

# Quantification in Archaeobotany: Charcoal Analysis and Fire-Wood Management

Raquel Piqué

Dept. Antropologia Social i Prehistòria. Universitat Autònoma de Barcelona  
Fac. de Lletres. Edifici B. 08193. Cerdanyola del Vallès. Barcelona. Spain.  
E-mail: ilphf@blues.uab.es

## Introduction

The study of charred wood remains, recovered from archaeological sites, has traditionally been considered from two different perspectives, depending on the emphasis placed on stressing the quality of the charcoal, as a testimony to landscapes of the past, or as a product of the cultural norms of past human groups.

From the first perspective, archaeological charcoal provides, above all, paleoecological information, which is held to be an authentic sampling of past vegetation, while the human factor, in the contribution of wood to the settlements, is minimized. The collection of fuel was produced at random and was governed by the Principal of Least Effort (Vernet & Thiébault, 1987; Vernet, 1986, 1990).

From the second perspective, however, the gathering of fuel would involve a selection of specific species of wood, depending on the preferences of human groups (Ford, 1979; Smart & Hoffman, 1988; Pearsall, 1989). The Principal of Least Effort did not always operate in the collection of fuel (Sackleton & Prins, 1992), as archaeological charcoal cannot necessarily be considered a sampling of past vegetation.

The differences in these two schools of thought are not limited to distinct perceptions about the origins of archaeological charcoal; in addition, the quantification of remains and its significance are appreciated in a different way.

From the paleoecological stance, the quantification of analyzed pieces of charcoal provides information regarding the relative importance of a species in the environment, and regarding the structure of past vegetation (Vernet, 1991; Chabal, 1988, 1992). In this sense, Chabal's claim is indicated, which considers archaeological charcoal to be a function of past vegetation (Chabal, op. cit.). The principal statistical instrument used to infer environmental change is the comparison of the relative abundance of taxa in the course of a sequence.

On the other hand, for researchers working from a paleoethnobotanical perspective, the quantification of charred wood remains can have various meanings. Some consider that the quantification of remains describes the pattern of fuel provision and the changes that occur in this pattern (Shackleton & Prins, 1992; Pearsall, 1988; February, 1992; Miller, 1991). Others also point out the danger of assuming a change or a stability of environment, where there may not be one, thus, confusing fluctuations in the course of a sequence, to be evidence of environmental changes, when perhaps they only reflect changes in the pattern of wood

provision (King & Graham, 1981). Also, in this case, the most used statistical instrument is the comparison of the relative frequencies, in which taxa appear, either among archaeological structures or levels.

Other researchers consider that charcoal does not lend itself to quantitative analysis, due to the factors which lead to its incorporation and preservation in archaeological deposits (Wilcox, 1974). They consider that the quantification of remains cannot provide us with information about past vegetation, nor the patterns of fuel usage. From this perspective, if the quantification of remains can't even provide us with information about the burnt biomass, then it will hardly provide us with the existing biomass of the environment. Their arguments are based on the anthropic origins of the remains, and on the impossibility of controlling the set of factors which take part in the formation of the record. Among these, the most important factor would be fragmentation, connected to combustion, or to post-depositional processes. Without doubt, the process of charcoal fragmentation is the least controlled of all the factors, that take part in the formation of assemblages; and at the same time, it is the most important factor, given that it directly takes part in the lesser and greater appearance of remains.

## Fragmentation and quantification of remains

Prior to any discussion about whether archaeological charcoal is a reflection of past landscapes or is the result of social action, the question must be asked: what is the significance of a large number of charcoal fragments, belonging to one taxon or another. In the case of charcoal, one fragment cannot be attributed to one individual; neither can we even be sure if all the fragments recovered from the same location correspond to one single branch. So we should ask ourselves what information can lead us to the quantification of charcoal remains and its quantitative analysis.

Understanding the formation processes of archaeological charcoal assemblages is the only way we have, to reach a better understanding of their significance. Even though, for each site, some of the formation processes will have been unique and specific, others can be analyzed jointly:

*-Process of combustion:* charcoal production is directly related to the interruption, either accidental or intentional, of combustion, and this is directly tied to the conditions, which cause combustion to take place. In this way the caliber of the branches, the type of structure used for combustion (open or closed, ground level or in an excavated pit, etc.) are non-constant factors, that can give rise to the

greater or lesser production of charcoal. Experimental work has permitted evaluating the influence of the structures used for combustion, in designated combustion areas, in the production of charcoal (March, 1992); and, according to these experiments, combustion which takes place in excavated pit structures would seem to produce a greater volume of charcoal.

*-Physio-chemical properties of wood:* it is also possible to determine the grade of resistance to burning and fragmentation. Various experimental studies have tried to evaluate if volume reduction and fragmentation are constants, or if, on the contrary, they depend on the conditions in which combustion takes place (oxidizing or reducing environments), the characteristics of the charred wood (size of the wood used) or of the specific properties attributed to each species (density, hardness or chemical components, specific to each taxon). Among the most representative and prominent work conducted in this area, is that of Bazile-Robert (1982) and Rossen & Olson (1985). From these studies, it can be concluded that the response of taxa to combustion is highly variable; but in addition, as the same authors point out, humidity and the size of the wood can also be determining factors in the conditions of combustion.

Due to all of these factors, it is thus not viable to establish corrective indices, that could permit the correlation of the initial volume of charred wood with the final volume of waste recovered during excavation.

Even though it is possible to correlate the volume of remains with the initial burnt biomass, it is certain that the taxa are usually represented in archaeological assemblages by a variable number of remains. We believe these quantitative differences to be related to the frequency and the manner, in which the wood was used, and not necessarily, to the existing biomass in the environment.

