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6

Governance of Renewable Resources

Insights from Game Theory

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Abstract

Renewable resources have the potential to be used in a sustainable manner but typically are not, often due to the existence of exploiters or free riders. This chapter analyzes free-riding behavior using the prisoner's dilemma-based public goods model and the producer–scrounger model. Overuse of renewable resources is examined under four investor–exploiter scenarios that are derived from modifications of the classic producer–scrounger model, and which vary in the degree of excludability of a discovered resource and in the cost of adopting each strategy. Two important factors are found to reduce overuse: when a finder's advantage can be created for investors, and when the costs of playing exploiter are increased relative to the costs of playing investor. Applying the investor–exploiter model to a fisheries scenario, discussion follows on how interventions designed to reduce overuse may be consistent with the existence of a finder's advantage. A variety of existing interventions can be seen as increasing the costs of adopting the exploiter strategy.

Introduction

Biological resources are able to renew themselves via reproduction and thus can be potentially harvested in a sustainable fashion. As is widely accepted,

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biological resources are currently overused, and this situation constitutes a major global conservation problem (Diamond 1989; Pauly et al. 2002). The use of biological resources by humans greatly exceeds that of animal herbivores, piscivores, or carnivores (Darimont 2015). Well-documented declines in tropical forests, bushmeat, and fish stocks are linked to human exploitation and have resulted in a reduction of harvest rates and benefits (Pauly et al. 2002). Halting the degradation and overuse of biological resources, while maintaining and enhancing human well-being, are critical steps that must be achieved if humankind is to transition toward a more sustainable society. In the classical "tragedy of the commons" scenario popularized by Hardin (1968), individuals who manage open-access common resources (i.e., a resource without a defined set of users or property rights) behave according to their own self-interest, thereby depleting a common resource used by all. Such overuse (or "inefficiency" in economic terms) can be reduced through various governance rules designed to curtail resource use by groups and individuals. However, to implement effective resource management interventions, the decision-making processes reached at the individual and group levels (and the factors which influence these decisions) must be clearly understood.

Problems of resource use are not unique to humans. A fascinating example of unfortunate resource management is provided by the Amazon molly (*Poecilia formosa*), a fish species that does *not* get its name by living in the Amazon—its distribution actually spans areas in Texas and Mexico—but rather because of a similarity between aspects of its reproductive system and the Amazon women of Greek mythology. According to legend, these women killed all of their male offspring and thus needed to travel to other villages to secure fertilization. Amazon mollies do not kill their male offspring; they simply do not produce any, because all their eggs develop into daughters, which are clones of their mother. Their form of asexual reproduction is rare and is termed gynogenesis (or sperm-dependent parthenogenesis): eggs still need to come into contact with sperm before they begin developing. This is a vestigial trait of their past history as a sexual species. Molecular evidence shows that the Amazon molly is the result of two sexual molly species hybridizing. All of the genes that the sperm contains are actively rejected by the egg.

This situation of mothers needing sperm while producing only daughters creates a problem of sperm supply. The species can only exist in the presence of at least one "sperm donor" species: another species of mollies that have retained males. Amazon molly females look very similar to the females of the sexual species, so males may have a hard time discriminating. As a result, the system can work, but only for a while. Amazons, by avoiding the need to produce males, are twice as fecund as their sexual sperm provider, because only females directly produce offspring. Therefore, Amazons avoid the so-called twofold cost of sex and, over time, ecologically outcompete their sperm-providing sexual species causing their extinction, which in turn, can lead to the Amazons' own extinction. To our knowledge, this is the only fish

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species for which there is a published mathematical proof that they should not exist (Kiester et al. 1981)! To account for their existence, Kiester and colleagues highlighted that other factors (e.g., spatial structure that allows the sexual species to persist) must be added to the basic population dynamic model to explain species coexistence (Kokko et al. 2008). Humans, of course, would rather not live in a spatial mosaic of local extinctions and subsequent recolonizations of their resources. The development of governance structures or rules (e.g., quotas on harvests) would thus be desirable to reduce the possibility of the tragedy of the commons.

One factor commonly associated with overuse of renewable resources is the existence of free riders (i.e., exploiters that take advantage of the investment of others). One example of free riding can be found in the creation of quotas to reduce overuse. Here, a governance rule imposes restraint on how much can be harvested. Individuals who engage in this restraint make an investment: their actions generate higher resource densities, which makes harvesting more profitable for all. Their investment, however, becomes vulnerable to exploitation by individuals who disregard the quotas, as these free riders enrich themselves by harvesting beyond set quotas (also known as "quota busting"). Such free-riding behavior is common yet detrimental to all, since it reduces the density of the resources generated by the investors' restraint (Munro 1979).

To explore further such exploitation strategies as free riding, and their impact on resource use, let us look at two different conceptual approaches: the public goods model based on the prisoner's dilemma (Axelrod and Hamilton 1981) and a modified version of the producer–scrounger model (Barnard and Sibly 1981). Our aim is to examine how these different approaches are related and can be linked to models of resource use, thus providing insight into more effective governance rules.

