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Simulation as a methodological tool: inferring hunting goals from faunal assemblages

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12.1 Introduction

In this paper I wish to address a neglected role of simulation in archaeology, that of a methodological tool. The development of middle range theory in archaeology has principally been by studying modern human societies. Inherent problems with such methods suggest that alternative approaches are required and simulation provides one such approach. The archaeological problem I will use to illustrate this is the inference of hunting goals of prehistoric foragers from the faunal assemblages of the archaeological record. First I will briefly explain why methods for such a task are required.

The application of evolutionary ecological theory to hunter-gatherer subsistence, particularly in the form of optimal foraging theory, has led to the recognition that hunters may adopt any one of a range of hunting goals. These may be related to the maximisation of energetic intake, the minimisation of foraging time, the minimisation of the risk of a shortfall in food supply, the satisfaction of a mixed set of nutritional requirements or other such goals. Understanding the nature of the goal adopted is a critical element in describing the nature of the foragers' adaptation to the environment and in explaining variability between the behaviour of individuals and groups. When archaeologists are faced with a set of faunal remains an inference needs to be made from such data as to the nature of the hunting goals that led to the formation of that assemblage. It is the problem of how such inferences can be made that I will tackle in this paper. Some general remarks on archaeological theory and method are initially required.

12.2 Archaeological theory and method

The central problem facing archaeologists today is not theoretical but methodological. As Binford has repeatedly argued (*e.g.* Binford 1977, Binford 1983) it is the question of how we can move from the statics of the archaeological record to the dynamics of past behaviour. The discipline is at present theoretically rich, with approaches ranging from systems analysis through marxist and structural archaeology to the post processualists (see Hodder 1986). Such theoretical diversity is healthy but cannot help to describe and explain past cultural development until there is an equally strong set of methodological tools to infer past behaviour from the materials of the archaeological record. Only then can competing theoretical approaches be evaluated and progress in understanding the past made.

Methodological, or middle range research, has principally been pursued by studying modern societies. As Robin Torrence (Torrence 1986) has recently discussed, such work can take a variety of forms. The most common is inductive, essentially drawing a set of correlations between types of behaviour and their material consequences. An alternative approach, which she adopts, is to set up some expectations concerning these relationships and test them with ethnographic data. Then, if the expectations are met, to use these to make the inferences from the archaeological data.

There are many problems with middle range research when dependant upon such ethnographic data within either a deductive or inductive framework. One, which Torrence herself meets, is simply the lack of suitable ethnographic descriptions, and societies upon which new observations can be made, which contain data on both the behaviour one is concerned with and the material residues of it. A second problem is that the bone and lithic assemblages of the archaeological record are often palimpsests from different occupations at the same site accumulating over many years. Ethno-archaeological studies of site formation typically extend over only one or two seasons and hence long term processes are not considered. A third problem is more fundamental and concerns the relevance of any middle range theory developed from studies of modern humans to the archaeology of pre-*sapiens sapiens* man, which after all constitutes the bulk of the archaeological record. These and other problems demand that alternative methods are required for developing inferential methods. The problem of inferring hunting goals from faunal assemblages provides a useful illustration of this need.

As I described above, hunter-gatherers may adopt any of a diverse set of hunting goals and it is important for archaeologists to infer correctly which of these was adopted in particular areas and times. One approach for developing appropriate methods may be to use ethnographic data. By this means relationships may be established between particular hunting goals and characteristics of faunal assemblages that can be recovered from the archaeological record. Such characteristics may be the size and species diversity of the assemblage, the types of species represented, their age/sex structure and body part representation. However a large sample of modern hunters, exploiting a similar set of species, with different and known hunting goals would be required for this. Moreover, faunal assemblages may accumulate over long periods of time during which there may be environmental changes (such as resource depletion or climatic change) posing the problem of whether these and taphonomic processes would destroy any patterning due to particular hunting goals. Clearly an ethno-archaeological approach for developing the inferential methods is difficult, though some progress could no doubt be made. An alternative, or rather complementary, approach is to use computer simulation. To explain how this may be done I will turn to a specific case study concerning the Mesolithic of Northern Europe.

12.3 Mesolithic assemblages and hunting goals

Attitudes to the Mesolithic period have changed dramatically in recent years from one considering it as a period of little importance to one recognising significant and dramatic cultural variability and change (*e.g.* Zvelebil 1986b). Studies of Mesolithic adaptation to the environment have focussed on a descriptive cultural ecological approach with the exception of Jochim's (Jochim 1976) seminal study of subsistence and settlement in the Danube valley. As with other hunter gatherer populations we need to ask what were the hunting goals of Mesolithic foragers and whether these did vary across space and time. There is a good set of faunal assemblages from the hunting of large terrestrial ungulates from southern Scandinavia and Germany from which inferences might be made if the appropriate tools were available. Table 12.1 provides

SITE	AREA M^2	RED DEER	ROE DEER	PIG	ELK	AUROCH
DENMARK[1]						
Aggersund	70.0	22.2	11.1	66.6	0.0	0.0
Vaengo So	100.0	18.9	20.5	35.7	0.0	24.8
Brovst	200.0	62.35	8.05	29.6	0.0	0.0
Dryholm	1000.0	37.3	15.5	34.2	2.25	10.7
Havno	1500.0	28.6	28.6	28.6	0.0	14.3
Aamolle	1850.0	35.3	41.2	17.6	0.0	5.9
Ertebolle	2800.0	17.1	43.4	35.5	0.0	1.3
Meligard	3100.0	33.3	25.9	40.7	0.0	0.0
GERMANY[2]						
Jagerhaus	139.5	30.8	25.6	43.6	0.0	0.0
Falestein	134.0	30.0	43.3	20.0	0.0	6.7
Inzigkofen	21.5	25.0	40.0	35.0	0.0	0.0
Lautreck	13.5	14.3	42.8	42.8	0.0	0.0

1. From Rowley-Conwy 1981, Rowley-Conwy 1983, Bailey 1978, Bay-Petersen 1978, based on MNI or bone proportions
2. From Jochim 1976, based on MNI

Table 12.1: Large ungulates in Mesolithic assemblages from Denmark and Germany (as percentages of the large ungulate total)

data on the large ungulate composition of later Mesolithic assemblages from Denmark and Germany showing that three large ungulates are predominant (red deer, roe deer and pig), but the frequencies of each vary markedly.

