Instructor's Guide

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Introduction:

The Sustainable Use of Fisheries is a flash-based game that allows multiple players to simultaneously exploit a model fishery. Here I present materials designed to use this teaching tool in an undergraduate course. Although this treatment may be at too advanced a level for most high school students, the game is flexible enough to be adapted for use in levels ranging from high school to graduate school.

The game presents a fishery as a metaphor for any communally-exploited resource. This imaginary fishery is scaled down so that the actions of 2-8 players influence the sustainability of the system. In the game "boats" represent the unit of fishing effort, and each player is free to decide how many boats to put out each year. The game simulates the economic consequences of different decisions: players who are successful at fishing have the potential to earn more boats, but unsuccessful players may lose boats and may even go 'out of business' completely.

The game is currently configured to play in two modes. In the first mode, each year the fish population is replenished to the same level regardless of how heavily it was exploited in the previous year. While ecologically unrealistic in the long term, this mode allows students to understand the exploitation dynamics that emerge when a resource is very abundant in relation to our ability to exploit that resource (a situation that resembles early human exploitation of ecosystem services). In the second mode, the growth of the fish population is realistically dynamic: the population in the current year is dictated by the fecundity of the species and the population surviving the previous year's fishing effort. In this mode, the fishery can crash and even go extinct.

In this packet I have tried to provide instructors with all that is needed to: 1. Explain the learning objectives that can be achieved using this game; 2. Understand the way the game works; and 3. Implement the game within the classroom setting.

Do you have suggestions on how to make this better? By all means send them here.

Background:

What makes our current societies unsustainable? Why is sustainability suddenly such a concern? What characteristics describe an unsustainable practice? What must be done to make our societies sustainable?

These are the questions that challenge the current generation of students.

In order to answer these questions and plan for a sustainable future, our students need to understand aspects of ecology, evolution, economics, and human psychology. ***The Sustainable Use of Fisheries*** is an inquiry-based activity platform that allows students to explore the intersection of these topics through a simple yet robust gaming atmosphere.

Robert Mathus was the first to point out (in his influential *Essay on the Principle of Population* of 1798) that simple mathematical principles suggest that human populations are doomed to overexploit their resources. Although waves of technological innovations have at times made Malthus' predictions seem overly pessimistic, we now appear to be at the beginning of an era where Malthusian collapses will be commonplace. At the heart of Malthus' insight was an understanding of exponential growth, the geometric expansion of populations enjoying adequate resources. Human growth appears to be exponential, and when placed in environments with abundant resources other organisms also appear to grow exponentially. Most natural populations do not show exponential growth because their resources are not infinitely abundant: give any population enough time to grow and pretty soon competition for resources will reduce the survival and reproductive rates of the population. When deaths and births are equal, the populations stabilizes; the size of the population at this stable point is called the "carrying capacity". Not all populations are stable at the carrying capacity: under a variety of ecological conditions the population can cycle up and down around the carrying capacity, but in either case it is competition for scarce resources that prevents the population from growing indefinitely.

There are many patterns of growth that can incorporate an upper limit or carrying capacity on population size, but the best-known model of this type of growth is called the logistic model. Logistic growth follows an S-shaped pattern, with rapid increase in the population size at low densities followed by steadily lower rate of increase as the population approaches the carrying capacity. At the carrying capacity growth stops and the population size stabilizes. There are a great number of complicating factors (weather and climate anomalies, competition with other species, predation) which can alter the basic pattern of growth predicted by the logistic model, but the growth of many populations is well-approximated by this model. Human beings are perhaps the greatest exception, as our recent population growth shows no sign of any limit.

For most periods of human history, humans have experienced unprecedented success. This is due in large part to our ability to harness two intertwined assets: a rapidly evolving culture and the cooperative enterprises it supports. What sets humans apart from other species is the scale on which we rely on culture and cooperation. Working together to constantly improve the technologies that allow us to survive and reproduce, humans have tapped into almost every available ecological resource on the planet. For many years these resources seemed inexhaustible, and in practical terms they were: when human populations were relatively low in density and technologies were primitive, ecosystem productivity was more than capable of replacing the resources consumed by humans. This is not to say that occasional collapses did not occur, leading to local extinction of people and some species, but for most of human history our species has been able to evolve technologies and migrate to maintain a practically inexhaustible supply of resources.

This is no longer true. We have reached the tipping point. We have covered the habitable portions of the globe, our populations have exploded to astounding numbers, and our technologies have evolved to the point where we are capable of extracting resources at a rate that outpaces the natural capacity for renewal. We are unsustainable, and this is in part due to our own evolutionary success.

Economists have been considering this dilemma for years. Using a metaphor called *The Tragedy of the Commons* (which was first introduced to ecologists by Garrett Hardin in 1968), economic theory has long recognized the potential for human beings to over-exploit their resources. This metaphor is valuable in part because of its simplicity. Imagine a “common” of abundant grass on which all members of a village are free to graze their livestock. At first the common seems like a wonderful arrangement, as all are free to share in its provision. But as each villager is more successful at building a herd, the pressure on the common increases. At some point there are too many animals on the common and the appetite of that livestock exceeds the ability of the remaining grass to regenerate. From an ecological perspective, things get progressively worse, because as the amount of grass is reduced the amount of new growth continually decreases. *The Tragedy of the Commons* suggests that unregulated, shared resources are doomed to collapse. But why? Why don’t the villagers simply restrain their use of the common to prevent its collapse?

