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Anthropological Cybernetic Model of Demography of the Island of Hvar

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A B S T R A C T

Intentions of the present investigation were to apply a cybernetic model in description of demography on the island of Hvar for a time period from year 1800 till now. The basic idea of the model applied in this anthropological study (LOPI) is that the rate of reproduction is given by the non-linear controller: Y2/Te(1-(Y3/G)). Constant G represents an environmental carrying capacity of a community with respect to the cohort of older people (no longer a part of the pool of reproductive inhabitants; Y3) sharing limited survival resources. The proportional constant 1/Te connected with the pool of reproductive inhabitants (Y2) correspond to the reproduction maximum.

The consistency of the model is evaluated through comparison between model data and census. The LOPI model describes incredibly well the demography of the island of Hvar from the year 1800 till 1940. After year 1950 there were more inhabitants on the island then the model would predict. This fact is connected with changes in the migration or also in the increased carrying capacity (G).

On the basis LOPI model, population dynamic oscillates in its development. The example of the island of Hvar has proved that population reaches a maximal number of inhabitants every 200 years. The oscillation of population dynamics is influenced by the migration processes. The mere fact that oscillating population size is connected to population genetics and probably also to sociocultural factors suggests that a cybernetics demographic model can be a guide in the holistic anthropological approach.

Introduction

It has been shown in our previous communications[1–2] that some aspects of anthropology could be viewed through application of cybernetic concepts on demography using the Systems Theory. Systems Theory was proposed as a reaction against reductionism with intention to revive the unity of science[3]. The basic idea in the theory is that the studied phenomena represent an interdependent web of structures: the system. Systems interact with their environment through

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inputs and outputs, and they acquire qualitatively new properties through a continual evolution that changes their structures.

Cybernetics is formally defined as the science of communication and control between parts of a system (animals, people and machines). The very name cybernetic has been introduced to science in 1948 by Norbert Wiener describing flow of information during control activities in engines or living organisms and their associations[4]. The term cybernetics is derived from the Greek word for steersmen and in the works of Plato cybernetics has been mentioned as a method of administrative managing of provinces. Over the last few decades it has become accepted to distinguish first- and second- order cybernetics. First order cybernetics is associated mainly with feedback control adaptational mechanisms. Modern, second-order cybernetics is more related to understanding the evolution of biological and social complexity than to controlling (steering) it. For this purpose, a positive feedback control is used together with the idea that observations are not independent of characteristics of the observer.

Rather than reducing human organization to the properties of its parts, Systems Theory focuses on the arrangement of, and relations between the parts that connect them into a whole. There are some distinctions between **organization and structure**[5]. Organization is the configuration of relationships among a system's components that gives the system its essential characteristics. Structure is the physical embodiment of that abstract pattern reflecting lower level mechanisms. This particular organization determines a system, which is independent of the concrete substance of its constitutive elements (e.g. particles, cells, people, etc.). Thus, the same ideas and principles of organization underlie various scientific disciplines (biology, technology, sociology, etc.), providing a basis for their unification in a logically higher order metasystem. Thus, being a higher hierarchic structure, the metasystem can consider criteria or decide on propositions the system of lower order may not be able to reflect or decide upon. In this way Systems Theory elaborate a holistic approach has also been used in anthropological studies conducted by our group[6–7].

Deleuze and Guattari[8] challenged the concept of hierarchic structures by proposing that many cultural phenomena have Rhizome structures. In the rhizomatic system each subject can and must have connections to all other subjects, unconstrained by any bifurcation.

One major characteristic of Cybernetics is its preoccupation with the construction of models with special emphasis on a dynamic nature of the system's substructures.

According to a definition, a model is a set of propositions or equations describing, in a simplified form, some aspects of our experience about a particular system (anthropology as a unity of biological and socio-cultural phenomena). Therefore, anthropological models have complex features[2]. The complexity is not only constrained to interactions between bio-genetic and socio-cultural factors since the environment is also relevant in the sense that many agents are acting in parallel.

