Research Article

# Gamification of the overexploitation of natural resources. An operational game based on System Dynamics

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**Overexploitation is the phenomenon that occurs when an economic resource is exploited at a rate faster than it can be regenerated by natural processes. It affects both renewable and non-renewable resources. Overexploitation, and the related effect of "overshoot," may lead to the complete destruction of the resource being exploited and the collapse of the economic system exploiting it. Nevertheless, overexploitation is common in the economy, although its mechanisms and consequences are often unknown to the public and to decision makers. The present paper aims at providing a tool to disseminate the concept of overexploitation by simulating it using the technique of "gamification." We created a simple boardgame based on a system dynamics model that maintains the basic elements that generate overexploitation. The game is called the "Moby Dick Game" and it is inspired by the whaling cycle of the 19th century. Other versions of the game can be used to simulate, for instance, oil extraction. The game was tested on several groups of students and interested people with different backgrounds. The players usually reported to have learned for the first time the mechanisms that lead to overexploitation and collapse.**

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## *Introduction*

Overexploitation occurs when a resource is exploited faster than it can reconstitute itself by natural processes, a phenomenon also called "overshoot" (Catton, 1982). For non-renewable resources, such as crude oil, overexploitation is obviously unavoidable. But biological resources, too, can be exploited at a rate much larger than their capability to regenerate themselves. The result is often the destruction of the resource and, sometimes, the species being exploited are brought to extinction. As a consequence, the economic system that exploited the resource is destined to collapse and, sometimes, to disappear entirely.

Overexploitation is not only common, but central to the way humans exploit resources, with examples as ancient as the destruction of the megafauna during paleolithic times (Haynes, 2018), (Wroe & Field, 2006). In modern times, the best example is probably that of overfishing. Already during the 19$^{th}$ century, some species of whales were hunted to near-extinction (Scott Baker & Clapham, 2004). During the 20$^{th}$ century, many other fisheries were overexploited and nearly destroyed (Hutchings & Myers, 1994), (Mullon et al., 2005), (Watson et al., 2013), (Thurstan et al., 2010), (Perissi et al., 2017), (Bardi & Perissi, 2020).

Why do people destroy the resources that make them live? It is sometimes argued that it is because they do not realize what they are doing. We may argue that it is for the lack of data that 19$^{th}$ century whalers brought to near extinction the species they were exploiting. Yet, they surely noticed that whales were becoming rare, but they never accepted the idea that they were depleting the whale stock (Bardi & Perissi, 2020). More often, overexploitation is assumed to result from the competition of economic agents. This effect was described by Garrett Hardin as the "Tragedy of the Commons" (Hardin, 1968). The "tragedy" occurs even though the operators (shepherds in Hardin's example) know exactly the size of the stock (sheep) they are exploiting. But their search for the maximization of their individual profits leads them to destroy the herds that make them live. Hardin's ideas may have led to the common belief that overexploitation can be fought by privatization. It is argued that if every single operator controls the resource they are exploiting, there would be no incentive to overexploit it. Unfortunately, it has also been shown that overexploitation takes place even when every operator completely controls the rate of exploitation. (Moxnes, 2000), (Moxnes, 2004). No economic agent operates in an economic vacuum, and the push for profit that comes from the market pushes them to overexploit the resource. Another tool to mitigate overexploitation is quotas imposed by governments. This method can be very effective but, unfortunately, quotas are often poorly designed and insufficient. That is reported to be the result of the resistance of operators who see quotas as negatively affecting their profits (Khalilian et al., 2010), (Pauly et al., 1998), (Pauly & Zeller, 2016). The best way may be by establishing "sanctuaries" where the resource cannot be exploited and has the time to regenerate itself. It is the philosophy of natural preserves, also recently proposed by Edward Wilson as "Half Earth" (Wilson, 2016).

