooperation, "altruism is not needed: successful strategies can elicit cooperation even from an egoist . . . No central authority is needed: cooperation based on reciprocity can be self-policing."[53]

This statement does not mean that the role of central authority and government fishery regulations are completely rejected.[54] Predictions of the Prisoner's Dilemma model are consistent with the policy aim that there should only be as much regulation as necessary, and as much communal cooperation and self-regulation as possible. Clearly, there is a role for central authority in certain instances. If the self-interest of the community of resource users conflicts with that of public interest, government has to be involved. This is particularly so when there is a conservation problem. Prisoner's Dilemma model predicts that a spiral-ling pattern in depletion of valuable resources will make cooperation among resource users impossible and lead to "tragedy of the commons". In such cases, the resource may be saved only by banning all fishing until the resource recovers.

The Prisoner's Dilemma model appears to be relevant also in regard to the choice of governmental management tools. License limitation as a management approach is strongly supported by the model; this measure limits access to the resource and enables the development of cooperation among licensed users. Although an exhaustive review of fishery management approaches from a Prisoner's Dilemma view cannot be attempted here, it can be said in general that any measure that would enable higher probabilities of encounter (w), and maintain the two conditions of the payoff matrix will be consistent with cooperation among users and the development of self-policing practices.

Among the numerous possibilities for the implementation of such policy measures, one can mention progressive taxation of harvests (royalties) so as to reduce the temptation payoff, T, and maintain a relatively high payoff for mutual cooperation, R. This emphasizes the importance of managers working with, rather than against, users -- the co-management approach. A word of caution on government regulation, given the emphasis on stability, is that drastic changes of rules is likely to destabilize existing cooperation. For cooperation to develop and persist, durable rules are necessary, whether arrived at by the users themselves or instituted by central authority.

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50. Axelrod, *op cit*, Ref 29.

51. *Ibid*

52. *Ibid*, p 169.

53. *Ibid*, p 174.

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Table 1

A spectrum of possible relationships among users of a common property resource (in this case, among fishermen).

1. Neutral Relations Among Fishermen

   Few fishermen utilizing a superabundant resource

2. Increasing Conflict Among Fishermen

   The number of fishermen increases and resource availability decreases

3. Conflict Management

   Fishermen evaluate the situation and decide that conflict is hurting all users; initial cooperation leads to "live-and-let-live" approach

4. Cooperation

   Emergence of mutually acceptable rules; user-group organizations; common property institutions

5. Culturally Stable Cooperation

   Many rules of resource use; time-stable common property institution imbedded in culture of group; "traditional societies"

6. Breakdown of Common Property Institutions

   Cooperation among users, common property institutions break down for various reasons

Player A	Player B: C — Cooperation	Player B: D — Defection
C Cooperation	R=3 Reward for mutual cooperation	S=0 Sucker's payoff
D Defection	T=5 Temptation to defect	P=1 Punishment for mutual defection

Fig. 1. The Prisoner's Dilemma game. The payoff to player A is shown with illustrative numerical values. The game is defined by $T > R > P > S$ and $R > (S + T)/2$.