Computer simulation can be used to develop the required methodology. To do this a model would need to be constructed to simulate Mesolithic hunting with the facility of attributing the hunters with different types of foraging goals. Then a series of experiments could be conducted to model the types of assemblages created by different goals and a set of criteria identified which could be used to draw inferences from the static assemblages of the archaeological record. The value of these criteria of course depends upon the accuracy and sophistication of the simulation model and a set of judgements as to the important variables contributing to assemblage variability and hence those to include in the model. The MESO-SIM model, which has been developed as part of my Ph.D thesis, aims to be used in this manner, being a simulation of Mesolithic foraging. It has also been developed for other ends concerning a study of hunter-gatherer information processing and decision making. Since I am using this to illustrate the potential of simulation as a methodological tool I will only give a brief description of MESO-SIM before showing the types of experiments and results that can be gained. I will not include any mathematical details some of which are included in Mithen 1987.

12.4 The 'MESO-SIM' model

'MESO-SIM' basically involves a simulation of a group of hunters foraging from one site for a fixed number of days (or hunting trips) and a fixed number of visits to the site. Each simulated day the foragers hunt individually taking decisions as to which resources to stalk and kill and then return to the base camp. Elements from each kill enter one accumulating assemblage. At the site before (or after) foraging the individuals exchange information about their foraging experiences. The model has three basic elements; a model of the post-glacial environment, a model of the hunting process and a model of decision-making and information processing. I will briefly describe these before explaining how the simulation is used.

12.4.1 The modelled environment

The aspects of the post glacial environment which require modelling partly depend on the type of hunting behaviour adopted by the Mesolithic foragers. On grounds of body part representation in certain assemblages (Legge & Rowley-Conwy 1986), the microlithic technology (Zvelebil 1986a), and healed wounds on bones (Noe-Nygaard 1974) one can conclude that this was of an encounter foraging type (see Binford 1980). This suggests that each of the available resources need to be modelled by five characteristics: probability of encounter, utility, pursuit time, probability of a successful kill, and processing time. The model allows five large ungulates to be available to the hunters—red deer, roe deer, pig, auroch and elk although the last two are often removed since these became extinct in certain areas of early post-glacial northern Europe. Each resource is separated into three classes, adult male, adult female and juvenile. Hence a total of fifteen different types of resource require modelling with respect to each of the five characteristics listed above.

The principal method for modelling these characteristics is to use quantitative relationships derived from an analysis of relevant ethnographic data between ecological factors that can be estimated by modern analogy (*e.g.* Jochim 1976) and these characteristics. For instance by using Marks' (Marks 1976) study of encounter foraging by the Valley Bisa a statistically significant relationship can be derived relating probability of encounter to the resources density and aggregation size. For each of the post-glacial ungulates these ecological factors can be estimated and then this relationship used to model encounter probabilities. Similar methods are used for the other four characteristics.

12.4.2 The modelled hunting process

As I stated above various aspects of the archaeological record indicate that Mesolithic large game hunting was by an encounter method. This can be modelled by using ethnographic data as to how such hunting is conducted. The resulting model in 'MESO-SIM' provides the basic structure for the simulation. Essentially a fixed number of hunters forage from a site for a fixed number of days per visit and a fixed number of visits. Each day a fixed number of minutes are available for foraging and the simulation tracks the activity of each hunter during each minute.

In each minute a hunter can be in one of six states: searching, encountering, pursuing, killing, processing and passive.

In the first minute all hunters are searching for game. The simulation uses encounter probabilities to test whether each hunter encounters a resource. If so he enters encountering state for the next minute, otherwise remains searching. In encountering state the simulation uses the probabilities for stalking the resource, resulting from the decision process of the hunter to be described below, to define whether the hunter returns to searching state by ignoring the resource or enters pursuit state by choosing to stalk it. If the latter, the forager will remain in that state for the pursuit time of the resource after which he enters killing state. Here, the simulation uses the probabilities of successful kill for the resource to test whether or not it is killed. If not, the hunter returns to searching, otherwise he field butchers the resource for its processing time. After that has elapsed he returns searching. If while searching the stalk probabilities for all resources fall below some predefined threshold this models the loss of motivation of the hunter for further hunting and he enters passive state for the rest of the day. Fig. 12.1 illustrates hunting states and transitions between them. Consequently the simulation tracks the hunting activity of each individual during each minute of the day. It is assumed that some part of any kill that any individual makes is returned to the site and enters one accumulating midden. Consequently the composition of this reflects the kills made by the group. As game are killed the environment becomes depleted. This also occurs since game are scared away by the presence of the hunters. However on a return to the site for a later visit it is assumed that game have returned to the unexploited and undisturbed densities. New kills enter the same midden as before.

When the hunters first arrive at the site a predefined number of days (usually five) are spent searching and stalking resources without actually making any kills. This provides the simulated hunters with a store of information about the environment which in the real world would have been carried over from previous visits or acquired when travelling to the site. During the day there is no contact between the foragers and decisions to stalk particular resources are taken by individuals. However at the end of the day the simulation models information exchange between the hunters, the most successful hunters being those who pass on the most information.

12.4.3 The modelled decision making process

When engaged in encounter foraging the hunter takes one crucial decision: whether or not to stalk an encountered resource. In 'MESO-SIM' this is defined on a probabilistic basis and a model is used to define the 'stalk probabilities' for each hunter for each resource at each minute of the day. These probabilities are defined using an equation that is referred to as the decision rule.

This has two principal elements, an information processing and a decision component. The first of these defines how information from the sources available to the forager is processed; four such sources are modelled. First, stored knowledge, that is information stored in the forager's memory concerning relatively constant factors such as the mean weight of different resources, their pursuit and processing times. Secondly is long-term experience, that is from the previous day's foraging from the site. This provides the forager with information concerning current and expected foraging efficiency. Third is short term experience, that is from the previous minutes during that foraging day providing information about his immediate needs. Finally, information from other individuals concerning their long-term experience that may be acquired during the information exchange process. Using a set of simple equations the model defines how information from these sources is processed to define probabilities for stalking each possible encountered resource. Since the resources vary in their attributes (some are easy to kill but provide little utility while others may be the converse), the stalk probabilities for each resource are different. Their values are dependent upon the decision component of the rule since this defines the hunting goal. Since the environment changes owing to the depletion of game from hunting and being scared away, and the hunters needs change due to kills either being or not being made, the stalk probabilities from the resources change within and between hunting trips.

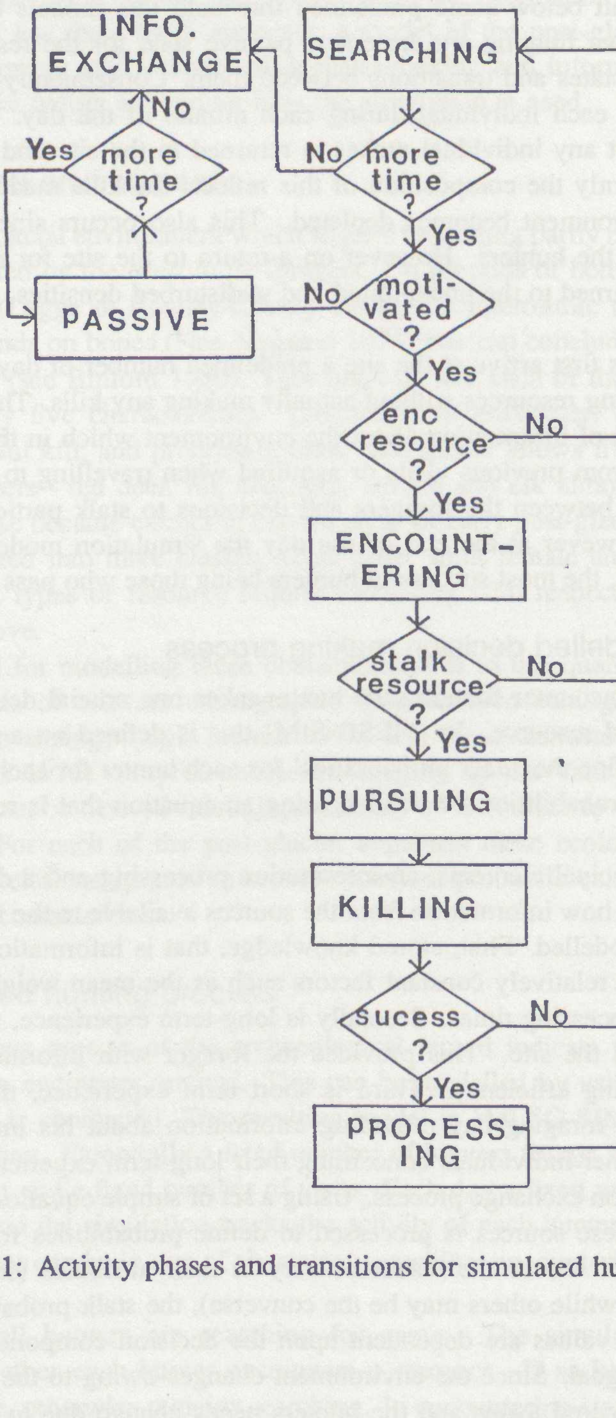

Fig. 12.1: Activity phases and transitions for simulated hunters

In general the types of hunting goals in the model are of a 'meliorising' type: the foragers are trying to improve on their foraging efficiency rather than maximise it (see Dawkins 1983, pp. 45–46). The basic goal attributed to the foragers is a 'long term utility increasing' goal, where utility is the rate of acquisition of food and raw materials. However additional elements may be added to modify this goal. For instance a satisfying element may be added which reduces stalk probabilities once a kill has been made during one day according to the degree to which the hunters needs have been satisfied. A second additional element that may be added with or without the satisfying element is a daily risk reducing element. This increases stalk probabilities with the time of day to reduce the risk of failing to make any kills. Consequently towards the end of the day the forager will have a high probability for stalking even the low utility resources that may have been ignored earlier. Other types of goals may also be introduced such as reducing the time spent hunting itself. Consequently there are a set of goals that can be attributed to the hunters and experiments can be conducted to investigate the relationship between hunting goals and assemblage characteristics.

12.4.4 The simulation model

The simulation program is written in Pascal with calls to FORTRAN NAG procedures for random number generators. It is run on the University of Cambridge IBM 3081 computer. A flow chart summarising 'MESO-SIM' is provided in Fig. 12.2. Each time the simulation is run sets of data relating to a range of issues can be derived, not only the composition (in terms of species and their age/sex structure) of the resulting assemblage that is of interest in this paper. In respect to these data the assemblages created each time the simulation is run are the result of the values given to twelve parameters which must initially be defined. These twelve parameters can be described in three sets.

First are those which define the size of the model and all take integer values:

- **NoPers** defines the number of hunters in the group (*e.g.* 5, 10).
- **MaxDays** defines the number of hunting trips per visit (*e.g.* 10, 25). The simulation defines the composition of the assemblage which would have resulted from hunting trips of all lengths up to this maximum (*e.g.* for MaxDays = 25, twenty separate assemblages will be simulated if there are five days of pre-hunting searching).
- **NoMins** defines the number of minutes available per trip (*e.g.* 300)
- **NoVisits** defines the number of visits to the site.