Bearing Einstein's aphorism: »everything should be made as simple as possible, but not simpler« in mind, we describe in this communication a cybernetic demographic model based on non-linear feedback control.

The purpose of this investigation is in line with necessity to perceive anthropology as a complex unity of gene structures, socio-culture and environment of human organization.

The primary aim of the present investigation was to apply a cybernetic model in description of demography on the island of Hvar for a time period between 1800 and present day, as well as to predict changes in population size. Another aim of this investigation was to emphasize specificity of a non-linear model application in anthropology supported by Systems Theory definitions. Therefore we constructed a model starting from an ordinary logistic model-using concept of specific reproduction processes in human communities (LOPI model). Simulations with the LOPI model were done using an OPSIM 285 program written in QBASIC ©.

The long and narrow island of Hvar is one of the areas in Europe where the demographic data of inhabitants is well documented. The history of Hvar and its inhabitants is also well known, with the colonization of the east of the island occurring mainly during the last 400 years as a result of immigration from the mainland following the Turkish conquest of the Balkans. According to a 1981 census[9] 11224 inhabitants in 25 localities (villages and small towns) have lived on the island of Hvar. A decrease in the number of inhabitants and big changes in population structure, particularly the increase of the aging population and women (i.e. age and sex) have been recorded in the past 8 decades[10]

The population of the island of Hvar has been constantly increasing, since 1857 until 1900 when it began to decrease. In the year of 1900, 18907 inhabitants have been living on the island of Hvar, which is the greatest known number of inhabitants living on the island based on the available literature[9,10]. The number of inhabitants started to decrease at the turn of the century. Due to a filoksera epidemics, wine production collapsed, forcing many Hvar inhabitants to emigrate to the United States of America. Another reduction in the number of inhabitants was caused by the onset of World War I and WW II. Neglecting a slight increase in the number of inhabitants in and around 1953, the number of inhabitants has been in constant decline until 1981. After 1981, the number of inhabitants on the island of Hvar started to increase.

Model

The cybernetic LOPI model is based on the idea that in the case of anthropological demography, a well-known logistic model has to be modified. The logistic model in the simplest way is formulated as follows:

$$dN/dt = rN - rN^2/K,$$

where N is a variable representing population growth, r is the initial rate of net population reproduction and K is the carrying capacity of the environment for population growth. In this way the equation describes decreasing rate of population expansion, while the solution of this differential equation is an »S« shaped curve, reaching maximum at »K«. The curve is given by:

$$N(t) = K/(1+\exp(-r(t-t0))).$$

The approximation of the growth process could be achieved by the following solution:

$$N(t+1) = N(t) + rN(t)(1-N(t)/K).$$

If a substitution is applied:

$$X(t) = N(t)/K,$$

the above relation could then be presented in the following manner:

$$X(t+1) = X(t) + rX(t)(1-X(t))...$$

This relation is also termed »logistic« and its solutions are elaborated in the chaos theory. The basic idea of the model applied in this anthropological study (schematized in Figure 1; LOPI model) is that the rate of reproduction is not given by the entire population, but by a popula-

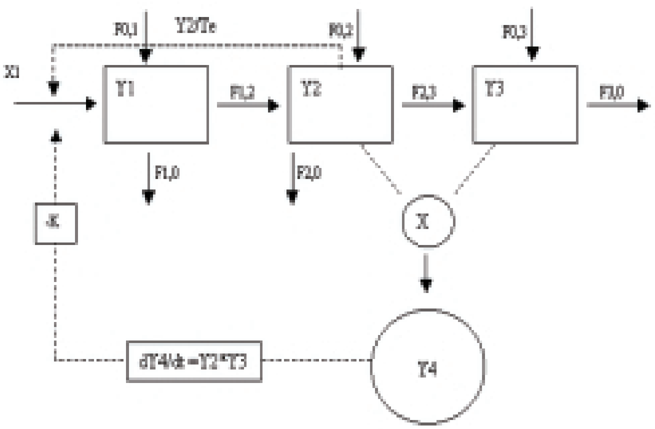

Fig. 1. Cybernetic LOPI model

tion's reproductive class (Y2). So we performed the following substitution:

$$r = Y2/Te,$$

where Y2 is a group of people from 20–40 years of age (reproductive group).

