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Decision making: Fishing production and fishers in the Black Sea

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Abstract

This paper explores empirical evidence as well as a theoretical model of fisheries in the Black Sea which have become depleted as a result of both environmental degradation and overexploitation. We examine overfishing and the optimal fish catch, and derive Evolutionary Stable Strategies (ESS) from a game theory perspective by using agent risk profiles. We explain how risk-averse fishers may choose to fish at unsustainable levels, even though it may reduce their overall fish catch in the long run. Risk attitudes of artisanal fishers within the frameworks of expected utility and prospect theories also have implications on risk aversion and non-cooperation. We explore how social norms between fishers could encourage cooperation in fishing at sustainable levels, but finds that these norms and information networks have not developed enough in the Black Sea to be effective.

Keywords

Black Sea; Fisheries; Risk profiles; Game theory; Artisanal fishers and risk aversion

1.1. Introduction

Tragedy of the commons as well as Elinor Ostrom's work on non-tragedy of the commons have been applied to environmental issues extensively. Given the evidence for the depletion of some natural resources, such as fish in the Black Sea, various riparian and non-riparian governments and international organizations have acted to stop and reverse the depletion trends by various meetings and agreements (Ostrom, 2000; Dietz et al., 2002; Schlager and Ostrom, 1992; BSC, 2009; GFCM, 2012). As we study risk profiles and different fishing strategies in this paper, we examine the situations under which individual fishers can be persuaded to adopt evolutionary stable fishing strategies. The size of the fishing firm we consider here is small and artisanal, which is representative of many fishing communities in the Black Sea (Berkes, 1986). The first sections of the paper are a literature survey on Black Sea fisheries, the time trends in landed fish, and game theoretic evolutionary stable fishing strategies. Risk profiles of artisanal fishers, prospect theory and conclusions are presented in the final sections.

1.2 Literature Survey on Black Sea Fisheries

The Black Sea is classified as an inland sea and has an area of 436,400 km^2 (168,500 sq mi), excluding the Azov Sea (Bakan and Buyukgungor, 2000). It is surrounded by six riparian countries and has a drainage basin over five times its own area, mainly from the deltas of the Danube and Dnieper Rivers (Mee, 1992). (Figure 1).

Insert Figure 1 here

The industrial activities of the region had taken a severe toll on the ecosystem. One of the most severe crises facing the Black Sea caused directly by human activity is the eutrophication of the waters- that is, the reaction of an aquatic ecosystem to an unexpected influx of fertilizers and/or sewage (Mee, 1992). Up to 95% of the shallow NW Black Sea and Azov Sea are prone to hypoxia, which resulted in the elimination of entire species of deep-water fish, which can no longer survive at low levels of oxygen. Mee (1992) used this ecological process to explain the sudden collapse of the fishing industry since the 1960s and 1970s. Only six of the 26 species of fish that were commercially caught and sold in the mid-20th century remain abundant enough to be viable economically to harvest (Mee, 1992). Overexploitation has also depleted fish stocks

(Leppakoski and Mihnea, 1996; Turan et al., 2005). This is partly caused by variations in regulations over the years. Policies to boost the fishing economy in the 1980s reduced size restrictions on certain fish caught, allowing much more to be harvested, resulting in a rate of fishing that could not be naturally sustained. The collapse of the landed catch in 1990 was also due to the growth of jelly fish (comb jelly or *Mnemiopsis leidyi*), which scavenged the eggs, and the larvae of the important fish in the Black Sea region (Turan et al, 2005). Leppakoski and Mihnea (1996) report that the Romanian Coast fish harvests of sturgeon (acipenser), Black Sea turbot (psetta), anchovy (engraulis), and gobies all were much lower level in 1990 than in 1971. Daskalov (2002) attributes the rise of total catch in the 1970s to a general shift away exploitation of large predatory fish to smaller pelagic fish.

A plot of both total and anchovy fish catch for the Black Sea from 1970-2010 is given in Figure 1. Total catch began to increase in the mid-1970s, with the average catch more than doubling between 1975 and 1985. However, the biomass began to be depleted due to comb jelly invasion and overexploitation, so that by 1990, the total catch had fallen to levels below that of 1970 . The maximum sustainable catch (MSY) threshold must have been crossed at some point during the late 1970s and early 1980s because the yearly catches sharply dropped soon after[i]. Due to these trends, it is more desirable to remain at sustainable fishing levels in the short run even when more fishing is possible, to retain the biomass to sustain future fishing (Die and Caddy, 1997; Garcia et al., 1989).

Insert Figure 2 here

This 1990 fisheries crisis prompted the 1992 Bucharest Convention by the Black Sea Commission for protection against pollution with a permanent secretariat which is still in existence today.[ii] Table 1 reports the relative percent of fishing stock composition for the six major Black Sea riparian countries in 2008 based on the General Fisheries Commission for the Mediterranean (GFCM) (2012) database.