Our approach with the present paper starts from the idea that a more favorable attitude toward fighting overexploitation by using quotas or sanctuaries can be obtained if the problem of overexploitation is better understood among operators and decision-makers. Overexploitation is, basically, a dynamic phenomenon typical of complex systems whose behavior is dominated by the interplay of enhancing and damping feedbacks. These systems can be modeled using system dynamics (Richardson, 2013), (Bruckmann, 1982), that is, using systems of coupled differential equations that describe the size of the stocks of the system and the flows between stocks.

Even simple models can reproduce the typical "bell-shaped" curve of the production of an overexploited resource (Perissi et al., 2017), (Bardi & Lavacchi, 2009). System dynamics models can also simulate more complex models, such as the whole world's economic system (Meadows et al., 1972). System Dynamics modeling is not supposed to be part of the knowledge of the general public. Therefore, a generally accepted method to disseminate the results of the models is the "gamification" technique (Hamari et al., 2014), (Sailer & Homner, 2020), (Cunico et al., 2021) (Busch, 2014), (Sailer & Homner, 2020), (Aparicio et al., 2012), (Seaborn & Fels, 2015), often used with training and educational purposes.

Some system dynamics games are based on user-friendly interfaces that allow players to operate a complex system dynamics model. A good example is the "Fishbanks" game (Meadows, 2020) where players take the role of fishing companies. A different approach consists in simplifying the game engine as much as possible in such a way to offer to players a completely "hands-on" experience, often emphasizing the interaction among players. Several of these simple games are described in "The System Thinking Playbook" (Sweeney & Meadows, 2010). Even some commercial videogames and boardgames involve the dynamic concept of overexploitation, such as "*Simcity*" (commercialized in 1989) and "*Warcraft*" (commercialized in 1994), and "*Catan*" (commercialized in 1995) (Chappin et al., 2017).

In this paper, we aim at developing game able to simulate the main feedback effects that dominate real world systems but remains simple enough that it can be designed as a boardgame. We chose fisheries as the system to be modeled, since we know that it as a field that can be approached using simple dynamic models (Bardi, 2007), (Perissi et al., 2017). In fisheries, the fundamental enhancing feedback effect is generated by the accumulation of profits that leads to the industry to increase the size of its fleet. This leads to an increase in production, more profits, and further increase of the industry's fleet. This effect would eventually lead to an infinite size of the fishing fleet, except that the depletion of the fish stock leads to a damping feedback that stops the expansion of the industry and, eventually, leads to its collapse and demise.

In creating a game that describes these phenomena, we reasoned that the interest of the players would be enhanced if the game was presented as related to something they are already familiar with. So, we labeled it as a simulation of the 19th century whaling cycle, the story told by Herman Melville in his "Moby Dick" novel (1851). Finally, we aimed at a game a certain "ludic" aspect based on the competition among teams of players. (Bardi & Lavacchi, 2009). Our game covers the same economic sector as "Fishbanks" (Meadows, 2020), but the two games have different structure and purposes and, to our knowledge, the Moby Dick game is the only boardgame that can dynamically simulate the exploitation of a natural resource without using computers. For instance, in the "The Fishing Game" by the Cloud institute for Sustainability Education, the probability of catching a fish is assumed to be independent of the fish stock and that, obviously, misses a fundamental element of the behavior of the system. Another simple boardgame simulating the behavior of a biological resource is the "Mammoth Game" (*The Mammoth Game from Creative Learning Exchange*, 2020). In this case, we find some simple dynamic elements describing population growth, but no mechanisms that lead to overexploitation. Earlier versions of the game engine of the Moby Dick game were described in previous publications (Bardi, 2015c),(Bardi, 2015a),(Bardi, 2016), and in the book "*The Empty Sea.*" (2020) (Bardi & Perissi, 2020). Here, we present an updated and more detailed version of this game, with the permission of the book publisher.