Framing of the Problem in a General Framework

Empirical studies of resource use, both in animal and human societies, often reveal the coexistence of at least two strategies in a population engaged in using resources. One strategy can be generally described as *investor* because it consists of investing in making a resource available. This strategy has received various appellations, such as *producing* or *cooperating*. The term "investor" is meant to apply whenever actions, as a net effect, lead to maintenance or increase in the resource of interest (possibly over time) in a dynamic setting. Investors increase the availability of a resource for a group (a resource has been newly discovered and made available for exploitation) but there is a cost associated with this behavior. An investment is not necessarily equal to "acting." Restraint from a behavior can still make an individual an investor in our sense, both when it requires installing new technology (e.g., using better equipment to harvest) and when it does not (e.g., by reducing harvesting effort); the

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latter captures the idea of choosing to invest in our children's future at a direct cost to ourselves (Sumaila and Walters 2005).

The second strategy, which coexists with the investor, is that of the *exploiter* and has been variously labeled as *scrounging*, *defecting*, *free riding*, *kleptoparasitizing*, *piracy*, or *stealing*. The exploiter does not pay the costs of generating new resources or maintaining them, but instead attempts to usurp some of the resources produced or maintained by others. It is worth noting that categorizing individual behavior along the investor–exploiter axis does not mean that this is the only trait axis along which individuals can vary. There could be individuals who are neutral along the investor–exploiter axis yet differ in other details. Variations outside this axis can then place an individual, as a net effect, as an investor or an exploiter.

Public goods models have frequently been used to understand the existence of investor- and exploiter-like strategies within populations of animals and human societies. These models can vary in the number of players, strategies, and the parameters and properties of the payoff functions. The simplest of games is the canonical version of the prisoner's dilemma. Here, investing yields a benefit, b, at a cost, c. Players face the payoffs detailed in Figure 6.1. Such configuration will comply with the key properties of prisoner's dilemma games if $b > c > 0$. A more general version of the prisoner's dilemma is presented in Figure 6.2, which shows the four outcomes.

When more than two players are involved, several models extend the possibilities of other similar collective action problems. Public goods games, for instance, involve a number of players that must decide on how much to invest from a private asset into a public fund that produces benefits to all players involved (Archetti and Scheuring 2012). The private cost of investing, however, is greater than the benefit the investor receives from her own investment in the public good if others also do not invest. On the other hand, if all players invest in the public fund, the sum of all payoffs to all players increases. This n-person prisoner's dilemma game creates a situation where the dominant strategy (or Nash equilibrium) is not to invest (cooperate) but rather to exploit (defect), creating a situation in which universal defection yields the worst possible outcome for the group. The socially optimum solution is for all players to cooperate (invest) (Archetti and Scheuring 2012).

	Cooperate	Defect
Cooperate	$b-c$, $b-c$	$-c$, b
Defect	b, $-c$	0, 0

Figure 6.1 Canonical version of the prisoner's dilemma, showing the payoffs of two opponents, who can either cooperate (invest) or defect (exploit). The first entry in each cell gives the payoff of the row individual; the second entry shows the payoff of the column individual: b, benefit; c, cost; $b > c > 0$.

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	Cooperate	Defect
Cooperate	*R* , *R*	*S* , *T*
Defect	*T* , *S*	*P* , *P*

Figure 6.2 General version of the prisoner's dilemma game. The first entry in each cell gives the payoff of the row individual; the second entry shows the payoff of the column individual: T, temptation from defecting; R, reward from cooperating; S, sucker's payoff; P, punishment payoff; $T > R > P > S$, $2R > S + T$.

Producer–scrounger models, by contrast, envision producers (investors) that discover a food resource and scroungers (exploiters) that exploit some fraction of the discovered food. These strategies are mutually exclusive in the sense that an individual can only adopt one or the other at any given moment. Players, however, can switch between strategies sequentially, so it is important to bear in mind that "producer" and "scrounger" do not refer to individuals but rather to strategies that individuals may adopt at a specific point in time. An individual that adopts the producer strategy searches or otherwise invests in making a good available at a personal cost of c. The good, once encountered, has some value b ($b > c$). In certain situations, as we see below, the model predicts some stable equilibrium frequency of producer and scrounger strategies within the population.

Both the prisoner's dilemma and producer–scrounger models envision a form of "social parasitism" in which some individuals can benefit from the costly behavior of others. Here, we seek to frame the problem in the context of resource use, identify how these models are related, and outline future work. We suggest that, to a large extent, the choice of conceptual approach to be adopted in analyzing renewable resource governance depends on the nature of the resources that need to be governed. These resource characteristics will determine when some individuals will behave in ways that benefit others, while others do not. Economists refer to these resource characteristics as the *rivalry* and *exclusivity* dimensions. Rivalry means that use of a resource by one makes it unavailable to others; this is what ecologists call depletion. The exclusivity dimension gives the extent to which others can be completely excluded from its use, something behavioral ecologists would refer to as defendability or despotism. Resources that are both nonexclusive and without rivalry are termed pure public goods. This means that once generated, everyone can benefit from the resource, irrespective of the strategy being used. At the other extreme, a resource with maximum rivalry and high exclusivity profits only the individual that made it available and/or its usurper.

A Simple Social Resource Use Game

Below, we examine four scenarios in a simple social resource use game that involves two strategies: investor and exploiter. These strategies are mutually exclusive in the sense that an individual can only adopt one or the other at

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any given moment. However, players can sequentially (and rapidly) switch between strategies. An individual that adopts the investor strategy searches or otherwise invests in making a good available at a personal cost of c ($c > 0$). The good once encountered has some value b ($b > c$), and we consider a group, G, of individuals. The proportion of exploiters in the group is p. We assume that resources are rivalrous (depletable) and consider four scenarios where exclusivity of resource use differs.

Scenario 1: Entire Group Exploits All Resources Made Available by an Investor

In this case, all individuals can use the resource made available by an investor. The investor's gain is:

$$W_I(p) = \frac{(1-p)Gb}{G} - c = (1-p)b - c. \tag{6.1}$$

The factor $(1 - p)$ is important because it means that gains can only arise when individuals adopt the investor ("cooperative") strategy; the greater the number of individuals who do so in a population, the greater the common good produced for all.

An exploiter's gain is:

$$W_E(p) = \frac{[(1-p)Gb]}{G} = (1-p)b. \tag{6.2}$$

It follows that $W_E(p) > W_I(p)$ for all values of p. As a result, the expected Nash equilibrium solution, or the evolutionarily stable solution in evolutionary biology, is noncooperative: the exploiter strategy spreads over the entire population even if this results in zero gain for all individuals in the population (Figure 6.3). This resembles the solution of the n-person prisoner dilemma game and

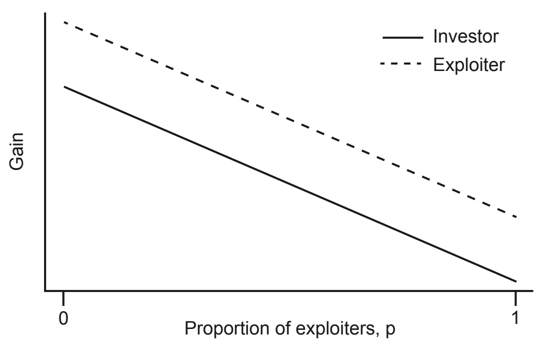

Figure 6.3 The gain (payoffs) for investors (producers) and exploiters (scroungers) as a function of the frequency of exploiters in a population. In this case, the payoffs to the exploiter are always higher than to the investor. The model thus predicts a population of all exploiters, which corresponds to the n-person prisoner's dilemma solution.

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is also the case of the pure public goods game. Empirical work with humans in the laboratory has shown that under the above conditions, individuals do converge toward a universal exploiter (free-riding) strategy when no communication is allowed among group members (Ledyard 1995).

Scenario 2: All Individuals Exploit Part of the Resources Made Available by an Investor

Now let us allow the investor to secure part ε of the produced resource for itself and refer to this as the *finder's advantage*. This situation may arise if agents are, for instance, involved in finding or making a good available that is not immediately available to everybody in the group. This delay makes it possible for the investor to secure part of the good before the arrival of others. Imagine, for instance, the discovery of a gold mine on public land; this would have a special effect on the individual that discovers it, as a result of its own producer behavior, and a secondary effect on all individuals. Now only the surplus, $(1 - \varepsilon)b$, is available to everyone else, including the finding investor and all other individuals playing investor. We assume limited excludability, $\varepsilon < 1$, otherwise the resource would be completely exploited by its investor.

When $\varepsilon < 1$, the investor's gain, which comes from its advantage as well as from joining the discoveries of other investors, is:

$$W_I(p) = \varepsilon b - c + \frac{(1-p)G(1-\varepsilon)b}{G} = \varepsilon b - c + (1-p)(1-\varepsilon)b. \quad (6.3)$$

The exploiter's gain is given by:

$$W_E(p) = \frac{[(1-p)G(1-\varepsilon)b]}{G} = (1-p)(1-\varepsilon)b. \quad (6.4)$$

When the level of excludability is low (i.e., the size of the finder's advantage is $\varepsilon < c/b$), then the equilibrium solution is that all should be exploiters (Figure 6.4). Note: Scenario 1 is a special case of Scenario 2, with $\varepsilon = 0$. On the other hand, if the level of excludability is high enough, $\varepsilon > c/b$, then investors do better than exploiters independently of their proportion; hence the stable solution will be for the investor strategy to spread until all play investor.

In a social foraging context, this scenario corresponds to the information-sharing model of Clark and Mangel (1986). Next we investigate cases when the surplus is available to only parts of the group, depending on the individual's strategy.

Scenario 3: The Surplus Is Shared by the Exploiters Alone

In this case, an investor only gains from resources produced by itself and exploiters can only access the surplus. This could happen if exploiters posed a

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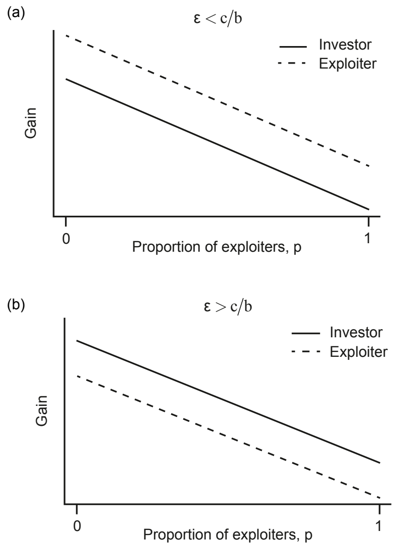