The answers to these kinds of questions are pursued by a field of study called “game theory”. Game theoreticians look at the world as if it is one big high-stakes game. The defining question of game theory is: what is the winning strategy? The characteristic of this winning strategy is that it should be the best choice of all available choices when played against all possible strategies. The archetypical game is called *The Prisoner's Dilemma* and encapsulates a wide variety of situations in which individual and collective interests conflict. *The Prisoner's Dilemma* imagines a scenario in which two people commit a crime together and are both caught by the authorities. While both have been taken into custody and are being interrogated in isolation, the case against them is not strong. In fact, the best hope of convicting the two criminals is to have them indict each other (we assume that the criminals show no contrition and therefore will not self-indict). If either should refuse to indict the other, the chances of achieving a conviction are lowered. The best overall outcome for both players would be for each to refuse to indict the other. But unfortunately the game is not played as a team: the accused are separated and therefore must make individual decisions. So from the individual point of view, should you indict or protect your comrade in crime?

The answer to this question depends upon the potential costs and benefits of each action, but if you assume that being indicted increases your chance of going to jail and being protected decreases you chance of going to jail, the best outcome for any individual is to convict the other. Why? Well, if you both protect each other that reduces the overall chance of either of you being convicted, but this is not the best possible outcome for either individual. The best possible outcome is for me to indict my fellow criminal, "cheating" him while he protects me. If I can manage to pull this off I am very likely to get off while he is likely to "take the rap". Of course he is thinking the same thing, so the logical thing is for us both to indict the other, which is likely to land us both in jail. What makes this a dilemma is that the best strategy for the group (in this case the two prisoners, who minimize their potential for conviction by both protecting each other) is not the best strategy for the individual (a single prisoner, who might walk away from the crime by ratting out his comrade).

Game theory has explored a large number of these scenarios in which the benefits to a larger group are compromised by the optimal strategy for the individual. Usually individuals who cheat can out-compete individuals who always cooperate. Ultimately insights from game theory can be applied to our understanding of evolution, and have been used extensively by behavioral ecologists to interpret and predict animal behavior patterns. What is remarkable in nature is how often cooperation between individuals seems to have overcome immediate individual interest. So if individuals can reap individual benefits at the expense of the group by cheating, what prevents cheating?

When organisms interact with each other in large, anonymous groups, cheating is the rule. Even if the group would do better as a whole if cheating were to end, when individuals interact anonymously there is an incentive to cheat and 'take more than your share'. What tips the scale away from cheating is the potential to recognize and punish cheaters. If the selfish actions of individuals can be identified and punished, the good of the group can be preserved and the *Tragedy of the Commons* can be avoided. There are a variety of theories about the role of punishment and how it emerged during our evolution, but one thing is clear: we are designed to detect and neutralize selfish acts.

Evidence for this instinct ranges in scale from individual social rebukes to the actions of international law-enforcement agencies.

One of the defining characteristics of humans is our ability to cooperate. We probably began cooperating in small social groups, as our closest primate relatives still do. A major human innovation was the establishment of the tribe, a group of about one-hundred-fifty people based as much on shared culture as it was on familial ties. While animals sometimes aggregate in groups that are as large or larger than human tribes, what makes the tribe different is its coordinated effort as a unit. A huge herd of herbivores or school of fish is essentially self-interested in nature; studies of these aggregations show that they form as a result of each individual trying to use the others as cover from predators. While the school of fish may look coordinated in its motion, there are no overriding group benefits to schooling, only the protection afforded to each individual by virtue of not being isolated and vulnerable. In contrast, human tribes engage in a complex social interchange of services that improve the chances of every individual surviving and reproducing; when it comes to human cooperation, the whole is much greater than the sum of its parts. This is not to say that the benefits of cooperation are always evenly shared or that cheating has been eliminated, but humans have managed to regulate the behavior of individuals in groups effectively enough to maintain a high value from cooperative coordination.

The tribe took human beings out of the realm of other animals. A cooperating tribe composed of individuals with specialized skills for hunting, gathering, sewing, and building can come to dominate its ecosystem, occupying not only the place of top carnivore but also role of top consumer of all ecosystem services. What has occurred since the tribe allowed humans to spread across the globe is an expansion on the tribal theme. Small family groups came together to form tribes, tribes allied themselves with other tribes to form tribal groups, tribal groups came together to form nations. The level at which cooperation occurs has progressively scaled up to the point that our nations coordinate the efforts of millions or even billions of people. The challenge at each step up to a new scale of cooperation has been to suppress destructive self-interest and cheating at the level below. A tribe must make sure that no individual takes more than his share to maintain the stability of the tribe. A tribal group must make sure that no tribe takes more than its share of resources so that the cooperation between tribes can be maintained. Now these struggles for ‘justice’ and ‘equality’ are fought at the scale of the nation, but that doesn’t mean that all struggles have been eliminated: cheating still occurs and must be regulated among individuals within a group, between groups within a super-group, and between super-groups within a super-super-group.