Second are a set of parameters which relate to the model of the environment:

- **SerFact** takes values between 0.0 and 1.0 and defines the 'richness' of the environment. Higher values result in game being encountered more frequently.
- **RiskFact** similarly takes values between 0.0 and 1.0 and relates to the technology used by the hunters and their success in killing game. A higher value increases the chance of successful kills following a stalk.
- **ScareFact** this also takes values between 0.0 and 1.0 and defines how quickly game is scared away by the hunters presence.

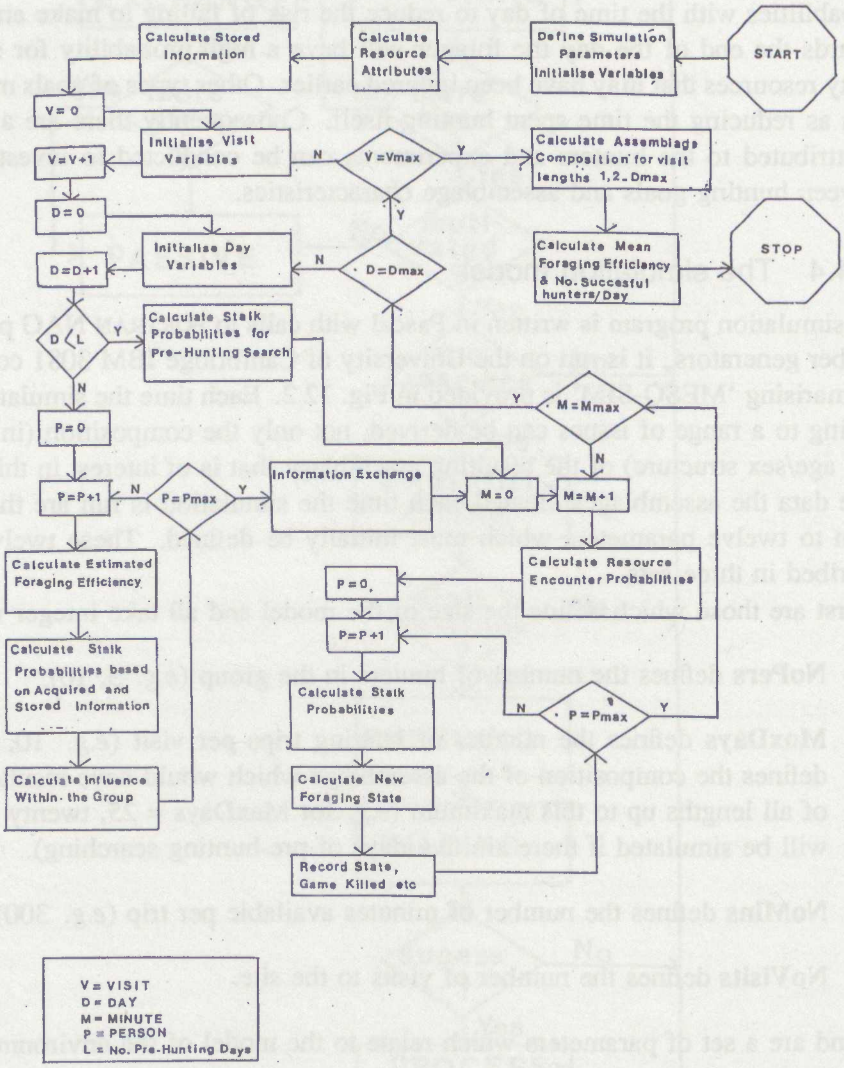

Fig. 12.2: Flow chart of MESO-SIM

The third set of parameters relate to the equations used for modelling the processing of information. These are the values of four constants which need to be used in these equations. The most important of these is

- **Attention** which defines the weight given to information from each of the previous foraging days (it is similar to the 'memory' parameter in Harley's (Harley 1981) ESS learning rule model).

The fourth set of parameters has two members. First is **HuntGoal** which defines the hunting goal attributed to the foragers (*e.g.* utility increasing with satisfying, or with risk reducing or with both or neither). Second is **RandStart** which defines the starting value for the random number generator seed. This is important since due to the stochastic element in the model even if all other parameters remain constant between runs a different set of random numbers will lead to a different composition for the assemblage.

12.5 Hunting goals and assemblage composition: experiments using 'MESO-SIM'

Returning to the main argument of this paper one can now see how computer simulation can be used as a methodological tool. Using the MESO-SIM model a set of experiments can be conducted to investigate the effect of four types of factors on assemblage composition:

1. the size of the group, length of stay and number of visits to a site;
2. the nature of the environment (in terms of resources available, game encounter frequency, the rate game are scared away and ease of killing game);
3. the hunting goals of the foragers; and
4. stochastic factors.

To illustrate some of these facilities and the types of comparisons that can be made between real and simulated assemblages we can consider some experiments made to investigate the variation in assemblage composition from the adoption of different hunting goals. These are only preliminary runs of the model to illustrate its use, not to make a significant investigation of the models behaviour.

As an example we can compare two contrasting hunting goals. Both of these have long-term utility-increasing goals and short term satisfying elements, but only the second has a risk-reducing element. For each goal eight runs of the simulation have been made each with different values for the 'RiskFact', SerFact' and ScareFact' parameters. Two values were chosen for each of these parameters making a total of 2^3 runs to explore all combinations. Each different set of values models a unique type of local environment. All other parameters had constant values between runs (NoPers = 5, MaxDays = 25, NoMins = 300, NoVisits = 5, Attention = 0.75, RandStart = 555). Only three species of ungulate were made available to the foragers, red deer, roe deer and pig since the comparisons I will make will be with later Mesolithic assemblages from Denmark and Germany when the other ungulates were very rare or extinct.