## *Research background*

Overexploitation is the tendency of economic agents to exploit a resource at a rate higher than the capability of the resource to regenerate itself. It is a common phenomenon that occurs in almost all economic sectors. In addition to non-renewable mineral resources (e.g. crude oil), a typical example is that of fisheries, where it is referred to as "overfishing" (Pauly, 2009). Only small communities seem to be able to avoid overexploitation, as described by Elinor Ostrom (Ostrom, 1990). The overshoot mechanism was explicitly described perhaps for the first time by Garrett Hardin in 1968 with the name of "The Tragedy of the Commons" (Hardin, 1968). The first quantitative study of the overexploitation of a specific resource is probably the one performed by Marion King Hubbert (Hubbert, 1956) who proposed that a "bell-shaped" production curve is a general feature of the exploitation cycle of crude oil. Today, the curve often takes the name of the "Hubbert Curve" (Figure 1). It was observed for several historical cases involving the production of mineral resources (Hubbert, 1982), (Cavallo, 2004), (Brandt, 2007), (Hemmingsen, 2010), (Bardi, 2014).

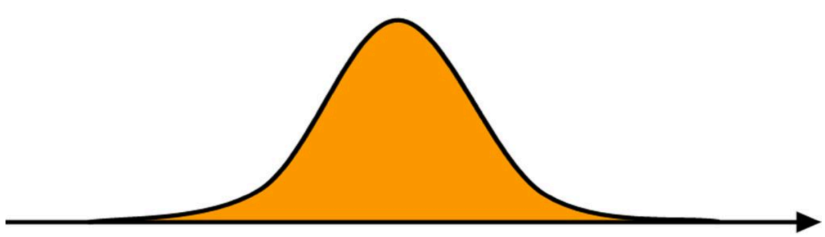

**Figure 1**. *Schematic representation of the Hubbert Curve. X-axis = time.; Y-axis = resource production*

The Hubbert curve is observed also for renewable resources. The cycle of the American whale fishery in the 19th century is an especially interesting case study for which detailed data for the main product of the industry, whale oil, are available (Starbuck, 1989), (Scott Baker & Clapham, 2004). A secondary product, "whalebone," used as a stiffener for ladies' corsets, followed the same cycle (Figure 2). In both cases, a clear "bell-shaped" curve is observed (See Fig. 2).

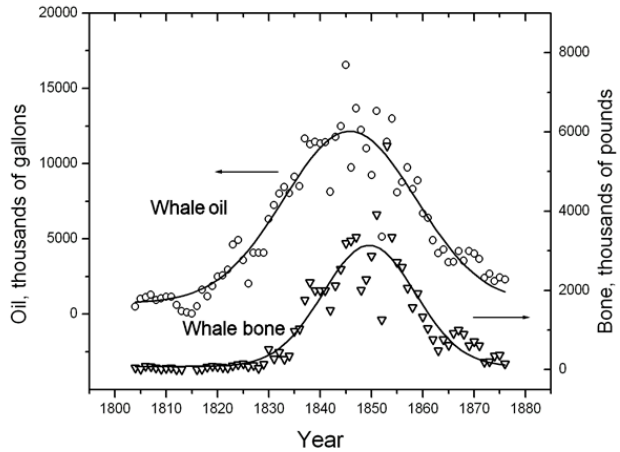


**Figure 2**. *Historical data (Starbuck, 1989) for the production of whale oil and whalebone by the American whaling industry. The data are fitted with a derivative of the logistic function that approximates the "Hubbert Curve".*

In qualitative terms, we may describe the 19$^{th}$ century whaling cycle as the result of the dynamic interaction of the whale population and the whaling industry. Commercial whaling started at the beginning of the century, spurred by the market for whale oil used as fuel for oil lamps. Initially, the hunt was directed to whales of species that were relatively easy to capture (mainly the "right whales," as it can be guessed from the name). The production of whale oil generated good profits that were in part re-invested in enlarging the whaling fleet. With more whaling ships in use, whales started being killed faster than they could reproduce, and their number started declining. Lower numbers of whales meant longer trips were for whalers and reduced profits for the industry. That made it more difficult for the industry to expand by building more ships. The production curve slowed its growth, peaked, then it started declining (fig. 2). When Herman Melville was writing his "Moby Dick" novel (published in 1851) the whaling industry had already peaked and was starting its decline. The perception of this decline may be the reason for the melancholic tone of the novel, even though Melville never mentions what whale oil was used for. Note that the decline of whaling is often attributed to the replacement of whale oil with kerosene, but it was only after 1860 that kerosene became a competitor of whale oil, more than a decade after that the whaling industry had started its decline. Kerosene entered the market not because it was better or cheaper than whale oil, but because whale oil had become scarce and expensive. These phenomena are characteristic of most historical cases of overexploitation.

## *Modeling Overexploitation*

The earliest mathematical model of overexploitation is the Lotka-Volterra (LV) model (Lotka, A.J., 1925), (Volterra, 1926). The model is normally understood as representing a two-stage predator/prey trophic chain and it is often referred to as the "rabbits and foxes" model. But the model actually describes the overexploitation of the rabbits on the part of the foxes. It was used (Volterra, 1926), (D'Ancona, 1942) to study a typical system in overshoot, the fishing industry of the Adriatic Sea during World War 1.

The Lotka-Volterra model was a precursor of the computer-based system dynamics models proposed by Jay Forrester in the 1960s (Forrester, 1971). These models could simulate overexploitation (Richardson, 2013) (Perissi, 2019) for real-world industrial systems, for instance the oil extraction industry (Bardi & Lavacchi, 2009) and the whaling industry (Perissi et al., 2017), (Bardi & Perissi, 2020). They could also be used to create aggregated "world models" designed to simulate the global economic system, (Meadows et al., 1972), (Forrester, 1971). A simpler version of the Lotka-Volterra was termed the "single-cycle Lotka-Volterra model" (SCLV) that can be used to simulate nonrenewable resources, or resources that are depleted so fast that they can be considered as non-renewable (Bardi & Perissi, 2021).

The gamification of these system dynamics models in the form of a boardgame can be attempted if the equations that describe the system can be turned into a "game engine" that uses dice or other mechanical randomizers to simulate the behavior of the system. This kind of gamification is possible with the simplest version of the Lotka-Volterra model (there are many versions, (Tyutyunov & Titova, 2020). The equations of this system are:

$R' = k_1R - k_2RC$ (1)

$C' = k_3RC - k_4C.$ (2)

Here, "$R$" stands for "Resources" which are exploited by transforming them into Capital, "$C$". $R'$ and $C'$ indicate the time derivatives, so $R'$ can be understood as "production", while $C'$ is the flow that builds up the industry's capital stock. $k_1$, $k_2$, $k_3$, and $k_4$ are positive constants. In the single-cycle variant of the model (SCLV) (Perissi et al., 2021), it is assumed that $k_1=0$. These equations have no analytical solution and are usually solved by iterative calculations. A typical result for the SCLV model is the "Hubbert Curve" described before. For the full LV model, the result is a series of repeating oscillations with the resource stock and the capital stock growing and declining one after the other. We verified that the SCLV model is often a good approximation to describe the historical data of the whaling cycle and also of other fisheries (Perissi et al., 2017).

In terms of the system studied here, $R$ is the number of whales, $C$ the capital (assumed to be proportional to the number of whaling ships), $R'$ and $C'$ are, respectively, the number of whales captured per unit time and the variation of the capital stock of the industry

To simulate the Lotka-Volterra equations as a mechanical game engine, we use a combination of the extraction of counters from a bag " (Munford, 1978) and 6-sided dice rolls. The prey stock (whales) is simulated using black counters in the bag, while white counters affect the probability of extracting a black one. Adding or subtracting black counters to the bag simulates the inflow and the outflow of the stock. For the other stock, the predator stock (whaling ships), we use tokens in the form of "ship cards." The game engine works in discrete steps (game turns), and we can rewrite the equations of the LV model in a discrete form taking $\Delta t = 1$ (one game turn).

$\Delta R = k_1R - k_2RC$ (3)

$\Delta C = k_3RC - k_4C$ (4)

The first term of the first equation, $\Delta R = k_1R$, (whale reproduction) may be simulated by adding by adding on each turn to the bag a number of black counters proportional to those already present. Alternatively, it may be neglected (no counters added).

For the second term of the first equation, whale captures (or "production"), $\Delta R$, can be simulated by extracting from the bag a number of counters proportional to the current capital stock $C$ (number of ships). For each extraction, the probability of extracting a black counter will be proportional to the number present in the urn. In this way, the number of extracted black counters is proportional to the product of the $R$ and $C$ stocks, apart from the randomizing effect caused by the extraction procedure. To keep simulating the LV model, the extracted white tokens are placed back into the bag. In addition, the total number of counters in the bag is kept constant by adding further white counters to replace the extracted black ones. Note that the case of the "Oil Game" it may be better not to replace the extracted black counters, as discussed in the appendix. After the extraction phase, the extracted black counters are transferred to the $C$ stock, transforming them into "whaling ships," according to specific rules described in the appendix. Finally, the second term of the second equation (depreciation) can be simulated by removing a number of counters proportional to the number already present according to a die roll for each counter in play. This game engine generates the growth of players' capital (whaling fleet) and production (whales) as a function of the number of black tokens in the urn. Overexploitation gradually reduces this number, so that players see their returns declining. If the game is played in a competitive mode, players try to catch as many whales as possible before the resource runs out. The result is the typical, bell-shaped "Hubbert Curve" and the game ends with the destruction of the resource.

The engine of the "Moby Dick" game can also be used to simulate the overexploitation of resources other than whales. We already mentioned that previous versions of the game used it to simulate oil extraction – in this case, the game was termed "The Oil Game" or, sometimes, the "Hubbert Game" (Bardi, 2015b). The game engine could also describe the overexploitation of other biological resources, for instance the hunting of the megafauna, or the extermination of bison in North America in the $19^{th}$ century, and many others. It may also be possible to use the game engine to create a collaborative mode. In this case, players are asked to operate in such a way to attain a stable state in which they do not overexploit the stock they are exploiting. We also call this mode the “Ostrom mode” since it tries to replicate the balance of internal checks among operators that avoids overexploitation in traditional societies. This approach is more complex and difficult than the competitive mode. Details about these and other versions of the game are described in the appendix.

## *The Learning Tool*

The operational game described here is normally be played in the competitive mode in about one hour by four teams of players. It means that a gaming session can involve 15-20 players, the size of a high school class. Having the teams playing to “win” is entertaining and we found that it is enjoyed by the players who may get engrossed in the game, especially in the versions that involve strategic choices (see the appendix). To avoid that the ludic aspects of the game could overcome its educational value, we found that it is important for the organizers to instruct the players on overexploitation before the game and to follow the game with a discussion on its meaning and on the results obtained. Introducing the game to players can be done by presenting and discussing the following points. Each is associated to one or more references, but there is ample documentation available on all those subjects

1. The history of the concept of “overexploitation,” from the ancient “megafauna” (Boissoneault, 2017) to modern overfishing (Pauly, 2009)
2. The case of the cycle of oil extraction in the US and the “Hubbert Curve” (Campbell & Laherrere, 1998)
3. The history of the whaling industry (Bardi & Perissi, 2020) including a discussion on Melville’s novel “Moby Dick”
4. How the 19$^{th}$ century whaling industry grew on the production of whale oil, at that time a fundamental commodity used to light oil lamps. How the industry couldn’t maintain its production because of overexploitation and how that caused the growth of the oil industry that found a market for a lower quality (it smelt bad) fuel: kerosene. and how whale oil production followed a bell-shaped curve (Figure 4).
5. The phenomenon of overfishing: with examples such as the extermination of the North Atlantic Cod, the destruction of the Pacific anchovy fisheries and many more. An extensive discussion can be found in the book by Bardi and Perissi, “The Empty Sea” (Bardi & Perissi, 2020).
6. Historical overexploitation cases other than those related to fisheries. These include the case of the Dodo, the American Bison, the Siberian Mammoth, and more.