Cooperation does not always last. Societies collapse, and the hallmark of these collapses is the breakdown of the social mechanisms that regulate destructive self-interested behavior. But what is interesting about these collapses is that they often follow as a direct result of the success of cooperation. A successfully cooperating unit is that which is has the highest possible rates of survival and reproduction, and this success leads to population increases. In the end if a society is to survive under the load of this population success, it must do one of two things: A) find a technological means by which to expand the base of its resources; or B) expand its regulation of self-interest to include limitation of population growth and resource consumption. Without getting into protracted discussion of this subject, it is fair to say that throughout human history we have been far better at expanding our base of resources than regulating our population expansion or resource consumption.

Although it is impossible to predict the future, it appears that the human species now encounters the last level of challenge in regards to cooperation. We live in large nations which aggregate the interests of a variety of cooperative units, and these nations compete with each other for a share of limited global resources. Our greatest challenges now reside at this international level, as we struggle to find ways to prevent the over-exploitation of shared ecosystem services. What we need is cooperation amongst nations, but some of the same dynamics that rule the behavior of small groups also rule the small community of nations. In order to prevent the collapse of the ecosystems on which we depend, we must find a way to regulate our use of ecosystem services.

Thus far, we have not been all that successful. Where resources can be owned by a particular group or individual, they tend to be better-regulated and preserved. But certain resources, which cannot be owned for legal or logistical reasons, are exploited as a global “common”. Predictably, these resources are often over-exploited. Global fisheries are a prime example: most of the ocean’s fishing regions are in decline, with certain species functionally extinct due to over-fishing. Because international law does not allow any particular country to claim the fish swimming in international waters, they are exploited without regard for future sustainability. Similarly, to this date there is little or no regulation of the earth’s atmosphere, which is shared by all of its inhabitants. As a result, the atmosphere has been used as a dumping ground for more greenhouse gases than global ecosystems can absorb, and our climate is changing in ways that will eventually destabilize the ecosystems on which we depend. How should we regulate these global resources, and how will we know if our regulations are adequate?

Policy makers and the general public frequently ask scientists to make predictions about the health and stability of individual species, local communities, or whole ecosystems. Invariably reputable scientists make these predictions in probabilistic rather than absolutist terms. This can frustrate non-scientists, who see such predictions accompanied by a probability as weak. So why can’t scientists make definite predictions, and how should we interpret their uncertain prognostications? Uncertainty enters biological systems because there are many, many processes that are dictated in whole or part by randomness. Will a particular mutation to a particular section of DNA produce a beneficial, neutral, or deleterious change? Will a predator encounter one of its prey? Will the interaction of two communities be stable or unstable? To answer any of these questions, one has to know what components can be estimated with certainty and which are uncertain. Uncertainties enter virtually all processes, and very few physical or biological phenomena are wholly predictable. In order to understand scientific predictions, we need to learn to deal with data produced by stochastic (i.e. random) processes.

The Sustainable Use of Fisheries allows students to explore all the above topics. I provide further readings in the Valuable Resources section, all of which expand on the various topics introduced above.

Below I provide a "Sample Implementation", but it should be noted that the game is designed to be sufficiently flexible such that a myriad of different inquiry-based approaches could be used to learn about population growth, the tension between selfishness and cooperation, group- or multilevel-selection, and regulation for sustainable resource exploitation. If you come up with novel ways to use this tool, I encourage you to contact me and tell me the story of how you use this game in your classroom.

How the Game Works:

Basic Procedure for Playing the Game:

1. The game begins with an introduction page. After students have read this introduction, they should click on the "**PLAY THE GAME**" button.
2. The next page is the **Game Set-Up** page. It provides some basic premises on which the game is based, and allows the game to be customized by the players. On the **Game Set-Up** page you must specify:
    a. the *number of players*.
    b. the mode as "REPLENISHING" or "DYNAMIC".
    c. the *catch probability of each boat*.
    d. the *fish carrying capacity per player*.
    e. the *fecundity rate of the fishery* (DYNAMIC mode only).
3. Once all the parameters are set on the **Game Set-Up** page, you can press ENTER/RETURN or click on the "fresh fish" crate to continue.
4. The next page is the **Player Set-Up** page. Each player should enter in her name and choose an avatar from the list of available avatars. Click on the fishing lures to the right and left of the avatars to scroll through the list of available avatars. Press ENTER/RETURN or click on the "**Next Player**" button to continue.
5. Once all players have been entered, play begins for Year 1. During each year, each player must enter in the number of boats to be put out to fish. The number of boats in the fleet and the current fish population are both displayed. To preserve the anonymity of this decision, player entries are displayed as asterisks ("*"). If a player enters in a number that is higher than her fleet total, the program assumes that she intends to put out her entire fleet. Press ENTER/RETURN or click on the "**Set Sail**" button to continue.
6. After all players have entered in the number of boats, their fishing success for the first year is shown alongside the current fish population size. Underneath the player's display, an update window also reports on the status of that player's fishing fleet.
7. The game continues until the fishery collapses, all players go out of business, or the game has been played for the twenty-year limit.