Insert Table 1 here

Anchovy is the largest catch for all countries at over 70%, with sprat coming in second at almost 20%. Together, these two species account for over 91% of all landings in fisheries across the Black Sea, providing indicators for analyzing economic impacts of the changing biodiversity of the region. During the 1960s and 1970s anchovies only made up around 54% of the total catch, and the rest were several other species such as the mackerel, whiting, and bonito. Overfishing and the ecological crisis of the late 1980s caused a substantial shift in the species makeup of the region, and many smaller species either died out or ceased to be included in the fishing stocks (GFCM, 2012; Eremeev and Zuyev, 2007; Oguz, 2005). Commercial species soon collapsed under the combination of overexploitation and new invasive predators, so that harvest yields sharply dropped across the basin by 1990. By the late 1980s, the fishing industry in the region directly supported almost two million inhabitants (Travis, 1993). Direct harvest losses incurred from the crash of the early 1990s cost the basin $240 million USD.

The reaction of local communities to these changes has been examined by analyzing the small scale fishing industry of the Eastern Black Sea from a new institutional economics perspective- that is, how small groups and communities both manage and govern their shared resources (Knudsen, 2008). Knudsen studied the traditional ecological knowledge (TEK) and the local customs of the community of Carsibasi on the Eastern coast of the Black Sea as a case to determine how these small fishing towns conduct business in the absence of formal regulations and in the face of the changing ecological makeup of the sea. Even though Turkey's

Ministry of Agriculture updates the national fishing regulations every two years, regulations on small boats are virtually non-existent due to the near-impossible task of enforcement and the implicit recognition that such regulations would cripple small subsistence fishers. Locals instead rely on a network of informal regulations and unwritten rules to bring order to the short but frantic fishing season in late spring/early summer. Knudsen (2008) found that it is the "ethical know-how" of fishing based on mutual respect and unspoken rules of courtesy amongst the fisherman of the community that allows the small-boat industry to thrive from generation to generation while also adapting to the changing ecological landscape of the Black Sea coast. Knudsen's analysis shows how artisanal and local fishers have had to adapt to the changing biological makeup of the Black Sea, and how their economic livelihood is directly related to the amount of fish available to them.

1.3 Maximum Sustainable Yield

While individual agents act and adapt to the conditions, the means of fishing, such as blast fishing, bottom trawling and bycatch, lead to overfishing that adversely affect the future biomass (see Reeves Reeves and Notarbartolo di Sciara, 2006; Gerlak, 2004). The concept of MSY is an estimate of an optimum fish catch each year that both maximizes current fish yield but also leaves enough of the biomass still unexploited in the sea to continue the yield in future. A function that can accurately model the maximum sustainable that yield obtainable by all fishing parties is given by Knowler et al. (2001).

$$Q_{t+1} = \sigma * S_t \qquad [1]$$

Here, Q_{t+1} is the total exploitable fish population available in the next year, σ is the natural survival rate of fish in the environment and S_t is the population that survives the year's harvest. S_t can be expressed as

$$S_t = Q_t - h(Q_t, E_t) \qquad [2]$$

where Q_t is the total population of fish at time t and h is a function of fish catch, which is a function of both Q, and E, the fishing effort exerted over the year.

Various methods of estimating a value for the amount of fish which can be harvested each year to maintain MSY have been proposed (Die and Caddy, 1997; Garcia et al., 1989). This estimator is an important component of an effective fisheries management structure for several reasons. First of all, many countries with fishing economies are considered "developing" and may not be able to afford regular, formal assessments of fish stock that occur in more developed countries (Die and Caddy, 1997). Most riparian countries around the Black Sea are in this classification and an estimator equation provides them with a theoretical limit on fishing to sustain the population without the costly physical assessment. Secondly, a theoretical estimate enables comparisons with current fishing levels to be able to make accurate predictions and policy recommendations for the ecological preservation of the species. Die and Caddy (1997) and Garcia et al, (1989) underline the limits of applying MSY estimators. The MSY should not be used as a benchmark or a goal for fish harvests both because of its unpredictability and the dangers of overexploitation even by a very small amount. Food and Agricultural Organization (FAO) of the UN and its Code of Conduct for Responsible Fisheries specifically differentiates between reference points not to be approached, such as the MSY value, and "benchmarks for safe exploitation" (FAO, 1995; Die and Caddy, 1997). .

The MSY estimator is an important piece in a game theory model for maximum payoffs which must be taken into account to study allocation between parties. Black Sea fishing is plagued with many problems, yet cooperation will increase the total available fish population by a series of mutual reductions in both pollution and overexploitation. The section below models one of these problems, that of overfishing, where the behavior of fishing parties are examined to see under which conditions cooperation will occur. The basic concepts of the model can then be extended to multiparty cooperation on overexploitation.

2.1 Evolutionarily Stable Strategies (ESS) in a Fishing Game

A game theory perspective can help explain environmental issues by indicating what actions people would choose to take regarding the harvesting of natural resources, and how these actions would impact the environment. Here we model the behavior of two artisanal fishers, the dominant firm size of the Black Sea region. This model can also be extended to the two-nation bilateral game on cooperation, or in equation form, to multilateral co-operations.