### **Significance of archaeological charcoal**

The interpretation of archaeological charcoal assemblages does not depend exclusively on the quantification and numerical analysis of remains. If the objective of quantification and its significance are not clear, then this work will provide very little information, towards an understanding of the significance of remains. For this reason, prior to the numerical analysis of remains, it is necessary to specify the previously established principles from which we are working. The quantification of remains and numerical analysis are narrowly connected to hypotheses of departure. For this reason, it is advisable to clarify, beforehand, the objectives of an investigation.

From the perspective outlined in this work, archaeological charcoal is, above all, the remains of human activity (Piqué, 1997). It is the result of diverse work processes, which a society constructs, in order to obtain the various kinds of benefits, which it requires to satisfy social needs. It follows, then, that these work processes are not the result of random organization, nor are they determined by the environmental conditions, where the human group is functioning; rather, they are established, regulated, and socially determined work processes.

The work processes that shape the productive sequence, of strategies developed for the management of forest resources,

begin with the search and extraction of rough materials from the surroundings. Through the administration, by a determined work force, of these rough materials, raw materials, instruments, and means for production are obtained, which allow the continued transformation of the resources into goods, fit for use and consumption. We are working from the hypothesis, which says that the work processes, practiced in the settlements, and the social relationship to production, determine the strategy for provision and the management of resources (Estévez, et al., ep. Terradas, 1996). The collection of wood, used as raw material, for the attainment of caloric and luminous energy, will be set, therefore, in the general strategy for provision of resources, generated by human groups, to insure their survival.

The strategy for the provision of woody fuel will be determined by various factors:

*-Social needs or demands.* That is to say, the quantity and quality of the energy, which permits the production and reproduction of the material conditions of social existence. This will determine the type of materials exploited, that is to say, the types of wood selected, and the nature of the exploitation or the intensity of the collection, the area of territory exploited, and the investment of time and energy. The demand for fuel will be determined by the number, the frequency and the intensity of combustion, related also to group size and the nature of the activities realized in the settlement.

*-Environmental supply.* The availability of woody species in the environment will determine the possibilities for the exploitation of resources. The nature and availability of vegetational raw materials depend on climatic factors, and edaphic factors, in the case of forest communities. Other factors that can influence the design of strategies for provision are the physio-chemical properties of the wood (resistance to combustion and flammability, resistance to mechanical transformations, morphology, etc.)

*-Development of productive forces.* The manner in which a society obtains its resources. Technological capacity also has an effect on the design of strategies for provision: possibility for the use of instruments, short or long distance transport of resources, etc.

The work processes, to follow, would be the management of the acquired product: comprehending the distribution of the product, if the provision is achieved jointly by different units of production, adaptation to social needs (drying, felling, etc.), and storage, in some instances.

The process of energy production involves the transformation of woody raw materials into energy through combustion. In this process, the activities required for maintenance of the areas, where combustion is accomplished (the adaptation or construction of an adequate space, periodic cleaning-up of waste) (Wünsch, 1991), are also involved. It is during this process that the raw material used undergoes the most important transformations.

Different types of energy are incorporated into different work processes. The fuel, transformed into energy, will play a part in the formation of other productive sequences, or will be used for other determined social needs (illumination, heat, alteration of the properties of other materials).



Generated waste is relocated through work processes, involved in the maintenance of areas where combustion takes place, and the maintenance of the social space (Wünsch, 1991). These work processes lead to the evacuation of waste, which when deposited, forms concentrations of waste. This waste is the material remains, of the collection of activities realized, and is what permits the reconstruction of productive strategies, of which the waste is a product.

The material evidence, of the development of work processes, related to the provision and management of fuel, and which allows their reconstruction, is basically the result of waste generated from the consumption of used raw materials. So, even though the process begins with the provision of woody raw materials, the recovered remains, in archaeological context, are the charcoal remains, which are generated during the process of energy production. In the same way, their final distribution obeys the strategies implemented for the adaptation and maintenance of the social space. For this reason, from the study of archaeological charcoal we can characterize:

The strategy for fuel provision, in that the remains of the consumption of raw materials permit the inference of how social needs have been satisfied, and which species were used in a preferred manner. The same also permits partial reconstruction of the tree and shrubby landscape in the settlements.

The transformation of raw materials into energy, through combustion, since carbonization is sign of the utilization of raw materials for energy production. Nevertheless, only the study of the areas, where combustion takes place, permits inference about the conditions, under which the combustion was accomplished.

The incorporation of the energy produced, into other work processes, can be inferred through the spatial distribution of energy producing elements, and their connection to concrete work processes.

The work to adapt and manage the areas, where combustion takes place, and the social space, can be inferred from the distribution of burnt waste.

#### **Quantification of remains and social management of fuel**

The study that we present here, regarding the social management of fuel, based on archaeological charcoal, has been carried out with materials from Tunel VII, an archaeological site, with recent chronology (the last century), of canoeing communities from the Tierra del Fuego (Argentina) (Estévez & Vila, 1995). The principal characteristics of the studied site are:

-it deals with anthropogenic shell deposits; in this type of site, units of extraction can be defined, according to levels of stratification, formed in the different moments of deposition. In these sites, there exist two types of differentiated stratigraphic units: shell accumulations, that usually are distributed in the periphery of the occupied space and have origins in the intentional deposition of waste, by human groups; layers of earth, which overlap in the center of the occupied space, due to natural processes of erosion, transport and deposition.

-Its recent chronology permits knowledge of the fundamental characteristics of the vegetational landscape,

and also permits testing the role of environmental supply in the strategy for fuel provision.

Charcoal was analyzed from 9 overlapping occupations, singled out according to the microstratigraphic relations of the sub-units. Each of these occupations was composed of a central unit of earth and of various anthropogenic shell accumulations and waste (shell deposits).

The quantitative analysis of the obtained data, from the analysis of the charcoal, was directed towards clarifying aspects related to the social management of fuel. For this, we include the statistical tests conducted regarding three big subjects:

valuation of the effects of depositional and post-depositional factors

fuel provision

fuel management

#### **Valuation of the effects of depositional and post-depositional factors**

In order to evaluate the reliability of the studied sample, the first thing to be discussed is the effect of depositional and post-depositional factors, in the formation of the record. Given that the characteristics of the studied stratigraphic units permitted the assumption, that the formative processes of these were different, the question that we considered was, whether or not this had an influence on the taxonomic composition of the studied assemblage; that is to say, if the observed differences, as much at a quantitative level as a qualitative level, were connected to these processes of formation.

As we have already mentioned, we could differentiate between units of earth, of a basically natural origin, with a slow depositional rate, and anthropogenic accumulations of shells, with a very fast depositional rate, comparable to catastrophic sedimentation. These sub-units have different rates of formation; for, during the time it takes to form one sub-unit of earth, various shell accumulations may have been formed. This different rate of formation could have affected, in a differential manner, the preservation of remains, depending on the sub-units. The average size of the charcoal fragments, from each sub-unit, could have been connected to differences in preservation (charcoal recovered from the same area, where it was produced, may be larger in size than charcoal, which has been redeposited; and in the same way, charcoal, that has been exposed for a longer time, may be more affected by mechanical factors, such as trampling.)

For example, units, with a greater number of fragments of small size, would only indicate a greater grade of fragmentation, and not necessarily, a more intensive usage of fuel; and the reverse, units, with fewer fragments of larger size, would only indicate a lesser grade of fragmentation, and not a less intensive usage. For this reason, it is important to determine if the differences in waste volume, recovered for each taxon (whether according to weight, or to the number of remains), are connected to a differential fragmentation, that is due to preservation processes, formation, or even, to the properties of the taxa, themselves. Only in this way can the results obtained, for each taxon in the different sub-units, be comparable.

In order to evaluate these differences in preservation, we have drawn from a fragmentation index, calculated from the relation between charcoal fragment number and weight, for each sub-unit and taxon. The grade of correlation was taken into account, between the two numerical variables that were taken, during the process of charcoal identification (number of fragments and weight), for each one of the stratigraphic units. By this, we hoped to observe if fragmentation displayed differences, related to whether fragments belonged to one taxon or another, or, to whether they came from one type of sub-unit or another.

A strong correlation between the two variables implies that the variable weight depends, in great measure, on the number of fragments (the more fragments, the more weight). If, on the contrary, the correlation is weak, it must be considered that fragmentation had occurred differentially, whether caused by depositional or post-depositional factors, or, by the type of taxon. Cross-reference of information, with other data regarding the stratigraphic units, will permit establishing when the observed differences are influenced by post-depositional factors or by productive activities.

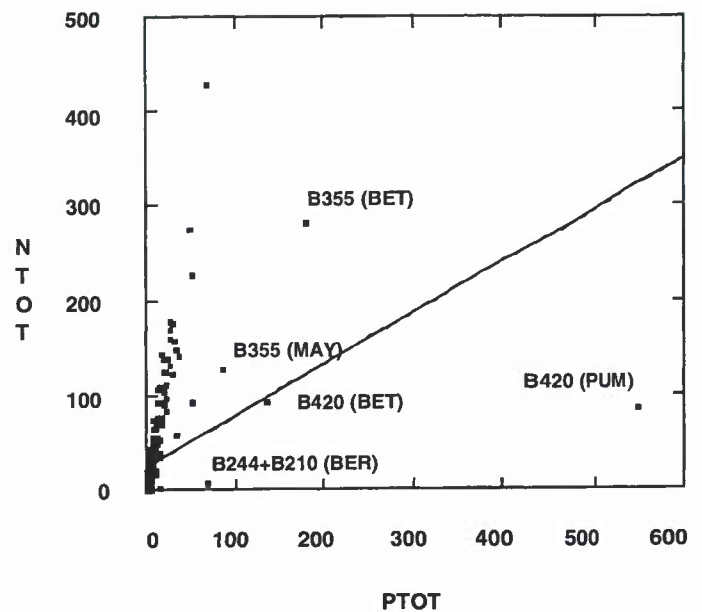
In the studied sites, differential fragmentation was analyzed, for each taxon, in each sub-unit. The statistical tools used were varied.

A data matrix was drawn up, where each row corresponded to a sub-unit, and in each row was recorded, the number of fragments and the total weight. From this matrix, a dispersion graph was created, with the corresponding line of regression. The Pearson correlation test was also applied. This permitted us to observe that individuals, with a differential fragmentation, existed (Figure 1); concretely, in three sub-units, some of the taxa present had larger fragments. If we exclude these cases, in general, there is a positive relation and a strong correlation between both variables (weight and number of fragments), which implies, that in the majority of the sub-units, fragmentation within each taxon is very similar.

The Mann-Whitney statistical test, that allows us to establish if the ordination of values for two populations, displays significant differences, or not (Shennan,1992), permitted testing the non-significance of differences in fragmentation, depending on sedimentary composition or spatial location, for the majority of the sub-units; (in this test, the sub-units, where large fragments of charcoal were detected, were not taken into account.) This test was applied to the average fragmentation indices of each taxon, and to the charcoal fragmentation indices for the sub-units, which were grouped according to composition (shell accumulations or earth), or, according to their spatial location (interior and periphery).

For this reason, we consider that the differential fragmentation of remains did not occur, due to the variables taken into account (composition and spatial location). The relation of remains weight/number is positive, except in some cases, in which specific pre- or post-depositional factors have acted, that would not affect the whole population, but only concrete units.

In such, the dependence of one variable with respect to another, allowed us to distinguish that these units of measure can be utilized, without distinction, in the studied site.



**Figure 1.** Spread diagram of weight and quantity of fragments, for the entire sample of items and variables. Labels identify subunits with outliers, causing low correlations values.

### Fuel Provision

In this case, the objective was to demonstrate that a strategy for fuel provision existed, characterized by a selective usage and systematic rejection of certain taxa. This strategy would be conditioned by the different work processes, conducted in the settlements, which would imply that, faced with a more or less constant offering of forest resources, the selection of one or another taxon will depend on the concrete necessity for certain fuels. This selective usage of wood will be reflected by a differential distribution of identified taxa, in the group of studied sub-units. In the first place, therefore, we must determine, what is the taxonomic composition, that characterizes the assemblage; that is to say, what taxa have been utilized in a recurring manner. Once we have established the expected taxonomic composition, we will be able to determine what sub-units stray from the norm, and study the causes for these differences in composition.

The tools used for the characterization of fuel provision are:

First, we have taken into account recurring appearance, that is to say, the number of units where taxa appear, independently of the number of identified fragments in each unit. We believe that recurring appearance can be considered as an index, for the preferential utilization of certain species. Now then, it is necessary to keep in mind, that the number of analyzed fragments for each sub-unit could be the cause, or not, for the appearance of certain taxa. To know if this is the reason, we have drawn up a correlation diagram, between the number of fragments and the number of taxa, per sub-unit. The correlation diagram (Figure 2) allowed us to observe that maximum taxonomic variability was not produced in the units with more fragments, although, the units with less variability were those that had fewer fragments. This diagram permitted us to establish a minimum number of fragments, from which the units can be considered as



statistically non-significant. Another aspect, that the correlation diagram permitted us to observe, was that the units with greater taxonomic variability were those that were

formed by the intentional accumulation of waste, probably since they contained waste from more than one combustion.

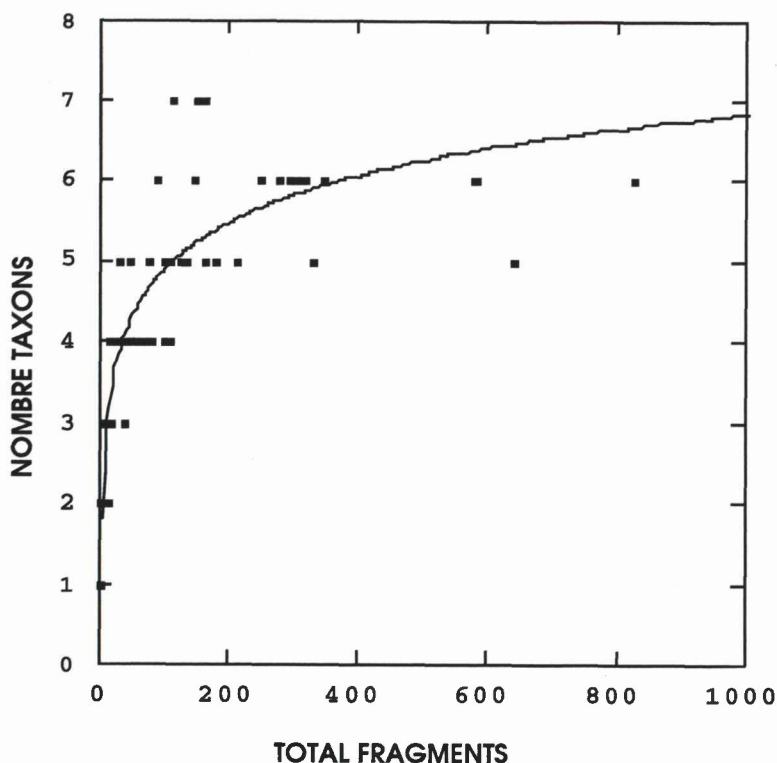


Figure 2. Correlation between number of taxons and number of items. The result is a logarithmic curve.

To compare if there exists a preferential usage of certain taxa, first it must be established if there is a differential representation of taxa, as much at a qualitative as a quantitative level. The recurring presence of taxa is what permitted us to characterize the strategy for provision, and the factors which are involved in the same.

Third, we analyzed the intensity, with which taxa were utilized (number of effectives), in the sub-units. We have considered that each sub-unit is equivalent to one stratigraphic unit that, as we have pointed out, presumably corresponds to a moment of deposit, and which implies that the more sub-units, where a taxon is documented, the more times it has been used. Nevertheless, a more constant usage does not necessarily amount to a more abundant usage; that is to say, the taxon, which has been used more often, is not necessarily the one used in the most intense manner. For example, kindling, which is used each time a fire is lit, would not be represented by the same quantity, as other fuel used in greater quantities. Working from the prior hypothesis, there exists a relation between waste volume and the intensity of wood usage, for which, the more utilized wood is the wood

that would have generated the most waste. Now then, some exceptions can occur; for example, a specific accumulation of fragments, of one taxon from the same spatial unit, could be a response to other causes (fragmentation of a larger

branch, that would only represent a specific usage, and not a systematic selection.)

The results, obtained for Tunel VII, permitted the observation that some taxa were utilized in a recurring manner, since they appear in all of the studied sub-units. Another group of taxa were also used in a rather constant manner (more than 50% of the sub-units) and, finally, a third group were used in a more sporadic manner (Table 1). Also, it was possible to observe that the hierarchical order of taxa was preserved, also taking into account the number of fragments or the weights of the same (Table 2). Given the fact that the two best represented taxa are also the most abundant in the environment, the secondary taxa, on the other hand, could have been collected in a more intense manner, as, even though they have not produced as much waste, a sufficiently constant use is observed.

Tàxon	Absència	Presència	Nº de casos
<i>Nothofagus pumilio</i>	3	61	64
<i>Nothofagus betuloides/ant</i>	4	60	64
<i>Maytenus magellanica</i>	10	54	64
<i>Berberis</i> sp.	21	43	64
<i>Chilliotrichum diffusum</i>	33	31	64
<i>Ribes magellanicum</i>	44	20	64
<i>Drimys winteri</i>	59	5	64
<i>Embothrium coccineum</i>	63	1	64

**Table 1.** Tabulation of subunits, where identified taxa are present. In the first column, appears the quantity of subunits, where identified taxa are absent, and the last column, the total number of subunits.

Tàxon	Nº frag.	%	Pes total	%	Casos
<i>Nothofagus pumilio</i>	3026	36.96	1098.550	42.35	61
<i>Nothofagus betuloides/ant</i>	3086	37.69	884.930	34.11	60
<i>Maytenus magellanica</i>	1425	17.40	394.360	15.20	54
<i>Berberis</i> sp.	509	6.21	184.110	7.09	43
<i>Chilliotrichum diffusum</i>	96	1.17	24.250	0.93	31
<i>Ribes magellanicum</i>	39	0.47	6.840	0.26	20
<i>Drimys winteri</i>	5	0.06	0.790	0.03	5
<i>Embothrium coccineum</i>	1	0.01	0.130	0.005	1
Total	8187	100	2593.96	100	64

**Table 2.** Tabulation of the quantity of identified fragments and total weight. In the right column, appears the number of cases, where each taxon has been identified

### Fuel management

In addition to characterizing the pattern for fuel provision in the site group, i.e., which taxa are used and with what intensity, our objective was also to characterize the pattern of fuel usage, in each stratigraphic unit. This would allow us to see if all the sub-units responded to one same pattern for fuel provision and management, or if, on the contrary, there existed sub-units that did not follow this pattern. As we have already stated, our hypothesis is based on the consideration, that work processes are what determine the pattern for provision, and for which reason, it can be expected that the pattern will not be homogeneous, for all of the sub-units. For this reason, the objective is to characterize the distribution of taxa within the units, i.e., the characterization of taxonomic

composition. By this, we have tried establish which sub-units follow a normal pattern, and, which sub-units deviate from this standard distribution.

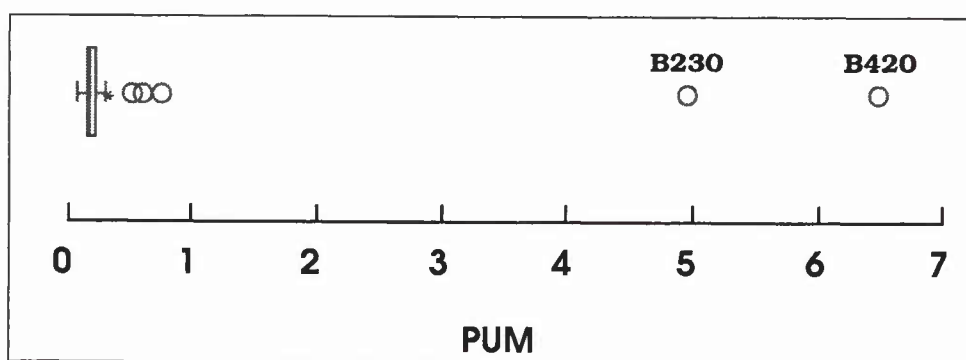
The application of descriptive statistics permits observing, which sub-units and which taxa, provide significantly different values from the rest, or are over-represented, in relation to the mean. The tools used are descriptive statistics (mean, standard deviation, etc.) (Table 3). We have analyzed the diversity among sub-units and the degree of this variability, from which we have calculated the number of units of standard deviation, existing in the interval formed by the mean and the extreme value of each taxon; the formula employed is: units of standard deviation = maximum value - mean/standard deviation.

	PUM	BET	MAY	BER	CHI	RIB	DRY	EMB
N OF CASES	64	64	64	64	64	64	64	64
MINIMUM	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MAXIMUM	426.000	281.000	148.000	75.000	21.000	5.000	1.000	1.000
MEAN	47.281	48.219	22.266	7.953	1.500	0.609	0.078	0.016
VARIANCE	4640.078	3974.809	1116.071	205.760	10.063	1.194	0.073	0.016
STAND. DEV	68.118	63.046	33.408	14.344	3.172	1.093	0.270	0.125
SUM	3026.000	3086.000	1425.000	509.000	96.000	39.000	5.000	1.000
C.V.	1.441	1.308	1.500	1.804	2.115	1.793	3.462	8.000
MEDIAN	23.000	22.000	10.500	2.500	0.000	0.000	0.000	0.000

**Table 3.** Tabulation of univariate descriptive statistics for all subunits. It has been applied to the relative frequencies of taxa at different subunits

The proportionate values for the index were sufficiently elevated, much higher than usually expected in normal distributions, which implies that the distribution of one specific taxon, among different sub-units, is sufficiently diversified, and that the differences among sub-units are not due to chance.

By finding out these differences, we were allowed to discover within which sub-units, taxa displayed extreme values, and, therefore, which sub-units were atypical. The formula used to calculate interior and exterior limits was based on inter-quartile and mean intervals (Emerson & Strenio, 1983). Box graphs allowed detection of the sub-units, with these extreme values (Figure 3).



**Figure 3.** Box graph: mean-weight of *Nothofagus pumilio* charcoal items

The previous study permitted us to differentiate among one group of units, with many effectives, another group with absences, and, a sufficiently homogeneous central group. Within this sufficiently homogeneous group, we studied the form of the distribution of frequencies, for each taxon, in all of the sub-units (without taking into account the extreme values). In its entirety, we discovered that, in no case, did the distribution of frequencies have the form of a normal curve. The test, X<sup>2</sup>, was also applied in order to establish the degree of significance of the distribution, resulting in all cases in a significantly abnormal distribution.

The next step, to follow, was to establish the causes of the observed variability. Thus, the possibility was considered, that those units that would have displayed extreme values, in relation to the number of effectives, could not be credited, so much, to a more intensive usage of a taxon, in one determined moment, but that they could possibly be related

to a greater usage time, or functioning time for each unit. Based on this hypothesis, there existed a correlation, between the usage time or the functioning time of one unit, and the volume of sediment, which would imply, that the more the volume of sediment, the greater the number of charcoal; if this correlation did not take place, it would be necessary to look for the explanation in the productive activities, or, the management of space.

The dispersion diagram, between sediment volume and fragment number, permitted the observation that there existed a certain correlation: i.e., that the more sediment volume that a sub-unit had, the more charcoal was apportioned. Nevertheless, this was not the only cause, which explained charcoal accumulation in the sub-units, since, although in some cases the taxa were over-represented in units with large sediment volume, in other instances, that was not the case. (Tabla 4). For this reason, we believe that the dynamic of the



accumulation of charcoal remains can, in some cases, be related to the functioning time of combustion areas, and, therefore, to the duration of the occupations.

Nevertheless, this fact does not explain why, in these sub-units, we do not find all of the taxa equally over-represented. Neither does it explain why, in other instances, greater fragment accumulation and over-representation of some taxa are produced in a manner, completely independent of sediment volume, i.e., from the time of accumulation. We believe that in these cases, productive activities, as much as strategies for spatial organization, can help to explain these atypical sub-units.

In Tunel site, the analysis of the correlation, between the number of effectives, per taxon, and the volume of sediment, permitted confirmation that the units that displayed extreme values, in general, are the units of earth, generated by natural sedimentation processes, which are located in the covered space of the unit of occupation. This shows us that the dynamic of remains accumulation could be related to strategies for spatial organization. Nevertheless, not all of the central units of earth displayed the same dynamic, with relation to sediment volume, waste or over-represented taxa.

It is necessary, then, to consider the possibility that factors, other than duration of occupation or productive activities, could also have affected the distribution of remains, in the sub-units. Strategies for spatial management could have influenced the distribution of charcoal remains in the sub-units. The central units of earth, which correspond to the areas of principal occupation, have a sedimentation rate

different from waste accumulation; the former, follow a fundamentally natural sedimentation process, while the latter are of an anthropic origin. Among the former, charcoal accumulation comes from dispersion from a combustion center, and the accumulation will be constant in function to the intensity of use, even though the quantity of charcoal, recovered in these sub-units, will depend on the greater or lesser intensity of the work, cleaning-up and preparing the occupied space.

In contrast, in the sub-units, where charcoal has its origin in the intentional concentration of remains, i.e., the sub-units produced, basically, by the work cleaning and preparing the area of occupation, the relation between sediment volume and remains volume will not stay distorted, as the relation between both is proportional: the peripheral waste accumulations will be greater, the more the waste deposited in them.

The correlation diagram permits observation that, in effect, there are quantitative differences between the two kinds of sub-units (Figure 4). One group of sub-units is characterized by its display of comparably low values for sediment volume, as well as for charcoal volume, while the other group has a tendency towards dispersion, and is characterized by its display of elevated values. The variable space allows us to observe that the central sub-units of earth are the ones, which have produced more sediment volume and charcoal fragments. In contrast, the peripheral sub-units generally display low values.

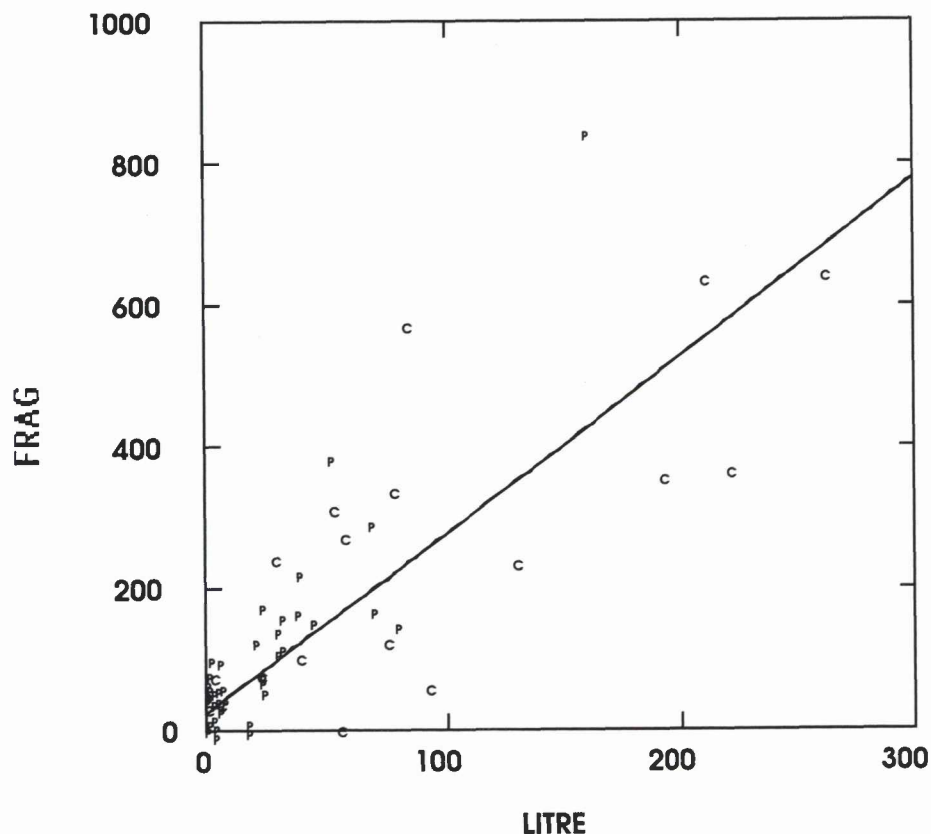


Figure 4. Spread diagram of volume (quantity of sediment from the archaeological unit) and quantity of charcoal fragments



These observed differences can be explained by unit formation time and by spatial organization strategies. While, during an episode of occupation, a central unit is formed, at the same time, various peripheral accumulations of waste can be generated. Therefore, the differences in sediment volume, between central and peripheral areas, is due to the non-corresponding formation times of both.

Finally, it appears that spatial management could be the cause for different dynamics, in remains concentration, between the two kinds of studied sub-units. The central sub-units, with greater sediment volume, are those, which have been formed during longer occupation times. In contrast, the peripheral areas can have had a lesser formation time, collecting a palimpsest of activities of lesser duration time, and, a lesser, though more concentrated, number of remains.

The differences between central and peripheral units does not only boil down to the quantity of remains and sediment volume; the density of remains (charcoal fragments per liter of sediment) is also different, being more elevated in the peripheral shell accumulations, with relation to the central accumulations of earth.

### Patterns for fuel usage

#### *The taxonomic composition of the sub-units*

In addition to determining how the taxa are distributed in the analyzed sub-units and the possible causes, our interest is centered on how the taxa relate to one another, within the sub-units, and on the taxonomic variability, among the sub-units. If, until now, we have concentrated on the analysis of individualized behavior of different taxa, within the sub-units, from now on, we will concentrate our analysis on the existing relation, among taxa, within the different sub-units. In order to establish this relation, we have applied the Analysis of Principal Components, to the relative frequencies of the four principal taxa, found in those sub-units, with more than 30 fragments, which are the sub-units, that according to prior analyses, we can consider statistically significant.

A prominent trait, of the assemblage tendency, is that the taxonomic composition tends to be different, between the central units and the peripheral units. While in central units, the tendency is towards mean proportions for all of the taxa, in the peripheral sub-units, in contrast, the characteristic is the predominance of one taxon or another. We believe that the explanation for this tendency is, again, strategies for fuel management. Peripheral units are the product of the specific

cleaning-up of combustion waste, and, therefore, reflect which wood is used, for determined instances of combustion, in each episode. In contrast, in the central sub-units, charcoal has accumulated from all of the instances of combustion, which have taken place during each occupation, and, therefore, is the sum of all of the specific instances of wood usage; and, it is for this reason, that the proportions among taxa remain stable.

Also, the principal components analysis allowed the observation that the prevailing taxa, in shell sub-units, varied for each one of the studied episodes.

The analysis of principal components reaffirms, once more, the differences between one type of sub-unit and another, due to different formation processes.

#### *Taxonomic composition, among kinds of sub-units (central and peripheral), for each episode*

Characterizing tendencies in taxonomic composition, among the different kinds of sub-units, for each episode, will permit us to establish changes in the pattern of wood utilization.

The structural sequence, or analysis of the internal articulation for each complex, will permit us to know the importance, during each episode, of the differences, among taxa, within the archaeological charcoal assemblage. This analysis is particularly useful, when the levels are very similar, or, appear homogeneous. The formula used to determine breakage or discontinuance, within the complex, is based on the estimate of theoretical frequencies, from the ones observed, using criteria of quadratic contingency (Laplace, 1975). In order to analyze the structural sequence, we have grouped on one side, the central sub-units of earth, and, on the other side, the shell accumulations and peripheral sub-units for each episode. We have done this, since as we have already seen, in the analysis of principal components, different dynamics are displayed. We can determine the contribution of each taxon to the non-homogeneity of the group from the *Lien* test table, which gives us the coefficient of the percentage of distance, from X2.

The analysis of the structural sequence has permitted us to establish the internal dynamic, within the complex, what taxa display significant quantitative differences, within each complex. In the same way, the graph produced from the *Lien* test table, has permitted us to observe which taxon has more importance, in the characterization of the assemblage, with relation to other episodes (Figure 5).

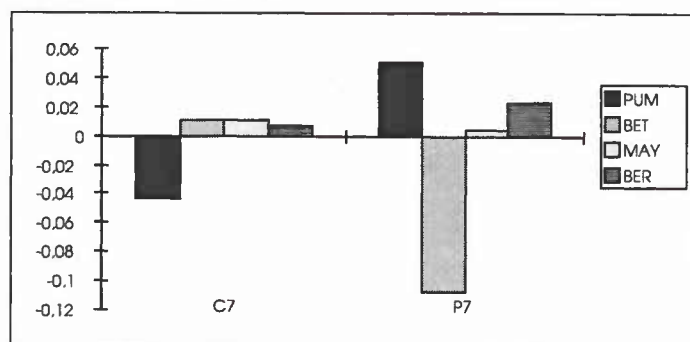


Figure 5. Laplace graph (test du Lien) of episode 7. C7= central subunit, P7= peripheral subunit

The structural sequence, for each episode, was analyzed, and it was characterized, for each individual episode, in relation to other episodes, which taxa had more weight in the definition of the assemblage. From this analysis, we can see that there is not always coincidence in the taxonomic composition of central and peripheral sub-units, for the same period. At a more concrete level, we see how there are episodes, which exhibit a more specialized usage of determined wood, while in others, there are no significant differences.

The conclusions, which structural sequence analysis and the Lien table allow us to make, are:

-there is alternation among the better represented taxa, which would indicate a differential usage of taxa in each instance

-in some episodes, breakage among taxa is very significant, which would indicate a more intensive usage, of the same. In the case where secondary taxa lack breakage, it would indicate, in some cases, an intense usage, as implied by, more elevated than normal quantities

-an inversion of the weight sign (+ or -) for taxa, within central and peripheral sub-units, is displayed. This is influenced by the dynamic, of sub-unit formation, and, therefore, disguises the reading of the pattern for wood utilization.

#### *Differences among episodes. Analysis of the structural dynamic*

Analysis of the structural sequence dynamic, based on the X2 test, permits comparing different levels, within a site. Applied to the Tunel VII episodes, it will permit us to see what the significant changes are, in the utilization of wood, throughout the course of the occupations. The Lien test table, again, will permit characterizing, in each episode, which taxa have more weight, in the structure of the complex.

Analysis of the structural dynamic was carried out on the central sub-units of one side, and on the sum, of the central and peripheral sub-units, of the other; the objective was to check the possible degree of distortion, provoked by the units, that have followed a differentiated process of formation.

The observed dynamic allows discovery, that in some episodes, the taxa, with greater weight in the characterization of the assemblage, are those, which we have considered to be secondary, that is to say, the ones that are not quantitatively more abundant; while in other episodes, the taxa, which have greater weight in the characterization of the assemblage, are the principal taxa. This points out, that the principal taxa are more abundant, within the site's environment, while the secondary taxa are those, which we can consider to be better fuel, in as much as, they offer a greater resistance to combustion. In quantitative terms, the greater weight of taxa, in the characterization of the assemblage, signifies that they are oversized, with respect to the mean.

#### **Conclusions**

The application of different statistical tests, on charcoal from Tunel VII, allows us to make an interpretation of the pattern for utilization and management of fuel, for each one of the individualized episodes. The joint valuation, of all of the results, gives us a primary approximation of strategies, for

the utilization and management of fuel, implemented by groups of Magellanic canoers, from Tierra del Fuego.

One of the aspects, that has permitted us to prove the statistical treatment of charcoal data, from Tunel VII, has been to define the range of social management for the space, in relation to combustion waste. The results have permitted us to verify, that maintenance work has influenced much of the charcoal distribution, within the space. For this reason, we consider that the characterization of the pattern for fuel utilization must first pass through an analysis of what the formation process, of the studied assemblage, has been. In the case of Tunel, we verified the range of waste management for all of the analyzed episodes:

-existence of a greater density of charcoal fragments in shell accumulations, than in the central sub-units of earth. This differential distribution would be linked to clean-up and maintenance work for the areas, where combustion takes place.

-Also, the number of remains displayed differences, among central and peripheral sub-units; the peripheral sub-units displayed less remains, than the central sub-units. This circumstance was related to formation time and sediment volume, of the involved sub-units.

-Also, taxonomic composition displayed differences, depending on whether it corresponded to central sub-units of earth or to shell accumulations. The former displayed more homogeneity, with respect to the proportional relation among taxa, while, the latter were differentiated, by the relative abundance of one taxon or another. Differences in taxonomic composition, among contemporary units, are related to waste management. In the central sub-units of earth, charcoal is the product of dispersion from combustion production centers, and, therefore, is the sum of different instances of combustion. This moderates differences, due to the particular collection of firewood, and gives a picture of the assemblage pattern, for the utilization of fuel. In contrast, in the peripheral sub-units, charcoal is an intentional accumulation, originating from the clean-up of combustion areas, and, therefore, often reflects particular instances of combustion.

With regard to fuel management within the settlement, it is more difficult to link the utilization of determined taxa with concrete productive processes. The reasons are diverse; first, the sub-units, where more taxonomic variability is documented, for the same episode, are the shell accumulations, but because of their formation process, they do not provide us with much information, about the differential utilization of fuel, depending on productive processes. Being sub-units, formed by the intentional accumulation of waste, implies that the remains, recovered from their interior, are not found in the place, where they were produced, but rather, where they were abandoned. They can contain elements, that have been abandoned jointly, but that are not necessarily linked to a concrete productive process.

Second, the centers of charcoal production, or the areas of combustion (which in principle, should be more easily associated to concrete productive processes), are mostly lacking in remains.



Referring to the explanatory hypotheses, regarding the taxonomic variability, observed in the occupations of Tunel VII:

-We can discard changes in the biotope due to natural causes (too short a lapse of time among the studied occupations)

-Nor would the cause be, an exhaustion of resources, due to over-exploitation, since, according to ethnographic data, the duration of the occupations was very brief, hardly even a few days. Nevertheless, we believe that an exhaustion of the dead wood, in the surroundings of the site, can have occurred, due to the presence of fewer individuals of some species, and to an intense exploitation of the same. (This could be the case with secondary taxa.) Now then, according to data, obtained for the different episodes, it appears that the time lapse, between occupations, can have been sufficiently extensive (based on dendrochronological data, 86 years elapsed between episodes 3 and 6), during which time, between episodes, the regeneration of the offering, of available fallen firewood and dead wood, is quite possible.

-the decrease in the offering of dead wood, in the environment, could explain the variability among sub-units, from the same episode. If the continued dynamic is, first, the utilization of dead wood, from the taxa with the best properties for combustion, then the longer the occupation, the greater the probability that the offering will be exhausted, and then, there would be a necessity to look for other fuel. Thus, the duration of the occupations can have influenced the strategy for fuel provision. This is a hypothesis to consider. We can point out, nonetheless, that in the episodes, where a larger number of shell accumulation sub-units are individualized, we will find that, in some of them, there is an abundance of remains from secondary taxa, and according to the stratigraphic correlation, these would be the oldest.

We could propose the hypothesis that those episodes, where there are proportionally more important quantities of secondary taxa, could be considered to be occupations of short duration, since the settlement is abandoned, before the decrease of dead wood, from those taxa, obliges a more intensive collection of other fuel. As occupations are longer, other taxa become more important. In the longer occupations, it would have been necessary to resort to fuel of lesser quality, in order to satisfy necessities for energy; in those episodes, the low quantity of remains, from secondary taxa, would be justly emphasized.

Nevertheless, the taxonomic diversity, between episodes, cannot be attributed to only one cause. It would be necessary to compare if the season, during which a site was occupied, has affected the accessibility, of certain kinds of fuel.

When referring to the variability among sub-units, of the same episode, the cause can have been the manner, in which collection was carried out. This was accomplished every day. It would explain the variability, since, if the necessary fuel to cover the energy needs of an entire occupation were collected at one time, a more homogeneous pattern would be expected among sub-units, of the same episode. In contrast, if the collection is accomplished every day, the observed differences among sub-units can be due to changes in the fuel catchment areas (that would explain the alternation in the appearance of principal species from the documented plant communities in the surroundings of the site).

In closing, the activities, carried out within the settlement, can have determined which taxa are utilized and at which moments. This should be contrasted with prior data, from studies performed on other materials in the site. From the study of archaeological charcoal, we can characterize the strategy for fuel management at any moment. But only after studying the entire site, will we be able to understand the factors, that have interacted in the determination of the strategy for collection.

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