8. At the end of the game, a display reports the success of each player alongside the number of boats they chose to put out.
9. To play the game again, students should refresh their browser window.

Hauls per Boat: Every boat placed out by a player has the potential to catch a total of 10 hauls. Once a player's boats are all filled, she cannot catch any more fish.

Probabilistic Outcomes: Rather than always providing players with the "average" outcome (i.e. a deterministic model), ***The Sustainable Use of Fisheries*** uses random number generation to provide some degree of uncertainty in the results (i.e. a probabilistic outcome). All of the uncertainty is generated by the method used to determine fishing success. After all players have decided how many boats they will put out for a given year, we know the total number of boats put out [BoatTotal]. Using the catch probability per boat per haul of fish [CatchProb] specified on the **Game Set-Up** page, the program determines the probability of catching each haul of fish using the following formula:

$$\text{Chance of some boat catching a particular haul} = (1 - (1 - [\text{CatchProb}])^{[\text{BoatTotal}]})$$

Although it may look a bit daunting, the logic behind this formula is pretty simple. We determine the chance of not being caught as the chance of not being caught by each boat, so the more boats there are the greater the chance of being caught. For each haul of fish, a random number between zero and one is generated. If the number is less than or equal to the calculated change of some boat catching that particular haul of fish, the haul is considered caught. For instance, if we have 10 boats out and a 10% catch probability, our calculated chance of catching each haul is approximately 65%. If our random number is less than or equal to 0.65, we consider that haul of fish caught. If it is greater than 0.65, that haul is not caught. If the haul was caught, a second random number is then generated to determine which player actually gets credit for "catching" the fish. Rather than being completely random in its selection of the successful fisher, the program weights the probability of each player being successful based on the number of boats she puts out. For instance, if one player put out ten boats, she will have twice as much chance of being the one who caught a particular haul as another player who only put out five boats. Because probabilities and random number generation are used to determine both the realized fishing success and which players are most successful, there is uncertainty in both the overall trajectory of the fish population and the relative success of each player. This means that if you set up and play the game several times using the exact same strategy for each player, you will not get exactly the same results. However, on average the games will produce the expected average results, and rarely will you get radical departures from this average. There's just enough uncertainty to keeps things realistic without allowing the "noise" generated by random processes to interfere with student understanding of underlying deterministic patterns.

Modes of Population Growth: As described above in *Basic Procedure for Playing the Game*, there are two game modes: REPLENISHING and DYNAMIC. In the REPLENISHING mode, the fish population is always replenished to its carrying capacity, which is determined based on the *carrying capacity per player* specified on the ***Game Set-Up*** page. REPLENISHING mode is ecologically unrealistic, but provides a loose approximation of the dynamics emerging when resources are extremely abundant. In DYNAMIC mode, the population is replenished based on the fecundity. After the population has been fished and the hauls caught have been subtracted from the current year's total, the next year's total is determined by multiplying the fecundity times the current year's remaining total and adding that number of "offspring" to the remaining total. If this new total exceeds the carrying capacity, it is truncated to the carrying capacity. In other words, population growth is exponential until the carrying capacity is reached; the program uses a "ceiling" model rather than the more complex "logistic" model of limited growth. For example, if the population remaining after this year's fishing is completed is 124 and the fecundity is 50%, the population next year will be 186 unless the carrying capacity is less than 186.

Fishery Economics: The fleet size of each player is determined by their fishing success. After each year, the program determines whether each player caught enough fish to maintain and/or grow her fleet. This determination is based on the number of hauls of fish caught per boat in the fleet (not the number of boats a player chose to put out). To maintain the current size of her fleet, a player must catch at least 2 hauls of fish per boat in the fleet. A player can grow her fleet: if she catches more than 4 hauls of fish per boat she adds one boat to her fleet, and if she catches more than 6 hauls of fish per boat she adds two boats to her fleet. The fleet can also shrink: if a player catches less than 2 hauls of fish per boat in the fleet, she loses one boat, and if she catches less than 0.5 hauls of fish per boat in the fleet she loses two boats. It is possible to do so poorly that all boats are lost; this occurs because a player exerted inadequate effort, the fishery declined too dramatically, or both. All players begin the game with five boats. Depending on the *number of players*, *carrying capacity per person* and *catch probability of each boat* you specify in the ***Game Set-Up***, this may or may not be economically sustainable. If you find that players lose all their boats even when they put out their entire fleets, try increasing the *carrying capacity per person,* the *catch probability of each boat*, or both.

Collapse versus Cycling: Depending on the parameters you set in the ***Game Set-Up*** and the way that players use their boats, you can either experience a total collapse of the fishery or cycling. If the number of boats available to each player raise the catch probability per haul to a fairly high number, it is likely that a collapse will occur and the game will terminate. However, if the population declines slowly, loss of boats may prevent total collapse and instead promote "boom and bust" cycles in which the fishery declines and improves and is "tracked" by the number of boats each player can maintain. For students with a more subtle understanding of how predator-prey dynamics work, it is a productive exercise to ask them to discover which conditions promote collapse and which promote cycling. Of course it is also possible for the fish population to be quite stable, but only if players come up with a regulation scheme that is both ecologically and politically reasonable.

Technical Considerations:

This game can be implemented in one of two ways. Basic users can direct their students to play the game as a *Flash* file here. Advanced users can download the entire folder containing the *Flash* file and supporting files; this folder enables you to embed the game in a course website or learning management system.

The computers used to play this game must have the latest version of *Adobe Flash Player* installed, which can be downloaded here.

A Sample Implementation:

I use this game in my *Ecology* class during the first of two units on sustainability. In this first unit, my goals are to:

1. get students to think about the impact of their individual behaviors on ecosystems and the services they provide;
2. allow students to understand the evolutionary challenges inherent in maintaining any communally-exploited resource; and
3. challenge students to apply their knowledge of ecological and evolutionary principles to sensibly regulate the use of a communally-exploited resource.

Prior to coming to this class session, students are asked to complete a relevant reading and assess their ecological footprint using an online footprint calculator (see **Valuable Resources** below for readings and a suggested footprint calculator). As a homework assignment, students are asked to report their ecological footprint; although these data are not anonymous to me, I collect class data in a manner that does not reveal any particular student's footprint. Before we play the game we discuss the concept of an ecological footprint and I present the overall average and distribution of the class footprints. Generally, the results of this exercise demonstrate clearly that each of us, even those of us who consider ourselves 'ecologically conscious', is exploiting resources at an unsustainable rate.

To understand why that is the case and to figure out what to do about it, we play the game. I ask my students to play the game with the intent to 'win' by becoming the most successful fisherman in their group's 'village'; this goal is usually reinforced by an extra-credit 'prize' for the most successful player in each group. This prize is only awarded when the fishery is sustainable; the best player in a crashed fishery is not rewarded. My 'prize' is usually a few points on the daily quiz; although most instructors will want to limit the value of such extra credit, it is important to offer something that will spur competition between the students. If students apathetically go through the motions without any motivation to win, the game will not be successful.

Although the game will allow anything from two to eight players, I break my class into groups of four to six. This number seems to be ideal for discovering the emerging properties of the system in each round.

In class we play three rounds:

1. **Game #1**, in which resources are constantly replenished;
2. **Game #2**, in which resources are dynamic and prone to overexploitation; and
3. **Game #3**, in which resources are dynamic but students are allowed to impose rules designed to prevent the crash of their fishery.

Worksheets that can be used in class to play in these three modes can be found here. Groups of players are asked to discuss a set of summary questions at the end of each round, and we discuss these questions as a class.

I usually allot about ninety (90) minutes of class time to play the game, and have had the best success playing the game within a computer lab. As there only needs to be one computer per group, it is also possible to do this in a wireless-equipped classroom with a few student laptops. Want to really maximize the value of the game? A USB wired or wireless numeric keypad allows students to play the game most efficiently because it allows students to very rapidly pass around the “game controller”; this speeds up play in class.

Game 1:

The learning objectives of **Game #1** are:

- Students should realize that any system that involves a shared resource will (on average) reward whoever exerts the most effort to exploit that resource.
- Students should identify the role that random factors play in the success of each player, but also recognize that on average the player who exerts the most effort will reap the greatest success.
- Students should discover that their overall fishing effort has no effect on the sustainability of the fishery, and explain why this is not realistic (and perhaps consider the conditions under which such ‘constant replenishment’ might be realistic).

To set up **Game #1**, students should set the following parameters:

Game Mode	Replenishing
Catch Probability	4%
Hauls per Player	100

For a more detailed version of normal game play procedures, see **How the Game Works** below. Explicit instructions aimed at guiding student work can be found on the worksheets here.

After students are broken into groups of four to six individuals, I explain to them that they are a fishing village competing with each other to be the most successful fisher. I unveil the prize for 'winning' and explain that the prize can only be awarded if the fishery is not completely depleted. Students are asked to set up the game (see above), with each student assuming an identity as a fisher by choosing an avatar and entering a name. I then ask students to play for the twenty 'years' of the game, each making independent and anonymous decisions about how many of their existing boats to put out per year; boats catch fish, so the number of boats put out represents fishing effort. Students can enter their decisions on any keyboard, but I find that having a wired or wireless USB numeric keypad (the kind used by accountants or other data-enterers) that can be passed around leads to the most efficient group play. As the students play, I circulate around the room to make sure that they are reading the results that occur after each year of play and that they are each making independent and anonymous decisions about how many boats to put out. Some groups may require a bit of prodding to move through the game at a sufficient pace. When the students are done with the full twenty years, I ask them to record their overall results (boats put out and fish caught for each player). I make sure that all groups record their results before playing again, but if some finish ahead of others I allow them to experiment with a different set of parameters.

Once all groups have completed this game and discussed the summary questions, we discuss them as a class. We go through the results from each group, identifying a 'winner' and comparing that player's strategy with others. On average the player who puts out the most boats is the winner, but it is not uncommon for a player who put out slightly fewer boats to be the winner. In these cases, the Instructor can elicit from students the role that random factors play in success, and point out the same applies to selective evolutionary processes. I have found that it also helps to elicit the stories of students who did poorly by putting out few boats; generally these students report that they were trying not to be too self-interested, and that presents an opportunity to explicitly state that individual self-interest wins in this version of the game.

Once the Instructor establishes that individual self-interest pays in this version of the game, she can segue to why. Explanations can be **evolutionary**, **ecological**, or **economic**.

From an **economic perspective**, those individuals who exert the most fishing effort (by putting out the most boats) have the greatest chance of reaping the most rewards throughout the game. This economic incentive for acting upon one's self-interest is augmented by the way that the game rewards fishing success in a particular year: if individuals are successful at catching fish, they receive more boats, allowing them to exert greater fishing effort in future years. For this reason, self-interested individuals can amplify their economic ability to pursue self-interest, creating a larger gap between individuals who are more or less self-interested in their behaviors. This economic realism also allows a single ‘wealthy’ individual to dominate exploitation of the resource.

From an **evolutionary perspective**, it should be obvious that immediate rewards go to those individuals who harvest the most fish. To make this clear to students, the instructor needs to reinforce that economic fishing success is a proxy for survival and reproduction: I like to tell students that in their fictional village, fishing is the way to both make a living and attract mates. Because in this version of the game the fish population remains constant regardless of how intensely it is exploited, there is only selection at the level of the individual. The fishery never crashes, and for this reason there is no selection against villages that intensely exploit their fishery.

From an **ecological perspective**, students should be able to recognize that the fish population ‘magically’ replenishes regardless of how many fish are caught in the previous year, which means that there is no price paid for maximizing fishing effort (and therefore no price paid for untrammeled short-term self-interest). Students should recognize that this is not realistic for most ecosystem services that we currently exploit, but may not be completely unrealistic under all scenarios. I explain this version of the game as a rough approximation of what early humans exploiting abundant ecosystems experienced: the only limitations to harvest were set by the ability of humans to ‘catch’ that resource, as abundant and inaccessible ‘sources’ continuously replenished the ‘sinks’ where humans harvested (think coastal fisheries before large boats could be used to fish). This explanation leads to the next phase of the activity, in which we assume that humans have developed sufficient technology for harvesting and/or have been harvesting for sufficient amounts of time; under this assumption, the ability of the ecosystem resource to replenish itself will affect the dynamics of the system.

Although this first round of the game may seem trivial, it accomplishes several important things. First, it allows students to learn the basics of how the game works. Second, it primes students with the idea that ‘individual self-interest wins’, which sets them up for over-exploitation of resources in subsequent rounds. Third, it gets students to start thinking about the real dynamics of ecosystems and how they would be predicted to respond to exploitation.

Game 2:

The learning objectives of **Game #2** are:

- Students should recognize that in this version of the game, the winning strategy for individuals within the village is still to put out as many boats as you have.
- Students should discover that if everyone in the group follows the winning strategy there is a high probability of crashing the fishery and therefore their economy (following individual self interest leads to collective loss -- in other words ‘The Tragedy of the Commons’).

- Students should infer that fisheries crash because the rate of harvest is greater than the rate of replenishment (fecundity).
- Students should realize that winning players employ the most self-interested strategy, but that winning groups employ a strategy that moderates self-interest.
- Students should conclude that unregulated, communally-shared resources are vulnerable to over-exploitation.

To set up **Game #2**, students should set the following parameters:

Game Mode	DYNAMIC
Catch Probability	4%
Fecundity	100%
Hauls per Player	100

Game play proceeds as in **Game #1** (see above); because only the way the game parameters are set differs, students do not need new instructions for playing **Game #2**. Explicit instructions aimed at guiding student work can be found on the worksheets here.

I allow students to play through **Game #2**, which should go faster than the first game. Expect to get some variation, but generally most groups contain at least one player employing the purely self-interested strategy of putting out their maximum number of boats per year. For these groups, a crash should occur by year 13 or year 14, leading to a massive decline in the total fleet of each player. Sometimes groups will recover from near-crashes by voluntarily under-exploiting the fishery once it declines, but this usually leads to many years of economic losses (loss of boats) and lowered harvest yields (lower catches). It is not uncommon for particular groups to see their village 'go extinct' by losing all of their boats after a major crash.

Once all groups have completed this game and discussed the summary questions, we discuss them as a class. We go through the results from each group, identifying a 'winner' and comparing that player's strategy with others. We compare the results for the winner in each group for **Game #2** with the results for the winner from **Game #1**. Invariably the total for **Game #2** is much lower, and the Instructor can elicit from students that this is due to a massive decline in the fishery due to successive years of large catch. The Instructor should press students for an explanation of why this is occurring, and they should be able to report that extraction rates exceed the fecundity rate. Occasionally I get classes in which all groups completely crash out their fisheries, in which case their is no 'winner' of the game.

In addition to identifying a winner in each group, I also compare the overall results of each group. Generally groups that showed less self-interested behaviors have higher overall catch totals, because they did not crash their fishery or crashed it later in the game. Pointing this out can lead to two different discussions. First, students should recognize that in the long term, it is actually better to exercise restraint than to exploit to the greatest extent possible. Second, students should recognize that if villages are competing against each other, the villages with the best fishing success are those with less rather than more self-interested behavior. Recognizing this, the Instructor can either reward the winning group, or set up the subsequent game to reward the winning group.

As in **Game #1**, the instructor can discuss the results of **Game #2** from an **economic**, **ecological**, and **evolutionary** perspective. The **economics** of the game change when we switch to the ecologically dynamic mode, as the externalities of exploitation (loss of future yields due to population depletion) are now included in the overall 'economy' of the game. Over-exploitation can lead to total collapse. This introduces a new **evolutionary** dynamic, as selection now acts not only to encourage maximum exploitation at the individual level, but also can suppress exploitation at the level of the village (or fishery). All this emerges from an **ecological** situation in which the human capacity to harvest fish is large enough to deplete the breeding population, leading to exponential population decline.

Most groups will not have successfully suppressed individual self-interest and will have at least partially crashed their fishery in **Game #2**. Pointing this out, the Instructor can elicit from students why individual self-interest still ruled even when it when the entire village suffered as a result. Students should identify the lack of regulation and enforceable rules as a major cause of over-exploitation, and come to the conclusion that being self-interested still pays when there is no punishment for doing so.

This discussion creates a segue to **Game #3**, in which students are allowed to create regulations for their fishery.

Game 3:

The learning objectives of **Game #3** are:

- Students should recognize that setting reasonable limits to exploitation requires ecological knowledge.
- Students should apply what they know about population growth to the problem of how to regulate their fishery.
- Students should discover that over-regulation can cause economic collapse.
- Students should discover that some regulations fail to prevent over-exploitation.
- Students should discover that the best regulation scheme takes into account the carrying capacity and fecundity of the fishery being regulated.

To set up **Game #3**, students should again set the following parameters:

Game Mode	DYNAMIC
Catch Probability	4%
Fecundity	100%
Hauls per Player	100

The only difference between play in **Game #3** from **Game #2** is that group 'villages' are allowed to create rules that regulate the exploitation of their fishery (see below). Explicit instructions aimed at guiding student work can be found on the worksheets here.

Before I allow students to play through **Game #3** I ask them to show me their regulation scheme and provide a rationale for this scheme. While I will correct inaccurate or flimsy rationales, I allow groups to use any scheme they can rationalize. An important aspect of this third round allowing regulations is that we assume that the enforcement of these regulations is perfect: players must expose how many boats they put out in each round, and whatever regulations and punishments are put into effect are perfected followed.

Once all groups have completed this game and discussed the summary questions, we discuss them as a class. We go through the results from each group, identifying a 'winner' and comparing that player's strategy with others. We also identify which group had the best overall catch, comparing each group's regulatory strategy to determine what methods work best. Be aware that some groups may under-regulate, leading to another crash; point out instances of poor regulation to the class. Another phenomenon to be on the lookout for is over-regulation; often, groups create such restrictive regulations that their fishing economy collapses. Discussing these instances helps students to determine what the best regulatory practices are.

Although there may not be a group that comes up with the 'perfect regulation scheme', the Instructor should ask students to consider what this scheme would entail. First, the Instructor should ask them to identify what information they need in order to properly regulate their fishery. They should identify these different categories of information:

1. The ***carrying capacity of the fishery***, because we want to maintain a fishery that is near its ecological maximum but also exert sufficient fishing effort such that competition between fish is not what limits their population size;
2. The ***fecundity of the fishery***, because this represents the percentage of the population that will be replaced by reproduction; and
3. The ***expected catch of each boat***, because this allows for estimation of future catch and proper limitation on the number of boats put out.

Although it is unlikely that any group will have employed the 'optimal regulation scheme', discussion should allow students to see that a yearly catch limit based on expected future reproductive output is most likely to maintain a sustainable fishery.

Playing this series of games gives students an understanding of why humans (or any species for that matter) are prone to overexploiting their resources. Prepared with realistic thinking about the way that ecosystem services are exploited by human beings, my students are better-equipped to think about the sustainable technologies and practices I introduce in the second unit on sustainability.

Valuable Resources:

The following readings are recommended as background material and to extend student appreciation of the issues presented in this game.

Source	**Recommended Use**
Hardin, Garrett (1968). The Tragedy of the Commons. *Science* 162(3859):1243-1248.	This is the classic article that introduced the idea of the “Tragedy of the Commons” to the science of ecology.
Gotelli, Nicholas J. (2008). *A Primer of Ecology*, fourth edition. Sinauer Associates (Sunderland, Massachusetts).	This book provides basic background on the topics of population growth and predation using a theoretical approach. Aimed at undergraduate biology majors, it is also accessible enough to be used by advanced high school students or non-majors.
Greenberg, Paul (2010). Time for a Sea Change. *National Geographic* October, p. 78-89.	This article is a terrific, accessible overview of the modern overfishing problem. It includes a number of really valuable infographics explaining the trophic dynamics of fisheries over-exploitation.
Ellis, Richard (2008). The Bluefin in Peril. *Scientific American* March p. 70-77.	For instructors looking for a specific species to use as a case-study alongside this activity, this article discusses the threat to bluefin tuna due to unregulated (or at least poorly regulated) exploitation. Its discussion of the need for tuna domestication suggests to students the consequences of not properly regulating our exploitation of dynamic ecological resources.
Safina, Carl (1995). The World’s Imperiled Fish. *Scientific American* 273(5): 46-53.	This article depicts role that overfishing and other factors have played in the decline of fisheries worldwide.