In a model of a fishing game, one can determine how intensively fishers would choose to harvest fish based on how many fish they expect to catch and how many fish they expect the other fisher to catch. Based on this knowledge, one can find a best strategy, or Nash equilibrium (NE), or in many of these instances, multiple best strategies for players to play. In the multiple best-strategy situations, over multiple rounds, the game may eventually converge to each fisher playing one particular strategy, called an evolutionarily stable strategy, or ESS. To determine which NE are ESS, they must meet one of two conditions presented below. Let A be the payoff of a strategy, let there be two strategies i and j, and let * denote Nash strategy. Then

Condition 1: $Ai^*i^* > Aij^*$ □ $j \neq i$ [3]

Condition 1 indicates that the payoff of both players using the NE strategy is greater than the payoff of one player using a NE strategy and the other player using any other strategy.

Condition 2: $Ai^*j > Ajj$ □ $j \neq i$ [4]

Condition 2 indicates that the payoff of one player using the NE strategy and another player using any other strategy is greater than the payoff of both players using strategies that are not the NE strategy (Barron, 2008).

Once cooperation quotas are set for limiting fish catch, one can look at various scenarios to see when fishers will cooperate with guidelines. Below is an example of a rather utopic game in which two players can either cooperate (restrict) with quotas or not (Matrix A). Suppose the total fish catch has a value of 4. Monitoring is costly and suppose, if incurred, monitoring costs 6. The payoffs can be structured such that the fishers are promised a payoff of 5 each (2 as catch plus a one-time[iii] subsidy of 3 each), the latter of which equal monitoring costs (if incurred) if they choose to cooperate within the sustainability guidelines. The present day payoff to the players in the game is now greater if they cooperate.

Matrix A

Fisher 2

Cooperate **Don't Cooperate**

Fisher 1	**Cooperate**	**5,5**	**0,4**
	Don't Cooperate	**4,0**	**2,2**

If both players choose to cooperate, then the fish population will remain at a sustainable level, allowing both fishers to gain a value of 5 from the sea, in catch and in subsidies. If one fisherman chooses to cooperate and the other does not, then the party that who does cooperate is able to take advantage of the game to gain a value of 4, while the other party loses out and gains nothing. While the fisher that chooses not to cooperate gains more than the other fisher, the fisher only gains 4, which is still less than he could have received had both of the fishermen cooperated. If neither player cooperates, then both of the fishermen only receive a catch value of 2 from fishing.

Calculating the NE from the game will result in two pure strategies and one mixed strategy. The first pure strategy is for both players to cooperate, the second is for both players not to cooperate. The third is a mixed strategy where both players cooperate 2/3 of the time and not cooperate 1/3 of the time. Played among rational players, these strategies may occur in one round, but played in multiple rounds and with multiple players, the strategies may move toward a particular equilibrium, depending on the characteristics of the players. The equilibrium that the players will move toward can be determined by testing for the evolutionary stable strategy. This strategy would be adopted by the entire players of fishers, and would not be moved away from, even if occasionally fishers deviate from the strategy. We can show the three NE of this game: X_1, Y_1 is where the players both cooperate, X_2, Y_2 where they both do not cooperate and X_3, Y_3 is the mixed strategy. The values in equations 5 to 7 are probabilities.

Nash Equilibria: $X_1 = (1, 0)$ $Y_1 = (1,0)$ [5]

$X_2 = (0, 1)$ $Y_2 = (0,1)$ [6]

$X_3 = (2/3, 1/3)$ $Y_3 = (2/3,1/3)$ [7]

Testing these three NE for ESS, we find that condition 1 is met for only the pure NE strategies (of players both cooperating and both not cooperating)[iv] but not for the mixed strategy. In other words, in an environment with many fishers playing similar games, both fishers will tend to follow the pure strategies of either cooperation or non-cooperation with guidelines. Which NE they will move towards depends on the initial conditions with respect to the mixed NE. For this example, if initially more than 2/3 of fishers choose to cooperate in fishing, then the population will move away from the mixed NE towards the pure NE where all of them will cooperate. This could also be called moral or societal pressure for the higher aim. If initially less than 2/3 of the fishers choose not to cooperate in fishing, then the population will move in the opposite direction towards the pure NE of all of them non-cooperating ((Figure 3).

Insert Figure 3 here

The analysis of the ESS indicates that it would take a significant portion of the fishers to cooperate in fishing before permanent cooperation could be achieved. However, if enough fishers cooperate, then the ESS indicates that a healthy level of fishing that protects the biomass could be achieved by limiting total catch to the MSY estimate.