Besides this component, the rate of reproduction was controlled by the carrying capacity of the environment represented through fraction of Y2 and Y3. The Y3 represents the group of people older then 40 years (aged people). Those basic model ideas (LOPI) were formulated within QBASIC program (OPSIM 285) according to the scheme presented in the Figure 1. The negative effect of Y2 and Y3 on the reproduction was realized through the derivative control from a dummy compartment (Y4) whose content is given by the time integral of Y2Y3.

The model dynamics is described by the flow constants: F0,i: immigration, F i,0 elimination by the mortality and emigration and by inter compartment transit due to ageing (Fi,i+1). Constants that have the influence on the condition of the first compartment are:

Te = proportional constant, i.e. reproduction
K = derivate constant.

Mathematics of OPSIM 285

The function of OPSIM 285 is to solve the condition in a net of compartments. The input (X1) for the first compartment designates children born during a one-year period. The input (X1) is subjected to control:

$$X1,j = Y2,j\ /Te – KY2,j\ Y3,j$$
$$= Y2/Te\ (1–Y3/G).$$

Content of the first compartment is given by:

$$Y1,1 = (Y1,0)(1–\ \ tF'1),$$

$$Y1,j = (Y1,j–1)(1–\ \ tF'1) + X1,j\ \ t,$$

where F'x represents Fx,0 + Fx,x + 1.

In a similar manner, the content of other compartments is given:

$$Y2,j = (Y2,j–1)(1–\ \ tF'2) + F1,2Y(1,j–1)\ \ t,$$

$$Y3,j = (Y3,j–1)(1–\ \ tF'3) + F2,3Y(2,j–1)\ \ t,$$

$$Y4,j = (Y4,j–1) + Y2,jY3,j1\ \ t,$$

j = number of time points: t = j t.

Results

The model simulations were made using OPSIM 285 program, while census data were used as a criterion. Minimal changes of control constants, while working in OPSIM 285 program, brought about imprecise estimates of the census data, so it was necessary to do numerous simulations. Approximately 50 simulations had to be performed in order to determine the most precise constants (Te and G) for the island of Hvar.

First and second compartment flow constants (F1,2 and F2,3) are identical (0.05) and represent the mean transit time of the compartments. The elimination constants for three compartments (F1,0; F2,0; 3,0) represent emigration and mortality and their values were taken according to demographic data on the Republic of Croatia (Jovanović, 1999). The optimal obtained values for input control were as follows:

Te = 1/7 (proportional control)
–K = –0.000018 (derivate control),
G = 1/KTe = 7936

Figure 2. depicts the number of inhabitants on the island of Hvar, as well as model predictions for this data in the period from 1800 to cca. 2020.

We can observe from Figure 2. that the model predictions follows the census curve. Model irregularity starts at about the year 1950, when a number of inhabitants in simulation become lower than census values. After 1950, the minimal census value occurs in 1981 and counts 11224 inhabitants, while simulated values show a minimal number of inhabitants in 1991, and counts 7099. Maximal number of inhabitants in this simulation approximately agrees with census values, even though it does not achieve value above 18000, and occurs in a ten-year time shift (year: 1910, 17997 inhabitants).

Simulation of the population size on the island of Hvar during a long time period

In order to describe the essential long term predictions of the population changes on the LOPI model basis we simulated three »scenarios«. Values of the controller constants used in these simulations are the same as those in the simulation for the island of Hvar. In this way we have been able to compare the population

