Natural Resources Management of Wild Species: an Evolutionary Approach

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Abstract: A genetic algorithm method was used to study the economic and ecological impact of hunting activities using a Genetic Algorithm approach, applied for a version of the Stauffer – Newmann model, adapted for a particular case of a Natural Resource Economics problem: the decision about the intensity of exploitation of hunted species.

Key-Words: Natural resources management, Genetic algorithm, Management strategy, Economic impact, Ecosystem

1 Introduction

Accounts of ecosystem change caused by human hunting activity are accumulating in time. There is growing concern about the evolutionary consequences of human intervention on phenotypic trait quality and the sustainability of wild populations ([1], [2], [3]). In this context, Biologists have made considerable progress in developing realistic simulation models to predict extinction risks for threatened species ([4], [5]). Economic scientists concerned with natural resource use had a limited role in these efforts. This limited involvement comes despite the growing acknowledgment by population biologists and simulation modelers that this additional input is necessary for these models to accurately reflect the impact of humans and human-dominated landscapes on these wildlife populations.

In 1997 Bak and Sneppen [6] introduced a particularly simple toy model of biological evolution (BS model). The model correctly reproduces such features of real evolution process as punctuated equilibrium, power law probability distributions of lifetimes of species and of the sizes of extinction events. In spite of the simplicity of the rules, the model exhibits extremely rich and interesting behavior. Bak and Sneppen were looking for a simple model which was supposed to exhibit evolutionary behavior, and which was also supposed to fall into the class of processes showing self-organised critical behavior. For physicists, self-organized critical behavior refers to power law decay of temporal and spatial quantities.

In [7] Stauffer and Jan have analyzed the simple evolutionary process proposed by Bak and Sneppen ([6]) in which the agent with the lowest fitness in a large population is repeatedly removed and replaced with another having fitness chosen uniformly at random in a given interval. Their have shown that many properties of the dynamics of this process can be calculated analytically. One year later, Stauffer and Newman applied this new model in [8] to the management of a natural resource: the fisheries.

In this paper we study the economic and ecological impact of harvest activities using a Genetic Algorithm approach, applied for a version of the Stauffer – Newman model in the particular case of a Natural Resource Economics problem: the decision about the intensity of exploitation of wild hunted populations.

2 Problem Formulation

Free hunting activities can cause a decline in the level of wild populations, thereby reducing the long-term sustainability of the activity itself. In order to keep the ecological balance between game species and forests intact, a sustainable hunting management is strictly necessary. To safeguard a sustainable forest resource it is therefore of crucial importance that the forest owners are allowed to take an active part in the management and regulation of wildlife. In the same manner, the private forest owner should also be allowed to adjust the forest practice to secure biodiversity and to promote wildlife as a resource.

Predictions concerning how species traits increase susceptibility to exploitation can be divided into two main categories: those pertaining to reproductive rates and those related to hunter behavior (see also [9]). Economic status is also important; it affects how much governments can spend on conservation efforts and how its people exploit natural resources. The situation in economically less developed countries often necessitates opportunistic and short-term exploitation of the local flora and fauna by its citizens, increasing the risk of local extinction.
Despite the risks, any studies and first-hand experiences clearly demonstrated undeniable proof that regulated hunting is a critical part of science-based wildlife management and it provides incredible widespread economic benefits to rural communities. This economic benefit is one of the most important tools to help end poverty.

Since hunting is a relatively labor-intensive activity, many in the local community realize employment opportunities. But the legal frameworks must ensure revenues are focused on wildlife and local communities and not gobbled up by general treasuries. These legal frameworks must also provide a mechanism for biologically-based hunting quotas and enforcement of those quotas.

The Figure 1 presents shortly the relation schema between governmental regulation policies, the non-governmental citizen organizations ant the legal structures that manage the hunting activities, from both ecological and economical points of view: the Silvic Offices.