Figure 6.4 The gain (payoffs) for investors (producers) and exploiters (scroungers) as a function of the frequency of exploiters (scroungers) in a population. (a) When $\varepsilon < c/b$, exploiter always has higher gain than investor that corresponds to the *n*-person prisoners dilemma solution. (b) In contrast, when $\varepsilon > c/b$, investor always obtains a higher gain than exploiter, and the model predicts a population of all investor. Finder's advantage is ε, the cost of investing is c, and b is the value of the resource made available by the investor.

serious threat to investors such that upon the arrival of exploiters, investors always left the resource they created or discovered; for example, a scenario in which farmers produce food that is then stolen by bandits. In this case, the investor's gain is:

$$W_I(p) = \varepsilon b - c. \tag{6.5}$$

The exploiter's gain is:

$$W_E(p) = \frac{[(1-p)G(1-\varepsilon)b]}{(pG)} = \frac{(1-p)(1-\varepsilon)b}{p}. \tag{6.6}$$

The equilibrium proportion of exploiter, p_e, is:

$$p_e = 1 - \frac{\varepsilon b - c}{b - c}. \tag{6.7}$$

If $\varepsilon < c/b$ then $p_e = 1$ such that no investors remain in the population and hence we have the *n*-person prisoner dilemma solution; that is, the resource is not provided (Figure 6.5). However, for the situation where the finder's advantage

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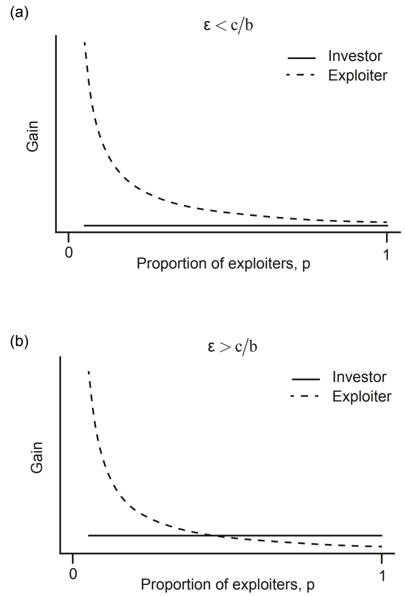

Figure 6.5 The gain (payoffs) for investor (producer) and exploiter (scrounger) as a function of the frequency of exploiter (scrounger) in a population. (a) When $\varepsilon < c/b$, exploiter always has higher gain than investor and the model predicts the *n*-person prisoner's dilemma-like solution. (b) In contrast, when $c/b < \varepsilon < 1$, investor obtains higher gain than exploiter if there are few individuals playing investor in the group and, vice versa, exploiter gains more than investor if exploiter is rare. Consequently, the model predicts a stable mixture of investor and exploiter. Finder's advantage is ε, the cost of investing is c, and b is the value of the resource made available by the investor.

is of intermediate value (i.e., when $c/b < \varepsilon < 1$, then $0 < p_e < 1$), we expect an equilibrium containing a mixture of investor and exploiter strategies; a mixed evolutionarily stable solution.

Scenario 4: An Investor Gains Its Advantage from a Discovered Patch and Shares the Rest with All Exploiters

The last scenario corresponds to the classic producer–scrounger game, where investors are the producers and exploiters are the scroungers. The producer's gain is:

$$W_P(p) = \varepsilon b - c + \frac{(1-\varepsilon)b}{1+pG}. \quad (6.8)$$

The scrounger's gain is:

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$$W_S(p) = (1-p)G\frac{(1-\varepsilon)b}{1+pG}. \tag{6.9}$$

Again we have an equilibrium mixture of investor and exploiter strategies (Figure 6.6) and the equilibrium proportion of producer is:

$$p_e = 1 - \frac{\varepsilon b - c}{b - c} - \frac{1}{G}. \tag{6.10}$$

Summary

The four scenarios illustrate that this investor–exploiter model predicts different outcomes depending on how resources are shared among the group members (degree of excludability). In turn, this is influenced by particular conditions of the environment (e.g., size of the finder's advantage, threats posed

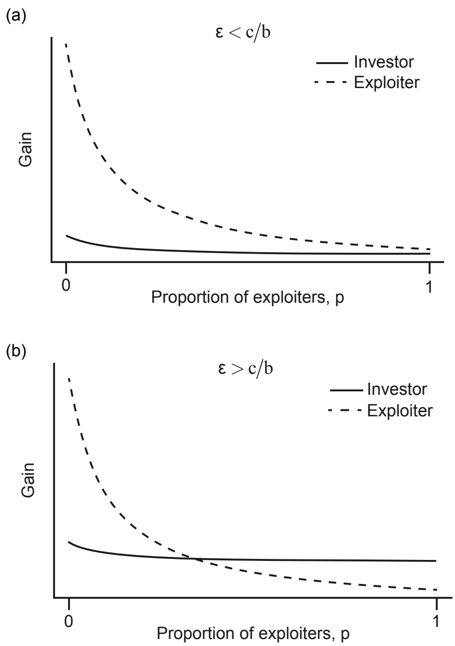

Figure 6.6 The gain (payoffs) for investor (producer) and exploiter (scrounger) as a function of the frequency of exploiter in a population. (a) When $\varepsilon < c/b$, exploiter always has higher rewards than investor, and the model predicts the *n*-person prisoner's dilemma solution. (b) In contrast, when $\varepsilon > c/b$, investor and exploiter have equal gain at an intermediate frequency of exploiter, a mixed evolutionarily stable solution. Finder's advantage is ε, the cost of investing is c, and b is the value of the resource made available by the investor.

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by exploiters). If none of the group members can be excluded from using the produced resources (scenario 1) or an investor cannot secure enough of the produced resources to cover its cost of investing ($\varepsilon < c/b$), then the model predicts the same noncooperative, all exploiter evolutionarily stable solution or Nash equilibrium as an *n*-person prisoner's dilemma game would do. If all individuals have access to the produced resource but the investor retains a large enough part of the resource ($\varepsilon > c/b$), then the evolutionarily stable solution or Nash equilibrium is the cooperative solution: everybody plays investor (scenario 2). In the remaining cases, a mixture of investor and exploiter is predicted. A crucial aspect of scenarios 3 and 4 is that investors have no access to resources produced by other investors. These cases correspond most closely to the classic producer–scrounger game model.

Next we investigate how these different scenarios affect resource use and management by applying this general model to a specific example: resource management of a renewable biological resource such as a fishery.

Basic Conceptual Fisheries Model

A great deal of modeling has been directed at understanding how harvesting efforts affect total fish stock biomass (Clark 1990; Hilborn and Walters 1992). This can be summarized in the basic conceptual model of fisheries as viewed from the perspective of both the entire fishery and an individual fisher or company (Figure 6.7). From the perspective of the entire fishery, the value of the resource extracted (fish) increases first with great extraction effort (e.g., number of fishing days or number of vessels), peaks at a maximum (the maximum sustainable yield, MSY), and then declines as more extractive effort is applied, because the stock has declined. Since the extraction process (e.g., fishing) is associated with a cost, maximum profits or "rent" (i.e., the maximum difference between the revenue and the cost curve: maximum economic yield, or MEY) are achieved at a level of effort lower than required to generate maximum sustainable yield (MSY).

While MEY or MSY may be viewed as reasonable targets or limits for society as a whole, they require some degree of regulation (e.g., quotas on total harvest). This is true because individuals using the resource maximize their net benefit by harvesting until their benefit equals their costs at the equilibrium point (EQ) (Figure 6.8). In practice, and especially in fisheries, this equilibrium point is far to the right of MSY and thus stocks are overharvested to a low level.

In well-regulated fisheries, a quota at or below MEY or MSY is allocated among agents: fishing at this level of effort will maintain the biological and/or economic productivity of the fishery. The key problem illustrated in Figures 6.7 and 6.8 is that society benefits most when the fishery is extracting MSY or MEY, but individuals benefit more, in the short term, by exploiting at a higher rate.

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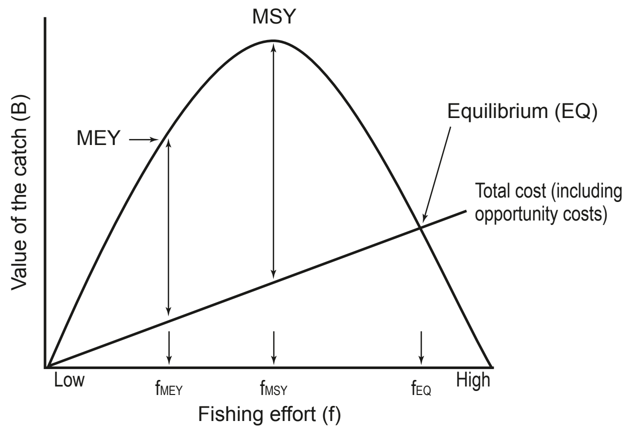

Figure 6.7 Conceptual model of fisheries as viewed by society. The total catch increases when fishing efforts increase until the maximum economic yield (MEY) or maximum sustainable yield (MSY) is reached. Afterward, total catch declines because of continued use, toward B = 0, when the stock is exhausted. However, equilibrium occurs when individuals maximize their net benefit (their total costs = B): here, effort is relatively high and stock biomass is low.

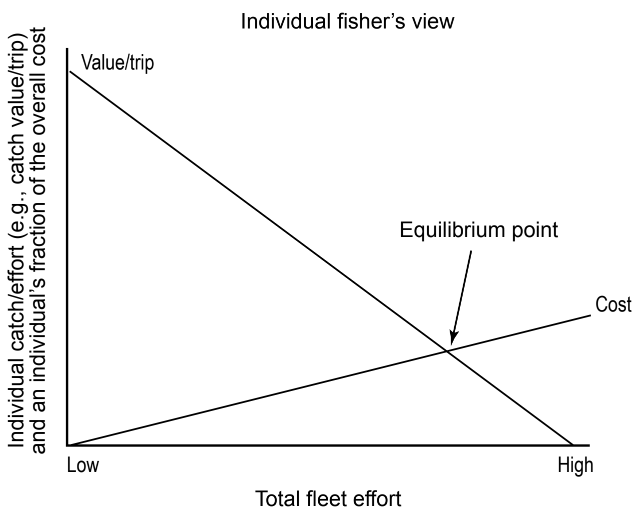

Figure 6.8 Conceptual model of fisheries as viewed by an individual agent. An individual fisher, fleet, or firm's benefits (value of the catch) and individual's fraction of the overall costs are shown on the y-axis as a function of the total aggregate catch effort. The individual fishers' catch per unit of effort, and hence their gross return, declines with aggregate effort using the stock biomass, and trends toward zero, as total fleet effort increases because the stock biomass becomes zero. Equilibrium occurs when individual value/trip equals the cost at relatively high total fleet effort.

