SOCIAL COOPERATION AND RESOURCE MANAGEMENT DYNAMICS AMONG LATE HUNTER-FISHER-GATHERER SOCIETIES IN TIERRA DEL FUEGO (SOUTH AMERICA).

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ABSTRACT
This paper presents the theoretical basis and first results of an agent-based model (ABM) computer simulation that is being developed to explore cooperation in hunter-gatherer societies. Specifically, we focus here on Yamana, a hunter-fisher-gatherer society that inhabited the islands of southernmost portion of Tierra del Fuego (Argentina-Chile). Ethnographical and archaeological evidences provide arguments that point to the existence of sporadic aggregation events, triggered by a public call through smoke signals of an extraordinary confluence of resources under unforeseeable circumstances in time and space (a beached whale or an exceptional accumulation of fish after a low tide). During such aggregations, the different social units involved used to develop and improve production, distribution and consumption processes in a collective way.
We try to analyse the social dynamics that explain cooperative behaviour and resource sharing during aggregations based on an agent based model of indirect reciprocity. Agents decide based on the success of public strategies of other agents. Fitness depends on the resource captured and the social capital exchanged in aggregation events, modulated by agent's reputation. Our computational results identify the relative importance of the resource with respect to social benefits, and the easiness to detect, and hence punish, a defector as key factors to promote and sustain cooperative behaviour among population.

KEYWORDS:
ABM, Cooperation, Computer Simulation, Yamana, Ethnoarchaeology.

1. -INTRODUCTION

Western thought has developed a long intellectual tradition exploring the reasons of cooperation, including theorists of XIXth Century such as Durkheim and Marx. Questions like why do people cooperate, and how cooperative behaviours are maintained, have been long-lasting issues in social sciences that brought an array of perspectives, which claim for the altruistic nature of human beings up to the idea that humans are naturally motivated by self-interest.

These questions provided the baselines to design an ethnoarchaeological research project addressed to unveil the dynamics embedded in aggregation and cooperation processes between hunter-fisher-gatherer societies that inhabited the coasts of the Beagle Channel in the uttermost extreme of South America (Briz et al. 2009). According to the ethnographical documents these groups, who called themselves Yamana or Yaghan, developed sporadic aggregation events when a whale or fish stranded on the beach (Gusinde 1937). In such occasions, individuals who discovered this exceptional accumulation of foodstuff made a public call with smoke signals in order to take advantage of windfall resources, gathering together several families otherwise dispersed. Cooperative activities related to production, distribution and consumption processes were improved and social norms were reinforced.

The general aim of our project is to identify the mechanisms involved in aggregation practices in order to strength social ties and to assess the role played by cooperation in historical change. The possibility to apply simulation in this case study enhanced the opportunity to explore the evolution of cooperative behaviours to the extent that the social dilemma, related to call or remain silent, can be formalized in a computer model used to distil the role played by different factors (e.g. scarcity and variability of resources, visibility of social units, reputation, etc.) in promoting or hindering aggregation events in the Yamana society.

2. -SOCIAL COOPERATION IN HUNTER- FISHER-GATHERER SOCIETIES

Studies about cooperation are an essential topic within social sciences. Cooperation is not only one of the most relevant forms of social interaction, but constitutes a key factor in understanding human development as a species as well as in explaining its social and historical becoming (Alexander 2008; Bowles & Gintis 2003; Boyd & Richerson 2005; Carballo et al. 2012; Henrich & Henrich 2006; Ingold 1988; Marx & Engels 1977; West et al. 2011).

Therefore, many debates about human nature as a cooperative species versus self-interest approaches have raised in different disciplines (Huxley 1888; Kropotkin 1902; Wright 2011). Within formal disciplines (and specially in life sciences) these debates are not limited to the study of human societies as they recognize cooperation as an ethological specific trait of some species such as primates (de Waal & Suchak 2010; Warneken et al. 2007) or eusocial species (Thorne 1997; Wilson & Hölldobler 2005) .

Regarding human societies, cooperation can be achieved in ways that work differently from a simple synchronized action that implies a mutual benefit as appears in some eusocial cases (Tarpy et al. 2004). Human cooperative attitudes, which are set out for developing at big-scale, have been recorded in anthropological studies under the umbrella of reciprocity and directly linked to other concepts such as redistribution and exchange (Durkheim 1909; Durkheim 1917; Malinowski 1961; Mauss 1931). Therefore, the fact that human cooperative dynamics far exceed relationships based on kinship or reciprocity (reciprocal altruism), constitutes an explanatory limitation for mainstream or traditional approaches such as classical evolutionary theory (Henrich & Boyd 2001). In recent times within the framework of Cultural Evolutionary Theory different hypothesis have been proposed in relation to the evolution of human cooperation (see for example Boyd and Richerson (2005) or Tomasello et al. (2012)).

Human cooperation implies not only the development of a historical memory (based on learning as well as on social transfer of knowledge), but on a long-term foresight of social consequences of individual behaviour, too. There is a continuous investment in time and effort addressed to develop and maintain cooperation through social norms and their institutionalization (Axelrod 1986; Gumerman et al. 2003), the generation of social prestige mechanisms (Henrich & Boyd 2001; Henrich & Gil-White 2001; Ohtsuki & Iwasa 2004), the establishment of coercive and punishing mechanisms (Boyd et al. 2010; Sigmund 2007; Sugden 2012), the inclusion and exclusion of the group (Field 1998; Henrich 2004), or the cost of signaling in cooperation and group-beneficial behaviour (Bliege Bird & Smith 2005; Smith & Bliege Bird 2005).

There is a general consensus on the fact that there is a surplus in reciprocity that overpasses implied material interests, which is addressed to be "(…) the kernel of social cohesion in general" (Narotzky 2007: 406). Even though cooperation is based on individual attitudes and decisions, its *raison d'etre* lies on its existence inside a network of social relations, being a structural element for human societies (Melis & Seemann 2010; Nowak 2006).