3 Evolutionary Algorithm for simulating hunting activities

Evolutionary computation comprises techniques that have been inspired in biological mechanisms of evolution to develop strategies for solving optimization problems. In Genetic Algorithms (GA), a population of individuals (candidate solution to a given problem) evolve using operators inspired from the theory of evolution by natural selection; the populations are formed by a (constant) number of individuals \( N \) described by \( b \)-bit sequences (the genetic representation, or chromosomes).

From a given population at a given generation, the next generation is obtained by applying the selection operator, followed by the crossover operator and the mutation operator.

In standard GA, the selection operator choose individuals with a probability proportional to its fitness; next, pairs of individuals are randomly combined with a crossover probability, by randomly choosing the crossover point. Finally, each bit of each individuals is mutated with a mutation probability \( p_m \).

Genetic Algorithms have therefore also been used already to model economic evolution ([10]) and learning processes. The model will be based on two main assumptions. First, the agents using the resource are not informed about its reproduction dynamics. And second, although profits are their only concern, they are not able to calculate the optimal extraction rate that would maximize present value of all present and future benefits.

3.1 The assumptions and codifications

Hunters have been shown to prefer to hunt larger bodied species. However, the harvest rate may reflect the encounter rate, which is controlled by hunter numbers, hunter behavior and prey biology. Increasing
size is also associated with slow reproductive rates, which increase vulnerability to extinction via hunting.

Like renewable resource, the wild population are developing according to a logistic growth law ([4],[8],[9]):

\[
d/(dt) N = r N (M - N)/M,
\]

(1)

where \( N \) is the current population size, \( M \) is carrying capacity and \( r \) is the intrinsic rate of population growth. The principle of sustainable harvesting ([9]) suggests that a population will remain stable even when individuals are harvested as long as off-take does not exceed \( d/(dt) N \). The extinction appear when the population do not exceed a biological limit \( EL \) (\([4],[8],[9] \):

are developing according to a logistic growth law

where

which increase vulnerability to extinction via hunting.

organizations use an alert level (AL) to ask for hunt (extinction level), but in general, the ecologist

capacity and

individuals are harvested as long as off-take does not

that a population will remain stable even when

The principle of sustainable harvesting ([9]) suggests

depending offspring

Mountains), we would get the following stock-

population that can be hunted in a given year, witch is

with knolled dimension of the population at a given

time: \( TP \) together with the minimal acceptable

reproductive population level (AL\(_n\)). For each species

we must have a Hunt quota (HQ\(_i\)), established by
government, representing the percentage from the wild
population that can be hunted in a given year, witch is

variable in time.

For each year on a chosen period (here

considered fixed at 100 years), we denote the hunt

quotas (% from TP) for each hunted species

[HQ\(_i\)(y1), HQ\(_i\)(y1), ..., HQ\(_i\)(y1),

HQ\(_i\)(y2), HQ\(_i\)(y2), ..., HQ\(_i\)(y2),

..., HQ\(_i\)(y100), HQ\(_i\)(y100), ..., HQ\(_i\)(y1011) ]

(2)

The Benefit of Silvic Offices (SO) in the \( k \) year, obtained by selling the product of the hunts, after the

payment of employees is quantified as

\[
Ben(y_k)=\left[ \sum_{i=1}^{n} (TP_i \cdot HQ_i(y_k)) \cdot Pr_i \right] (1-VAT) - CW
\]

(3)

(Pr\(_i\) = HT+TT is the average benefit obtained for a

hunted animal from the specie \( i \), as sum of the hunting
tax and the trophy tax. The cost of work \( CW \) of an SO

is supposed to be constant in time. The other benefits

that foresters can obtain from a hunted fauves are ignored).