2.2 An Alternative ESS Game: What if there are no incentives for cooperation?

Suppose that there are no incentives for cooperation. Such a game is given in Matrix B below:

Matrix B

		Fisher 2	
		Cooperate	**Don't Cooperate**
Fisher 1	**Cooperate**	**5,5**	**0,5**
	Don't Cooperate	**5,0**	**2.5,2.5**

In this situation, cooperation or non-cooperation by a single party have the same payoffs (5) unless both parties do not cooperate. Then the payoff for each is 2.5. In this game, there are two pure NE where the players will either both choose to cooperate or both choose to not cooperate. However, only one ESS strategy may be eventually adopted by all fishers over multiple games among multiple fishers.

Nash Equilibria: $X_1 = (1, 0)$ $Y_1 = (1,0)$

$X_2 = (0, 1)$ $Y_2 = (0,1)$

Testing for ESS, we find the payoff of the two strategies that are not the NE are higher than the payoff of one player using the NE strategy and the other player using any other strategy. This illustrates that both players playing cooperation is not an ESS but both players playing 'don't cooperate' is an ESS strategy. The fishers over time will move toward this ESS strategy of non-cooperation. Therefore, if the payoff to the party who does not cooperate is the same as the payoff if they cooperate, non-cooperation by **all** parties is the ESS solution. This is not a socially desirable outcome for the preservation of the environment and of the fish biomass.

2.3 Overcoming the Problem of Non-Cooperation

Finding that non-cooperation is the only ESS NE solution for the example in Matrix B may help explain why we observe tragedy of the commons with respect to fisheries in most emerging economies, as well as in the Black Sea. The results of the previous section, the ESS and prisoner's dilemma models, may indicate that it is difficult or even impossible for players to cooperate without any outside intervention, but other factors may exist that can support cooperation.

Empirical tests of prisoner's dilemma games have often found that players take actions that do not fit the standard expectations for the game. For example, in a public goods game in which players are given an endowment and make the choice to contribute money for a collective good, the standard game theory model indicates that no players will contribute to the collective good, as there is no individual incentive for them to do so (Ostrom, 2000). This is similar to the prisoner's dilemma and ESS models for fisheries where the best strategy for each player is to not cooperate with one another to gain a higher payoff. When the game is tested among participants, players tend to contribute between 40 to 70 percent of their endowments in the first round, and while contributions fall in repeated rounds, they remain above zero. Finally, if players are given the option to punish other players, some will punish players who do not cooperate, even though they should have no incentive to do so. The results from these games indicate that players tend to cooperate to a greater extent than standard models would predict (Ostrom, 2000). If these experimental observations are extended to the case of fishers in the Black Sea, then it is possible that individuals will be more likely to cooperate with one another successfully, such as in the Carsibasi case in Turkey.

To determine whether players can cooperate, it is important to explain why they are not following the NE strategy, even though it would appear to be in their self-interest to do so. Ostrom (2000) explains these results by differentiating between three types of players. "Rational egoists" fit the traditional economic model of players who rationally seek to maximize their own gains. "Conditional cooperators" are players who are willing to cooperate to achieve higher gains so long as they expect other players to cooperate as well. Estimates find these people make up a significant proportion of the population, ranging from 40 to 60 percent of people. They attach an extra value to trust and cooperation, which can make their internal payoffs different than just the monetary values that are expressed in the game. "Willing punishers" are players who choose to punish players who do not cooperate for the common good, even though it may be costly to them. The presence of willing punishers and conditional cooperators who are more willing to cooperate and enforce cooperation can prevent situations similar to the prisoners' dilemma from occurring (Ostrom, 2000). The presence of these types of players in the population of fishers would increase the potential for cooperation.

A variety of contextual factors are important to whether individuals will be able to form social norms to cooperate and govern a common resource effectively. One important factor is whether the use of the resource can be monitored (Dietz et al., 2002). While observing the total amount of fish in the sea is not a feasible possibility, local fishermen may be able to monitor the people who are fishing in the sea (Acheson, 1975). Another important factor is whether the economic system is in a state of rapid transition, since a stable system of social norms may be unable to develop (Dietz et al., 2002). Face-to-face communication is also an important determinant of whether cooperation will occur. In experimental tests of the prisoner's dilemma, face-to-face communication was a major determinant of the level of cooperation that occurred (Ostrom, 2000). The Black Sea is a fairly large body of water with many different languages spoken on its shores, so face-to-face communication between everyone would be impossible, but smaller local groups of fishermen along a national shore would possibly be able to develop these relationships.

For social norms to successfully develop, the group must be able to exclude outsiders to control entry into the group to prevent a large influx which would potentially destabilize the system. Once again, on the level of the entire sea this would be difficult, but in local groups of fishers it would be possible. This type of cooperation and social norms are similar to the TEK and social structure observed in the Carsibasi region.

Finally, fishers would have to take the responsibility to monitor and enforce the rules governing fair usage of the waters (Dietz et al., 2002). At the local level this would be possible, but not guaranteed. Overall, there are some conditions in the Black Sea that would encourage workers to cooperate to take care of the fisheries, but other factors that may discourage cooperation. Based on the empirical evidence showing that fish populations have decreased over time, these social norms appear to not have developed enough to prevent overexploitation.