After the game is over, the learning targets of the players are:

1. Understanding the origin of the “bell shaped” curve. After that the competitive version of the game is over, players are invited to plot their production data on a graph: they will find the same “bell-shaped” curve that had been shown to them before for real historical cases (see fig. 4). This curve has been often misunderstood in the many past discussions about “peak oil.” The game should help players understand that the curve is not an arbitrary idea set forth by geologists (Schneider-Mayerson, 2015), nor a myth (Lutz, 2012), but a natural result of the attempt of operators to maximize their profits.
2. Understanding that the maximization of profits, typical of free markets, leads to manage resources in such a way to destroy them. A discussion on the use of quotas may be appropriate and the teacher may also introduce players to the work of Elinor Ostrom (Ostrom, 1990) who found that overexploitation does not occur in small, traditional communities.
3. Understanding how even theoretically renewable resources (whales) can be destroyed if they are exploited faster than they can regenerate themselves. The mechanism of the “tragedy of the commons” as described by Garrett Hardin (Hardin, 1968) may be introduced to them.
4. In the version that takes whale reproduction into account, the players can learn how easy it is to reach the “tipping point” that leads to the extinction of an overhunted biological species.

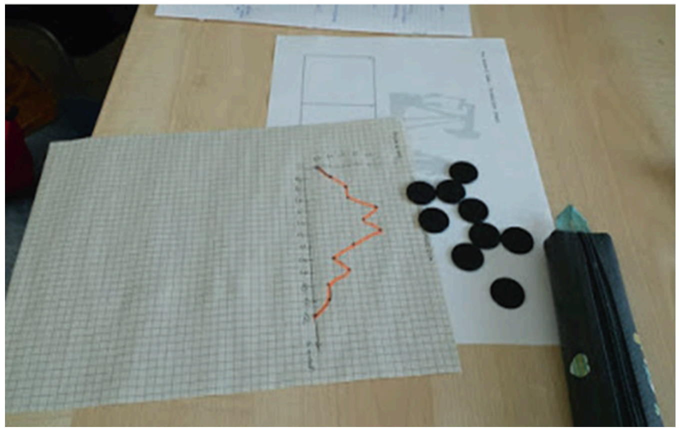

**Figure 4.** *Results of a game session showing an approximately "bell-shaped" curve plotted on squared paper.*

After 7 years from its initial presentation, in 2015 (Bardi, 2015c), various versions of the game described here have been tested for adults and students of different ages, and also by researchers other than the present authors (Celi, 2019), (Istituto Petrarca, 2017). The most extensive testing was performed over three academic years with the undergraduate students of the "Laboratory of Resources, Technology, and the Environment" class, part of the curriculum of "Economic Development and International Cooperation" of the school of Economics of the University of Florence. We can say that in all cases the game was well received and that the players reported that they had enjoyed the experience. It was also clear to the game proposers that players had progressed in their understanding of dynamical phenomena and overexploitation. This evaluation can only remain qualitative: a quantitative validation of an operational game as a learning tool is normally difficult, or even impossible. For instance, in the general review on SD gamification by Cunico et al. (Cunico et al., 2021), we find no mention of how these games could be validated. Other reports about operational games also do not mention validation, see e.g. the report on "Fishbanks" by Ruiz-Peréz et al. (Ruiz-Pérez et al., 2011) . This is not a shortcoming of the concept; it is part of the way these games are. They are working tools, they evolve, change, and adapt to different circumstances, conditions, and learning needs. So, the value of the game is best judged by the individual players and proposers who will surely modify it to suit their specific purposes as done, for instance, by Celi (Celi, 2019) who developed a computer-aided version.

## *Conclusion*

We developed a game engine that we used to create a boardgame that can simulate the dynamical phenomenon of overexploitation of natural resources, in particular for the whaling industry. We found that the game can be a useful learning tool, provided that the players are prepared before playing by an extensive description and discussion of the phenomenon of overexploitation. At the same time, it is clear to us that the game is not intended as a tool to indoctrinate players to accept a specific view. The game only shows that, given certain conditions, human actions directed to maximize profits may lead to overexploit and destroy natural resources, as has happened many times in history, not just with whales. But overexploitation is not a fixed destiny; it is the result of human actions. As Elinor Ostrom showed in her studies (Ostrom, 1990), humans can and do get together to find strategies to avoid overexploitation. It is up to the teachers and the managers of the game to take a balanced approach and to make players understand a basic fact that's well known to modelers: "all models are wrong" (Sterman, 2002). The Moby Dick game is a tool to understand what is *not* to be done to move toward sustainability for a better world. Getting there for real requires goodwill and unavoidable sacrifices.

## *Appendix: Rules of the game*

### *The Basic Game*

This section describes the detailed rules of the basic version of the game engine. It is assumed to be played with the title of the "Moby Dick game", a simplified simulation of the whaling cycle of the 19$^{th}$ century that led to the near extinction of the whale species hunted at that time. Playing this version requires only material that may be found at home or purchased from office equipment suppliers (Figure 4).

The game needs:

1. Bag with black and white counters. About 100 of each color are needed. Roulette chips, marbles, coins, or beer caps are all suitable for the game.
2. Whaling ship cards. Any recognizable counter or card will work. 3D ship tokens may be more attractive for young players.
3. One or more six-sided dice.
4. Paper and pencils to keep the game record. Squared or graph paper should be used to plot the evolution of the game.
5. Players may choose to wear accessories such as Captain Ahab's top hat and sailor-style wool caps to add atmosphere to the game.

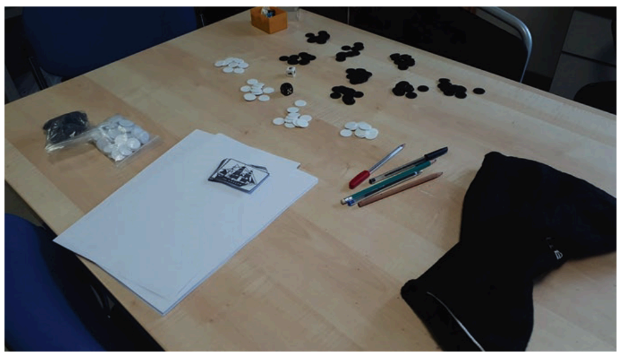

**Figure 5.** *The game equipment: black and white tokens, whaler cards, paper, pens, and a bag for the extraction of the tokens.*

Players are divided into teams, each one taking the role of a whaling company and starting with one ship card. A typical number of teams is 4, but the game was tested with up to 8 teams. The bag is filled with black and white counters. A typical value for a 4-team game could be 60 black and 60 white counters. Black counters are supposed to represent whales, although they should be understood as the landings that one ship can provide in one year of activity. One person takes the role of game master and the game takes place in turns, each representing a unit of time that may be taken as approximately one year. With 4 teams and 60 black counters, the game typically lasts 1-2 hours. Here is a description of the game turns

1. *Start.* Starting first on each turn gives a small advantage so the playing order may be chosen at random or by rotation at each turn.
2. *Whaling phase*. Each team draws tokens from the bag. Each whaling ship card owned by the team entails drawing two tokens. The players keep the black disks and put the white disks back into the bag. The number of tokens in the urn is maintained constant by the game master who adds to the bag a number of white counters equal to the total of black counters removed.
3. *Ship maintenance phase*. Each team rolls a 6-sided die for each whaling ship owned. The ship is supposed to be lost (sunk or demolished as obsolete) on a result of "1" or "2" and the corresponding counter is removed from the player's assets. During this phase, each player can also buy new whaling ships for three black counters each. These counters are then discarded.
4. *Book-keeping*. On each round, players keep track of the number of whaling ships they have and of the number of whales captured. The game master keeps track of the number of black counters remaining in the bag.


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5. *End of the game.* Typically, the game should last about 10 rounds, but the exact number should not be known to the players. It may be determined by the game master by rolling a die starting with – say – on the 8th turn and declaring the game over for a roll of 1, 2, or 3. The game also ends when all the players go bankrupt, having lost all their whaling ships and having no more "money" (black counters) to buy new ones. At this point, the winning team is determined, depending on the total number of black disks they still have. The winner is the one who has the highest score.
6. *Optional.* To simulate whale reproduction, at the end of each turn the game master adds black counters for a total of 10% of the black disks in the bag. The number is calculated by rounding down. That is if there remain 50-60 black counters 5 are to be added. If 40-50 black counters are left, 4 are added, and so on. If there remain fewer than 9 black counters, nothing is added. In any case, the total number of black counters in the bag never exceeds the initial number

The basic game is competitive, just like whaling was (and still is) in the real world. The whaling teams try to capture the largest number of whales they can. In a typical session, initially, players rapidly grow their whaling fleets. Then, they find it more and more difficult to catch enough whales to keep their fleets growing. During the final turns of the game, they are competing for the scant remaining resources, and their fleets tend to shrink to smaller numbers. The game ends when 1) all players go bankrupt: they own no more black counters and no more ship tokens. 2) whales go extinct (no more black counters in the box) – this is announced by the game master, or 3) after a pre-set number of turns, e.g. 8-10 turns.

At the end of the game, the winning team is the one which has the largest number of black counters and ships (each one counted in terms of a resale value of one counter per ship). This condition determines the strategic choices of the players: during the last turns they have to avoid overspending their profits in ships that may be lost to depreciation without yielding any profits.

### *Variants*

The rules of the basic game are only indicative and are often changed during actual game sessions. If there are more than 4 players, the organizers should increase the number of counters in the bag. The opposite should be done when there are less than four players. The game can be slowed down by reducing the yield of the whaling boats (for example, one draw per turn from the bag instead of two) or by increasing their cost (for example each ship could cost four black counters instead of three). The game can also be speeded up by having players starting with more than one ship. Variants can also introduce strategic choices for the players. In the basic game, the players can only decide whether to use the accumulated black counters to buy new ships or not, but there are ways to provide other strategic choices. A possibility is to use more than one bag of counters, each one representing a different ocean, e.g., Atlantic, Pacific, and Indian. Each bag has a different initial black/white counter ratio that should not be revealed to players. In this setup players must decide which bag is more productive than the others on the basis of the fuzzy knowledge they gain from the results of previous extractions. Other strategic rules are possible, such as limiting the number of ships for sale at each turn, forcing players to bet for them. There are many more possibilities, the only limit is to be careful to avoid that the ludic aspects of the game do not obscure its educational aspect.

Systems other than whaling can also be simulated. The game engine needs no modification to simulate the overexploitation of other biological resources, from mammoths to the dodo, with black counters described as prey units and players accumulating "hunter cards". In the case of non-biological resources, we already mentioned "*The oil game"* which was an early version of the game engine used to simulate the extraction cycle of crude oil. In this case, extracting from the bag was described as "drilling," black counters were described as "oil fields," and white counters as "dry holes" (drilling that led to no results). A problem that emerged in these sessions is that some players objected to the use of the game engine noting that, in the real world, nobody would search for oil more than once in the same location. The areas where oil has already been found or not found would be avoided (that shows that some players grasped the meaning of the simulation!). The objection was countered by not replacing the extracted black counters with white counters in the bag. This procedure simulates the reduction in the areas where the search is performed. Note that in the Oil Game players have the possibility of investing part of the profits obtained from oil into renewable energy in order to simulate the energy transition. More details can be found in previous papers (Bardi, 2015c), (Bardi, 2016).

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**Ethical questions**. The paper does not include any "research on human beings or animals". It was tested on students or ordinary people who freely decided to participate. No data, medical or otherwise, was collected from or asked to them and none is reported in the paper. They remain anonymous, except for those who explicitly agreed to have their names and their pictures reported in the paper (fig 5.).

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