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Cyclical Visitor-Behavior Patterns of Urban Forest Recreation Environments and their Determinants – A Statistical View

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Abstract: Urban forest recreation environments have their particular rhythms, not only natural periodicities, but also periodicites of their human members (vistors, rangers,...). A human forest ecosystem as a basic unit of analysis can be defined as an interaction between the population, the organization of forest and the technology in response to the environment. In order to manage such forest ecosystems information about the recreation demand of visitors is needed, particularly about the rhythms of the visitor flow. A scientific project in Stuttgart, a town in South-Germay, provides for an example. The central objective of this paper is to detect periodicities in a time series of frequencies of certain groups of visitors, observed by a fix video camera over one year (March 1999-March 2000) (n=1421 measurements). A not widespreaded statistical method, the spectral analysis, will be applied on the data. Certain periodicities can be found, especially a day-cycle, week-cycles and year-cycles for the various groups of visitors. Impacts of weather (sunny, cloudy, rainy) and weekday (weekend or not) have significant influence on the visitor flow. A simulation illustrates the shape of the cycles, which are detected.

INTRODUCTION

Urban forests as human ecosystems have their particular rhythms, and member of Homo sapiens – vistors, residents, rangers – are part of them. To manage this forests without a sense of these rhythms is unrelastic, myopic and not sensible. The concept of „human ecology" proposed by Hawley (1950, 1986) can serve as theoretical framework for both urban forest management and urban forest research. The human ecosystem as a basic unit of analysis is defined „by the interaction of *population*, *social organization*, and *technology* in response to *environment*" (Machlis, 1989, p.158). This interaction can be recognised as a mutual adaption of this four components in a biological sense

In Germany there is a lack of detailed knowledge not specially of the biological ecosystem or of the social organization but of the visitor behavior and of its rhythms. Therefore the focus of this paper lies on the research of visitor behavior and its periodicities in a forest recreation environment. A forest science project in the forest of Stuttgart provides for the database. The research issues of this statistical-method orientated paper are:

1. Are there any periodicities in the visitor flow over one year?
2. Differ various groups of visitors as walker, jogger, cyclist in their periodicities?
3. Are there any impacts of weather or week-day on the frequencies of visitor?
4. Is it possible to simulate the visitor flow over one year?

THEORY

The concepts of forest recreation environment in Germany differ widely form the concepts in the USA. In the USA this theme is discussed under the heading of park and wilderness management. That means ecosystems f.ex. forests are diveded in one part, the park, which is easy accessible for visitors and in another part, the wilderness, which is not accessible for visitors, because there is a lack of clear path, roads... and in the whole a lack of safety. Due to the ecological micro structures of German forest ecosystems there is no park culture in Germany. The forest have to fullfill simultaneously multiple demands: recreational needs, nature protection and natural ressources (wood...).

Although the views of forest recreation environment in USA and Germany don`t accord, the theoretical concepts of park management, f.ex. suggested by Agee & Johnson (1988) can be used by German forest scientists and environment psychologists for research and design of forest recreation environments, particularly the theory of human ecology. The roots of human ecology lie primarily in general ecology, sociology, and anthropology. It is faced with the relation between physical environment and behavior. The two key assumptions of human ecology for Machlis (1989, p.161) are: „Assumption 1. Homo sapiens is both biological and cultural. A significant portion of human social behavior is biologically determined... Assumption 2. Homo sapiens is ecologically interdependent with the natural world." Support for the first assumption comes strongly from the discipline of socialbiology (Wilson, 1975). Johnson & Agge (1988, p.6) stress on four elements of biological and social systems:

(1) „Ecological systems are continually changing.
(2) There may be substantial spatial heterogeneity in impacts from particular action.
(3) Systems may exhibit several levels of stable behavior.
(4) There is an organized connection between parts, but everything is not connected to everything else".

The temporal and spatial properties of both parts the biological part and the human part seem to be essential for the consideration of forest (human) ecological systems. Marlies (1989) asks the question, what we need to understand an ecological recreation area in order to mange it wisely. Beside the knowledge about the physical environment, information of the various groups of human populations, that use the park and their visit flows is needed.

This brings us to the viewpoint of this paper: to look on the temporal properties of visitor flows in recreation areas. Form a statistical perspective you have a time series of observed behavior frequencies of different kinds of visitors f.ex. walker (Möbus & Nagel, 1983; Schmitz, 1989). You can analyze time series in the time domain or as here suggested in the frequency-domain, which is up till now not widespreaded in the social sciences and particularly in the environmental psychology (Larsen, 1987; Mc Burnett, 1997). In its most general form, spectral analysis involves decomposing a time series into several periodic functions. It is somewhat like a regression analysis in that the objective is to account for variance in the data by fitting a model, whereby the model is nonlinear. Brigola (1997) and Butz (2000) offer introductions in fourier-transformation, an other word for spectral analysis. The harmony in music or the moon cycle can be helpful to understand the basic ideas of spectral analysis.

Suppose a periodic oscillatory wave as the tone „a" of a violin, which can be made visible by an oscillator. This observed wave as a kind of time series y_t will be understood as a combination of certain pure waves (sinus tone in music). Such a wave can be characterized primarily by a **periode P** or a **wave length**, that is the time, in which a cycle once recurs. The moon cycle has a period about P=26 days. 1/P is the **frequency f**, the proportion of the cycle, which is realized in one time unit. For example 1/26 of the moon cycle is realized in 1 day. The **amplitude A** describe the height of the wave. If you take the unit-circle with the circumference of 2π , than you can get the **circle frequency ω**$=2\pi$f. You can move the whole wave on the time axis. This was called **phase θ**. The cosinus- and sinus-functions have periodic properties. Therefore this function will be used for the following function (1) with k different harmonic waves:

$$(1) \qquad y_t = \sum_{j=1}^{k} A_j \cos(\omega_j t + \theta_j) + e_t$$

where e_t is a stationary random series and t is the time. Using the trigonometric identity $\cos(\omega+\theta) = \cos(\omega t)\cos(\theta) - \sin(\omega t)\sin(\theta)$. Equation 1 can be written as

$$(2) \qquad y_t = \sum_{j=1}^{k} a_j \cos(\omega_j t) + b_j \sin(\omega_j t) + e_t$$

where $a_j = A_j \cos \theta_j$ and $b_j = -A_j \sin \theta_j$.
The function f in equation (2) is periodic in t in the sense, that

$$(3) \qquad f(t+P) = f(t), \qquad (-\infty < t < \infty)$$

To estimate the parameters, the Fourier coefficients a_j und b_j, the Least-Squares method can be applied. The sum of quadratic errors e_t is thereby to be minimized.

As mentioned before the variance of the time series can be decomposed into the variances for each fourier-frequency f_k. This is called **periodogram**:

The sum of $I(f_k)$ over all f_k is the total variance of the time series σ^2_y. As in regression you can express each periodic function with its variance components as proportion to the total variance. In regression analysis this proportion is called coefficient of determination. The function I_k can also be used for **white-noise-testing** (Fisher's Kappa). If the time series consists only out of white noise, than the normalized y-coordinates of the periodogram $I(f_k)/2\ \sigma^2_y$ has a χ^2-distribution with 2 degress of freedom (Schlittgen, 2001, p.88). If there is some periodicity in the data, one period of the periodogram must show a big value. Therefore the maximum of $I(f_k)/2\ \sigma^2_y$ will be used as empirical test-value Z. The probability of H_0 „White noise" is:

$$(4) \qquad I(f_k) = n \cdot (a_k^2 + b_k^2)/2$$

$$(5) \qquad P(Z > z) = 1 - (1 - e^{-z})^{(N-1)/2}$$

whereby z is the observed maximum of the periodogram and N is the number of timepoints. For a periodogram-interpretation the following issues must be taken into account:

(1) Alising: Only periods P till 2*time units can be observed. To detect a two-week-cycle for instance one measurement per week on two weeks is at least necessary. If there is a cycle with lower frequency it cannot be detected, but it appears hidden as long wave. Therefore it is

important to choose a adaequate decomposition of the observed time series.

(2) Leakage: If the time series is short, there is not only a great peak in the periodogram in the main frequency, but also in the nearby frequencies. This effect decreases with increasing n.

(3) Missing-Values: To detect periodicities in a time series it is necessary to have a series without missing values.

For the last problem Schlittgen (2001, p.183f) offers several solutions. One is to replace the missing values with the average over all data. Another method takes into consideration the specific autocorrelation structure of the values nearby the missing value. At first the p-order autoregressive process AR(p) is estimated. At second the predicted values which replace the missing values are estimated by minimizing the following sums of squares of errors e_t (SS) with known autoregressive parameters α:

$$(6) \quad SS = \sum_{t=p}^{N} e_t^2 = \sum_{t=p}^{N} (y_t - \hat{a}_1 y_{t-1} - ... - \hat{a}_p y_{t-p})^2$$

If the partial derivatives of (6) $\delta SS/\delta y_t$ for each missing value is set to zero the predicted values are the solution of a linear equation system.

Up till now only one series is observed. If you consider simultaneously more than one time series, the multivariate spectral analysis offers you many possibilities for the analysis (Priestley, 1996, p.660). One of them is the **coherence-diagramm**, which shows for each frequency, how much the two time series are correlated. The coherence-coefficient varies between 0 and 1.

To test the influence of weather and weekday on the visitor flow a regression analysis will be used, which take into account the specific autocorrelation structure of the data, f. ex. a regression with an AR(2)-process of the random component e_t (Mutz, 1998, Becker et al. 1998) and x_j as the predictors:

$$(7) \quad y_t = \sum_{j=1}^{m} \beta_j x_{jt} + \varepsilon_t$$

$$u_t - \alpha_1 u_{t-1} - \alpha_2 u_{t-2} = \varepsilon_t$$

After the presentation of the mathematical-statistical background we return to central question of this paper. Within the scope of one year several cycles (day, week, month, year) are expected to recur. The cycles of different visitor groups don't differ very much, only such between jogger and walker. The joggers start earlier in the morning or later in the evening with their forest-visits than the walker. In will be supposed, that at weekend and at sunny days the frequencies of visitors rize at maximum.

METHODS

The data are taken from a forest-science project of Janowsky (2002). The central objective of this project was to work out a forest-paths-concept for the forest of Stuttgart, a town in South-Germany, which fullfill not only the economic, but also the leisure demands for this forest. In one part of this study the visitor flow over 1 year should be observed. The data are collected by an observation-study which took place one year each day from 6 a.m. to 10 p.m. (March 1999 - March 2000), whereby the monitoring was done by a motion-sensitive fixed video camera. The data for the statistical analysis are generated by counting the behavioral events on the videotapes, aggregated for 8 time-units of 2 hours per day. Not only the total visitors are counted, but also different groups of visitors: walker, jogger, cyclist and others (cars...). The last one are not included in the statistical analysis due to its low frequencies. Additionally the weather is categorized in three groups: sunny, cloudy and rainy. For the regression analysis the categories are transformed by effect coding into dummy-variables (Cohen & Cohen, 1983). For a detailed discussion of the design and sampling see Janowsky (2001).

Because of breakdowns of the video camera only n=191 days out of 366 days can be analyzed. In order to apply the spectral analysis, the above mentioned method was used to replace the missing values with estimated values. Additionally a cubic polynomial week-trend was assumed. To estimate these values very precisely, for each month a model was fitted. The *proc autoreg*-procedure of the statistic software-program SAS was used with a slightly different algorithm as described above. Figure 1 and Figure 2 show the time series without and with replacement.