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Application of Investor–Exploiter Models to Fisheries

Can the investor–exploiter modeling approach offer insight into fisheries management? To approach this question we must establish correspondences between the investor–exploiter game and fisheries. One tool commonly used in fisheries is the establishment of quotas that limit total catch effort. Quotas are divided between agents (individuals and firms) and are designed to maintain stock biomass near MSY. To bring this into the investor–exploiter framework, we assume that individuals who agree to abide by such a system are investors; that is, they invest in restraint to maintain the stock levels. Exploiters, on the other hand, are agents who do not invest in restraint while exploiting the stock. They can be framed as engaging in "quota busting" by harvesting beyond a specified quota.

Therefore, the investor–exploiter model is applicable at the level of an individual agent (whether fisher or firm). First consider a typical public goods fishery (Figure 6.9). The x-axis represents the proportion or frequency of individuals that engage in the exploiter strategy on that play of the game. The x-axis also represents stock biomass (with higher biomass values to the left). Any increase in the frequency of exploiters will reduce total stock biomass because they exploit the stock without investing in restraint; they do not abide by the quota agreement that attempts to maintain stock biomass at MSY. Investors exhibit restraint and thus abide by the quota system. Their payoff is highest when all invest (Point A: no exploiters), and investor payoff declines as the frequency of the exploiter strategy increases because stock levels are reduced. Exploiter always obtains higher payoffs than investor because it harvests more fish, but its payoffs also decline with increasing frequency of the exploiters strategy (again because total stock biomass is reduced). The equilibrium is a population where all individuals engage in the exploiter strategy (Point B) leading to the *n*-person prisoner's dilemma solution and overexploitation (as seen in scenario 1).

How can we avoid the *n*-person prisoner's dilemma solution that results in overexploitation of resources? Examination of scenarios 2–4 reveals that one important factor involves the existence of a finder's advantage which produces an extra benefit to investors and is unavailable to the exploiter strategy. Are there conditions in fisheries where the resource is rivalrous and excludable?

One possibility lays in the creation of a benefit that would be exclusive to the investor strategy. Such a mechanism would lead to a decline in the exploiter payoff curve (Figure 6.9) because exploiters would have access to less resources. A finder's advantage could be accomplished through various certification programs (e.g., the Marine Stewardship Council), where agents engaged in the investor strategy invest in abiding by various regulations that limit their catch. All other fishers whose investment in restraint is unknown or undocumented would be playing the exploiter strategy, because they are likely not abiding by quota agreements or are otherwise fishing unsustainably. One could argue that

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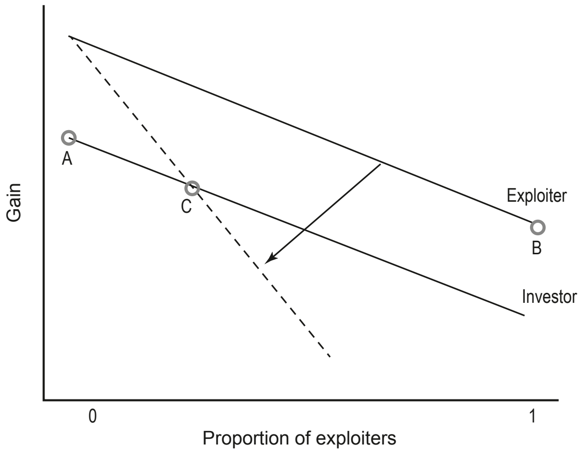

Figure 6.9 The conventional fisheries model of Figure 6.8 presented as a classic form of the investor–exploiter game (solid lines). Investors exhibit restraint (e.g., use large mesh nets, limit days fishing, or avoid Marine Protected Areas) and this results in maximum economic yield; exploiters do not invest in such measures and, as a result, always achieve a higher catch (higher gain). The game theory solution is for all to play exploiter (Point B). Note, however, that the highest overall catch is when all play investor (Point A), which exceeds the catch at the equilibrium of all playing exploiter. One way to avoid a group of all exploiters is when the negative frequency dependence of payoffs to the exploiter strategy is stronger (has a more negative slope) than for the investor strategy. This can occur if investor obtains a special protected share of the resource that exploiters can never access (i.e., a finder's advantage). Another way is for exploiter to pay a strategy-specific cost. For instance, if there is punishment for widespread failure to invest in restraint, then actions such as fines or boycotts force the gains obtained by exploiter to decline (dashed line) faster than the gain to exploiter, such that there is now an equilibrium balance between investor and exploiter where the lines cross (Point C).

the certification provides a finder's advantage to the investor and thus could make the payoff lines cross at some intermediate frequency of investor and exploiter. In theory, certification programs allow consumers to select between cheaper products from fisheries with less oversight and more costly products caught according to sustainability criteria. However, in practice, due to the incentive structure, it can be true that certified fisheries are unsustainable and/or that sustainable fisheries cannot afford certification (e.g., Jacquet and Pauly 2008; Christian et al. 2013).