Many studies about cooperation vs. competition carried out on social sciences are based on Game Theory (Axelrod 1997; Elliott & Kiel 2002; Nowak & Sigmund 2000; Skyrms 2004). Within them, a cooperator is defined as someone who pays a cost for another individual to receive a benefit (Nowak 2006). The extreme stylization that this definition implies faces conceptualization of cooperation that appears in anthropological disciplines, where social variability and critical reading of the ethnographical documentation makes difficult to reach single and simplistic definitions.

The study of hunter-gatherer societies has been of paramount importance to reach a knowledge about "human cooperation" as it happened in social simulation (Mithen 1994). Apart from the fact that during most of our history we have been hunter-gatherers and that currently this kind of societies still exist (Henrich et al. 2001), a long evolutionary history of cooperative production in foraging societies is probably responsible for the universal human tendency to cooperate (Hill 2002). In spite of existing debates about the suitability of using these groups as examples of how early humans could have behaved (Estévez & Vila 1996), its study allows us to open our minds in this sense as they exemplify this feature best (Apicella et al. 2012), and also to understand how such tendencies evolved (Hill 2002).

We define cooperation as a social relationship that allows certain social and economic practices to take place in a particular way in which different social agents get involved: these agents develop production, distribution and consumption processes collectively so that profits/returns/payoff for all the individuals who participate get increased. The profits/returns/payoffs, which are not necessarily only material are neither immediate nor uniform (there is not necessarily a proportional relation between investment and benefits). Social benefits such as reputation, which can be materialized in future material benefits, may play an outstanding role more important than immediate material benefits
Ethnographical documentation about this society as well as general anthropological background knowledge allows us to have a clear idea about how cooperative practices would have taken place in our case study. It also allows us to enrich the range of pay-offs, which are focused on the reproduction of different aspects of social life that could have been derived from an aggregation event. On one hand, increase of labour force and "technological knowledge capital" could have lead not only to educate the younger in particular manufacturing (transfer of knowledge) but in a more general way to innovate. On the other hand there are other pay-offs regarding social organization: rites of passage or other "cultural reproduction" activities such as singing, explaining myths and tales or playing.

3. -MAKING HYPOTHESIS ABOUT SOCIAL COOPERATION. ETHNOARCHAEOLOGY AND COMPUTER SIMULATION: BRIDGING THE GAP

Thorough the history of archaeological research, considerable efforts has been devoted to theoretical and epistemological reflections about the relationship between the archaeological record and the dynamics of past societies. The need of a methodological improvement to go beyond the fragmentary nature of material evidence and to reach a solid interpretation of the social and historical processes (Lull 1988; 2005) has been a long-standing aim in the archaeological inquiry. In this sense, New Archaeology explicitly tackled this issue engendering different interpretative tools such as the extensive use of models or the development of Middle Range Theory (Binford 1977).

It is important to remark here that we consider ethnoarchaeology as a methodological tool for the development of new methods, techniques and hypothesis in archaeology (Agorsah 1990; Aldenfender 2001; Béyries 1997; Béyries & Pétrequin 2001; Carlson 2009; David & Kramer 2001; Estévez & Vila 1996; Gould 1980; Roux 2007). For us, ethnoarchaeology entails the critical use of ethnographical, ethnological and historical sources about recent past societies (Axtell 1979; Carlson 2009; Davidson 2006; De Rojas 2008) and ethnographic living societies (Politis 2007). The general aim is to obtain analytical tools for answering social questions, improving our archaeological methods and/or hypothesis (Briz 2010; Zurro et al. 2010) through the dialectical contrast between archaeological method and results and ethnographical sources (Estévez & Vila 1996).

Computer simulation offers the opportunity to include theoretical foundations on the basis of empirical observation of the archaeological and historical records. This allows on one hand to find evidence and assumptions about a given historical/social process and, on the other, to analyse its dynamics, its logical implications and, hence, the plausibility of a given hypothesis or interpretation. Likewise computer simulation constitutes a powerful tool to assess how a practice may evolve in a particular time frame. Thus, it brings the possibility to experiment in archaeology and consequently to narrow the range of plausible paths to investigate past societies.

Agent-based modelling is characterized by the way the abstraction of the target system is constructed. In an ABM there is a direct correspondence among the entities observed in the real system - and the interactions among them - and agents that represent individually and explicitly those entities in the computational model (Edmonds 2001). ABM makes easier the abstraction of the target system, giving the opportunity of implementing idiosyncratic characteristics of past social human dynamics, e.g. heterogeneity, autonomy, explicit space, local interactions or bounded rationality (Epstein 1999), but obliging at the same time to the logical consistency of formal models.

Even though within ABM in archaeology there are some complicated models that attempt to reproduce or emulate real empirical archaeological data and high-level patterns, in the present case we use an experimental or exploratory approach to build simple and heuristic models focussed on controlled experimentation, theory building and hypothesis generation (Premo 2010) (see examples of this type of research in Kohler & van der Leeuw (2007) and Kohler et al. (2012)). This approach allows us to explore different conditions and variables involved in the emergence, development and resilience of a given social phenomenon or process. By systematically varying these variables and conditions of experimental parameters, we are able to study the range of plausible conditions that affect, as well as to what extent, the phenomenon under study (Premo 2010).

Consequently, computer simulation is used here as a tool to build a model focused on the evolution of social cooperation in a hunter-fisher-gatherer society from Tierra del Fuego. The ethnographical sources and ethnoarchaeological results provide the basic social rules and variables followed by the agents of the simulation.

4. -LATE HUNTER-FISHER-GATHERER SOCIETIES OF FUEGIAN CHANNELS. CASE STUDY: THE YAMANA SOCIETY.

Yamana or Yaghan was a hunter-fisher-gatherer society that inhabited the uttermost tip of South America during XIXth and XXth Centuries (Gusinde 1937). Over 7000 years, the societies that established on this region developed a long-lasting social organization based on fishing, hunting and gathering strategies as well as on the development of nautical technology (Orquera et al. 2011). These marine-coastal economies persisted until European arrival at XVIIth Century and collapsed three centuries later, following the same colonization trend of the rest of America.