Government actions can be taken to encourage the responsible use of the sea, yet policies that focus on rules and regulation tend to harm social norms that direct the use of the common sea. Government regulations towards the commons tend to be ineffective because they are slower to react to changes in the social, political, and economic setting in which they are implemented, which often makes them ineffective. Policies towards the common resource of the sea also tend to be difficult to enforce, so fishers can often circumvent restrictions (Dietz et al., 2002). Experimental evidence also indicates that government programs and rules to encourage responsible fishing could actually harm social norms that encourage farmers to cooperate. In tests of prisoners' dilemma games, imposing external incentives to cooperate on players made them much less likely to cooperate after these incentives were removed (Ostrom, 2000). Evidence indicates that directly regulating fisheries would potentially crowd out social norms and would not be an effective solution to overexploitation.

The better government policy would be to support social norms on a local level that encourage fishers to cooperate and conserve resources. Governments can encourage these norms by respecting the rights of groups of fishers to organize and by giving them a medium to settle their disputes. This will legitimize and strengthen the system of norms without harming the system (Ostrom, 2000). Governments in the Black Sea can use these strategies to support cooperation among fishers in the Black Sea without relying on extensive rules and regulations.

The games discussed so far show the importance of payoffs and social norms to reach desirable social outcomes for preserving MSY. Risk preferences of fishers also modify games when a player's perception of risk often create results that do not match model predictions. In the next section, we discuss risk preferences and how they may further affect artisanal fishing in the Black Sea.

3.1 The Influence of Risk Preference on the Fishing Game: Expected Utility Theory and Prospect Theory

Factors of risk and loss aversion of artisanal fishers will also play an important role in determining which NE players will choose to play. In choosing a strategy, each player faces uncertainty about the strategy the other player will select. When players take this risk into consideration, they often face choices between a risky strategy (with both a higher potential payoff- higher possibility of a loss), and a safe strategy (with a lower payoff-lower possibility of a loss). For example, in the previous ESS game between two fishers (Matrix A), two pure NE would be played which were ESS but between the two, cooperation would maximize the gains for both players. That strategy for both is then *payoff dominant*, indicating that players should play this strategy to receive the highest payoff of 5. Yet players who are *risk-averse* would dislike the possibility that they could gain nothing, and could avoid the risk by choosing to not cooperate, allowing them to get payoffs of either 4 or 2. In this case, risk-averse players with a short time horizon and a large discount rate for the future will choose to not cooperate, which is considered the *risk dominant* strategy. This is a further refinement of the findings of ESS strategies and the outcome of non-cooperation is not socially desirable.

Some scholars have argued that rational players should always choose the payoff dominant strategy because they expect to maximize their gains and they expect the other player to do so as well. This argument relies on the idea that players will be able to make decisions based on a "collective rationality" where "rational individuals will cooperate in pursuing their common interests if the conditions permit them to do so" (Harsanyi and Selten, 1988, p. 359). However, other scholars reject this viewpoint and argue that risk-averse players will choose to play the risk dominant strategy to avoid the possibility of a loss. They argue that it is not possible for players to form together as one group that makes collectively rational decisions. Because players will not successfully cooperate and make decisions together, they make individually rational decisions in which they do not cooperate with one another, and are likely to choose the risk dominant equilibrium (Straub, 1996)[v].

Experimental evidence indicates that participants tend to choose the risk dominant equilibrium in many games[vi]. These studies emphasize the importance of the risk dominant strategy and indicate that the more risk-averse fishers are, the less likely they will be to cooperate in some situations. Observation of each individual fisherman's preferences is not a realistic option, but because individuals' social and economic environments have been shown to affect risk preferences, they can give some indication as to how risk-averse the players would be.

Past macroeconomic experiences, such as an economic recession, have been found to increase risk aversion even after the event passes, although the effect eventually fades. For younger individuals who have less lifetime experience, this effect is also greater (Malmendier and Nagel, 2011). Many of the fishers in Black Sea have been exposed to negative economic conditions in the Soviet Union following its dissolution in the 1990 s, when growth in the region was highly unstable. Based on these economic experiences we can expect most of the fishermen to be more risk-averse and less likely to cooperate with one another.

Differences in risk taking by gender may also play a role in how risk-averse individuals may be. Many studies have found that women tend to be more risk-averse than men regarding financial risk taking in the United States (Jianakoplos and Bernasek, 1998), and in making consumer decisions and lifestyle choices (Hersch, 1996). While generalizing the data to other situations and individuals outside the United States is very problematic, these studies may indicate that the fishers in the Black Sea, who are generally men, would be more risk-averse if their group included a larger proportion of females to males. We do note, though, that gender differences in risk aversion for small agents in environmental studies need to be studied further before any generalizations can be made at present.

These observations on how fishermen would view uncertainty generally rely on a traditional economic view of risk known as Expected Utility Theory (EUT). EUT generally adopts the view that players are endowed with a certain preferences towards risk that make them either risk-seeking, risk-neutral, or risk-averse. The preferences of a player are based on the utility, value or satisfaction he gains from different amounts of income which can be expressed as:

$$U(s,d) = (s+d)^r \quad [8]$$

where s represents the initial endowment of money held by the individual, d represents the amount of income gained by the individual, and r is some parameter that represents the rate at which an individual's utility increase, and U(s,d) indicates the level of utility the individual receives from the endowment and gain in income. EUT also finds that individuals will measure the expected value of uncertain outcomes by combining the probability of each outcome with the utility they would receive from it. This can be modeled with the equation:

$$EU = \sum_{k=0}^{n} p_k U_k \quad [9]$$

where n is the number of possible outcomes, p_k is the probability of outcome k, and U_k is the utility of outcome k. This model assumes that people will be consistently either risk-seeking (r>1) or averse (r<1) depending on the parameter r (Harrison and Rutström, 2008).

While EUT may make sense in many situations, evidence from psychology indicates that people often act in ways that do not match the model. One major problem with the theory is that people's risk preferences are not consistent, and can vary between being risk-averse and risk-seeking depending on the situation (Rabin and Thaler, 2001). The failure of expected utility to accurately model human behavior has led researchers to modify expected utility theory and develop another model for describing human behavior under risk, known as Prospect Theory (PT). Prospect Theory argues that when people are presented with a risky choice, they do not take into account their initial endowment, but are mainly concerned with how they frame the choice as a gain or a loss. PT also finds that individuals generally frame a loss as being more painful than an equally sized gain, a condition known as *loss aversion*. The findings of this theory lead to a different utility function defined separately under gains and losses as

$$U(d) = d^{\alpha} \qquad \text{if } d \geq 0,$$

and

$$U(d) = -\lambda(-d)^{\beta} \qquad \text{if } d < 0 \qquad [10]$$

where α and β are parameters for the level of risk aversion and λ is the coefficient of loss aversion. Prospect theory also states that individuals attach much greater weight to low probabilities than the measures found in expected utility theory. This difference can be accounted for by a weighing function of the probabilities, which can be modeled by

$$W(p) = p^{\gamma} / [p^{\gamma}+(1-p)^{\gamma}]^{1/\gamma} \quad [11]$$

where W(p) is the weight attached to the probabilities, p is the actual probability, and γ is a parameter defining how the probabilities are weighed. After the weighted probabilities are accounted for, the expected utility is found in a similar way to expected utility theory with the summation

$$EU = \sum_{k=0}^{n} W(p)_k U_k \quad [12]$$

where n is the number of possible outcomes, $w(p)_k$ is the weighted probability of outcome k, and U_k is the utility of outcome k (Harrison and Rutström, 2008). This model indicates that when people are making risky choices, they do not have a consistent preference for risk, but make choices according to how they weigh probabilities and frame the decision as a potential loss or gain.

The Black Sea area has been subject to political turmoil, invasions of hostile species and long term trends of pollution and overexploitation. Given the many problems faced by fishers with the dwindling catch and landed fish in the Black Sea, the differences between EUT and PT have important implications on how fishers will react to risk. Studies find that individuals will be either risk-seeking for losses of moderate or high probability, risk-averse for losses of low probability, risk-seeking for gains of low probability, and risk-averse for gains of a moderate to high probability (Tversky and Kahneman, 1992). This structure, known as the *fourfold* pattern, indicates that the fishers will make decisions based on whether they anticipate a low or high probability of the other fisher defecting, and whether they frame receiving the lower value as a higher loss or a lower gain. Given that the fishers obtain some value out of the fish that they catch, it is reasonable to expect that they will view each outcome as either a lower or higher gain, and not as a loss. Considering the evidence that players eventually tend toward the risk dominant strategy, and the appeal of the risk dominant strategy to the other player, it would also be reasonable to assume that the fisher would expect the probability that the other fisher would defect to be at least moderate or higher. This indicates that in this situation both players frame their payoffs as gains and expect there to be a moderate chance that the other player will defect and substantially lower their payoff. According to the fourfold pattern, in this situation we would expect the fishers to be more risk-averse, and thus less likely to cooperate.

Another important factor affecting player cooperation is whether players can communicate with one another during the game. In the study of games with both risk and payoff equilibria by Clark et al., (2001), players who were not allowed to communicate did not tend to move toward a payoff dominant equilibrium but did tend to do so when communication was allowed. These findings are very similar to the arguments in the previous section, which found that social norms and communication can support cooperation between players. This may indicate that with communication, trust and collective rationality may be able to develop, so that players can make decisions in the best interest of the group, and not just for themselves as individuals. If social norms and communication between multi-national Black Sea fishermen can develop, fishers may be more likely to cooperate to keep the harvesting of fish at a moderate level. While the continuing fall in the fish population indicates that fishermen have not yet developed these norms, supporting cooperation and communication among the fishermen can encourage them to fish at a more sustainable level.

Overall, we generally find that fishers' risk aversion would negatively affect their ability to cooperate with one another to harvest fish at a sustainable rate. This is based on observation of their lifetime experiences with economic depression, and the short time horizon and a large discount rate for the future in which they frame the gains or losses that they experience while fishing. Lack of trust and lack of strong social norms regarding fishing also seems to weaken their ability to choose the risky strategy, even though it may be better for the environment overall.

3.2 Conclusions

Both the empirical evidence and our theoretical model indicate that fisheries in the Black Sea are strongly at risk of facing further decline. Many fish species have disappeared over the past few decades, as pollution, invasion of hostile species and overexploitation contributed to sharply declining fish catch. This phenomenon has many implications for the household income and protein intake of households around the Black Sea.

Our theoretical model indicates that, although there is some possibility of cooperation, the common property of the sea will tend to encourage risk-averse fishers to overfish at unsustainable levels. Social norms may be one way of encouraging cooperation and trust among fishers, but they have only developed in a limited way. These findings indicate that government policy should focus on encouraging fishers to have individual incentives to restrict how much they fish. The most effective policy for this would be for governments surrounding the Black Sea to provide a network of information for fishers that choose to restrict their fishing to a more sustainable level. The riparian countries have already been cooperating on limiting pollution since the Bucharest Convention of 1992. However, there is little cooperation on sustainable levels needed for maintaining future harvests, except randomly enforced local limits on the size and type of catch. An information and education network could alter the payoffs to fishers and also change their risk attitudes so that it will be in each of their interests to fish at a level that the environment can support.

An area of research that should be addressed in future is a more detailed multi-national study of the social norms and attitudes of individual fishermen in the Black Sea. By gaining further understanding of these informal rules, governments in the region will be able to work with fishers more effectively and successfully encourage them to fish at a supportable level. From an empirical standpoint, spreading knowledge and awareness about the MSY of total fish catch as well as potential biomass loss from pollution and species invasion could lead to a greater sense of collective rationality. In a large basin region such as the Black Sea's, local communities practicing sustainable harvests are not able to see the larger picture of runoff pollution, overexploitation by other country fishers, or changing biodiversity. Reducing aggregate fish catch to a sustainable level in such a large body of water will require both education and coordinated policy action by individual countries and regional economic coalitions.

[i] Note that all riparian countries except Turkey had political regime changes in 1990 s which may have affected the catch but we do not have any studies on the impact of political changes in the fisheries sector.

[ii] For more information on the pollution control aspects and three protocols, see http://www.blacksea-commission.org/.

[iii] We are not suggesting perpetual subsidies on fishing which are subject to potential abuse and asymmetric corruption. This is a one-time subsidy for this particular example. Past observations show that successful subsidies which achieve real outcomes are set for a short and limited time period and are not extended regardless of pressure and of bargaining.

[iv] Calculations are not reported here for parsimony and are available on request.

[v] The players' choice between choosing either a payoff or risk dominant strategy reflects a choice between two different methods with which each player can maximize their payoffs. By choosing a payoff dominant strategy, the player chooses a *maximax* strategy, in which he seeks to gain the maximum possible outcome. By choosing a risk dominant strategy, the player chooses a *maximin* strategy, in which he seeks to maximize the smallest possible gain he can receive with certainty (Pearman, 1977). The choice between either a maximin or a maximax strategy indicates two different ways players may choose to make decisions, depending on how much they prefer certainty over risk.

[vi] An experimental study conducted by Schmidt, et al. (2003) tested players to find that players generally responded to changes in the risk dominant strategy, and did not respond to changes in the payoff dominant strategy. The authors argue that this study indicates that risk dominant strategies are important in determining whether players will be able to cooperate, and, while payoff dominant strategies are also important, they seem to have less of an effect (Schmidt et al., 2003). A study by Straub found that when players play repeated games, they tended to converge away from the payoff dominant strategy and toward the risk dominant strategy (Straub, 1996). Together, these studies indicate that players tend to be risk-averse and thus are less likely to cooperate to gain a higher payoff.

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Table 1. Black Sea Landing Composition by Country and Species in 2008 (in tons)

Species	Bulgaria	Georgia	Romania	Russian Fed.	Turkey	Ukraine	Total	%
Anchovy	**28.0**	**25938.0**	**15.0**	**9070.0**	**225344.0**	**4298.2**	**264693.2**	**71.74**
Sprat	**4310.0**	**0.3**	**234.0**	**7814.0**	**38999.0**	**21110.8**	**72468.1**	**19.64**
Horse mackerel	**180.0**	**8.0**	**11.0**		**14741.0**	**365.6**	**15305.6**	**4.15**
Whiting		**15.0**	**55.0**	**96.0**	**10986.0**	**8.6**	**11160.6**	**3.02**
Bluefish	**25.0**				**1787.0**		**1812.0**	**0.49**
Mullets nei	**0.0**	**1.0**	**8.0**	**81.0**	**1518.0**	**91.5**	**1699.5**	**0.46**
Turbot	**55.0**		**47.0**		**458.0**	**251.4**	**811.4**	**0.22**
Red mullet	**17.0**				**706.0**	**45.2**	**768.2**	**0.21**
Picked dogfish	**23.0**		**10.0**			**79.2**	**112.2**	**0.03**
Pontic shad	**29.0**		**47.0**	**2.0**		**16.6**	**94.6**	**0.03**
Raja nei						**54.2**	**54.2**	**0.01**