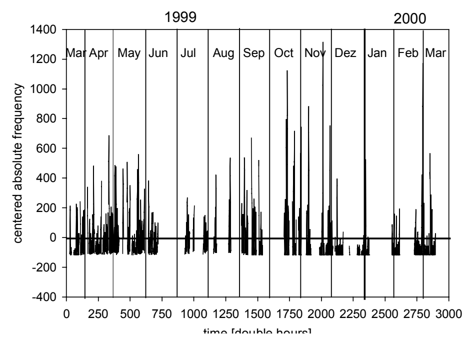

Figure 1.: Raw time series without missing value replacement

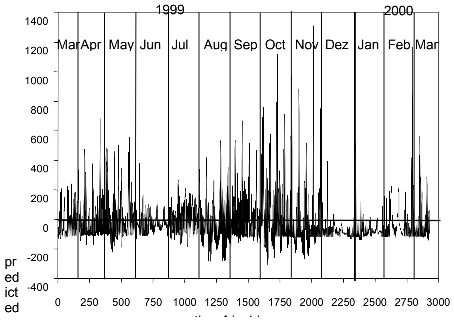

Figure 2.: Time series with missing value replacement

The total structure of the time series can be maintained by the replacement. In June 1999 or in Januar 2000 there is lack of data. Therefore the estimations are rather poor. But without substitutions spectral analysis generates misleading results. At the end 2928 double hours from 53 weeks with 5-7 days and 8 double hours per day build up the database for the spectral analysis, which is outperformed by the *proc spectra*-procedure of SAS.

RESULTS

First, descriptive statistics are calculated to describe the distribution of the frequencies. Table 1 shows the essential statistics of the distribution of frequencies over one year, seperated for the visitor groups, and total.

	M	STD	MIN	MAX	CV
walker	84.0	143.9	0	1372	171.3
jogger	27.4	34.7	0	399	126.6
cyclist	4.3	7.4	0	51	172.5
total	115.6	165.5	0	1428	143.1

Table 1.: Descriptive statistics of the raw frequencies over the whole year March 1999-March 2000 (n=1421 double hours).

As expected the walkers has the main proportion to total with a mean value of 84 per double hour and day. Than it follows the group of the joggers with a mean frequency of 27.4 and the cyclists with 4.3. The distribution is strongly asymmetric with few very high values f.ex. a maximum of 1428 visitor in double hour. To avoid biased estimates in spectral analysis these few outliers (>99% of the distribution) are replaced by the mean value. Additionally the time series was centered before the spectral analysis takes place.

Second, it was tested whether the time series is white-noise (random fluctuation). Fisher's Kappa was calculated for each visitor category (total, walker, jogger, cyclist): T_{total}=251.88 $p<0.01$, T_{walker}=158.87 $p<0.01$, T_{jogger}=96.12 $p<0.01$, $T_{cyclist}$=300.35 $p<0.01$. All four time series show significant periodicities. But it must be taken into account that the high sample size makes it difficult, to maintain the statistical hypothesis H_0. Other white-noise-tests as Bartlett`s Kolmogorov-Smirnov Statistic however show similiar results.

Third, the periodogram will be estimated for each visitor group and for total. Figure 3a,b show the periodograms for total and for the group of the walker. Instead of the fourier-frequency f=1/P the period P is used.

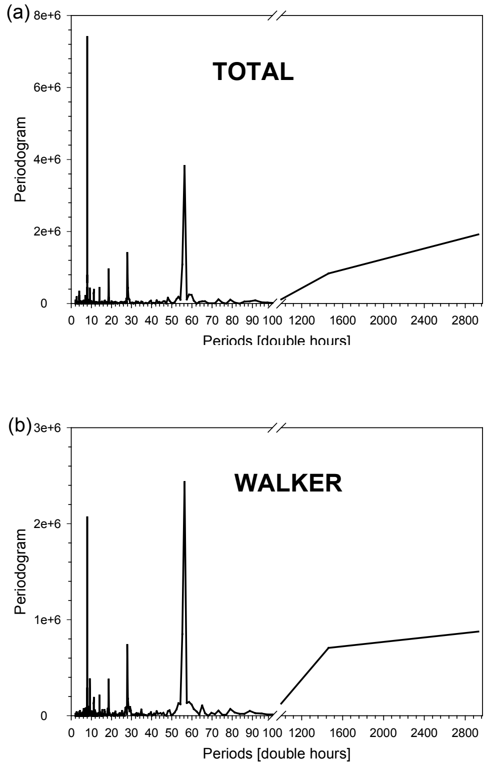

Figure 3.: (a) periodogram for the total time series (b) periodogram for the time series of the walker

The similiarity of the periodogram of figure 3a and 3b is obvious. The peaks in figure 3a indicate important cycles: at period 8 a day-cycle, at period 18.65 a 1/3week cycle, at period 27.5 a 1/2week cycle and at period 56 a week cycle (=7 days * 8 hours per day). Additionally a 1/2year-cycle at period 1464 and a year-cycle at period 2928 recur. 17.2% of the total variance of the total time series is accounted by the day cycle, 8.9% by the week cycle, 4.5% by the year cycle and 1.9% by the 1/2year-cycle. Similiar results can be found for the walker.

Therefore the day- and week-periodicity are more important than the year-cycles. Significant month-rhythms are not observed. The time structure of the visitor flow is mainly influenced by the group of the walkers. Nearby the big peaks you can find many small peaks, which probably indicate a leakage effect. Due to the high importance of the day cycles, the time series needs at this time area more differentiation. Random fluctuation in the data can be another cause for this phenomena.

In figure 4a,b you can find the periodogram of the groups of the joggers and the cyclists.

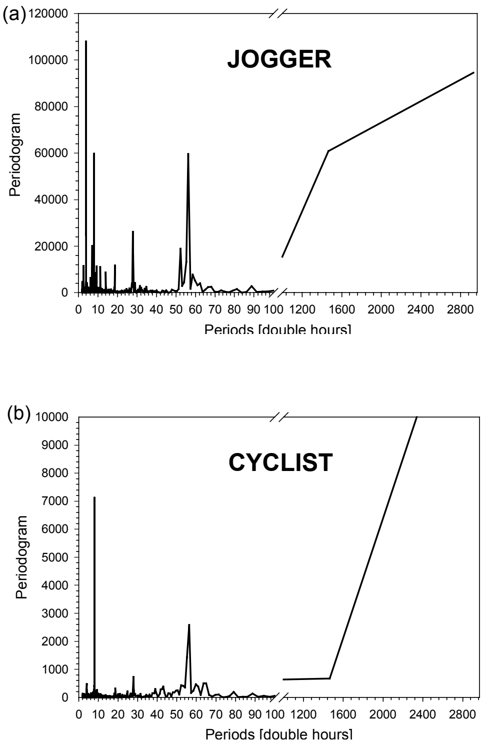

Figure 4.: (a) periodogram for the time series of the group of the jogger (b) periodogram for the time series of the cyclist

If you compare figure 3a/3b with figure 4a/4b the similiarity between this figures is apparent. The peaks in figure 4 at period 8, 18.65, 28 and at period 56 indicate a day-, 1/3week-, 1/2week- and week-cycle. A 1/2year- and year-periodicity is also found, particularly for the jogger. But there are also differences. Concerning the joggers it can be found at period 4 a 1/2day-cycle, which has the greatest explained variance-portion. It follows the 1/2year and the year-cycle in explaining the total variance of the time series at second best. While for the joggers the day-/year-periodicities play a central role, the year-cycle is essential for the cyclists. This frequency explains about 20.5% of the total variance in the time series of the cyclists. Riding a bike or jogging depends heavily on the season (warm/cold). Jogging is a sport, which takes place almost early in the morning or later in the evening, which explains the half-day-cycle.

Fourth, coherence-diagrams can illustrate, how much the time series of a special visitor group is connected to the time series of another group for certain frequencies. In Figure 5a, 5b, 5c the coherence-diagrams for the correlations between each of the time series of the three visitor groups are shown. Instead of the periods the circle frequency 2πf was used. Walker and jogger, walker and cyclist show high correlations (>.60) rather in the higher frequency domain with circle frequencies smaller than 1.0 or periods beginning at 6 (3/4day) ending at 2928 (year).

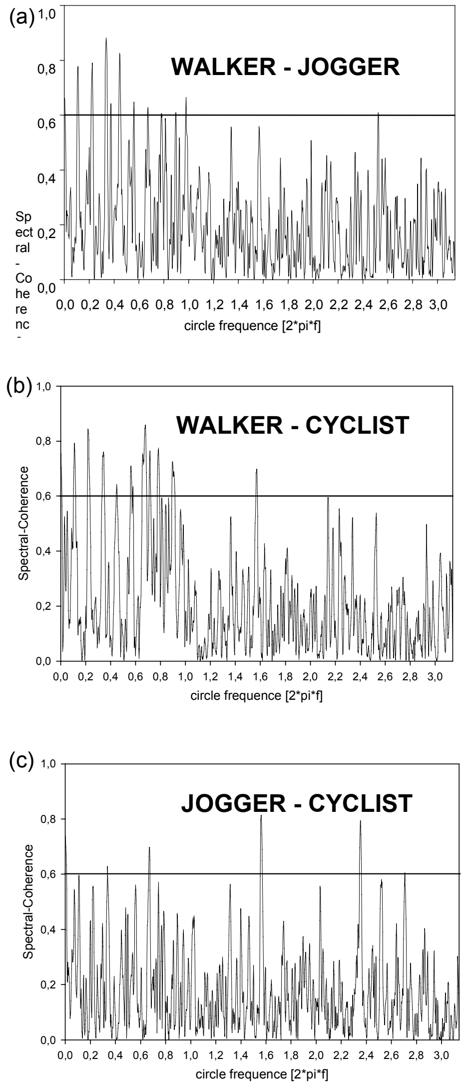

Figure 5.: spectral coherence diagram for the time series of (a) walker-jogger (b) of walker-cyclist (c) jogger-cyclist, seperated for each circle frequency. (vertical line=correlation of .60).

In the coherence diagram *jogger-cyclist* (figure 5c) the correlation for the circle frequency under 1.0 are not so high as in the in the latter one, but there are single peaks at circle frequency at 1.57 and at 2.6, which indicate a high correlation of the 1/2day-cycle and 1/3day-cycle of the two time series. While for joggers and cyclists intraday cycles are strongly joined together, for walkers and cyclists, walkers and joggers week-cycles are strongly related. In spite of differences between the three visitor flows this result claims some support for the strong relation of the three time series, particularly concerning the week- and year-cycles.

Fifth, a regression with an AR(3)-process was calculated to prove, whether weekday and weather has an impact on the total visitor flow. This analysis is only outperformed for the month of april, because for this month over 80% of the data have non-missing values in all variables. 74.3% of the frequency-variance can be accounted by the model. As expected a significant effect of the weather was found. Sunny weather simultaneously increases the frequency about 39 persons, rainy weather decreases the frequency about the same number of persons. Cloudy weather has no effect. But also when the weather is nice at one time, two hours later, but not four hours later, the frequency of visitors increases. For the weekend the flow of visitors increases too. If the weather is nice and it is weekend, then four –not two– hours later the flow of visitors is strongly raised. This results are only valid for the month of april.

Sixth, a simulation is done to illustrate the shape of the cycles which are detected. Figure 6 shows the predicted mean-centered time series from a 1-day-, 1/3week-, 1/2week-, 1/2year-, year-cycle using the estimated fourier coefficients a_j and b_j and equation (2).

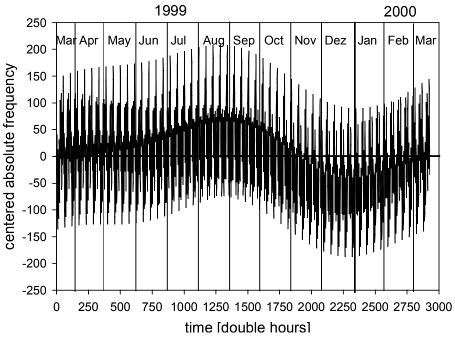

Figure 6.: Simulated time series over 1 year

In figure 6 you can well recognize the day-periodicity and the year-cycle, beginning in march, increasing till august and decreasing heavily in november and december.

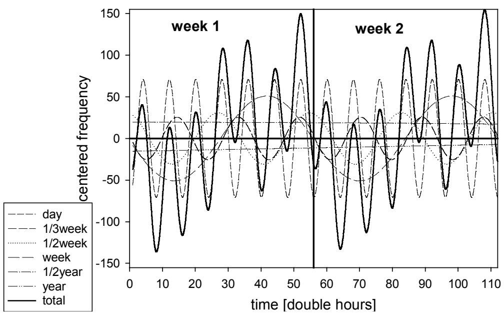

Figure 7.: Simulated time series for two weeks in march 1999

Figure 7 decomposes the simulated time series of figure 6 into its components or basic waves for two weeks in March 1999. The strong influence of the day periodicity on the total periodicity can be demonstrated. This day-cycle is overlayed by certain week cycles, which bring about the chacteristic shape of the total frequencies in one week.

CONCLUSIONS

Urban forests as human ecosystems have their particular rhythms, and member of Homo sapiens – vistors, residents, rangers – are part of them. To manage this forests without a sense of these rhythms is unrealistic. Therefore special methods of data gathering and data analysis must be choosen to find such periodicities. The data are taken from a forest-science project of Janowsky (2002). The central objective of this project was to work out a forest-paths-net-concept for the forest of Stuttgart, a town in South-Germany, which fullfill not only the economic, but also the leisure demands. One area of questions emphasizes the visitor flows at a important position in this forest.

The study should *at first* prove, whether there are any periodicities in the visitor flow over one year. Certain periodicties can be found. Particularly a day-cycle, but also week and year-cycles play an important role in explaining the whole time series. Month periodicities are not detected. The coherence diagramms claim some support, that this result can be generalized over all visitor groups (walker, jogger, cyclists).

Secondly, the study should give an answer to the question, whether the weekday (weekend or not) or the weather at certain hours have a strong impact on the visitor flow. Such influences can be found, especially lagged influences of weather.

Thirdly, the estimated fourier coefficient allows us to simulate the time series of the total visitor flow. The peaks of high visitor frequencies in summer (july, august, september) and rather low frequencies in winter (november, december) were obvious.

This paper should introduce in a statistical method, not very widespreaded in the social sciences and the forest science using an empirical example. The problems of this methos as alising, leakage, missing value are discussed. New perspectives as the multivariate version of spectral analysis was outlined. This method allows to connect under an ecosystem or human ecology perspective natural periodicities of forests with the periodicities of humans, particularly their utilization behavior f.ex. walking, jogging...

The next generation of statistical analysis of periodicities has just started in the psychology and social sciences under the title of „chaos theory“. But the proponents of this movement recommend in a first step the application of spectral analysis (Robertson & Coombs, 1995; Kiel & Elliott, 1997; Alisch, 2001). A detailed discussion of this new, very sophisticated, but not yet established methods would go beyond the scope of this paper.

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