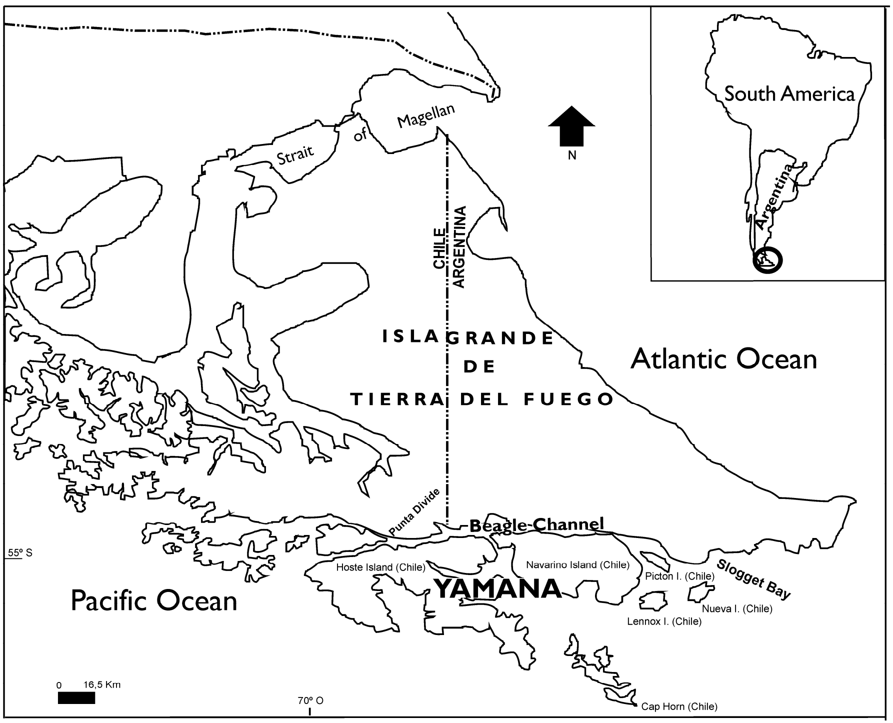

Fig. 1. Map of Tierra del Fuego

According to archaeological and ethnohistorical information, this society developed a hunter-gatherer and fishing economy specialized in the management and exploitation of maritime resources: pinnipeds, seabirds and guanacos hunting, shellfish gathering and fishing (Orquera & Piana 1999; 2009). In order to avoid resource depletion, a high level of mobility on canoes of small groups (even single canoe) was the most common behaviour. But, in any case, cooperation seems to have been an equally important element in daily practices, involving both relatives and non-relatives.

Evidence for cooperative activities is clearly documented in historical written sources and most of them are related to food procurement: guanaco hunting (Bridges, MS: 08-14-1872, 06-15-1877), seabirds hunting (Bridges, MS: 03-28-1870; Hyades and Deniker, 1891: 359-360; Gusinde 1937: 509), fishing (Bridges MS: 11-20-1871, 01-02-1872, 07-17-1877; Gusinde 1937: 531), mussels and mushrooms gathering (Bridges, MS: 10-26-1870, 06-14-1872, 06-15-1877; Gusinde 1937: 523) or to the acquisition of bark to make the canoes (Gusinde 1937: 424; Hyades & Deniker 1891: 350).

Fig. 2. Landscape of the Beagle channel

However, historical documents provide an interesting case in which communal participation, reciprocity, social reputation, and norms were enhanced and more explicitly ruled. This dynamic occurred when a cetacean or massive fish stranded on the coast (among others: Bridges, MS: 05-26-1872; 01-15-1872, 03-19-1872; Lothrop, 1928; Gusinde, 1937: 355, 375 and 532-533).

According to the sources, when a person discovered a whale drifted ashore, he/she lighted a fire in order to communicate the nearby families the finding by smoke signals (Gusinde 1937: 990; Martial 1888: 181). If the signal was perceived, an aggregation episode could take place, getting together a high number of people to share the feast; this scenario also provided the opportunity to celebrate youngsters´ initiation ceremonies and communal works (Gusinde 1937: 789-790). The steps after the animal discovery were precisely ruled: the person who discovered the animal was considered the "responsible"/holder of a fair and tidy distribution. Commonly, mature and reputed men agreed with him/her about who would process the whale since not everyone had the experience and skills to accomplish the task (Gusinde 1937: 578). This specialist, called "wálaputës" in Yamana language, selected the assistants to accomplish the activity (Gusinde 1937: 558).

It is important to remark here that whale stranding was an unpredictable event, and people did not develop the technology to hunt these sea mammals in the open sea. However, occasionally if a wounded whale swam near the coast, Yamana people got closed to the prey with their canoes to kill it using their harpoons and spears (Gusinde 1937: 460; Lothrop 1928: 33).

The paramount value of a whale in Yamana social life can be traced in different lines of evidence. First, references about whale stranding are frequent and detailed in the historical accounts; there were specific terms to name the parts of a whale (Bridges 1933). Likewise all sources agree that the event was a festive social occasion and profusely describe the atmosphere of happiness and enthusiasm provoked by a whale stranded (Chapman 2010; Gusinde 1937: 375). Second, historical records indicate that whale blubber and mushrooms were the only edible resources people habitually stored using preservation techniques. While the first one was preserved dehydrated, whale blubber was preserved in peat-bogs (Gusinde 1937; Orquera

& Piana 1999: 197-198). Consequently, in peat bog areas the accumulation of portions of whale was a real option, despite of the social rule of common consumption with other members of the society. Third, relevance of whales for Yamana way of life is demonstrated in the fact that they are embedded in the mythology and narratives of this group who had songs to bring them to the coast (Gusinde 1937; Fig 3). Finally, social norms sanctioned the person who did not notify the community the presence of a stranded whale (Bridges, 1876: 57, cited in Orquera & Piana 1999). A quarrel took place if the individuals were discovered and they were left aside in next episodes of food sharing. Thus, cooperation as a social positive value was strengthened even though there was food surplus.