Source: Background Documents on the Black Sea Fisheries, GFCM, Jan 2012, p. 14, http://151.1.154.86/GfcmWebSite/SAC/WGBS/2012/GFCM-Background-Doc-BlackSea-Fisheries.pdf

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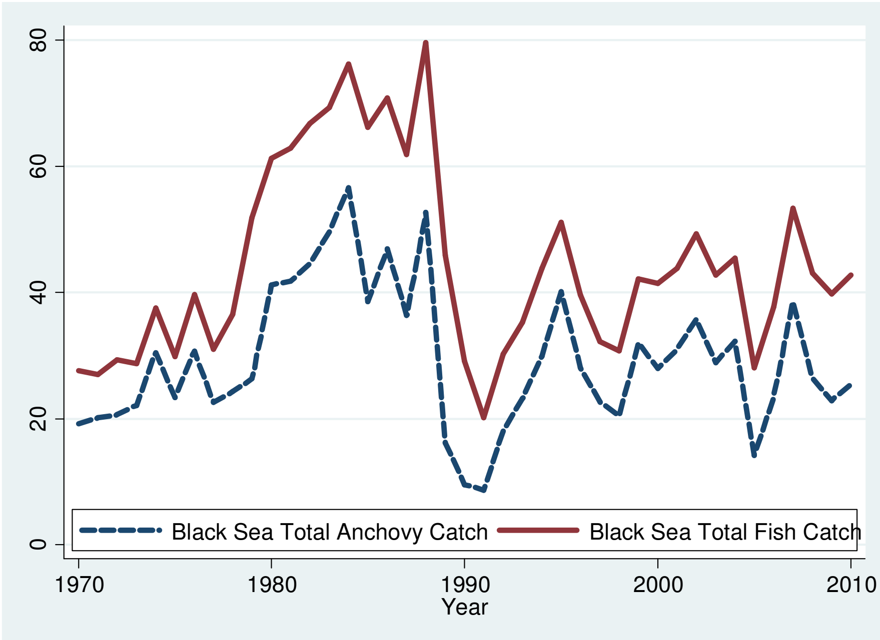
Figure 1: Drainage in the Black Sea Area

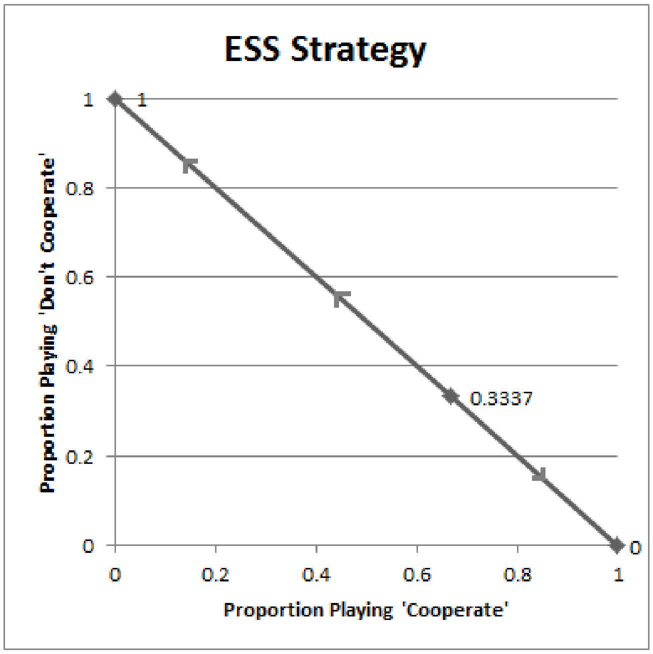
Source: With permission from *UNEP/GRID-Arendal, 2006,* http://www.grida.no/graphicslib/detail/drainage-in-the-black-sea-area_f058

Figure 2: Plot of Total and Anchovy Fish Catch in the Black Sea, 1970-2010 (thousands of tons)



Source: Data plotted from
http://www.fao.org/figis/servlet/SQServlet?file=/work/FIGIS/prod/webapps/figis/temp/hqp_90882 85911198033225.xml&outtype=html

Figure 3: Movement Toward Pure Nash ESS and Proportion of Cooperating/Non-cooperating Fishermen



ESS Strategy
Proportion Playing 'Don't Cooperate'
Proportion Playing 'Cooperate'
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1
1
0.3337
0