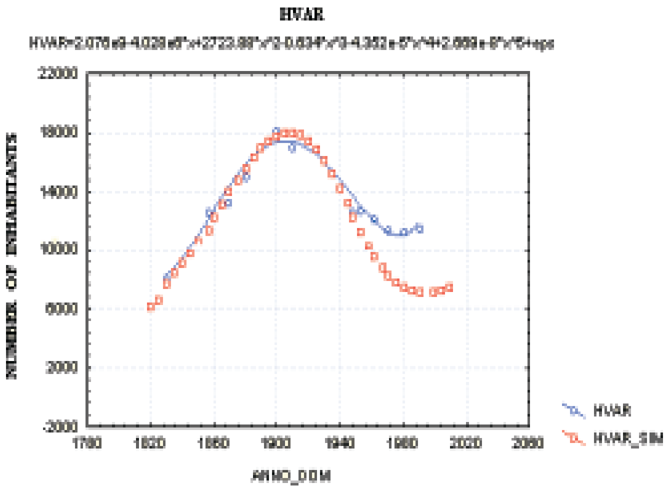

Fig. 2. Number of inhabitants on the island of Hvar from 1880 to 1991 year and a modelprediction values

changes during the past, and also in the future.

On the basis of the existing values for input and flow used in the first simulation (island of Hvar), a simulation with OPSIM 285 program was conducted again (STA 1). A greater number of points were taken (N = 201), in an effort of achieving a better representation of future population size. Preliminary volumes of the Yi (2800, 2600, 1200, 1000) were changed to lower values (10, 10, 7, 0), to allow a more precise observation of population size movements during long periods of time. Simulation of the island of Hvar population size during a 1000 years (STA 1) shows that population is oscillating, in time periods of about 200 years between maximums.

In the second simulation (STA 2) the flow for compartment 2, reproductive compartment (F2,0) was changed. Previous flow, which was 0.007, was enlarged to 0.014 with the aim of presenting a greater emigration from the island. Increasing elimination constant (emigration and mortality) from second compartment (STA 2), decreases oscillations between upper and lower curve amplitudes, that is, a balance is slowly restoring. In other words, with a larger emigration, a population size movement has a goal to reach a balanced state, or a constant number of inhabitants.

In the third simulation (STA 3) the flow for compartment 2 (reproductive compartment) was changed to – 0.014, representing immigration scenario F(0,2). Because of large values in results, less points were used than in previous simulations (N = 50). With immigration, the number of inhabitants constantly increased (STA 3).

Flow F(2,3) has neglected the influence on results.

Figure 3. represents all the three simulations during a long time period with flow changes for second compartment (F2,0).

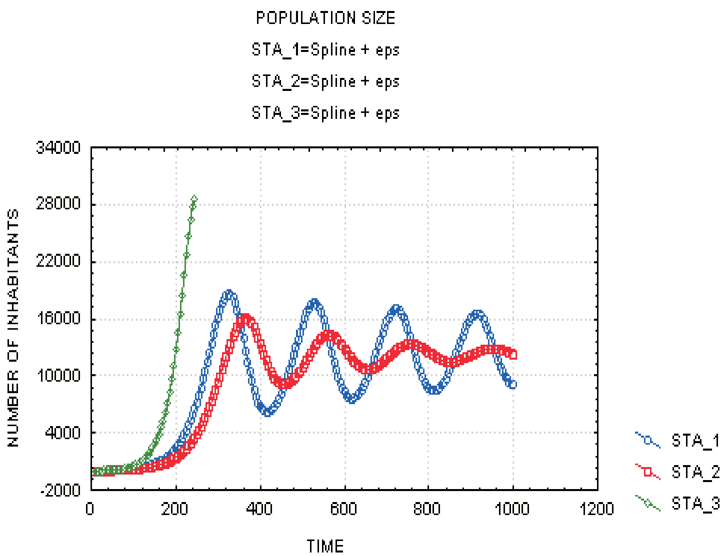

Fig. 3. Long term simulation of population size on the island of Hvar

Discussion

The established (studied) LOPI model offers a very good description of demographic changes on the island of Hvar between the years of 1820 and 1945. The obtained results suggest there was a steady increase in the number of inhabitants of the island until the turn of the century (1900), after which depopulation of the island began. It should also be noted that LOPI model predicted a maximum number of inhabitants (18,000). As may be seen in Figure 2., the discrepancy between the census data and the data predicted by LOPI model, begins to manifest after 1950. The predictions about population of the island generated by LOPI model are lower than the real values that become constants (at approximately 11,000 inhabitants) for the period after 1980. Although at a later time and at a lower population size (7,100 inhabitants), the model also predicts population stagnation. The »number of inhabitants model« predicts the number of inhabitants based on calculations of the number of newborns (X1), elimination from certain age compartments, mortality, emigration and the process of aging. The »number of new-borns« model generates according to the controller as described in the section describing the model. In a simple form, the relation may be expressed as:

$$X1 = (Y2/Te)\ (1 - (Y3/G)).$$

Compared to the relation of model prediction and census, this controller shows that system reproduction of over than 130 years (1820–1950) may be successfully described with two controller constants. The proportional constant 1/Te reflects maximum reproduction that would be achieved if the cohort of older people sharing limited survival resources with other cohorts did not exist. The estimated value of the maximum reproductive constant for the island of Hvar is 1/7. This means that if one took 100 people in the reproductive compartment (50 marriages), those people would annually give birth to 14.3 children. Furthermore, since transit through a reproductive compartment lasts for 20 years, the number of children during this period would amount to 285.7 children, or 5.7 children per marriage (14.3 20 = 285.7). However, reproduction decreases for factor 1-Y3/G, so for the year 1900, it should be expressed as Y2/7 5769/7 = 824, and (1-Y3/G) (1–5868/7936) = (1–0.7394) meaning that reproduction would amount to only 26% of the maximum, yielding 1.5 children per marriage.

Constant G represents the environmental carrying capacity of a community with respect to the population of no longer reproductive inhabitants. For the island o Hvar, G equals 7936. The overall capacity of the island amounts to 2G which could be deduced in the following way: if Y3 would be equal to G there would be no reproduction (Y1=0) while Y2 would be approximately equal or greater than Y3 due to differences in transit time of these groups (0.058 / 0.045). Thus, the island of Hvar could maximally support between 15870 and 18164 inhabitants or 52.9–60.5 people per square kilometer. Population density average for the Republic of Croatia was 56 in 1900 and grew to 84.6 in 1991. The environmental carrying capacity G depends on the size of the investigated region (in square kilometers) and should be expected to reflect the sociocultural conditions established in a given community. The latter primarily refers to the dominant practicing economy type and population profile (rural or urban). Constant G is probably higher for urban settlements than for rural ones. However, a legitimate question of the smallest size of a settlement testable by the LOPI model poses itself. If this model, i.e. its controller could be translated into a stochastic model, it could be applied on the level of single families and used in assessment of spread of surnames in certain localities.

Based on simple hypotheses about characteristics of LOPI controller, it is incredible how well this simple model manages to describe demographic changes on the island of Hvar during 130 years. From the standpoint of the model, the well known Filoksera epidemics was not registered as a significant event, while the observed deviations starting in 1950 suggesting there were more inhabitants on the island of Hvar than LOPI model would predict, were the first discrepancy between model predictions and census data. However, general »historic« trends were incorporated into the model, suggesting its application in the analysis of smaller regions of the island and even on the level of settlements. In terms of the applied model, we could explain this finding primarily by changes in G constant of the controller, or changes in migratory movements of the island population. Changes reflecting in the vital statistics, i.e. increasing age of the overall population should also influence model predictions. It should be noted here that the model's dynamics allows for verification of natality and mortality. We compared already published results[7] with model predictions for the period between 1971 and 1981. Mortality and natality may be expressed using following figures: annual mortality on the island ranged between 135 and 168 people, and annual natality between 126 and 178. Based on the model of elimination from the system for the given period ($Y_i F_{i,0}$), mortality ranged between 148 and 164, and natality (X1) between 138 and 161 people. In comparison with available data, we can conclude that over input and output, our model generates a good prediction of demographic changes on the island. Therefore, a census exceeding model predictions could probably be attributed to immigration onto the island[11]. Also, a change in maximal capacity G most probably occurred. Changes in environmental carrying capacity may be directly tested only in cases for which data on age structure is available. Such data may be directly fed into controller mechanism and thus obtain the relationship between Te and G. This approach will be further elaborated in our future research.