Source	Recommended Use
Nowak, Martin A., Robert M. May, and Karl Sigmund (1995). The Arithmetics of Mutual Help. *Scientific American* 273(1): 76-81.	Although a bit old, this article provides valuable background on how cooperation evolves. Using a combination of game theory and examples from animal behavior, they illustrate the evolutionary tension between competition and cooperation.
Musser, George (2005). The Climax of Humanity. *Scientific American* 293(3): 44-47.	The introduction to a special issue entitled "Crossroads for Planet Earth", this article provides some global context for discussions on the sustainability of human exploits. Many of the other articles in this special issue are also valuable.
Diamond, Jared (2005). Collapse: How Societies Choose to Fail or Succeed. Penguin Books (London, England).	If you are looking for some historical context for the subject of ecological over-exploitation, this book provides very accessible and well-researched episodes of societal collapse due to mismanagement of resources.
Brown, Lester R. (2009). *Plan B 4.0*. W.W. Norton and Company (New York, New York).	This is an essential book for any student of sustainability. It contains a few sections pertaining to fisheries and discusses the international agreements necessary to reestablish sustainable fisheries. It also provides an excellent overview of other over-exploited resources. A PDF of this book is available for free from the Earth Policy Institute.
Milinski, Manfred, Ralf D. Sommerfeld, Hans-Jürgen Krambeck, Floyd A. Reed, and Jochem Marotzke (2008). The collective-risk social dilemma and the prevention of simulated dangerous climate change. *Proceedings of the National Academy of Science (USA)* 105(7):2291-2294.	This is certainly a more advanced article, but will be interesting to students who want to extend the concepts taught by this game beyond the issue of fisheries over-exploitation. The authors tested a simple game designed to understand human behavior in the face of potential climate change disaster.
de Waal, Frans B.M. (2005). How Animals Do Business. *Scientific American* 292(4): 72-79.	This article provides numerous examples of the ways in which animals use social behaviors to avoid being cheated. It can be used to spur discussions contrasting and comparing human behaviors with those of other animals.

Source	**Recommended Use**
Nadeau, Robert (2008). The economist has no clothes. *Scientific American* April, p. 42.	This one-page opinion piece suggests that modern economics fails to consider ecological limits. It makes an excellent companion to what students discover as they transition from playing this game in ‘replenishing’ mode to playing in ‘dynamic’ mode.
Rockström, Johan and collaborators (2009). A safe operating space for humanity. *Nature* 461:472-475.	This is a more accessible summary of the larger “planetary boundaries” article published by Rockström and collaborators in *Nature*. It provides students with some context for game play, both in the specific case of fisheries (as a form of overexploited biodiversity) and for ecosystem services in general.

The following websites are recommended as background material and to extend student appreciation of the issues presented in this game.

Source	**Recommended Use**
Ecological Footprint Quiz by the *Center for a Sustainable Economy* http://myfootprint.org/en/visitor_information/	After entering their life habits, this page tells students exactly how many earths we would need if everyone on the planet lived that same lifestyle. This way of framing the footprint really opens students up to discussions of social equity and resource sharing. There is some decent explanation here of how the calculations are made, enough to get students talking about the meaning of their personal footprint.
Evolutionary Games Infographic Project *by Chris Jensen and Greg Riestenberg* http://egip.christopherxjjensen.com	Understanding game theory can help students understand multilevel selection and the underlying social dilemmas present in the *Tragedy of the* Commons. If you would like to provide your students with more background on game theory, these graphic images are helpful teaching tools
VirtualLabs in evolutionary game theory *by Christophe Hauert* http://www.univie.ac.at/virtuallabs/	Although a lot of these simulations may be too advanced for undergraduate students, if you want to expand your treatment of the *Tragedy of the Commons*, there are many game theory simulations that you can run on this valuable site.

Source	Recommended Use
Easy Iterated Prisoner's Dilemma *by Chris Jensen and Jean Ho Chu* http://www.christopherxjjensen.com/research/projects/online-cooperative-resource/easy-iterated-prisoners-dilemma/	Another way for students to further their understanding of social dilemmas is to look at the iterated prisoner's dilemma (IPD). This flash-based tool provides students with the opportunity to set up their own tournaments and experiment with different social environments in order to understand how cooperation might emerge from evolutionary processes.

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This project is part of the larger research program of Christopher X Jon Jensen. To learn more, visit his webpage.

Terms of Use:

This is **version 1.1** of the *The Sustainable Use of Fisheries Instructor's Guide*, January 2013.