Another possibility lays in increasing the costs of adopting the exploiter strategy, which again should lead to a reduction in the exploiters' payoff curve (Figure 6.9). A significant body of work has focused on elucidating the conditions and collective arrangements (institutions) under which groups of individuals can manage renewable resources more sustainably (i.e., use the investor strategy rather than exploiter).

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Policies (interventions) are the mechanisms by which individuals can be encouraged to play investor rather than exploiter (free rider). These often involve increasing the costs of adopting the exploiter strategy and include, for example, command-and-control, conditional payments, access rights, and punishment (see Figure 6.1 and Appendix 6.1). Interventions alter behavior and lead to the reallocation of resources among actors (Ostrom 1990). Thus it makes sense to categorize interventions in terms of how they intend to affect behavior (Börner and Vosti 2013). For example, positive incentives (e.g., subsidies or payments for environmental services) can reduce biological resource overuse by transferring financial resources in a society from beneficiaries of external biological resource services to owners of these resources. Negative incentives or disincentives (e.g., taxes) can have the same effect on the biological resource, by transferring financial resources from biological resource users to the beneficiaries of external service beneficiaries.

While the standard environmental policy model would predict the same biological resource outcome independent of the policy instrument, we know from behavioral economics that the direction of the financial resource transfer can have different effects on the response of resource users and external beneficiaries, such as through motivational crowding (Bowles and Polania-Reyes 2012). Another mode of intervention that can be labeled "enablement" addresses the conditions affecting collecting behavior. This could include redistribution of property rights (e.g., land reform), education, technology development, or the management of beliefs and norms, such that cooperative (investor) behavior prevails among a defined group of resource users. Examples of interventions in each category are provided in Table 6.1.

Recent work has focused on social norms and the role of leadership in affecting behavior. Social norms are rules of behavior that we expect others in our group to follow; when they do not, we expect such deviant behavior to be punished or shamed. Young (2008) defines social norms as "*customary rules of behavior that coordinate our interactions with others*." The expectation of

Table 6.1 Examples of different interventions intended to affect behavior.

	Intervention/ Type	**Intended impact channel**	**Example**
Incentives	Conditional transfers	Compensation for opportunity costs of resource maintenance	Payments for environmental services
Disincentives	Command and control	Increase the costs of resource degradation	Resource use limits subject to fines or punishment
Enablement	Establishment of property rights	Encourage long-term investments in resource maintenance	Decentralization
	Management of norms and beliefs	Behavioral change	Nudging, awareness-raising

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shunning by others in the group would sustain the compliance of the group, and therefore it could provide an endogenous institution to solve social dilemmas like the tragedy of the commons. Norms, however, do not always align social and individual interests.

In the case of resource use, norms could regulate (without the need for an external authority) actions related to technology (e.g., fishing gear), efforts used to extract resources, and the sharing of costs or benefits. Baland et al. (2006) argue that social norms can shape behavior by either limiting the action set of the players or by changing the preferences of the players. Maintaining a social norm (making sure that everyone is doing his or her fair share of making the norm to be preserved) is individually costly but benefits all. Norms are sustained through shame, guilt, and embarrassment (Elster 1989) and can emerge and be evolutionarily stable for solving common-pool resource dilemmas (Crawford and Ostrom 1995; Sethi and Somanathan 1996). These norms could be used, then, to encourage resource users to switch from scrounging–exploiting to producing–investing by transforming the relative payoffs to the player from the two strategies.

Finally, the role of leadership in galvanizing group cooperation figures prominently in social sciences. One way that leaders can resolve cooperation dilemmas is to lead by example, whereby leaders contribute first and encourage group members to follow (Gaechter and Renner 2014). Another way is to act as a punishment authority. However, evidence from development economics suggests that leadership can also have a negative effect (Bardhan and Mookherjee 2002). In fact, Kosfeld and Rustagi (2015) show leaders of groups engaged in forest commons management vary in their motivation to punish, and this has implications for the performance of groups in managing their forest commons. Leaders who emphasize equality and efficiency see positive forest outcomes. Antisocial leaders, who punish indiscriminately, see relatively negative forest outcomes. In addition, experiments in the field conducted in Mali show that leaders are more effective in inviting community members to contribute in public goods games (Alzua et al. 2014). These results highlight the importance of leaders in collective action and, more generally, the idiosyncratic but powerful roles that leaders may play, leading to substantial variation in group cooperation outcomes, by encouraging members to shift toward investing strategies.

Future Directions

The investor–exploiter model provides an alternative view of renewable resource management. Its main application here has been to fisheries, but we assume that other renewable resource management problems—those that involve excludability of the resource, and affect both investors and

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exploiters in resource maintenance efforts—could potentially exhibit similar properties.