The influence of migratory trend change has been investigated through simulations (Figure 3.). The arrival of immigrants leads to population growth while emigration, or increase of $F_{i,0}$ causes its steeper decline.

Long-term model predictions reveal oscillating characteristics of both population and effective breeding size. The character of oscillations (amplitude and rhythm) depends on the relationship of constants in the main controller. It should be pointed out that age structure of the population changes depending on the maximum or minimum values. Maximum for the population of inhabitants older than 40 years of age precedes population minimum, while minimum Y3 occurs in the point of upward inflection. If one should take these as predictions of the real general trends, then one could ask oneself about sociocultural factors possibly related to these oscillations. The mere fact that population size is probably related to culture, social structures (well being), and a population's ability to survive in an ecological niche, suggests that the observed oscillations should be accompanied by cultural changes on the island. According to Deluze's and Gattari's »rhizomatic« system terminology[8], the observed migratory trends[11,12] could be viewed as subjects of Multiplicity. Multiplicity compromises »determinations, magnitudes and dimensions« that cannot increase in number without multiplicity changing in nature, and cannot be measured by the simple act of counting. Multiplicities are held together by simple deterritorialization which itself is a product of migrations. Based on the relationship of individual G-capacities, one could probably speculate about hierarchical or rhizomatic population structure on the island. However, anthropological application of cybernetic models (from our side at least), is not aimed at controlling the investigated community in ways dictated by political and economic pressures. From the standpoint of cybernetics, such pressures stem from the meta-system affecting. unity of genetics and sociocultural forces. For example, when a relative increase in aged population occurs, it is followed by a decrease in effective inbreeding size.

We do not have the illusion that cybernetics (numbers and equations) could ever replace anthropological fieldwork, but we do propose however, that cybernetic would be guide for the holistic approach in anthropology.

Finally, it should be noted that controller Y2/Te (1-(Y3/G)) we used, is very easily transformed into a Y3(t+1) = aY3(t) + rY3(t)(1– (Y3(t)/G)) controller used in event description according to chaos theory. However interesting, this line of research will be pursued at a later time.

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ANTROPOLOŠKI KIBERNETIČKI MODEL DEMOGRAFIJE OTOKA HVARA

S A Ž E T A K

Namjera je ovog istraživanja bila primijenit kibernetički model za opis demografije otoka Hvaru u vremenskom razdoblju od 1800. godine do danas. U te svrhe postavljen je ne linearni model (LOPI) koji se temelji na slijedećem kontroleru: Y2/Te(1-(Y3/G)). Konstanta G predstavlja kapacitet okoliša za održavanje broja starijih (ne više reproduktivnih osoba; Y3) u uslovima ograničenih resursa. Konstanta 1/Te zajedno s reprodukcijskim dijelom populacije (Y) odražava maksimalnu godišnju stopu reprodukcije..

Konzistencija ili vjerodostojnost ocjenjena je usporedbom predviđanja modela s podacima cenzusa. LOPI model nevjerojatno dobro opisuje demografske promjene na otoku Hvaru za period od 1800 do 1940. godine. Nakon tog perioda, od 1950. Godine na otoku ima više stanovnika nego što to predviđa model. Do ovih nepodudarnosti došlo je zbog promjena u migracijskim tokovima ili zbog povećanja kapaciteta okoliša (G).

Na osnovi LOPI modela, dinamika stanovništva neke zajednice oscilira u svom razvoju. Na primjeru otoka Hvara dokazano je da populacija dostiže maksimalni broj stanovnika svakih 200 godina. Procesi migracije djeluju na dinamiku oscilacija populacije. Oscilacije u veličini populacije prouzrokuju i promjene u genetici populacije otoka a također vjerojatno dovode do promjena sociokulturnih čimbenika. Ova činjenica upućuje na to da kibernetički demografski modeli mogu biti valjani putokaz za razumijevanje antropološkog holizma.