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So Many Zebras, So Little Time: Ecological Models and Counterinsurgency Operations

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Overview

Force ratios are an important variable in warfare and in nature. On the Serengeti, large zebra herds are constantly hunted by small prides of lions. But with their overwhelming majority, why don't the zebras unite and attack the lions? Hooves can be as deadly as claws when used correctly. And conversely, if the lions are such effective predators, why are there so many zebras?

Ecological interactions between predators and their prey are complex. Sometimes the few prey on the many; picture a whale devouring thousands of docile microorganisms. And sometimes the many prey on the few, as with killer bees attacking an unsuspecting person. During the past century, the mathematics underlying different types of survival strategies for attacker and evader have been worked out by ecologists, and we now have a fairly good understanding of such relationships.

While not a perfect metaphor, it is striking that these quantitative ecology models greatly resemble behavioral interactions during counterinsurgency operations. While a predator-prey model alone may be too simplistic to fully describe counterinsurgency, there are more detailed ecological models of competition that better capture the essence of the problem.

The purpose of this paper is not to provide definitive solutions, but to suggest a framework for other researchers to adapt and expand upon. Indeed, many of the models discussed are common to both ecologists and economists. The goals of both types of modeling are similar: maximizing profits in terms of food or money at the least risk—death or bankruptcy.

From our preliminary work on the possible applications of ecology to counterinsurgency, we hope that others more adept at the use of these quantitative models will make significant contributions to the area of predictive ability in combating terrorism and understanding unconventional warfare.

Ecology and Counterinsurgency

The climate of conflict during the early 21st century has caused a reexamination of techniques and tactics used in counterinsurgency (COIN). The complexity inherent in warfare and other (seemingly different) complex systems can be modeled in similar ways. The interaction of competing and cooperating groups with differing goals, tendencies, and talents lends itself to mathematical analyses, which often result in predictions of ways to perturb systems to reach desired outcomes. Occasionally, these predictions are not intuitive.

We explored the notion that ecological modeling of species interactions might approximate the interactions found in counterinsurgency. First, we found that models describing the relatively simple interaction of two animal species in a predator-prey relationship (what ecologists call *predation*) and similar models (for example, viral infection of a host) were inappropriate because of oversimplicity, violation of critical assumptions, or both. Second, we discovered that models of between-species competition for resources approximated the struggle between insurgents and counterinsurgents for military and political control over a host nation's population. Third, we concluded that this set of models implies that various aspects of a counterinsurgency campaign—fighting insurgents, controlling crime, and winning popular support—are probably inseparable.

This paper is intended to stimulate thought and further work in using biological models and metaphors for predictive purposes in warfare. It is important to note that modeling of this kind can only provide insight, not answers. Using the initial framework outlined here, more extensive analysis, modeling, and simulation could be used to derive historical insights about past COIN campaigns and aid in planning future ones.

Biology as a Mindset. Biology is more than a laboratory science; it is a way of thinking about the natural world. Biological metaphors provide powerful ideas about how the natural world functions, and many parallels between natural and manmade systems have been drawn in technical, policy, and popular literature.[1]

Within the field of military and war studies, biological metaphors are often used to convey powerful ideas about human behavior. For example, an influential article by David Killcullen uses the terms *adaptation*, *evolution*, *competition*, *ecosystem*, and *environment* to describe various phenomena during a counterinsurgency campaign.[2] Notably, these words are all from the same subspecialty of biology.

The study of this subspecialty, commonly called ecology, evolution, and animal behavior (EEB), is more than merely observational; it is also mathematical and can be predictive. Empirical and theoretical works are often performed simultaneously by one or more investigators to illuminate nature's mysteries. Experiments can be performed to test models, or new data can be used to inform new mathematical theory. This quantitative approach has been highly successful since the beginning of modern biology a century ago and continues in cutting-edge fields such as bioinformatics and genomics.

The similarities between biological ideas and observations of warfare raise the question: might mathematical models of biological processes be useful for understanding—and perhaps predicting—certain aspects of warfare? Here, we investigate whether ecological models may be relevant to the study and practice of COIN.

How the Weak Win Wars. It has been posited that powerful modern nations—the United States, Soviet Union, Great Britain, France—have only yet been beaten in battle or driven to stalemate via insurgent tactics. These tactics include guerrilla warfare and terrorism and typically have a large psychological operations (PSYOP) component. The general success of insurgencies warrants study. However, since the Vietnam era there has been little development of new analytical methods for understanding COIN.[3]

What is counterinsurgency? Typically, the term is meaningless without an initial insurgency. Generally speaking, COIN involves a rebellion (the insurgents) against an authority (the counterinsurgents) for control of a population (everyone else).[4] The rebellion or authority may be from the area where the action is taking place, or, as is often the case, the rebellion may find safe haven outside this area.