The graphs in Figs. 12.3 to 12.8 illustrate the composition of the resulting assemblages. Each graph shows the percentage contribution of one of the ungulates to the assemblage total; those labelled 'run B' are created with the second goal, that is with the daily risk-reducing element,

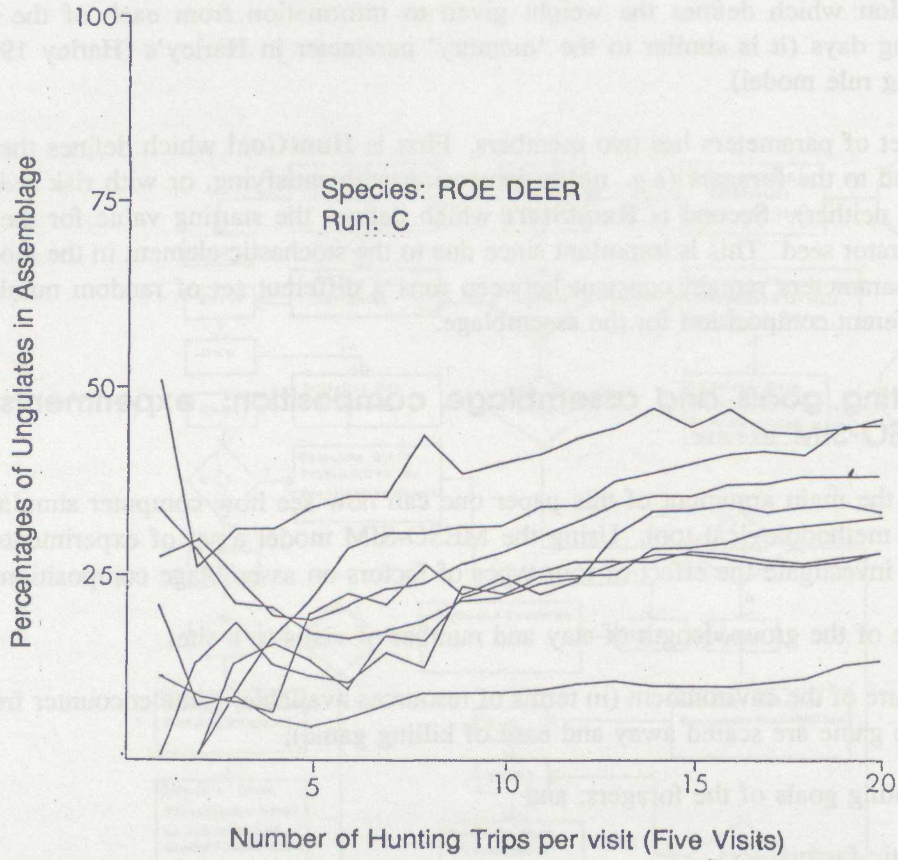

Fig. 12.3: Roe deer in assemblages from hunting goal without risk-reducing element

while those labelled 'run C' are from the use of the first goal. Each graph has eight lines, one relating to each run of the simulation.

Two aspects of the graphs can be considered. First, the affect of the length of visit to the site (*i.e.*of the hunting trip) on the composition of the assemblage. As can be seen this does have a marked effect on the assemblage composition for the hunters without the risk reducing element in their hunting goals (*i.e.* run C). In these assemblages, roe deer (Fig. 12.3) gradually increase in their frequency as the hunting trips get longer while red deer (Fig. 12.5) decreases after an initial rapid rise in some cases. Pig (Fig. 12.4) remains constant or slightly falls, although in two cases it is dominant in the smallest assemblages. In contrast assemblages resulting from hunters with a risk-reducing element (Figs. 12.6–12.8) experience little change in composition as the length of hunting trips increase.

Contrasts between the hunting goals/assemblages can also be drawn on a second variable, the relative frequency of the different species. Assemblages from a non-risk-reducing goal tend to be dominated by red deer and have roe deer as the least frequent species. In the assemblages

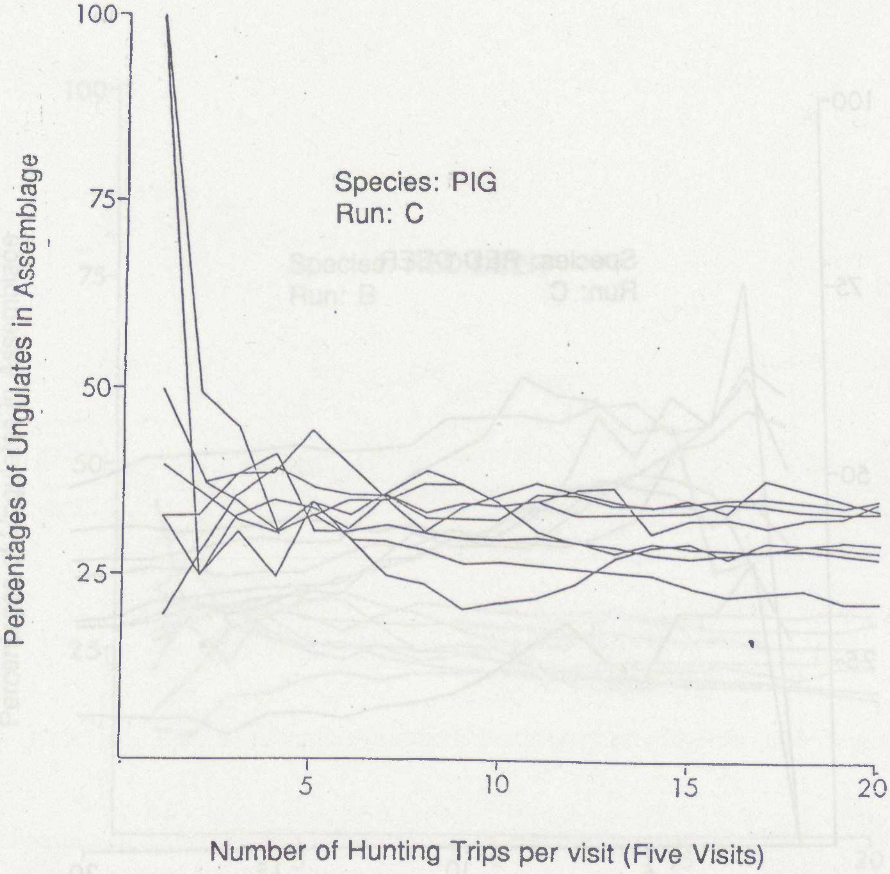

Fig. 12.4: Pig in assemblages from hunting goal without risk-reducing element

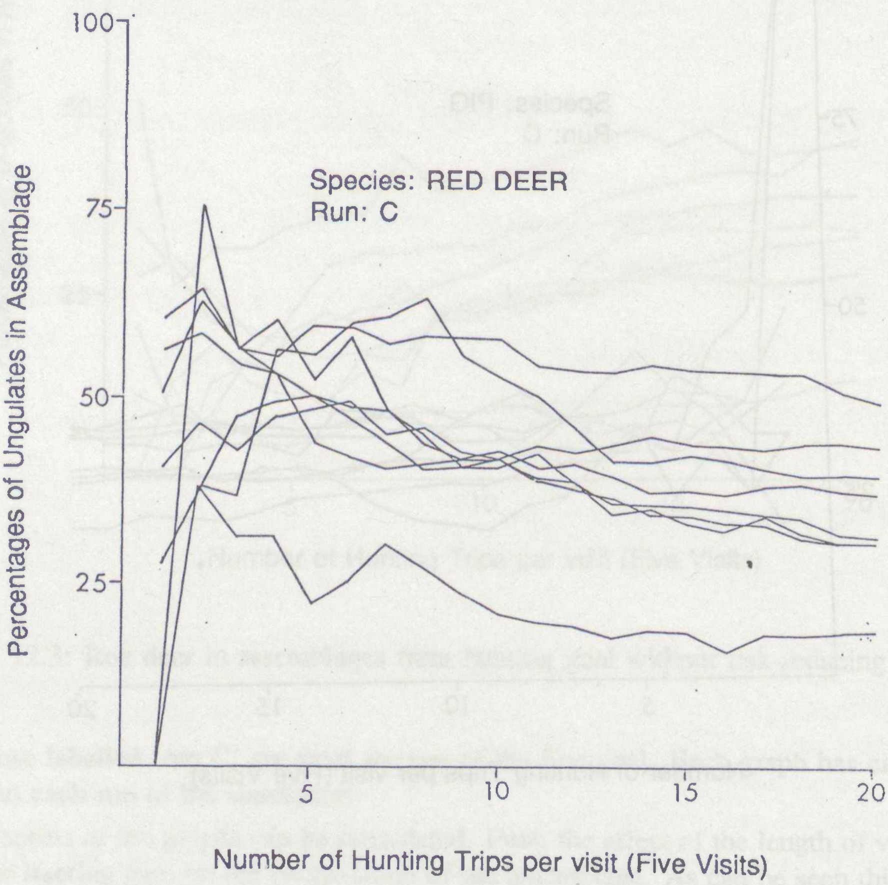

Fig. 12.5: Red deer in assemblages from hunting goal without risk-reducing element

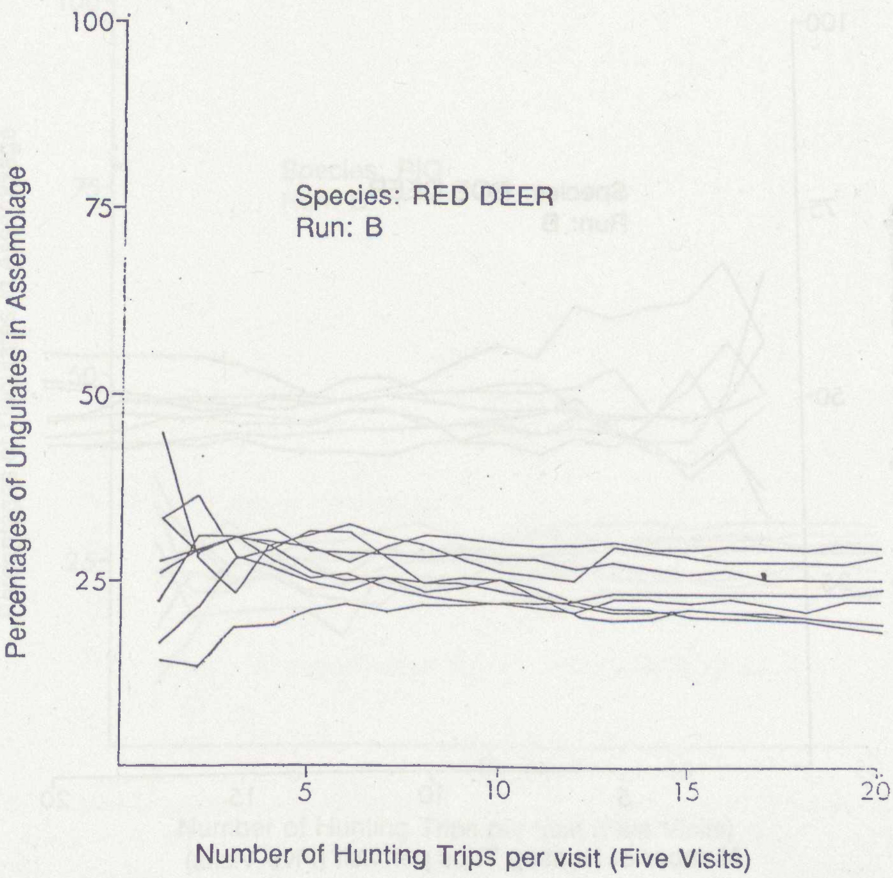

Fig. 12.6: Red deer in assemblages from hunting goal with risk-reducing element

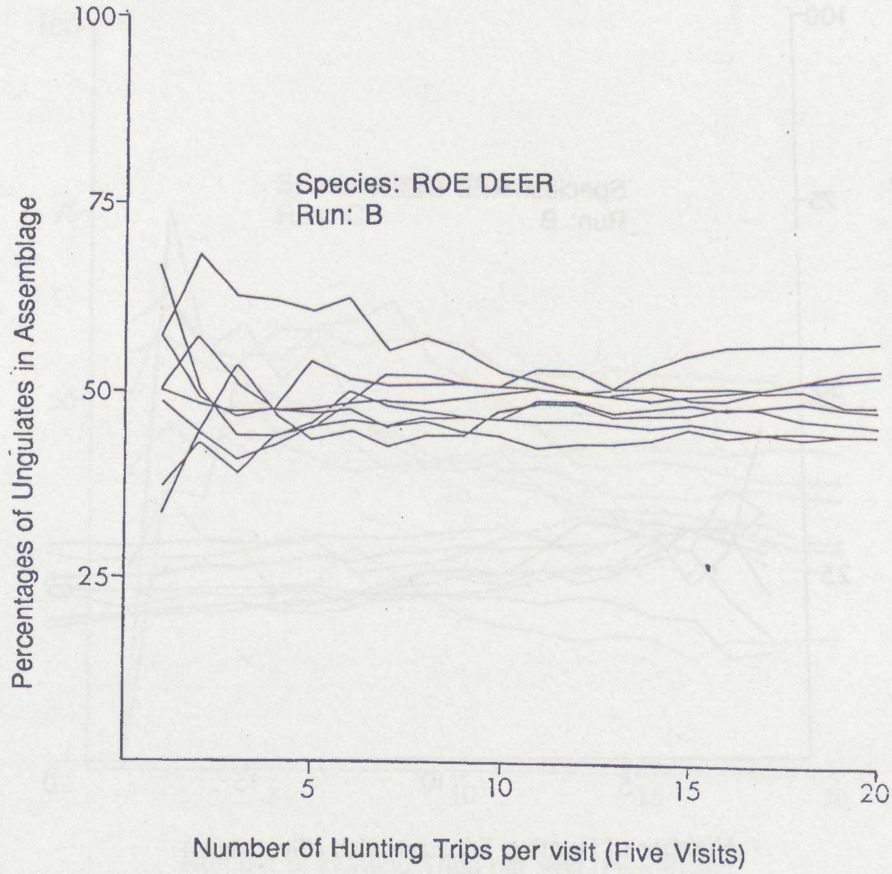

Fig. 12.7: Roe deer in assemblages from hunting goal with risk-reducing element

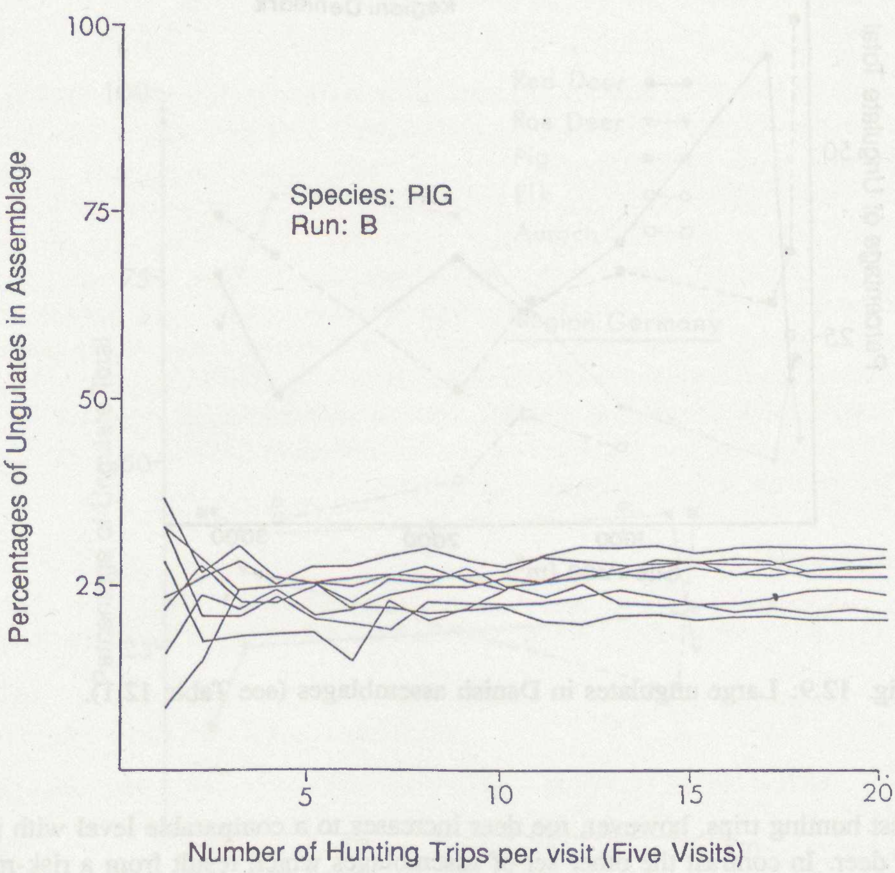

Fig. 12.8: Pig in assemblages from hunting goal with risk-reducing element

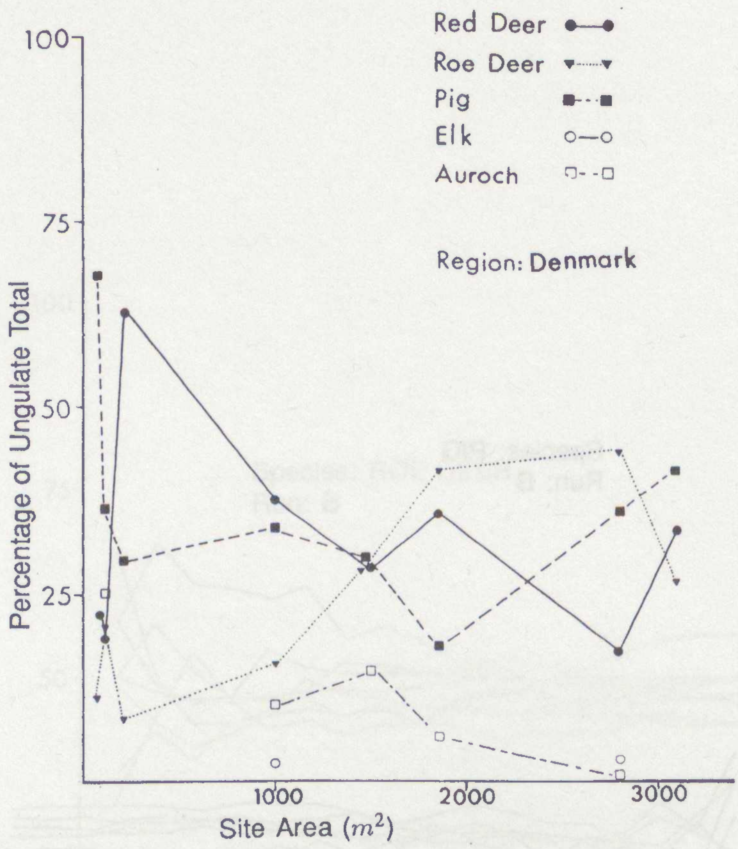

Fig. 12.9: Large ungulates in Danish assemblages (see Table 12.1).

from the longest hunting trips, however, roe deer increases to a comparable level with pig and sometimes red deer. In contrast the other set of assemblages which result from a risk-reducing element in the hunting goal have roe deer as the dominant species and pig and red deer at similar lower frequencies. Consequently there appears to be a clear set of criteria for distinguishing between these two goals from static faunal assemblages. Of course other goals may lead to similar characteristics and a more complete set of experiments is required.

To make comparisons with real assemblages we need to know initially the length of hunting trips which created these. To do this we can use the direct relationship between site area and length of occupation in hunter-gatherer camps that has recently been described for hunter-gatherers by O'Connell 1987. This allows us to plot the frequencies of the ungulates in the Mesolithic assemblages against the area of the site and then make direct comparisons with the graphs in Figs. 12.3–12.8. Fig. 12.9 plots the Danish assemblages and Fig. 12.10 the German ones using the data presented above.

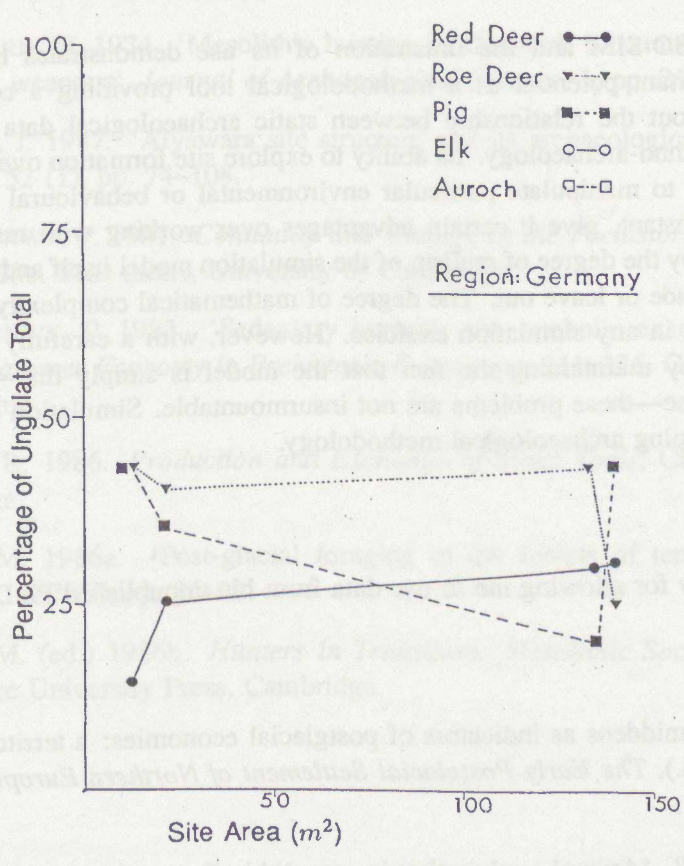

Fig. 12.10: Large ungulates in German assemblages (see Table 12.1).

It is clear that the graph in Fig. 12.9 has similarities with those in Figs. 12.3–12.5, the assemblages created without a risk-reducing element in the hunting goal. Roe deer increases with site size/length of hunting trip, red deer experiences a sudden rise and then gradually falls while pig has a sudden fall then remains fairly constant. Consequently utility increasing hunting goal without a risk-reducing element may be inferred. In contrast to this the German assemblages show little change in composition with site size and roe deer is the dominant species indicating a risk-reducing element to the hunting goal. Clearly a more detailed set of experiments is required and other data such as the age/sex structure of the species need consideration before these inferences can be held with confidence. However, the principle of using simulation as a methodological tool is illustrated by these examples.

12.6 Conclusion

The description of MESO-SIM and the illustration of its use demonstrates how computer simulation has an important potential as a methodological tool providing a complementary approach to learning about the relationship between static archaeological data and dynamic human behaviour from ethno-archaeology. Its ability to explore site formation over long periods of (simulated) time, and to manipulate particular environmental or behavioural parameters at will or to hold these constant, give it certain advantages over working with real people. Of course, it is also limited by the degree of realism of the simulation model itself and the dilemmas of which variable to include or leave out. The degree of mathematical complexity also remains a substantial problem, as in any simulation exercise. However, with a carefully and logically constructed model and by maintaining the fact that the model is simply that—a tool to be used for a specific purpose—these problems are not insurmountable. Simulation can provide a significant aid for developing archaeological methodology.

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