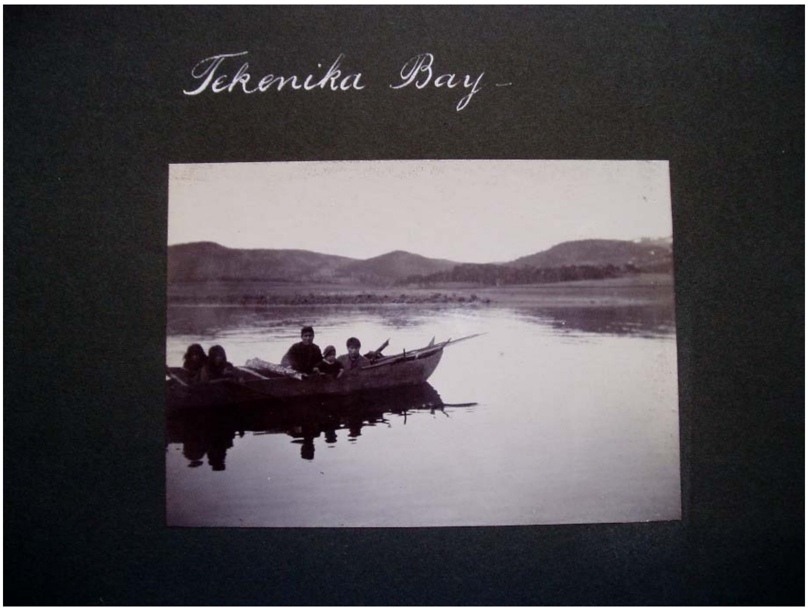

Fig. 3. Yámana canoe in the Tekenika mission (courtesy of South American Missionary Society)

This study aims to quantify the incidence and interaction of each variable involved on this specific dynamic of social cooperation in order to clarify the relevance of reputation and imitation strategies for achieving a particular social behaviour.

5. -DESCRIPTION OF THE WWHW MODEL

PURPOSE AND BASIC ASSUMPTIONS

WWHW (Wave When Hale Whale) is an agent-based model developed with the aim of exploring the emergence, resilience and evolution of cooperation in in hunter-fisher-gatherer societies, such as Yamana society, in which individuals face the social dilemma of calling and sharing a highly profitable but unpredictable resource. The model abstracts the main factors that, in our opinion, might condition the evolution of cooperation:

- A social mechanism of indirect reciprocity that promotes cooperation;
- The stochasticity of the natural events that generate opportunities of cooperation;
- The characteristics of these events that determine their visibility – i.e. the ease for people to find them – and the chances of being detected if someone does not cooperate (defect);
- The relative benefit of the social activities that people develop when they gather together in aggregations.

Another important assumption of the model is the evolutionary mechanism in the imitation process of strategies. The appendix A includes a complete description of the model following the documentation protocol ODD (Grimm et al. 2010). The supporting material provides an applet of the model, implemented in NetLogo 5.0 (Wilensky 1999) and the source code.

ENTITIES, STATE VARIABLES AND SCALES

The spatial environment is represented as a 2-dimensional plane regularly divided into *M*x*M* equal-size spatial units, called Patches, that represent water, beach and land spatial cells (Fig. 4). The relevant parameter of the spatial distribution of patches is the *beach-density* that determines the number of beach patches where whales can strand.

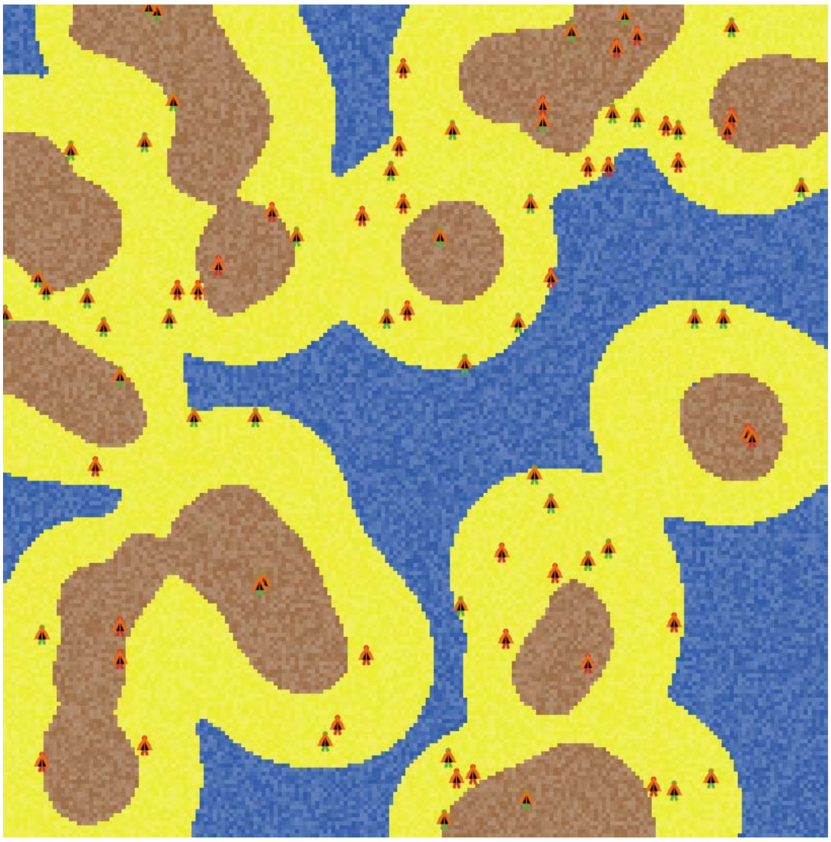

Fig. 4. Two-dimensional representation of an environment, consisting of 201×201 patches (blue for water patches, yellow for beach patches and brown for land patches)

There are two types of agents: People and Whales. People agents represent households/canoes; they move looking for beached Whales and make decisions about whether to call or not other People when a beached Whale is found. The number of people remains constant in the course of a simulation run. On the other hand, Whales are non-mobile agents and represent a scarce but important source of meat that appears from time at one of the beach patches, providing perishable food.

The WWHW model is characterized by a set of variables of different nature: the study parameters (Table 1) are the exogenous variables established by the user that define a computational experiment under analysis, a given scenario, and that remain constant in each run; the entities' variables define the state of each individual entity (agent), namely People (Table 2) and Whales (Table 3), at each period of time; and a set of global variables that determine some accessory features of the entities and the model.

TABLE 1. STUDY PARAMETERS

Parameter name	Brief description
prob-beached-whale	Probability that a Whale beaches at each time period. Whales appear at one of the beach patches (the beached whale process is fully described in the Process Section).
social-capital-vs-meat-sensitivity	Parameter in the range [0,1] that modulates the relative importance of the *social-capital* vs. *meat* in the fitness function –the higher value, the more relative weight of *social-capital*–.
vision	Maximum distance (measured in number of patches) within which People can see beached Whales.
signal-range	Maximum distance (measured in number of patches) of the signal (e.g. smoke) created by cooperative People at the location of a beached Whale to help others to find the resource.

distance-walked-per-tick	Number of patches that a People agent can move at each time period.
prob-mutation	Probability of an error or an exploratory strategy in the imitation process of People's strategies.
rounds-per-generation	People can imitate other strategies (selection process) every *rounds-per-generation* periods of time.
beach-density	Fraction of beach patches. The rest of Patches, corresponding to the (1-*beach-density*) of the total of patches, are equally divided into land and water Patches.
people-density	Density of People in the 2-D space (measured as the total number of People divided by the total number of patches).

TABLE 2. PEOPLE'S STATE VARIABLES

Variable name	Brief description
prob-cooperation	Probability of a People agent cooperates. We suppose there are only two strategies of cooperation: always cooperate (*prob-cooperation=1)* and always defect (*prob-cooperation=0).*
last-public-prob-cooperation	The last public *prob-cooperation*. Whenever a People agent makes a public call and someone comes, or defects and someone observes her defection, this variable is updated with the current *prob-cooperation*.
meat	Stock of Whale meat held by a People agent.
social-capital	Stock of social capital acquired by a People agent.
fitness	Value of a People agent's success, determined by the variables *meat* and *social-capital*, used in the imitation process.
reputation	Variable in the range [0,1] that represents the reputation of a People agent.
{n-calls-history, n-been-caught-history }	Vectors that contain respectively the times a People agent called others and an aggregation happened, and the times she defected and was caught by someone, in the *last history-size* of generations

TABLE 3. WHALES' STATE VARIABLES

Variable name	Brief description
my-range	Radius (measured in number of patches) within which the Whale is visible by People. This range is equal to the vision of the People if the Whale has not been made public (i.e. if no agent has made a signal for this Whale), or the signal-range, if a People agent has already made the Whale public (by creating a signal).
caller	If the Whale is public, this variable stores the People agent who made it public by creating the signal; otherwise the variable has a "nobody" value.
public?	Boolean variable which is "true" when the Whale is public (i.e. a People agent created a signal indicating the location of the Whale), and "false" otherwise.
Life	The number of time periods that a Whale will stay in the environment before disappearing. It is decreased in one unit after each period.

PROCESS OVERVIEW AND SCHEDULING

The scheduling of the set of events that take place in discrete time-steps (or "ticks") is represented in Figure 5.

Fig. 5. Flow diagram of the schedule of execution. The order in which agents are chosen in "for each"statements is always random to avoid bias in agent selection

With probability *prob-beached-whale* a Whale appears at a randomly chosen beach patch (*beach-a-whale* procedure). A beached Whale is detected (*be-seen* procedure) by any People agent without target and at a distance of *my-range*, or closer, from the Whale. When a People agent detects a Whale, moves (*walk* procedure) towards it until she arrives at its same Patch; if not, the agent moves randomly. In all cases, the distance travelled corresponds to the parameter *distance-walked-per-tick*.
When a People agent reaches a Whale and nobody has publicly announced its presence yet –the state of the Whale is private- she makes a decision, in particular she creates a signal with probability *prob-cooperation* changing the state of the Whale to public (*call-others* procedure). The limit distance *my-range* depends on the state of the Whale, i.e. is it or not *public?* If the Whale is not public the variable *my-range* is equal to the parameter *vision,* which represents the natural distance at which a People agent can see the food source. However, if the Whale is public, i.e. a People agent has already called everybody else creating a public signal, *my-range* gets the value of the parameter *signal-range*.
The reputation of a People agent depends on her public history of past actions, stored in two vectors: *n-calls-history* and *n-been-caught-history*. If a People agent decided to call everyone else and there was a witness of her action, she adds a unit in the current generation period of the vector *n-calls-history* (*be-rewarded* procedure). On the other hand, if the agent decided not to call and there were witnesses of that defection, she adds a unit in the current generation period of the other vector *n-been-caught-history*.
Then, each People agent updates her reputation (procedure *update-reputation*). The reputation Ri of the People agent i is computed as the division between two moving averages according to the next equation:

$$R_i = \frac{\sum_{j=1}^{h}\left(\#Cooperate_j\right)\delta^j}{\sum_{j=1}^{h}\left(\#Cooperate_j \cup \#BeSeenDefecting_j\right)\delta^j} \in [0,1] \qquad \text{EQ. 1}$$

The term $\delta \in [0,1]$ corresponds to the discount factor parameter *history-past-discount*. This parameter takes into account how important is the *shadow* of the past in terms of reputation. Values close to one mean that events in the past and the present are equally important for the population, however values close to zero give much more weight to recent events than decisions taken in the past. The term $\#Cooperate_j$ corresponds to the j element of the vector *n-calls-history*, and the term $\#BeSeenDefecting_j$ to the j element of the vector *n-been-caught-history.* Both vectors always collect the last *history-size* (h index) registers of the agent's generations.
Note that the reputation of a People agent only can change when she makes an action (cooperate or defect) that is observed by someone else. If she defects but she is not caught, the reputation does not change, and similarly, if she cooperates but nobody comes to the call, the reputation does not change either. This feature matches the hypothesis that reputation is a kind of social tag that someone always receives from the others, and cannot be changed by her owner.
Afterwards (*rot-and-be-eaten* procedure), People exploit the Whale, storing *meat*, and participate in social activities, storing *social-capital*. We simplify the process of storing *meat* and *social-capital* assuming that: (1) the number of ticks a Whale stays in the model is fixed, and (2) the gain per tick of these stock variables –marginal gain– for any People agent depends only on the number of People sharing the Whale at each moment and her reputation. Following these assumptions, the marginal *meat* per tick $\Delta M_i(t)$ that a People agent i gets in an aggregation of size N, -she consequently has to share the meat with $N\text{-}1$ individuals- is formalized by a bell-shaped function:

$$\Delta M_i(t) = e^{-\alpha\left((N(t)-1)-\mu\right)^2} \; with \; \Delta M_i(t) \geqslant 0 \qquad \text{EQ. 2}$$

The terms α and μ module the width and the peak location of the function. Depending on the value of μ, the function shows increasing and decreasing returns in different ranges of N. Although it is possible that the real exploitation of a whale by households initially showed increasing returns with the size of the aggregation we set $\mu = 0$ focusing our analysis on the range of decreasing returns that depicts a more critical scenario for the evolution of cooperation.
On the other hand, the marginal *social-capital* per tick $\Delta SC_i(t)$ that a People agent i obtains in an aggregation of size N is computed by the following function:

$$\Delta SC_i(t) = R_i\left(1 - e^{-\alpha(N(t)-1)^2}\right) \; with \; \Delta SC_i(t) \geqslant 0 \qquad \text{EQ. 3}$$

In this case, the function is monotonically increasing with the size of the aggregation N, and has a superior asymptote at the reputation of the agent Ri. We suppose that a People agent's reputation conditions her capacity to gain social capital form others – i.e. if someone has bad reputation it is more probably that nobody wants to join her in social activities–. All these assumptions match the hypothesis that social capital always grows with the number of people participating in social activities, although as this number increases, the marginal contributions of new participants decrease because they are probably redundant, limiting the gain of *social-capital*.

The fitness function quantifies the success of a People agent and takes into account the last two stock variables:

$$F_i(t) = \theta SC_i(t) + (1-\theta)M_i(t) \; with \; \theta \in [0,1]$$
$$where$$
$$SC_i(t) = SC_i(t-1) + \Delta SC_i(t)$$
$$M_i(t) = M_i(t-1) + \Delta M_i(t)$$

EQ. 4

The term θ modulates the relative importance of each factor and corresponds to the model parameter *social-capital-vs-meat-sensitivity;* the higher value of θ, the more importance of *social-capital*.

Finally, when a period of *rounds-per-generation* ticks is reached, a process of imitation occurs (*select-cooperation-strategy* procedure). The selection process is implemented as a random tournament: each agent chooses randomly another in the population with probability directly proportionate to its fitness, if the picker has got less fitness she copies the strategy of the choice, or explores a new strategy randomly chosen between the strategy space with probability *prob-mutation*. It is important to note that the value copied into the variable *prob-cooperation* is the variable *last-public-prob-cooperation*. The hypothesis is that a People agent only can imitate observable values, i.e. the strategy of a People is observable whenever there was a witness of her behaviour, cooperation or defection. After the imitation process, People agents initialize their variables *meat*, *social-capital* and *fitness* to zero, but do not change their reputation and their vectors of past history.

6. -Analysis and results

Design of experiments

The WWHW model has been designed as a "tool-to-think-with". It is not meant to provide precise quantitative predictions, but to assist researchers in understanding the mechanisms and conditions in which people might cooperate and call each other when they find a beached whale. The inferences we want to get are from the kind of "the *vision* does or does not favour cooperation in the society" or "the frequency of beached whales does or does not favour cooperation in the society". In order to get this, the analysis is focused on the asymptotic behaviour –the long run– of the system. In this model, when People can explore (random mutation) besides imitating strategies, the system becomes ergodic and consequently the asymptotic behaviour is independent of the initial conditions (Izquierdo et al. 2009). We let each simulation run a sufficiently long time to guarantee that the effects of the initial conditions have disappeared, and replicate several random and independent samples for each parameterization to get statistics accurate enough[1]. The state of the system is represented with the average cooperation of the population (denoted by the term cooperation *C* from now on), and it is computed and recorded for each tick.

Stationary regimes

The Figure 6 shows the histograms of the stationary regimes for different combinations of the parameters *social-capital-vs-meat-sensitivity* (θ) and *vision* (υ), when the *prob-beached-whale* (P_{bw}) is 0.05 (similar results are obtained for other probabilities). A first inference from these results allows us to make a simple characterization of the stationary behaviour. The system mostly reaches one of the two stationary regimes that we have defined as "All Cooperation" (AC), whenever $C \geqslant 0.9$, and "All Defection" (AD), whenever $C \leqslant 0.1$. The rest of regimes are almost negligible, and they are gathered in the "Majority Cooperation" (MC) regime, whenever $0.5 \leqslant C < 0.9$, and "Majority Defection" (DF) regime, whenever $0.1 < C < 0.5$.

1 The initial state for all simulations corresponds to a population of fifty-fifty cooperators and defectors randomly distributed. in the space. The core parameters {*vision, social-capital-vs-meat-sensitivity, prob-beached-whale*} are explored fixing the rest of the parameterization: {*people-density=0.002 (82 agents); beach-density=0.5; prob-random-move=1; distance-walked-per-tick=4; signal-range=50; rounds-per-generation=50; prob-mutation=0.025; history-size=10; history-past-discount=0.8; tournament-size=5;*}. Time limit for a simulation is 10^5 ticks, and 50 replications have been run for each experiment.

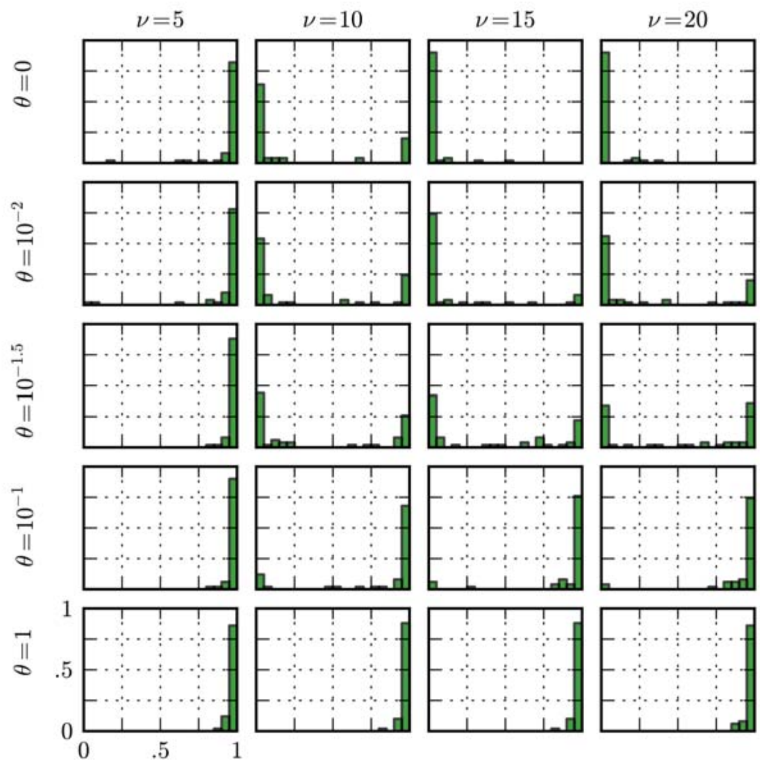

Fig. 6. Array of histograms of the stationary cooperation for a combination of the parameters social-capital-vs-meat-sensitivity (θ) and vision (υ), when the probability P_bw is 0.05. Results show that the stationary behaviour of the model concentrates in the region of All Cooperation (percentage of cooperators close to one) or the region of All Defection (percentage of cooperators close to zero). simulations in between these extreme cases are unlikely.

Interpretation of these computational results is rather intuitive. When $\theta = 0$, that is, there is no indirect reciprocity in the society and agents' fitness is driven only by the consumption of *meat*, the AD regime is reached in almost all cases –with the exception of low values of vision (υ) that we will explain afterwards–. However, when the value of *social-capital* grows –in terms of fitness– and consequently the social reputation mechanism has effects on the imitation process, the AC regime becomes the most important, even for very low values of θ.

For the sake of clarity, the results are showed in a different way in the Figure 7. Here, the frequencies of the stationary regimes in two different cases, with and without indirect reciprocity, are showed for several probabilities of beached whale.

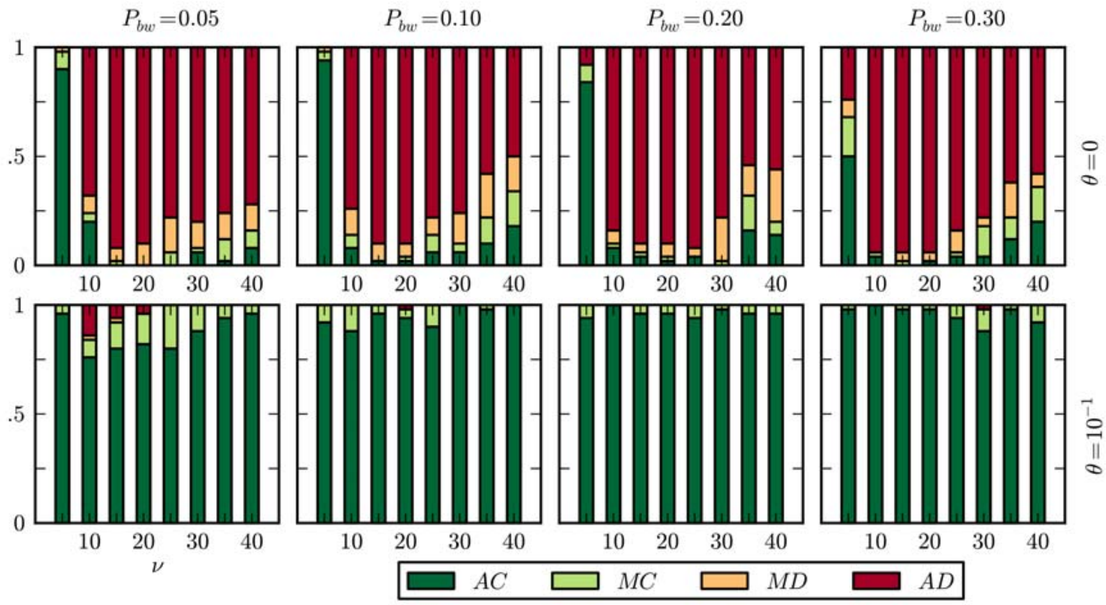

Fig. 7. Above, the bar plots of the frequencies of the stationary regimes for the case without indirect reciprocity θ=0, when the parameter vision varies and the P_bw is fixed. Below, the same plots for the case with indirect reciprocity (θ=0.1).

THE EFFECT OF VISION

In order to understand the effect of *vision*, we show in the Figure 8 the average cooperation when the probability of strand remains constant and *vision* and θ vary. In the range of θ in which both AC and AD regimes are possible, we see that *vision* pushes the levels of cooperation up for all frequencies of beached-whale (i.e. the higher values of *vision* the higher values of cooperation). The explanation is quite intuitive too, as far as vision grows the visibility of scarce resources and the chances of detecting defectors grow as well. When there is no indirect reciprocity ($\theta = 0$), the first feature reduces the difference in terms of fitness of cooperators and defectors because the probability of finding meat grows for everybody despite of their strategy. When the indirect reciprocity mechanism works ($\theta > 0$), the second feature clearly reduces the advantage of any selfish behaviour, because defectors tend to have low reputation.

There is a particular and interesting result when vision is significantly low ($\upsilon = 5$). In this case, the system always reaches cooperation, even for $\theta = 0$ when defection should be the expected regime. To explain this contra-intuitive result we have to go to one of the assumption of the model: the imitation of public strategies. The hypothesis of the model is that a People agent only can imitate observable values. Under this assumption, only when an individual makes a public call and someone comes, or defects and someone observes her defection, her strategy becomes public. When vision is low, a defection is rarely detected, so when someone imitates a defector, she is really imitating the last public behaviour of the defector, which probably corresponds to a past cooperative strategy since cooperation implies making public the strategy. Therefore, the imitation mechanism reinforces positively the cooperative behaviour, and this effect dominates the system behaviour for low values of *vision*.

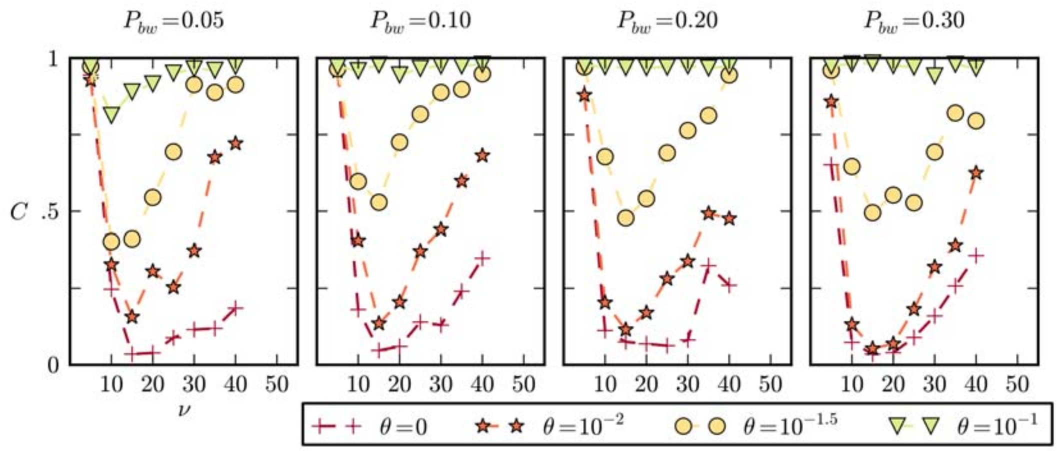

Fig. 8. Each graph shows the average cooperation at the end of simulations for different values of θ when the parameter vision varies, and the probability P_bw is fixed to a particular value.

7. -CONCLUSIONS

It is already well known that there is an universal human tendency to cooperate. The purpose of this research, therefore, is going far beyond. We aim to understand the conditions and mechanisms through which cooperation is given in order to analyze how social ties (that are part of human nature) work.

Even though Yamana society is just one more example, this case study provides the opportunity to analyze cooperation in terms of a very specific and time-constrained dilemma. In this particular case, we already know on the basis of ethnographical sources, that people promote cooperative attitudes and penalize those who do not cooperate. Social norms act as a way to regulate individual behaviour (in this case of the agents, which are understood as a social unit or household/canoe) in relation to what we can consider a social standard that is promoted.

This paper shows the state-of-the-art of the case study and first results obtained through the experimentation process. The model shows that just polarized behaviours are stable. The system reaches a regime where a cooperative norm is established or a regime where selfish defection is generalized; intermediate results are very unlikely. Our analysis shows that two key parameters influence the chances that population coordinates in one or other state. If the resource is the element that completely determines the survival fitness of the population, general defection is the most probable outcome. However, if social life modulated by reputation becomes relevant in the society, even for low values, then benefits from aggregation are salient. Thus a strategy that capitalizes social reputation proves to be more successful, and consequently the cooperative norm is promoted. The other relevant cause is the effect of vision, how easy is to find the resource and hence to detect a possible defector. In general when social capital matters, vision enhances cooperative behaviour. These computational results support in a formal way the hypothesis about the influence of variables that appear to be of paramount relevance such as the role of reputation and imitation of strategies in promoting or hindering cooperation, the fact that individual behaviour becomes social when decisions (cooperate or defect) are made public, or the opportunities of cheating and social punishment, among others.

Likewise, these results show that a stranded whale not only afforded food, raw materials but also provided the conditions to enhance social capital in Yamana society and to reinforce a network of relationships that is crucial for social reproduction (such as providing a scenario to develop youngster initiation ceremonies). In other words, the exceptional accumulation of food mainly offered the possibility to perform practices and to materialize norms that create and recreate the *habitus* (Bourdieu 1977) of the social life. Consequently, the value of the whale cannot be reduced either to its nutritional content or to the possibility to gather people otherwise disperse, as it produces a context for displaying social prestige and for a public demonstration of generosity (that could be utterly used to obtain mates, to reinforce social networks to cope with stress conditions etc.). This situation could explain the apparent low incidence of storage of whale blubber at individual/household level.

It is interesting to remark here that evidence attained by this case study provides experimental and empirical support to signaling theory (Bliege Bird and Smith 2005) to the extent it highlights the paramount importance of symbolic capital for obtaining benefits with material consequences. At the same time and in relation to hunter-gatherer research, these results show the value of reputation in a society with relative low levels of social heterogeneity or inequality among households.

The combination of ABM models and ethnographical sources within the framework of an ethnoarchaeological approach offers a heuristic and valuable tool to unveil the mechanisms embedded in cooperation practices; it has proved to be useful to formulate new hypothesis and to notice the strength of social ties and the effort invested in their maintenance. Cooperation, as a particular type of social behaviour, may generate contexts where other social dimensions are enhanced: in our case study, ceremonies and many other activities were carried out during aggregation events in which cooperation was an essential factor.

This research constitutes part of a broaden project addressed to explore cooperation in hunter-gatherer societies and to develop archaeological methods and theory in hunter-gatherer inquiry such as identifying the materiality of cooperation in the frame of aggregation events (Briz et al. 2009; Zurro et al. 2010). To accomplish this general goal the dynamic of cooperative behaviors has to be disentangled. Thus, the future agenda entails the construction of a solid corpus of hypothesis, on the basis of historical reports and simulation results, in order to elucidate what kind of archaeological variability is considered relevant in social aggregation/cooperation episodes. From our concern an accurate identification of the variables implied in these social phenomena will lead to recognize unambiguous anthropic markers of social cooperation to be extended to different case studies.

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Ref Type: Unpublished Work

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