The literature has various definitions of insurgency and counterinsurgency, three of which are:[5]

- A *counterinsurgency* consists of those military, paramilitary, political, economic, psychological and civic actions undertaken by a government to defeat a subversive insurgency.

- An *insurgency* is a struggle for power (over a political space) between a state (or occupying power) and one or more organized, popularly based internal challengers.

- An *insurgency* is a struggle for control over a contested political space, between a state (or group of states or occupying powers), and one or more popularly based, nonstate challengers.

The first key point in all three definitions is that an authority in the contested area is defending its right to control a territory against a rebellion. The rebellion is implicitly assumed to be smaller and less powerful, else they would be the governing authority. The second key point, in the second and third definitions, is that the authority and rebellion are fighting over *political space*, which includes control of the "hearts, minds, and acquiescence of the general population" in the contested area. This contest is to be distinguished from battles over what is merely *physical space*, territory itself—a key distinction between this particular form of irregular warfare and traditional conventional warfare.[6] Inherent in this definition is that PSYOP and other nonkinetic techniques are at least as valuable as traditional kinetic techniques in winning these battles. Finally, the third and most inclusive definition takes into account the transnational nature of some contemporary insurgencies, noting that one or more states (authorities) may battle one or more external or internal challengers (rebels). This last definition, by Killcullen, is probably the most useful.

To use ecology models to understand COIN, at least one large generalization is necessary: that similarities exist across most COIN environments. This assumption is particularly germane in light of recent discussions about the new "global insurgency" and its similarities to and differences with "classical insurgencies."[7] There have been some changes in how insurgencies operate in the modern age. Communications have improved and financing is different. However, this does not necessarily mean that the essence of insurgency has been significantly altered. If there are generalities about COIN at a fundamental level despite adaptational differences over the decades, then we can ask whether there is a set of ecological models that addresses these similarities and can be applied to past, present, and future insurgencies. If so, what are those models?

Simple Models: Us versus Them

The interaction of insurgents and counterinsurgents on an asymmetric battlefield resembles the perennial struggle between predator and prey. Mathematical models of predation are some of the oldest in the field of ecology and evolutionary biology and date back nearly a century to seminal work resulting in the influential Lotka-Volterra equations.[8]

On the surface, the simple metaphor of predator-prey interactions is appealing. Predators are suited to killing prey, and prey, in turn, are quite often adept at escaping their common predators. When observed in nature, these "arms races" have resulted in at least a temporary equilibrium; where they have not reached equilibrium, no interaction can be observed because the prey have gone extinct. The symbolism is obvious.

Furthermore, observations from nature suggest numerous overt mechanisms by which prey avoid extinction.[9] They can reduce the kill rate by decreasing local prey density (therefore increasing predator search time) or increasing "handling time" (time taken to kill a prey item). Prey can also use such strategies as occupying territory within which predators cannot hunt. Small rodents can burrow, for example. Prey can always persist at low densities in such spatial refuges. There

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also may be a victim "carrying capacity"—a maximum number of kills per day—because predators have eating limitations. Waning prey populations can be reinforced by immigrants from populations that are not being preyed upon. All of these scenarios have counterparts in human warfare.

This metaphor begs the question: do quantitative models of predator-prey interactions among animal species have any relevance for understanding interactions during a counterinsurgency campaign?

Imagine a pyramid describing categories of people in the contested area of a COIN campaign (figure 1). At the base of the pyramid is the general population—people who just want to go about their lives. The middle contains, in far smaller numbers, the criminal element of the population. These people are most likely not part of the rebellion, but rather take advantage of a weak or distracted authority to better their circumstances. Finally, at the top of the pyramid are the insurgents, or rebellion. Historical data put this group at about 0 to 1 percent of the population in the contested area.

In theory, one could separate these three groups with regard to counterinsurgency operations. That is, one group from the authority could concentrate on political affairs (targeting the general population), another group could conduct policing (targeting criminals), and a final group could perform "hunter-killer" operations (against the rebels). This is in contrast to individuals or units performing all of these three basic COIN functions. In this framework, a simple predator-prey model may be valuable for simulating what takes place during COIN at the top of the pyramid. A historical example of this would be Operation *Phoenix* during the Vietnam War.

The population models used to describe systems of predator-prey interactions are systems of equations that allow us to measure differences in rates between two variables (mathematicians call these *differential equations*). The most widely influential predator-prey models are those originally constructed by Lotka and Volterra. In essence, the Lotka-Volterra predation model is a system of such equations describing the interaction between predator and prey. This interaction is commonly symbolized as (+, –) because the effect of the prey on the predator is positive (+), and the effect of the predator on the prey is negative (–).

The Lotka-Volterra "growth" equations for authority and rebellion describe how predator and prey populations change in size based on natural birth and death rates and the interaction between predator and prey. The notion of predator and prey fighting to "win" is attractive on its surface. The key question is whether this biological model accurately depicts the interactions and relationships between authority and rebellion in a COIN ecosystem.

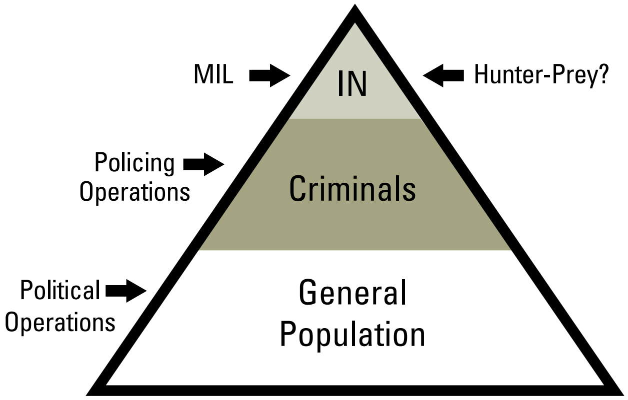
Numerous assumptions accompany the Lotka-Volterra predation model. Some are nonnegotiable, while others can be accounted for by making adjustments such as adding new variables. Five key assumptions are:

- Prey population growth is limited only by predation.
- The predator is a specialist that can persist only in the presence of prey.
- Individual predators can consume an infinite number of prey.
- Random encounters occur in a homogenous environment.
- There is a closed system with no migration.

In natural systems of animal predators and prey, these assumptions often hold true—at least insofar as their violation does not severely disrupt the outcome of the system. However, in COIN, the actors (the rebellion and authority) most likely violate these assumptions to the point that the model is ineffective. For example, the rebellion is probably limited in size by more factors than the authority kill rate. Furthermore, the authority does not receive a genuine positive (+) benefit from killing rebels (with regard to population size/growth) and furthermore can "persist" without the rebellion. There is most likely some degree of migration for the rebellion and authority in and out of the contested area (although this particular situation can be alleviated by modifying the model to account for this). Finally, the environments within which the rebellion and authority encounter each other are always heterogeneous, and encounters are often nonrandom. To summarize, the predator-prey framework is probably oversimplified and not very useful for understanding COIN.

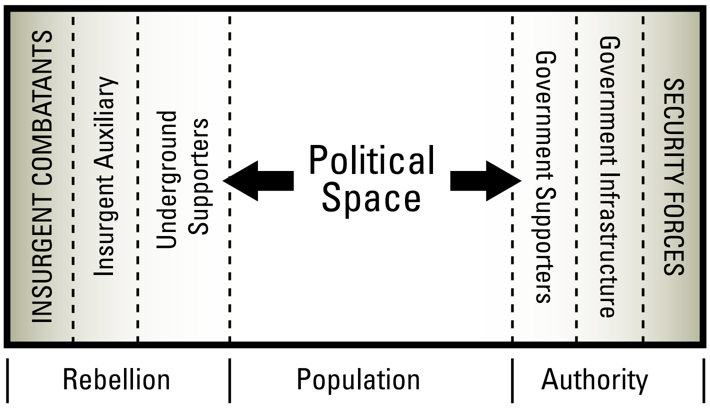
The overarching problem with relatively simple, two-species interaction models (like predation interactions) is that they do not include the major aspect of COIN that distinguishes it from conventional warfare: the role of the population in the success or failure of the authority and rebellion. A successful COIN campaign is not won when the most rebels are killed; rather, it is won when the most "political space" is controlled. The authority does not "grow" when members of the rebellion

Figure 1. General Population Pyramid and Its Interactions During a Counterinsurgency



Key: IN = insurgents, MIL = military operations

Figure 2. Competition between Authority and Rebellion over Population



are killed, as the predation growth equations require. With that said, both the authority and rebellion can grow in some sense when they win the hearts, minds, and acquiescence of members of the population. These individuals will effectively join one side and increase its size.

Another class of ecological models, competition models, takes this into account and may be more useful for describing the complex conflict ecosystem of COIN.

Competition Models: Parts of the Whole

COIN is about more than killing insurgents (that is, "countering" is more than "killing"). Killing the enemy is not the primary objective; rather, it is to outcompete challengers to control political space made up of the hearts, minds, and acquiescence of the population. The authority can be viewed as a coalition of security forces, government infrastructure that supports the authority, and persons within the population who firmly support the authority (see figure 2). Similarly, the rebellion can be seen as the group containing actual insurgent combatants, the auxiliary forces that directly support them, and indirect supporters in the population who make up the underground movement that opposes the authority but does not directly fight. In the middle is the neutral general population.

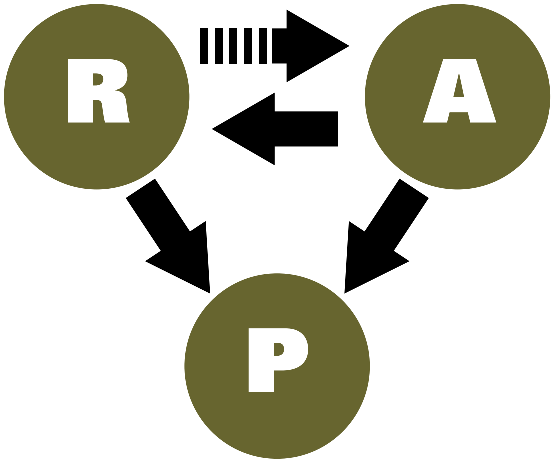
Hence, access to and control of the population in the center of figure 2 is what the competition between authority and the rebellion is about. Luckily, there is another class of ecological models that may in fact be relevant and useful: models of competition for resources between two species.

Ecological competition models can be seen through the prism of COIN as more inclusive, taking into account not only the insurgents and counterinsurgents but also the larger civilian population within the contested area. Calculations based on historical COIN data suggest that the number of insurgents and counterinsurgents as a percentage of persons in the area of operations is very small. Typically, reliable data from COIN are hard to come by, but where information is available, insurgent combatants have been less than 1 percent of the overall population, and counterinsurgency or security forces about 1 to 2 percent of the population. Hence, by ignoring 97 percent of the persons in the area of conflict—among other reasons—simple ecological models like those describing predator-prey interactions fail to completely capture the reality of COIN.

Competition in nature comes in a number of forms, and ecologists have developed different mathematical competition models to describe them. One example is *exploitation competition*, described as the negative interaction of two or more species for a limited resource within the environment. The species *indirectly* harm each other by using nonrenewable resources that the other species needs. In nature, for example, this resource might be food—an item that can ultimately constrain the local population growth rate of each species. However, this common form of competition in nature does not accurately describe what occurs between the authority and rebellion during an insurgency.

A simple extension of exploitation competition is more realistic and applicable. Termed *interference competition*, it occurs when species seeking a resource harm each other's ability to gather it.[10] Here, there is indirect competition for a limited resource and direct competition between the competitors for access to the resource (the interference). A simple human analogy is the competition between a couple on a date drinking one milkshake with two straws. In an exploitation competition, the winner drinks more of the milkshake. In an interference competition, both people drink, but one person pinches the other's straw.

Figure 3. Ecological Relationships in Authority, Rebellion, and Population "Food Chain"



Here, there are three "species" or actors involved: authority (A), rebellion (R), and population (P). In the model, A preys on R, and both compete for access to P (a precursor to winning support: a means to an end). Such "competition for access" to P can be considered predation (that is, conflict) for the purposes of this model. After Okuyama and Ruyle's diagram,[11] this three-actor "food web" is depicted in figure 3.

This interference competition model is more realistic than others we have considered and dismissed because it more accurately describes the complicated "food web" of COIN. In interference competition, species are not classified strictly as competitors or predators but rather can play multiple roles. This is most likely the rule in nature, not an exception.

Unfortunately, from the standpoint of COIN, interference competition can allow, and even promote, coexistence of competitors on a shared resource. This is in contrast to exploitation competition, where, in theory, the Competitive Exclusion Principle[12] would hold, and one of the competing species would go extinct. In fact, with interference competition, assuming that the Competitive Exclusion Principle operates and that one species (the authority) is the "top predator" over the other competitive species (the rebellion) for coexistence to occur, the rebellion must be better at competing for the resource. This is precisely what we tend to see in COIN campaigns that lead to stalemate or loss for the authority. Obviously, if the authority is better at preying on the insurgency and is equally good at competing for the population, the authority will win.

There are some additional assumptions necessary for these types of interference competition models to work. One is that the resource being competed for is in limited supply; otherwise, there would be no competition. This is a reasonable assumption for COIN, particularly when viewed at a subnational scale (for example, a district).

Another simplifying assumption of these competition models is that there is a closed system. (This is an assumption of most every simple scientific model.) In other words, the authority and rebellion receive no exogenous support. This is most likely violated in a majority of cases. Indeed, it has been wagered that rarely does an insurgency survive without exogenous support.[13] Such migration effects are also common to animal systems and can generally be accounted for with additional variables/factors (that is, migration rate of R in and out of the system) in the primary sets of equations. Additionally, migration may not matter if its rate is low. It may also occur in some parts of the area of operation and not in others, allowing the model to be more accurate in some provinces than in others.

The reality of counterinsurgency—for example, the current war in Iraq—can certainly involve multiple actors in multiple simultaneous rebellions. Although outside the scope of this paper and more mathematically intensive, the three-way interaction depicted in figure 3 can be extended to *N* groups using matrices and can incorporate additional features.[14]

The above scenario relies on the simplifying assumption that the authority preys on the rebellion unidirectionally. This assumption is perhaps reasonable if we suppose that authority manpower is easily replaced (or substantially more easily replaceable than that of the rebellion). If this assumption is relaxed—if we allow the rebellion to *substantially* prey on the authority—the model becomes more complex. Of course, each predator cannot prey on the other equally, and thus one can assume for the sake of the model that A is the top predator in the system, and effectively R does not prey on A (that is, the predation rates are normalized to that of R on A).

It is important to note that there can be benefits or costs to A successfully preying on R. The key point is that, in this competition model, the goal is to obtain access to the resource (P); predation of A on R is only beneficial inasmuch as it increases access to P. As depicted in even the simple model shown in figure 3, there can clearly be both direct and indirect feedback to A due to direct predation on R.

All things considered, interference competition models from ecology are a relatively simple quantitative approach to modeling, understanding, and perhaps predicting COIN at a very simple, fundamental level. However, to make a more realistic model, many factors need to be changed or added, and it is still not clear that some of the fundamental assumptions (for example, logistic growth rates) are realistic or meaningful. In addition, all of the detailed mechanisms of *how* predation and competition occur have been left out.

Luckily, some ecologists have felt the same way about their systems of study and have pondered the same issues, even though the Lotka-Volterra competition framework has been generally useful for decades. Below, we describe another more advanced and more recently developed class of ecological models that may be useful for COIN based in game theory.

Adaptive Dynamics

Modeling competition between species that also simultaneously prey on one another (interference competition) is complicated in comparison to simple competition without interference. Although many studies have observed interference competition in nature, formal models are still relatively rudimentary. One issue is that the individual behaviors underlying the interference are quite varied and complex (this is also true of modern COIN warfare).

Ecological population models, like the ones discussed above, do not take this array of behaviors into account. These individual-level behaviors may have important influences on group behavior, something ecologists are only now coming to terms with. Similarly, differences in individual ability, competitiveness, experience, social interactions, and similar factors may have influences on overall group success.

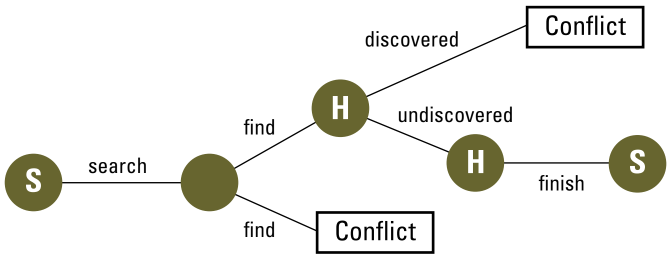
A complementary approach to the Lotka-Volterra population models is based in the field of mathematics called game theory. The key difference between ecological population models and game theory models for effectively modeling the same behaviors is that population models dispense with biological detail in favor of simplicity, while game theory ignores underlying "genetic detail" (the "how" of behavior) but utilizes ecological realism to describe the system.

This relatively new area of study, adaptive dynamics (AD), is effectively a combination of game theory and population biology. It is now being used in ecology and other fields to understand complex adaptive systems that involve a few moving parts and a discrete number of variables that, when combined, have more complicated properties as a collective (so-called emergent properties[15]). Such systems are encountered both in nature and on a battlefield. Familiar examples of this are ants forming a bridge to cross a gap, hundreds of fish swimming in schools, and birds flying in flocks.

There are two key incorporations that AD adds to the basic competition model described above. First, individuals can be in different behavioral states at different times (for example, searching, handling, fighting), incorporating a mechanistic reality into the model. These states and actions occur at certain frequencies, and the frequency at which one actor (say, the authority) is doing something (searching for population members to influence) may depend on the frequency with which the other actor (say, the rebellion) is doing something else (hunting for members of the authority). Second, individuals weigh the gains and losses from each action (as much as possible) and then attempt to perform the optimum behavior based on their state and the state of an interacting individual.

A decision tree associated with this type of model is shown in figure 4. The tree keeps track of all possible events and actions that could occur to a member of the authority.[16] (The opposite can be done for events and actions of a rebellion member.) In ecological competition, such trees are used to keep track of foraging behavior;[17] here, we modify this slightly. In our example, the authority member is assumed to be in one of three distinct states: *searching* for a member of the population to "consume" (win over to the authority's side), *handling* a member of the population (talking to them, making deals, and so forth), or

Figure 4. Example of Counterinsurgent's Game Theory Decision Tree



Key: S = searching for prey, H = handling prey *fighting over* a population member with someone from the rebellion (interference competition). This is an oversimplification but a useful one, as it captures the general goals and strategy behind COIN.

The states change according to events and choices that the authority member faces. Sometimes the response to an event is predetermined, and sometimes an action requires a choice. Tradeoffs to decision choices include energy and time, and so each decision has associated consequences.

These decision trees intersect with game theory; for each decision, we know the costs and benefits associated with each choice/decision and the probability associated with each choice. From consequences and probabilities, a modeler can arrive at a "payoff function" that is associated with a given strategy. Generally, one follows a strategy that maximizes this payoff function.

For the purposes of mathematical analysis, these probabilities are variables. For example, the probability of a member of the authority being discovered by a member of the rebellion while handling a population member might be called x; therefore, the probability of not being discovered is $(1–x)$, and so forth. In simulation studies, different reasonable values, hopefully based on actual field data, are tried for different variables, and in this way, a spectrum of outcomes can be determined from a number of variables.

In addition, within the conflict boxes shown in figure 4 are "conflict decision trees" (not shown). The conflict box does not necessarily mean that a conflict occurs, only that it is *possible* for one to occur. Similar to the main decision tree, the authority member can either "be careful" (avoid) or "dare" (threaten) the rebel, and if a conflict ensues, it can either be won or lost. If won, the authority can in theory continue to handle the population member; if lost, the authority is relegated to searching (at best).

Because this type of model is essentially designed around the problem at hand, there are fewer assumptions to be violated by reality because there are more details incorporated into the model. However, these AD models also have their peculiarities. One, for example, has to do with the notion of a payoff. Every model of this type, even in ecology, must have some kind of short-term currency to approximate long-term cost or benefit of actions. In ecology and evolution, the payoff approximates reproductive fitness, which is the ultimate survival and reproductive power of a type of individual with a certain combination of genes. In COIN, it is even harder to estimate the payoff associated with killing one rebellion member or winning over one member of the population to be pro-authority. With regard to warfare, this is an area that must be given much careful consideration.

Adaptive dynamics models, in the end, can offer predictions about the best strategies for providing the highest payoff when facing an opponent in a game who is expected to play a number of strategies with certain probabilities. It can predict consequences of various choices/actions and recommend strategies. This is conditional, of course, on the correct variables, states, and probabilities being included in the model.

Modeling War: What Is It Good For?

Models are, by definition, not reality. They are deliberate oversimplifications of reality constructed systematically to gain insight into how a complex system of interacting factors operates in principle. As in the theoretical study of complex systems and networks in biology or economics, we propose that models can serve as an admittedly crude framework for understanding fundamental components of COIN warfare.

Specifically, in this initial effort, we have borrowed a class of model from ecology called interference competition models, in which two species compete for a common resource while simultaneously one preys on the other. On the surface, this closely resembles what we see in a COIN system: a conventionally powerful authority (the top predator) competes with individuals from the rebellion for access to political space comprised of control over the general population; simultaneously, the authority and rebellion prey on each other.

One general weakness with this kind of model is that biological realism of the behaviors involved is ignored for the sake of simplicity. For example, there is an assumption of interference without considering its mechanism or adaptive value. In nature, a given animal in one state might attack and in another state might flee. In this sense, individuals within species are treated like "aimless billiard balls" that randomly encounter each other and subsequently act aggressively. For many ecological purposes, this is acceptable; general insight about population dynamics can be gained while ignoring the realism of complicated ecosystems. It is currently unclear how directly applicable this model will be to understanding the underpinnings of COIN.

"thinking like a biologist" can in and of itself provide food for thought with regard to studying and planning for COIN and other forms of warfare

As an alternative, we can consider an adaptive dynamics model, based on game theory and population biology. An AD model, while more complicated, is valuable in that it is more descriptive of the behaviors of individuals alone and during interactions than are the Lotka-Volterra models of competition (compare figures 3 and 4). While more difficult to work with, these models may in fact be better at describing the intricacies of COIN warfare. One caveat is that because they are a relatively recent development, AD models are not understood at the same level of depth as the Lotka-Volterra competition models.

Neither of the proposed model frameworks is perfect for understanding complex human behavior. Assumptions are sometimes violated. Details are glossed over; ties are drawn across vastly different areas of study. Metaphors are occasionally taken just a step too far. However, we think there is a good deal of value in this discussion. Our hope in introducing the topic of using ecological models to understand COIN is twofold.

One, we reason that "thinking like a biologist" can in and of itself provide food for thought with regard to studying and planning for COIN and other forms of warfare. Although comparing warfighters to foraging birds (for instance) may seem silly or juvenile on the surface, the problems that foraging animals face are literally life-and-death—they forage and find prey, or they die. Similarities between some forms of animal behavior and that of soldiers on patrol, for example, are striking, and therefore, there may be some genuine value in this line of thought.

Two, we believe that variations on these models may be useful for sketching out the broad strokes of the behaviors that occur during unconventional warfare and can thereby capture some major elements of it, allowing for general insights to be obtained. It is not immediately clear if a simple or a complex model is best, nor is it clear whether descriptive and vague models or very specific models are the answer. It is, furthermore, not clear that there *is* an answer.

There are additional, complicating issues with regard to employing ecology models in the study of unconventional warfare. These are not necessarily "problems" but things that should be taken into careful consideration during development or application of these models. One issue is scale-dependence. The dynamics of interaction between authority, rebellion, and population depend on the scale one looks at. To some extent, there is also an issue of density dependence, a complicating and common issue in population ecology. Some models may apply at one scale (for example, a village or city) but not at another (for example, a nation). Larger scales may also hold more heterogeneity.

Another issue is asymmetry of support. By this we mean that, to be judged as successful, A and R require different levels of popular support. In ecological terms, R needs to consume less of P than A does to maintain equality. At present, it is not clear to us if or how a model needs to be modified to take this into account.

an increased emphasis on adaptation, evolution, behavior, metaphors, and models would have great benefits in the new climate of conflict in the early 21st century

A final issue of note is "means versus will." The model only addresses the means to fight but ignores the reality of political will to keep fighting. This again may be asymmetrical, with the authority finding it more difficult to maintain political will, particularly as an occupying force. Like asymmetry of support, it is not clear if this is a factor that can be ignored with regard to the models.

The general discussion of employing ecological models to study warfare leads to some other matters for discussion. One of these matters with regard to COIN is a debate about the proper or necessary ratio of the authority troops to those of the rebels or, alternatively, those of the authority to members of the population in the area of operation. Both traditional and modern books and manuals recommend a ratio of 10 to 20:1 for A:R and 20 to 25:1,000 for A:P.[18] This is largely based on experiences from previous COIN campaigns, which are generally dated. Additionally, historical data indicate that there is not necessarily a direct relationship between the ratios and relative success. It is possible that further quantitative analysis using models such as the ones presented in this paper could shed light on this issue. The validity of using competition as opposed to predator-prey models seems to suggest that hunting insurgents, policing criminals, and exercising political control (see figure 1) are not easily separable.

Through all of this, a key general issue is how one measures success in COIN. We ascertain that access to the population is a means to the end goal of support of the population via the cliché of winning hearts, minds, and acquiescence. Within our ecological model of competition, this is represented as members of the population effectively joining the authority or rebellion, thus increasing their population size.

In this paper, we have been asking how the study of warfare could benefit from ecology. But what about the reverse: Could the field of ecology benefit from the study of war? Hard science research often progresses in fits and starts spurred by the whims of investigators' groupthink about what is fashionable (or fundable) at any given time. Often, the status quo persists under a critical mass of powerful scientists until they decide that a shift is in order. Some areas of ecological theory discussed in this paper are underdeveloped despite their potential value. More specifically, such complicating factors as adaptive behaviors, spatial heterogeneity, and prey refuges have generally not been incorporated into the theory, and their effects on the system have not been well investigated. If these factors are critical to the understanding of COIN via ecology—and they may well be—initial work within the military community could stimulate ecologists to work on variants of these models, thus creating a cycle of quid pro quo for all involved.

There may be additional fields of study within the social sciences that can benefit from such work and may also contribute to it. One example is the recent thesis by Edward Evans and James Spies entitled, "Insurgency in the Hood: Understanding Insurgencies Through Urban Gangs."[19] The authors suggest that it is difficult to obtain unbiased, accurate data about insurgencies and that it is easier to study organizations such as gangs as a surrogate to gain insight to generalities of use to the warfighter. We further suggest that preliminary results from ecological models of COIN could be compared to data such as that from urban gangs which, at a fundamental level, operate somewhat like insurgencies.

Finally, we can consider these questions: What does modeling COIN using ecology mean for warfighters or war planners? Are the models useful for determining how to win, how not to lose, or how to avoid Pyrrhic victories? How should lessons from biology be incorporated into warfighter education, training, and doctrine? This paper has raised more questions than it has answered. Some of them are: Can the variables in the ecological models be measurable in a COIN framework? Are there accurate data, and are these data specific to a particular insurgency? What are the relevant outputs of these models? Will the outputs be descriptive or prescriptive?

In the end, we return to the idea stated at the beginning of this paper: biology is more than laboratory science; it is a way of thinking about the natural world. An increased emphasis on adaptation, evolution, behavior, metaphors, and models in these areas would have great benefits in the new climate of conflict in the early 21st century.

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Notes

[1] See, for example, Raphael Sagarin, "Adapt or Die: What Charles Darwin Can Teach Tom Ridge about Homeland Security," *Foreign Policy* 138 (September-October 2003), 68–69; Ori Brafman and Rod A. Beckstrom, *The Starfish and the Spider* (New York: Penguin Group, 2006); Richard Dawkins, *The Selfish Gene* (Oxford: Oxford University Press, 1976). See also Nassim Nicholas Taleb, *The Black Swan: The Impact of the Highly Improbable* (New York: Random House, 2007).

[2] David Killcullen, "Counterinsurgency *Redux*," *Survival* 48, no. 4 (Winter 2006–2007), 111–130; and see also by Killcullen, "Twenty-eight Articles: Fundamentals of Company-Level Counterinsurgency," Joint Information Operations Center, Australian Army, Summer 2006, 29–35.

[3] See the very interesting commentary on this by John A. Nagl, *Learning to Eat Soup with a Knife: Counterinsurgency Lessons from Malaya and Vietnam*, 2d ed. (Chicago: University of Chicago Press, 2005).

[4] Nathan Leites and Charles World, *Rebellion and Authority: An Analytic Essay on Insurgent Conflicts* (Santa Monica: RAND, 1970).

[5] The first quotation is from the Australian *Joint Services Glossary*; the second from Gordon McCormick, Steven B. Horton, and Lauren A. Harrison, "Things Fall Apart: The 'Endgame' Dynamics of Internal Wars," *Third World Quarterly* 28, no. 2 (March 2007), 321–367; and the final is from David Killcullen, "Three Pillars of Counterinsurgency," remarks delivered at the U.S. Government COIN Conference, Washington DC, September 28, 2006.

[6] The U.S. Defense Department's 2006 Quadrennial Defense Review notes that transforming the Department of Defense to a state in which it is prepared for unconventional warfare is a major priority.

[7] See Killcullen, "Counterinsurgency *Redux*," note 1.

[8] Alfred J. Lotka, *Elements of Physical Biology* (Baltimore: Williams and Wilkins, 1925); Vito Volterra, *Variazioni e fluttuazioni del numero d'individui in specie animali conviventi*. Mem. R. Accad. Naz. dei Lincei. Ser. VI, vol. 2, 1926.

[9] See, for example, Nicholas J. Gotelli, *A Primer of Ecology* (Sunderland, MA: Sinauer Associates, Inc., 1995), chapter 6.

[10] This is also often called "intraguild predation." The simplest definition is probably "a form of competition that involves a fight or other active interaction among organisms." See <www.biochem.northwestern.edu/holmgren/Glossary/Definitions/Def-I/interference_competition.html>.

[11] See figure 1 of Toshinori Okuyama and Robert L. Ruyle, "Analysis of Adaptive Foraging in an Intraguild Predation System," *Web Ecology* 4 (2003).

[12] The "Competitive Exclusion Principle" of competition states that, in a simple system with two species competing for a single resource in a homogenous environment with no other interactions, two species cannot compete for the same limiting resource for a long period of time.

[13] See Nagl.

[14] G.A. Polis, C.A. Meyers, and R.D. Holt, "The Ecology and Evolution of Intraguild Predation: Potential Competitors That Eat Each Other," *Annual Review of Ecology and Systematics* 20 (1989), 297–330; M. Arim and P.A. Marquet, "Intraguild Predation: A Widespread Interaction Related to Species Biology," *Ecology Letters* 7 (2004), 557–564.

[15] See Steven Johnson, *Emergence: The Connected Lives of Ants, Brains, Cities, and Software* (New York: Scribner, 2001).

[16] Wouter K. Vahl, "Interference Competition Among Foraging Waders" (Ph.D. diss., University of Groningen, 2006), chapter 6. See also F. Huntingford and A. Turner, *Animal Conflict* (London: Chapman and Hall, 1987).

[17] See also P.H. Crowley, "Hawks, Doves, and Mixed-symmetry Games," *Journal of Theoretical Biology* 204 (2000), 543–563.

[18] James T. Quinlivan, "Force Requirements in Stability Operations," *Parameters* (Winter 1995), 59–69; see also Field Manual 3–24, *Counterinsurgency* (Washington, DC: Headquarters, Department of the Army, December 2006).

[19] Edward R. Evans and James R. Spies, "Insurgency in the Hood: Understanding Insurgencies Through Urban Gangs" (Master's thesis, Naval Postgraduate School, 2006).