Further work should extend the model to actual systems. This will involve the difficult task of identifying individuals engaged in playing investor from those engaged in exploitation. One possibility might occur in tuna fisheries. Tuna fishing is frequently conducted with the aid of fish aggregating devices (FAD), which in the past consisted of palm fronds and currently are made of metal and/or concrete. FADs take advantage of the propensity of tuna to swim under floating objects (Floyd and Pauly 1984). Investing in FADs can be very costly, but the agent that does so can expect to be able to harvest the fish that they aggregate. Other agents who do not invest in FADs can, if they are able to locate them, raid the FADs as thieves or scroungers. In this case, producer involves investing effort in the construction of FADs. By doing so, producers have a higher likelihood of harvest from them (because they know their exact locations), and thus they stand to gain from a finder's advantage.

A second possible example involves the Philippines, where legislation authorizing the creation of marine reserves by coastal municipalities has led to hundreds of such reserves. Local fishers play investor when they invest in restraint by not fishing within the reserve. However, they can also obtain enhanced fishing in areas adjacent to the reserve due to their enhanced knowledge of local conditions and the likely movement of fish out of the reserve to adjacent waters, due to their high population sizes inside reserves. This enhanced fishing can perhaps be considered as an investor's (finder's) advantage. Exploiter then consists of fishing in the reserve, a behavior that is sometimes adopted by the fishers of neighboring municipalities, or by industrial vessels. Again, it is uncertain whether this fits the investor–exploiter game. If it did, it would result in the stable equilibrium of both investor and exploiter strategists, and stock biomass levels would remain higher than if the *n*-person prisoner's dilemma solution existed (Pollnac et al. 2001).

In principle, the investor–exploiter approach might also help us address a long-standing problem in resource extraction by quantifying illegal harvest. If a resource extraction system has an internal equilibrium with investor and exploiter strategists, the model predicts that the payoffs to those playing investor are equal to those playing exploiter. Consider a fishery system with certification in place. The catch of investor strategists that are certified can be readily quantified because they gain from transparency (e.g., amount of fish biomass harvested). From this quantity, given the assumed equilibrium frequency of investor and exploiter, one could potentially generate an estimate of the (illegal) harvest by the exploiter strategists if the total number of fishers is known.

Resource management is complex, in part because both the resource and the exploiting agents are heterogeneous and operate on different scales. The majority of successful examples of collective resource management come from individual case studies of local resource use settings (Pretty 2003). While these

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studies highlight factors that have led to better outcomes, far too little is known about how sustainable biological resource governance can emerge at national, regional, and global scales.

Conclusions

Economists view renewable resource management as a problem of efficiency, because of the existence of free riding, and biologists use the producer–scrounger game to study how individuals divide up into investors and exploiters, depending on environmental conditions or species attributes. These two views have necessarily evolved for specific purposes, but they do have commonalities. In the underlying theoretical models, for example, changes in resource attributes affect behavioral responses in similar ways, and different interventions (policies) can affect the level of human cooperation much as changes in costs and benefits affect the frequency of producers and scroungers in a group.

To achieve interdisciplinary synergy, the alignment of terminology and theoretical concepts poses a major challenge. Our sustained interest in understanding the curious dynamics of animal species, such as the Amazon mollies, which mismanage their resources, may offer sufficient proof of the potential benefits to be gained by pushing toward more integration among disciplinary theoretical frameworks in biological resource management and beyond. We hope that this contribution serves as an initial step in this direction.

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Appendix 6.1: Punishment

In human societies, evidence suggests that cooperation can be enhanced by disciplining free riders, either through punishment or by forming rules and enforcing them (Fehr and Schmidt 1999). A study by Ostrom and Nagendra (2006) of multiple forests owned by states, communities, or private firms revealed that regardless of the property rights regime, forests were in better shape

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when the users were involved in the design, monitoring, and sanctioning of the rules that governed them. A growing number of studies have now identified coercive behaviors in biological systems as an important aspect of cooperation. In biology, punishment refers to cases where the act of punishment reduces the punisher's fitness at least initially, i.e., without taking into account any changes in its partner's future behavior (Raihani et al. 2012). If this was the end of the story, it would be hard to understand how punishing behavior could evolve. One solution appears to be that punishment can become *self-serving* if the changes of partner behavior or identity make it beneficial for the punisher. It may also be that the initial reduction in fitness—the cost of punishing—does not really arise in the first place.

A series of experiments in coral reef fish help to illustrate these points. A fish, the scalefin anthias (*Pseudanthias squamipinnis*), has a problem in the presence of other fishes, such as sabertooth blennies (*Petroscirtes* spp.) which attack anthias and other fish victims from behind. The bitten fish then chases the blenny, but is this "retaliation" costly? An initial energetic cost is presumably present, but this behavior has been shown to decrease the probability of future attacks by the same fish. Here, a public goods situation appears to be created for the entire shoal, because chasing also increases the probability that the attacker next time chooses to target another fish species. Finally, an experiment showed that blennies appear to be able to discriminate between fish that do and do not chase them, even if they look alike (to us) (Bshary and Bshary 2010), making "self-serving punishment" the best explanation overall. This, however, should not be taken to suggest that cost-free or even low-cost punishment is necessarily the norm in nonhuman societies (Pollock et al. 2004).

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