The quantity \( TP_i \cdot HQ_i(y_k) \) represent the reduction of

the hunted population in the year \( k \). The new offspring

population will be calculated as

\[
TP_{(y_{k+1})} = r \cdot TP_{(1- HQ(y_k))} \cdot [M- TP_{(1- HQ(y_k))/M}
\]

(see also formula 1). For our algorithm, the utility

function will be the sum of all benefits along the entire period:

\[
B = \sum_{k=1}^{100} Ben(y_k)
\]

(4)

3.2 Description of the evolutionary genetic algorithm

The main purpose of this algorithm is to select a list of

hunt resources management strategies which maximize

the utility function described in the formula (4). An

individual “strategy” is an ordened list of hunt quotas

for a given period, as presented in the formula (2). The

“population” of strategies was fixed at 40.

Any individual \( J \) is evaluated using the fitness

function \( P_J \):

\[
P_J = B(J)/\max \{ B(s) \}
\]

(5)

which is determined at each generation by simulating

economic activity of SO on a period of 100 years.

After each evaluation, an elitist selection is operated

on the population, (first 4 strategies, in order of fitness,

are preserved unchanged, the other 36 are submitted to

the recombination process).

The recombination process of the selected

individuals is a partial exchange of the hunt quotas

between two strategy codifications; the selection of

exchanged quotas is randomized. After, the new

obtained strategies take the place of the older ones.

According to a mutation probability \( P_{mut}=0.1 \)

each individual strategy is submitted also to a mutation

process (arbitrary modification of one of the hunt

quotas).

The new “population” (at the time \( t+1 \)) is

reevaluated, and all the process will be repeated until a

predefined number of generations (=200 in our case) is
obtained. The genetic algorithm can be shortly described as

```
START
g := 1; (count the generations)
generate initial population P;
compute fitness for individuals J ∈ P;
WHILE g < G DO
BEGIN
  g := g + 1;
  select population P' by means of selection operator
  produce children H from P' by crossover;
  newP := (P - P') ∪ H ;
  apply mutation to new population newP ;
P := newP
  compute fitness for new population newP ;
END.
```

4 Results of simulation

In the simulation process, we choose to investigate only one to maximum three species at once, focusing on the feral pigs, bears and cervides, for that we disposed of some concrete data about the maximum carrying capacity $M$ and the rate of population growth $r$.

One of the best strategy obtained by simulation consist in the use of a good fixed quotas (Fig. 3). If the maximum offspring is high enough to cover the quotas the benefit will be almost the biggest one possible.

In this very favorable case, the hunted population remains very high and stable in spite of the hunt. Convergence of total benefits depends only on the mutation rate. By the other part, this strategy is dependent on the nature of hunted species and is unstable to minor change in the dimension of the wild population. This changes are allways produced by aleatory factors, then the strategy must be more flexible to the changes.

Note that the maximum quotas policy (see Fig. 4), applied in the simulation for 60 years, produces a constant negative benefit, even I the case when the population of wild animals rests constant in time. A change of strategy (here consisting in reduction of the quotas at half) produce benefit after 5 years, but the stability of the model is obtained only after 30 years.

A stable "exploitation" cycle (Fig.5) was obtained by simulating a cyclic dynamic evolution of hunt policy on a long period of time. The winning strategy supposed to establish the quotas in order hunt a fixed number of wild animals on a given period of time, and to adapt each 4-5 years the level of this quotas, in function of the dimension of the wild population. This strategy do not produce the same level of benefit as the first selected strategy (Fog. 3), but is more stable to mutation, or to unexpected variation in the dimension of wild population.

5 Future works and development of the model

Simulations showed that targeted policy of quotas in hunting activities can be more viable at long term, first because is more stable that the maximum benefit quotas policy, and secondary, because the modifications in the level of wild hunted population reproduce the a similar behavior that the natural logistic law (Fig. 5). Then the simulation approach
allowed us to verify responses as evolutionary changes in trait values rather than short-term consequences.

We conclude that evolutionarily enlightened management may accommodate hunting activity. This has far reaching implications as income from hunting is often channeled into rural economies. As an essential follow-up, we propose a more exhaustive study of the possible non-governmental organizations feed-back, in term of quantified ecological aspects of wild species population variations, and the introduction of land-use characteristics in this model.

References: