When all agents die.
Analyzing the "failures" in an agent-based model of human foraging

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KEYWORDS

Hunter-Gatherer, Simulation, Modeling, Agent-based Modelling, Survival Analysis

ABSTRACT

When running many times a simulated social scenario, we find often situations in which all agents die, even although the simulated population appears to grow in the first steps. Is this a signal that something is wrong in the computer model or its implementation? We analyze this issue in our computer model of cooperation and cultural diversity among hunter-gatherers in prehistory. We have calculated more than 11.000 possible parameter combinations, taking into account the growth and decay of the population and the availability of resources in the environment. When the initial population is too scarce or too big for the local availability of resources, initial population begins to decrease until it disappears. This can be a very trivial test for the Malthus condition, but we have discovered that there are other important correlations affecting social and economic factors that should be explored.

KEYWORDS

Agent-Based Models, Hunter-gatherers, Parameters Test, Social Simulation

1- INTRODUCTION

Scientists build artificial societies because we want to understand the social mechanisms that may explain social behavior at macro-levels from a clear understanding of individual behavior (Gilbert 1996, Ylikoski 2011). That is, why and how a "society" seems to have worked in the past. Social simulation is then a hypothesis about social functioning and a deduction test for that hypothesis (Barceló & Del Castillo 2016). The deductive nature of this "automatic explanation" has advantages and disadvantages:

-the advantage is that some kind of validation seems possible.

-the disadvantage is that it is just a formal validation; that is, a test that the hypothesis may be true *within an artificial* (although objective) formal system. We will never test within a simulation whether any human society behaves like the model's predictions (Vergne & Durand 2010), but we can say that such historical trajectory is *the more probable* given some well defined prior assumptions.

The easiest way of rejecting a hypothesis about a social mechanism that we believe may have existed in prehistory, is proving that in circumstances where such mechanism was in action, this particular society could not exist for enough time. That is, if all social agents die, our test has not passed the deductive test. If all die in the virtual world and we know that some survived in the empirical world, then the virtual world does not fit what we know about the empirical (Barceló & Del Castillo 2012). The question is then, which parts of the virtual world do not work properly?

In this paper, we discuss how models may be used to make inferences about the most remote past, when humans depended for subsistence on hunting and gathering. Our hypothesis begins as an extremely abstract model and adds degrees of behavioral sophistication, which influence the results. These influences are discussed in a step-wise fashion so that the reader can see how changes to the model's assumption influence outcomes. Although the models being used in this paper are agent-based computer simulations, we describe the interaction of variables in the models using equations. To understand how this is translated into an agent-based model the reader is referred to commented code published recently at NetLogo User Community (https://ccl.northwestern.edu/netlogo/models/community/)

2- TESTING DIFFERENT SCENARIOS

2.1- FIRST SCENARIO: FORAGING BEHAVIOR

We have implemented a series of computer models in which "virtual" hunter-gatherers survive on what they randomly find around them, with null technology for resource acquisition, with a catchment area constrained only by technical limitations in transport and mobility, and without any mechanism of social interaction allowing for cooperation: there is no transfer of food, technology or labor force. This scenario is typical for foraging behavior, where it is assumed agents should find, capture and consume food containing the most calories while expending the least amount of time possible in so doing (Winterhalder & Smith 1981, Smith 1983, Stephen and Krebs 1986). If such an assumption were true, we would say that hunter-gatherers survival would depend just on the availability of resources, and the nature of economic behavior would be merely adaptive.

In our virtual world, agents are not individuals but reproductive units (two adults and a number of descendants). The amount of labor available for hunting and gathering is based on the number of members the reproductive unit has, and the survival threshold also adjusts to the number and age of members (fixed at 2920 kcal for a "virtual family of 4 members). Mortality is defined as a non-linear function according to which each time an agent ("family") cannot obtain energy up to the summed survival threshold of the entire family, it loses one of its members (labor unit), so that survival threshold and labor capacity is redefined. Essential agent behaviors and model parameters, such as the population threshold used to determine when new families will be born, are discussed in our previous publications (Barceló et al., 2014, 2015).

We have formalized an hypothetical model in which, social agents survive only if they have success in acquiring energy available in the environment by means of hunting and gathering, that is, labor *(*l_i), mediated by the efficiency of available technology (β_i) .

$$f_{i(t)} = \frac{1}{1 + \frac{1}{hi(t) \times li(t)^{\beta i(t)}}}$$

$f_i(t)$ measures the ability to obtain resources according to each agent's individual ability. Its maximum value is 1, indicating the amount of work available (l_i) and the effectiveness of current technology β_i to compensate the local difficulty (h_i) of obtaining the resources existing at that place. When the value of $f_i(t)$ is less than 1 (but greater than 0), we can deduce that the working capacity and technology available only allow obtaining a proportion of the available resources.

The amount of energy acquired by agent *i* is then:

$$E_i = R_j f_i(t) - Surv_i$$

That is, the amount of resources existing around (R_j) multiplied by the ability to acquire that resource at that place (f_i). Given that storing capacity is assumed to be inexistent, what the agent takes from the environment is just what it needs at current time -the survival threshold-, which is a constant that in the case of humans can be fixed in terms of the calories intake an adult needs to survive ($Surv_i$).

In this first scenario, we have modeled a virtual world in which resources are randomly distributed (R_j) in a patched world, with constant irregularity (standard deviation of a Gaussian variable), and random difficulty of access (another Gaussian variable). The year cycle has two differentiated seasons, so that in the cold-dry season, the availability of resources is half of the availability of resources during the warm-humid season.

A rich world scenario would be that in which there are plenty of food and resources available, and the reduction of resources during the cold season has no effect on survival. We have modeled different hypothetical "rich world scenarios", on the assumption that the mean of resources in the environment at the worst season exceeds 13 times the survival threshold of virtual families.

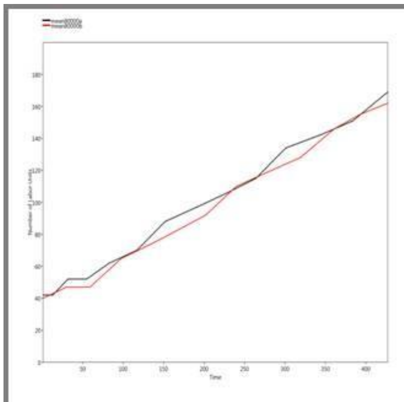
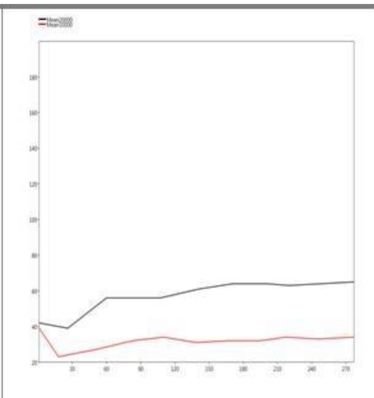
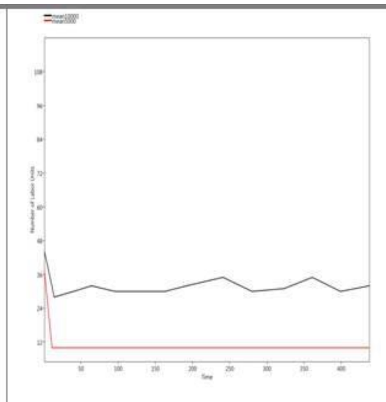
		
Increasing Population of sedentary individuals in the richest world scenarios. (two scenarios with a mean of 80000 kcal at the warm season –and 40000 kcal at the cold on.	Stable Population of sedentary individuals in medium riche world scenarios. (two scenarios with a mean of 10000 kcal at the cold on; another scenario with a mean of 5000 kcal at the cold on.	Stable Population of sedentary individuals in relatively poor world scenarios. One scenario with a mean of 5000 kcal at the cold one; one scenarios with a mean of 2500 kcal at the cold one.

Fig 1. *Results of the first scenario foraging behavior and with an in increasing resource irregularity fixed for a standard deviation = 1000 kcal.*

It is not any surprise that in these conditions, most agents live and population grows if there is enough food for everyone. In all simulated scenarios of sedentary agents, a population will survive or even increase, provided there are resources well ahead the survival thresholds. Agents will die when there is not enough resources.

Given that resources have been simulated in terms of a Gaussian variable with a fixed standard deviation, it becomes easy to calculate the probability of finding enough resources for survival using normal probabilities. In the scenario with a mean of 20000 kcal of energy in the environment at the warm season (and a uniform irregularity estimated in terms of a *sd* = 1000), there will be 0 probability to find some area with a quantity of resources below the survival threshold. In the cold season of the same scenario, the probability is also 0. In "poorer scenarios", the probabilities to find places where survival is not possible are still very low when the mean of resources if fixed at 5000 kc or 4000 kc (0.0188 and 0.14 respectively) and very high in the cold season of the poorest scenario simulated (mean of 2000, 0.668 probability).

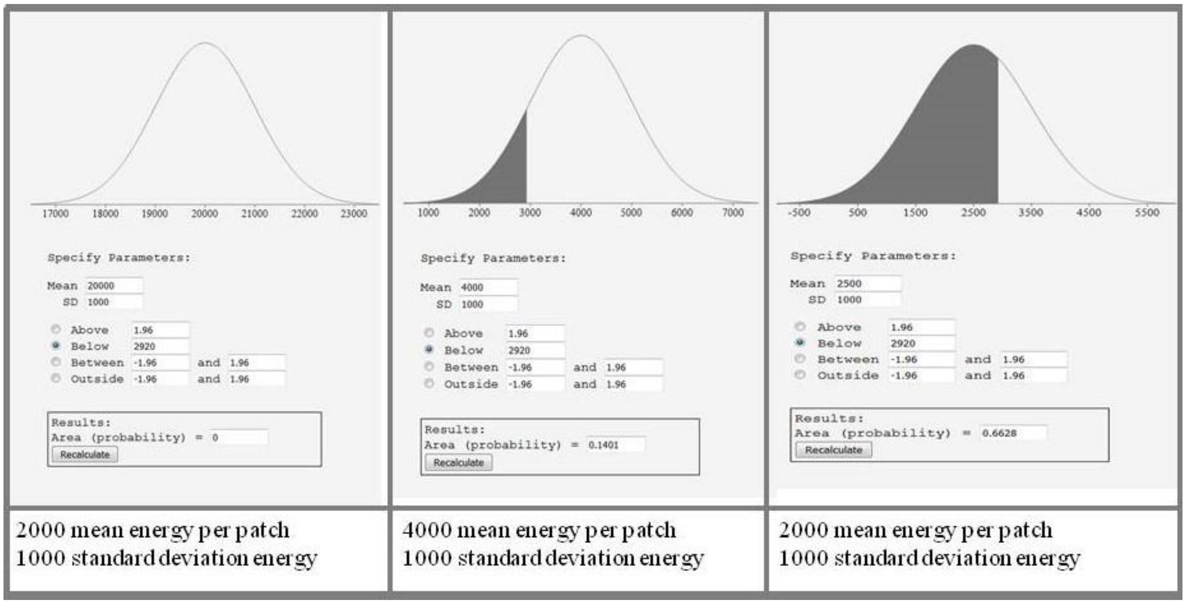


Fig 2. *The results show the probabilities of finding enough resources for survival in three different scenarios of resource availability.*

Then, the prior probability of survival can be computed from the probability of availability of enough resources (Barceló et al. 2014). A specificity of our model is that agents do not extract from the environment what it exists, but there is an additional external factor that may affect the probability for survival: the different levels of difficulty to acquire those resources. The more mobile the resource –animals- and the more difficult the spatial accessibility, the higher the difficulty, and therefore the more labor is needed to obtain resources up to survival threshold. When more labor is needed, survival is less probable because survival threshold increases. In our initial simulations, this difficulty does not impact significatively.

Agent behavior changes drastically when during part of the year resources diminish below survival threshold. In our model, resources diminish at odd cycles ("cold" season) and they recover the initial value at even cycles ("hot" season). We have implemented in such a way that at odd cycles, when resources do not regenerate naturally, the amount of resources available in each cell should be equal to the half of what existed at the hot season minus what the agent extracted at the previous time-step. At the next cycle, resources on each cell are re-initialized to the value they had at the last hot season. Obviously, in rich enough worlds, seasonality does not have any impact, but when the mean of resources in the cold season is below survival threshold, survival is at risk.

2.2- SECOND SCENARIO: SOCIAL DECISIONS

We have introduced a social mechanism to increase the probability of survival when an agent does not find enough resources locally: move-to-another-place. This has been implemented as a social decision. Two options are open to election:

1. Stay at place
2. Move to another place.

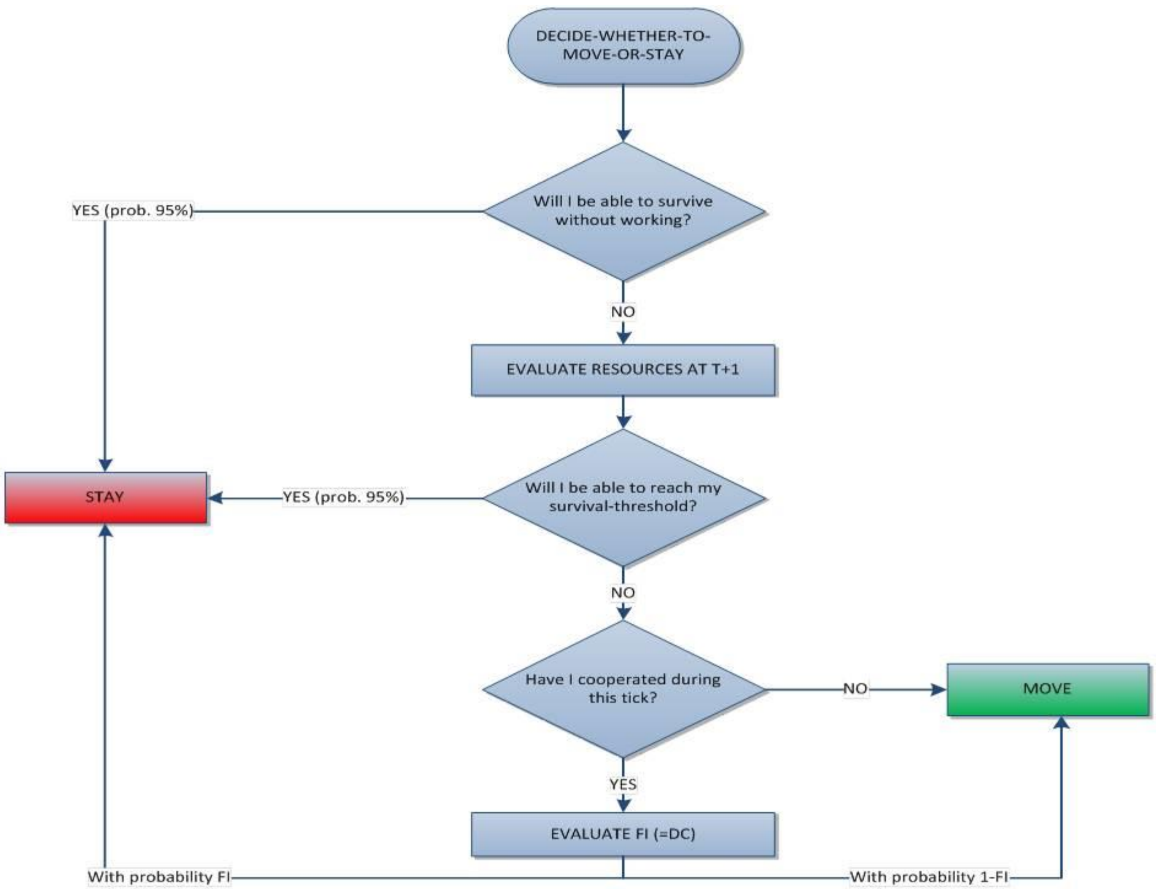


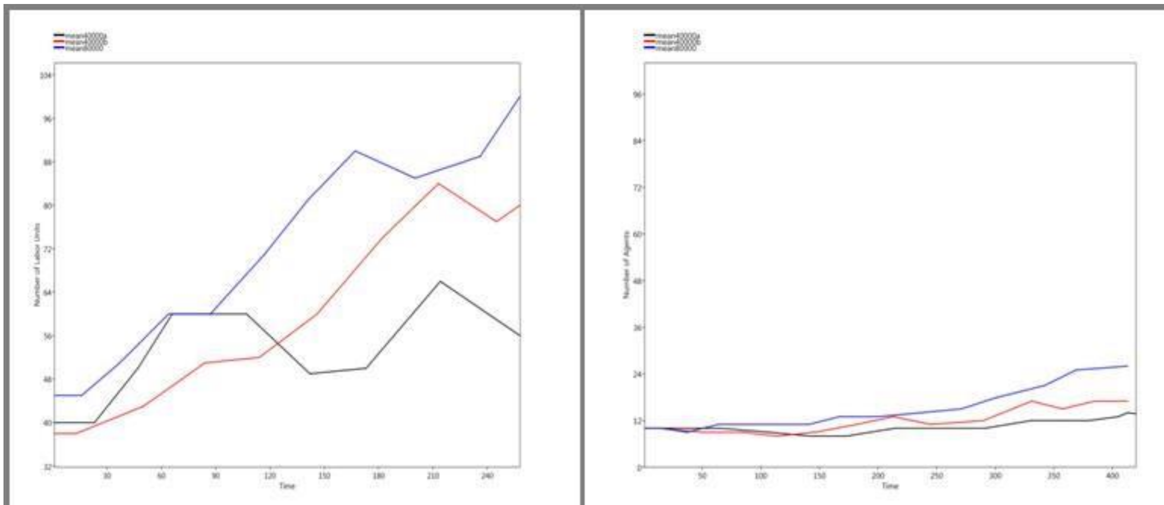
Fig. 3 *Functional diagram of the model showing agents' decisions process.*

At first, the agent evaluates about its chances of surviving in the next season. The expected quantity of resources at next cycle is calculated by the agent on the basis of its knowledge of the current season and the nature of the next season, and on the amount of energy it has already taken from environment at the present cycle. Consequently, if

$$Expected\ R_{i\ (t+1)} - e_{i\ (t)} > Expected\ \text{survival-threshold}_{\ (t+1)}\ ,$$

on the next time-step, the agent remains at the patch and it does not move. Otherwise, it moves randomly to any other unoccupied patch in a fixed neighborhood, calculated on the basis of available technology for transport and movement. Because the condition is to move to an empty patch, there is not any chance that two agents coincide at the same patch. In any case, we have added a small amount of random noise (a randomly selected 0.05% of agents always move). If next season is a hot one, even the proportion of resources it has extracted in the previous season will be naturally reproduced, and survival will be possible. In case the next time step is a cold season, local resources will reduce drastically, and moving to another place will be imperative.

In ideal conditions, that is, when the availability of resources in the cold season exceeds seven times the survival threshold, introducing mobility does not affect survival, and population grows, both at the level of the number family members and the number of families in the territory, although the growth of families increase at a much more slower scale.

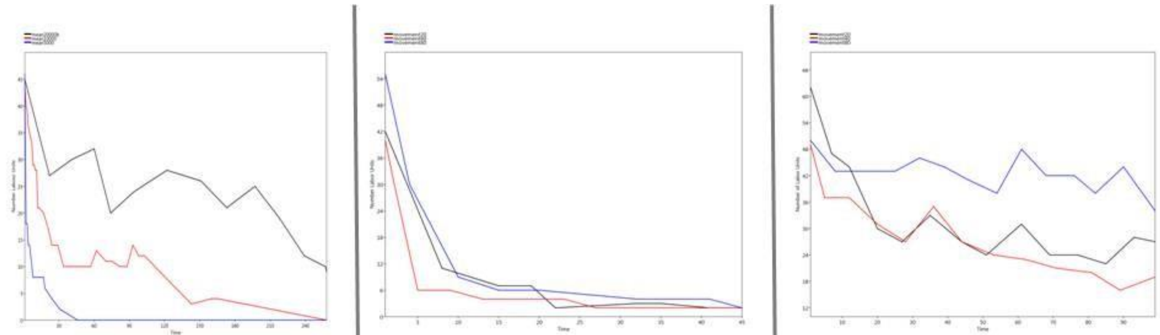


Increasing Population of mobile individuals in the richest world scenarios (two scenarios with a mean of 40000 kcal at the warm season –and 20000 kcal at the cold one; one scenario with 80000 kcal at the warm season –and 40000 kcal at the cold one. Resource irregularity fixed for an standard deviation = 1000 kcal.	Increasing Population of mobile agents ("virtual families") in the richest world scenarios (two scenarios with a mean of 40000 kcal at the warm season –and 20000 kcal at the cold one; one scenario with 80000 kcal at the warm season –and 40000 kcal at the cold one. Resource irregularity fixed for an standard deviation = 1000 kcal.

Fig. 4: *Survival comparative charts explains how introducing mobility in a rich world (when the availability of resources in the cold season exceeds seven times the survival threshold), does not affect survival, and hence population grows.*

The reason of the differences in the rate of growth lies in the social nature of reproduction. Within a family, the number of members increase geometrically linearly related with the availability of resources, whereas within a territory, the number of families increase arithmetically depending on the internal growth of family members: new families are created within old families, when the previous one exceeds a population threshold.

To our surprise, when introducing small amounts of mobility (up to a 2% of the territory) in most cases, even at relatively rich worlds, *all* agents die, when in the sedentary scenario survival was guaranteed. The rate of decreasing population is logically related with the mean of resources.



Decreasing Population of mobile individuals in poor world scenarios Number of Individuals *(one scenario with a mean of 20000 kcal at the warm season –and 10000 kcal at the cold one; one scenario with 10000 kcal at the warm season –and 5000 kcal at the cold one; one scenario with 4000 kcal at the warm season –and 2000 kcal at the cold one. Resource irregularity fixed for an standard deviation = 1000 kcal.* Amount of mobility: 2% of territory in all cases.

Decreasing Population of mobile individuals in a very poor world scenario (a mean of 5000 kcal at the warm season –and 3000 kcal at the cold one). Resource irregularity fixed for an standard deviation = 1000 kcal. Amount of mobility: 12,5% of territory (20x20patches), 50 % (40x40 patches), 100 % (80x80).

Decreasing Population of individuals in a medium rich world scenario (a mean of 15000 kcal at the warm season –and 7000 kcal at the cold one). Resource irregularity fixed for an standard deviation = 1000 kcal. Amount of mobility: 12,5% of territory (20x20patches), 50 % (40x40 patches), 100 % (80x80).

Fig.5: *Comparative charts showing the variation in the conditions of survival introducing small amounts of mobility*

Starvation and population extinction only happens when the prior probability of survival in the cold season is below 55%, based on the number of patches where resources are above survival threshold for a virtual family of 4 member in average. However, it is relevant that even at higher prior probabilities, population diminishes, when in the same circumstances, sedentary populations grow. In any case, the key factor is still the availability, irregularity and accessibility of resources. The amount of mobility has no impact in the rate of mortality. We have simulated scenarios where agents are allowed to move in the immediate 2% of the total environment looking for enough resources, in the immediate 12,5%, 50 % and even at the entire territory. In the absence of any other factor, mobility in itself cannot increase the probability of survival.

In our results we see that when resources diminish, families decrease their number of members, and hence the amount of labor available to compensate the local difficulty of accessing existing resources. If the simulation started with families of four members (where the number of members is a Poisson distributed parameter with small values of lambda, that is, with very small variability), the mean number of labor units per family rapidly converges to two. In such conditions, although survival threshold also diminishes, the probability of acquiring enough resources is affected by the local difficulty.

Mobility increases stochasticity in all simulated scenarios. That is, at each run of the same scenario (with the same values at the same parameters at start-up), the evolution of the population differs. This is a consequence of the increasing irregularity in agents' revenues. The mean energy acquired by labor unit is fairly constant in all simulated scenarios, but when adding mobility, its standard deviation also increases, varying enormously from one cycle to the other. That means that although most agents behave in the same way trying to extract the maximum amount of energy they could find locally, the local availability varies. We have fixed such an irregularity assuming a Gaussian distribution with a standard distribution of 1000 kcal. This value should be interpreted as a very small irregularity in the richest world (12.5 % of variation) and increasing irregularity as the mean of resources is lower, arriving to 40 % of variation in the poorest scenario).

If mobility increases stochasticity, then it cannot be interpreted as an adaptive decision to increase the expectances of survival. To-move or not-to-move is no "prisoner's dilemma", because there is nothing to win with moving if resources are above survival threshold, and nothing to win with staying if resources are below.

2.3- THIRD SCENARIO: INTRODUCING TECHNOLOGY

The use of technology for increasing revenues is the definitory characteristic of human beings since *homo habilis*. We have studied the probable effects of technology in medium rich worlds (where the amount of resources in the environment at the worst season exceeds two times what a family of 4 members needs for survival).

In medium rich scenarios of sedentary individuals, the effects of technology on population growth are small but relevant. Much more evident are its effects on mobile populations. If survival is at risk when opting for mobility even at a medium rich scenario, technology multiplies the effects of labor on the accessibility of resources and the probabilities for survival and it reverts population decrease.

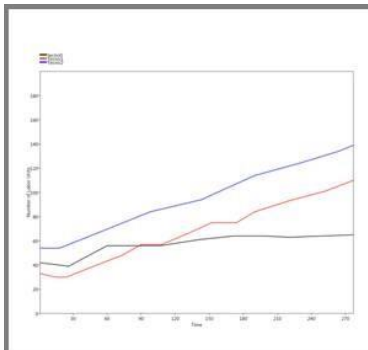
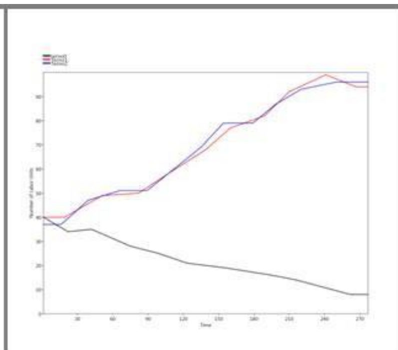
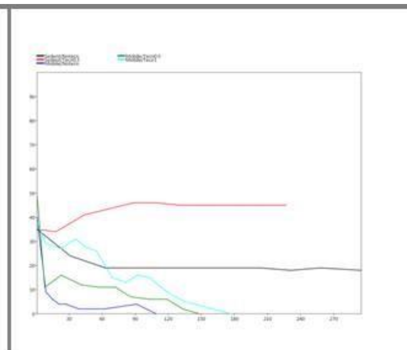
		
Increasing Population of sedentary individuals in a medium rich world scenarios (one scenarios with a mean of 10000 kcal at the warm season –and 5000 kcal at the cold one. Resource irregularity fixed for an standard deviation = 1000kcal.	Decrasing/Increasing Population of mobile individuals in a medium rich world scenarios (one scenarios with a mean of 10000 kcal at the warm season –and 5000 kcal at the cold one. Resource irregularity fixed for an standard deviation = 1000 kcal.	Decrasing/Increasing Population of mobile individuals in a poor world scenarios (one scenario with a mean of 6500 kcal at the warm season –and 3250 kcal at the cold one. Resource irregularity fixed for an standard deviation = 1000kcal.

Fig.6: *The advantages of technology related with three different scenarios of sedentary/mobile/resources abundance.*

At poorer environmental conditions, technology by itself cannot revert the effects of mobility increasing stochasticity, and as a result, most agents die in relatively short periods of time.

2.4- FOURTH SCENARIO: THE EFFECTS OF COOPERATION ("COLLECTIVE HUNTING")

Cooperation in a hunting-gathering band does not imply the transfer of subsistence, because what an agent acquires is limited to its current needs. Consequently, there is no surplus of food to be transferred, but there is always a surplus of labor not used when resources are rich enough and easily accessible with the current labor capability.

In the simulation, agent *i* receives cooperation in form of labor (additional labor units) from agents that have labor in excess for their own survival, only in the case it is unable to reach its individual survival threshold on its own, and there is an agent with an excess of energy in the vicinity. The probability of cooperation is inversely proportional to its distance. If the amount of energy and the level of productivity is enough, the agent will act individually and collect as much energy as it needs. There is no compensation for the excess of labor exchanged, or calculation of differential costs. That is to say, there is no obligation to "return the favor". There is a constraint in the quantity of labor a "rich" agent can transmit to an agent "in need". Each agent has a "FREE-LABOR" attribute expressing the number of labor units the agent can lend to another without compromising its own survival.

The number of labor units a family needs to reach her survival threshold is:

$$\left[\frac{\overline{e_i}}{h_{i\left(r_{i-\overline{e}_i}\right)}}\right]^{1/\beta_i} - l_i$$

where the first term is the additional number of labor units the family needs to reach her survival threshold; and the second term, l_i, is the actual number of labor units the family has.

If the first term is greater than the second term, it means that the family does not have enough labor units to reach her survival threshold. Therefore, the value of ST (equation 4) will be greater than zero (and thus FREE-LABOR = 0).

In those cases where both terms are equal, the number of necessary labor units will coincide with the number of labor units the family has. Consequently, the value of ST will be zero (and also FREE-LABOR = 0).

However, if the second term is greater than the first term, it means that this family has plenty of labor units to reach her survival threshold (and thus ST = 0). The result of the subtraction will be negative (the family has extra labor units). The value of this subtraction (with changed sign) is precisely the amount of free-labor the family will lend another family in need.

With this supplementary labor, the system calculates the aggregated productivity [$\Delta f_i(t)$] of an agent member of a group $G_i(t)$ is calculated:

$$\Delta f_i\ (t) = \frac{1}{1 + \frac{1}{\left[h_i\,(t).\ (\sum j \in G_i\,(t) l_j\,(t)^{\delta\beta_j(t)})^{\theta_i\,(t)}\right]}}$$

where $G_i(t)$ is the total amount of labor the group of agents that cooperate with agent *i* and $\delta\beta_i(t)$ the maximum technology within the group. There is an additional parameter modifying the total effect of aggregated labor at the social aggregate ($\theta_i(t)$), capturing the idea that cooperation is less needed when there are plenty of resources. In other words, it measures the added value that cooperation brings to production returns. Productivity after cooperation is assumed to depend on labor productivity $p_i(t)$ in such a way that the higher the productivity the lower the expected returns of cooperation. Given a parameter $0 < x_i < 1$

$$\theta_i(t) = 2 - (x_i)^{\alpha}$$

where α is a free parameter, so that 0 <= α <= 2. Therefore, θ_i is between 2 (when that particular patch is very poor in resources, $x_i = 0$), and 1 (when that particular patch is very rich in resources, $x_i = 1$). In general, we have calculated

$x_i = r_i$ / (mean_resources_on_patches+3*standard deviation of resources on patches)

Such an assumption produces a probability around 0.001 that x_i be greater than 1. In any case, if the result of the above equation is below 0 or above 1, x_i is reset to 0 and 1 respectively.

Preliminary results show that in a majority of scenarios, cooperation does not increase the probability of survival.

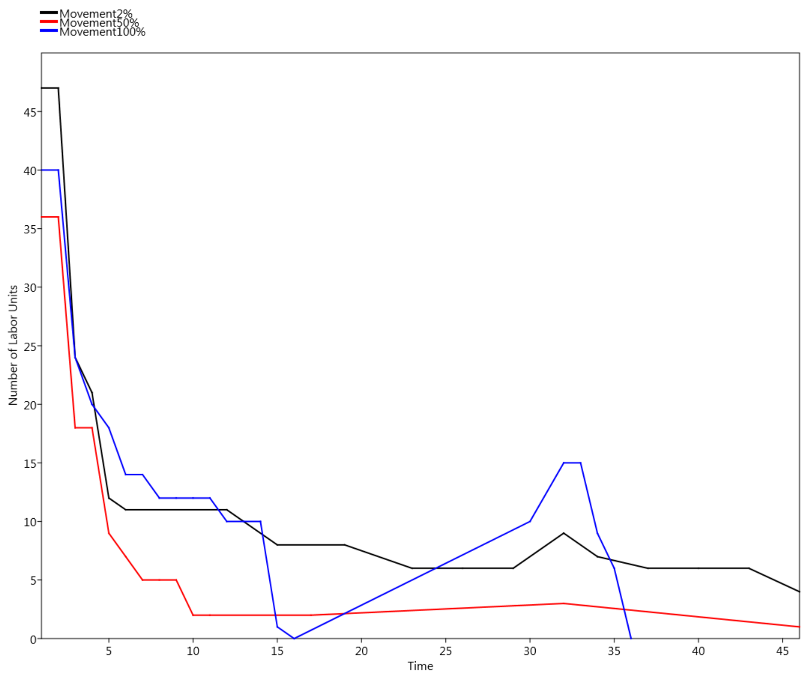


Fig. 7 *Decreasing population of mobile cooperative individuals in a poor world scenarios (one scenario with a mean of 6500 kcal at the warm season –and 3250 kcal at the cold one. Resource irregularity fixed for an standard deviation = 1000 kcal.*

This result is clearly unexpected. Cooperation drastically depends on the distance over which social interaction can be defined. The amount of cooperation is inversely proportional to the distance between agents. In our simulations we have not measured any significant impact of interaction radius, given that the decrease of population is fairly similar when interaction is limited to the 2% of territory immediate to the agent, when maximum allowed distance is fairly large (50% of territory around the agent), or there are no distance limits to build a cooperation network.

A possible explanation of this result is the increasing stochasticity of human survival in conditions where cooperation is necessary. Cooperation may contribute to survival, but if agents rely on help from neighbors to take decisions, the final result is affected by uncertainty. Only when the technology for movement –transportation- allows to contact with any neighbor in any place, there is a clear increase in the chances of survival. However, when there are barriers to cooperation, be physical distance or social distance (cultural identity)-, the advantages of cooperation are hardly evident.

3- CONCLUSIONS

Prehistoric hunter-gatherers have been studied many times from the point of view of animal foraging behavior, stating that human agents also forage in such a way as to maximize their net energy intake per unit time. This is not the proper place to discuss modern work on optimal forager theory. Nevertheless, it is obvious that if humans were in the past just like any other animal forager or predator, we would say that prehistoric hunter-gatherers survival would have depended just on the availability of edible resources.

Given a determined quantity of resources, the single most obvious constraint of human action in a particular environment is population size, especially when the means of production seem to be underdeveloped (hunting-and-gathering). This is the old Malthusian view on population increasing exponentially while food production would have increased only linearly, in constant increments. However, when survival is not affected by the volume of existing resources, but by the "difficulty" of acquiring them, the dynamics of the system are not as evident as it would seem.

As a partial criticism to the traditional Malthus hypothesis, we have assumed an additional external factor that may affect the probability of survival, and it is the different levels of difficulty to acquire existing resources: the more mobile the resource –animals- and the more difficult the spatial accessibility, the higher the difficulty, and therefore the more labor is needed to obtain resources up to survival threshold. When more labor is needed, survival is less probable because survival threshold increases. In our simulations, we see that when resources are high enough, the probabilities of survival are high in case population size is limited. When resources are low, survival is at risk. But when resources are middle-to-low and difficult to obtain, the agent should take social decisions to increase the probabilities of survival.

When resources diminish, families decrease their number of members, and hence the amount of labor available to compensate the local difficulty of accessing existing resources. In this scenario, mobility by itself is no solution. In ideal conditions, that is, when the availability of resources in the cold season exceeds seven times the survival threshold, introducing mobility does not affect survival, and population grows. However, when introducing small amounts of mobility (up to a 2% of the territory) in most cases, even at relatively rich worlds, *all* agents die, when in the sedentary scenario survival was guaranteed. The rate of decreasing population is logically related with the mean of resources. Our simulations show that mobility is only a partial solution to compensate for the low volume of resources at place, but it does not compensate for the increasing difficulty of resource acquisition. Mobility just increases stochasticity. That is, at each run of the same scenario (with the same values at the same parameters at start-up), the evolution of the population differs. This is a consequence of the increasing irregularity in agents' revenues.

If mobility increases stochasticity, then it cannot be interpreted as an adaptive decision to increase the expectances of survival. To-move or not-to-move is no "prisoner's dilemma", because there is nothing to win with moving if resources are above survival threshold, and nothing to win with staying if resources are below. In any case, our model is too simplified in the sense that prehistoric hunter-gatherers nor hunter-gatherer bands known in historical times never displaced randomly and hunted-gathered at any place within a constrained neighborhood (Grove 2009). Displacement among hunter-gatherers can take many different and varied forms, including the displacement of all the population or a part of it, wandering randomly through the lowest cost-surface until finding the richest place, or the place where enough resources are most accessible, or going directly using the most direct and fastest way to the place where there is a memory of plenty of resources

Technology can be used to increase local difficulty, but its effects are constrained by its efficiency. High efficiency indicates that all local resources can be managed independently of its difficulty of acquisition given the extreme performance of available technology. Low values are characteristic of human groups with hardly evolved instruments, in such a way that only a part of locally available resources are effectively managed. The efficiency of food preservation techniques is another technological factor, related with the overall level of development of means of production. Both factors –quantity of people to work and technological efficiency act upon the difficulty of acquiring and transforming resources into subsistence and hence on survival.

However, hunting seems to have been in the past a much more complex activity than expected, whose success and hence the posterior probabilities of survival are less deterministically affected by the availability of animals in the area or the efficiency of available technology. We need to incorporate social dynamics well beyond the standard animal foraging model: animals rarely cooperate, but cooperation is what made us humans. If a social agent cooperates with another agent, the chances of hunting success are higher, even in the case of low animal availability, or the difficulty in capturing them with available technology. To reproduce what we know from ethnological research, cooperation in our model is not totally "free". An agent will cooperate with another:

1) when someone in the appropriate neighborhood will ask for help given its inability to survive using its own means. This neighborhood is constrained by the technology for mobility (MOVEMENT global parameter)

2) There is enough cultural similarity among both agents (the survival threshold needed to define the possibility of labor exchange is defined according the local circumstances).

3) The helping agent has labor in excess, and the only it can contribute is with what it does not need for its own survival.

4) Only one agent can be helped at each time. The procedure is implemented so that all possible FREE-LABOR is given to the first agent asking for help. The remaining FREE-LABOR is invested in surplus (additional energy) when the current value of the STORING FACTOR is set > than 0.

Our results are unexpected. Even in the case of cooperation, most agents die when resources are scarce. Then, why cooperation is not enough for overcoming the risk of starvation? Because we are in a hunting-gathering scenario, where labor is used to "acquire" an already existing resource. There is no production, and therefore the amount of subsistence extracted from existing resources is not directly related to the amount of labor nor the efficiency of available technology. Cooperation in a foraging model only contributed to extract the most from the local area, compensating for the difficulty of acquisition, but it does not increase the volume of existing resources. Our model allows to understand the main difference between hunting-gathering and farming societies. The availability of resources remain the main factor for survival, and mobility decisions should take into account displacement over great distances looking for more resources, but also the possibilities of finding more help. This conclusion may contribute to understand the big migrations that have been attested in the archaeological record.

We are conscious that connections to archaeology are only left implicit in this paper. For the moment, our aim has been to create a theoretical model of the possibilities of survival in prehistory, when technology was poorly efficient and it hardly contributed to survival. There is a theoretical impossibility in obtaining empirical data to test the expectations prehistoric people had about the advantages of mobility, the effects of available technology and the risk minimizing factor that comes from the possibility of increasing labor force cooperating with neighboring groups. We have intended just some formal validation; that is, a test that the hypothesis may be true *within an artificial* (although objective) formal system (Hasan and

Tahar 2015, Yanow and Schwartz-Shea 2015, Fforde 2017). The past cannot be reconstructed from archaeological data alone, because a given dataset contains insufficient regularities for predictive theorizing. Our computer model is just a hypothesis about *the more probable* behavior given some well-defined prior assumptions, and it adopts the form of a deductive statement, whose foundation is merely formal. The model has been parameterized using ethnological analogies and results of previous archaeological experiments (Barceló et al., 2015). In any case, the model can be easily enhanced by introducing some archaeological corollaries of agent behavior, like the production of garbage as a sub product of hunting and gathering, the material remains of residential places or burials signaling the number of deaths. A quantification of those elements would allow a partial empirical testing of the hypothetical model (Windrum et al. 2007, Conte and Paolucci 2014, Geller 2014, Lee et al. 2015).

In the Social Sciences, models are often presented uncritically as faithful representations of reality. In this paper, we make no such claim. We argue instead that our model of hunter-gatherer survival is useful as devices for interrogating some prior hypotheses about human behavior in Paleolithic times. Does it mean that the model is wrong? Not necessarily (Epstein 2008). We have not yet explored alternative and more complex scenarios, because we were interested in simulating the simplest scenario to evaluate the effects of social cooperation and the transfer of labor force in the worst imaginable conditions. In any case, even this most simplified and abstract model suggests the enormous variation of effects a single decision or strategy had, and it contributes to understand the basis of randomness in human action, especially at times where social organization was dependent on local resources and the local configuration of those resources.

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