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Dispersal time for ancient human migrations: Americas and Europe colonization

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Abstract – I apply the recently proposed intermittence strategy to investigate the ancient human migrations in the world. That is, the Americas colonization (Bering-bridge and Pacific-coast theories) and Neanderthal replacement in Europe around 45000 years before the present. Using a mathematical equation related to diffusion and ballistic motion, I calculate the colonization time in all these cases in good agreement with archeological data (including Neolithic transition in Europe). Moreover, to support these calculations, I obtain analytically the effective speed of colonization in Europe $v_{eff} = 0.62$ [km/yr] and related to the Aurignacian culture propagation.

Introduction. – Archeological data suggest that the dispersal process of early modern human (*Homo sapiens*) beginning in Africa around 55 000 years ago [1–3]. From there, hunter-gatherer populations engaged long travels of thousand of kilometers. The interesting point becomes related to the dispersal-time of these ancient migrations. A general framework, out-of-Africa theory [1], is now available but the specific details are still missing. For instance, the colonization process of the Americas at least 12 000 years before present (BP) is not still clear. Four theories, related to possible routes, have been discussed and proposed (see [4,5] and specially [6], for a general discussion): a) The Bering-land-bridge theory, where migrants from the northeastern Asia crossed the land bridge between Siberia and North America. Hunter-gatherer pursued animals spending few thousand of years in the dispersal processes from North to South America (a critic revision in [7]). b) Pacific-coast-route theory, where explorers from southeastern Asia followed the coastline using small boats and taking few centuries to complete the migration [8]. c) Pacific-crossing theory, where inhabitant of Australia (or near islands) continued travelling to east and reached South America. d) Atlantic-crossing theory, where resident of Iberian peninsula crossed the Atlantic by boats, following the edge of glaciers existent in that epoch. The discussions are still open with respect to these possibilities, but the first theory (Bering bridge) is the most accepted one and the second (Pacific coast) is also quite persistent. The other two, (c) and (d), are weakly supported by the scientific community but not excluded.

In this paper I will not discuss which one of the four possibilities is more plausible than others. I will consider the time involved in these kind of human migrations. There are mathematical universal aspects which permits, under reasonable assumptions, to estimate the travel time in every case. A key which connects these human ancient movements with mathematical models is found in the papers by Bénichou *et al.* [9–11] (also [12] for an introduction). For finding hidden target, intermittence in the behavioral search is an optimal strategy. Essentially, and enough for us, a first phase of intensive search for food (among others necessities) is considered as a process with a diffusion coefficient D. The second phase, a fast (ballistic) motion with velocity v, is related to relocation in unvisited regions. We consider the first phase (diffusion) related to the niche exploitation phase and associated with the characteristic time τ_s (a parameter of the theory). For instance, hunter-gatherer motion of our ancestress is closely related to seasonal climatological conditions and then, in this case, $\tau_s \sim 1$ [yr]. Other example, the Neolithic transition in Europe (agriculture dispersal) where human groups occupied a territory in term of human-generations before beginning a travel, searching for others lands. In this case, one expect $\tau_s \sim$ number of generations $\times 25$ [yr] where I assume one generation of the order of 25 years.

Table 1: The table shows the numerical results of this work based on eq. (4). I test the theory with the Neolithic transition in Europe (first column). With respect to the Americas colonization, the case of the hunter-gatherer (Bering-land-bridge theory) and Fisherman-gatherer (Pacific-coast theory) was considered. Also, the propagation of hunter-gatherer in Europe some 45000 years ago, Aurignacian-culture dispersion and Neanderthal extinction, corresponds to the last column. The main prediction is related to the dispersal time τ (the last file) in every case.

TABLE 1	Europe Neolithic	Americas Bering bridge	Americas Pacific coast	Europe Aurignacian
D [km^2/yr]	60	80000	1620000	5000
v [km/yr]	1	400	900	100
τ_s [yr]	5×25	1	4	1
τ_D [yr]	-	4050	200	7200
τ_f [yr]	-	45	20	60
x [km]	-	18000	18000	6000
τ [yr]	-	2715	140	4820

As mentioned, we use the ideas of intermittence to consider ancient human migrations. Nevertheless, there are interesting previous works related to Levy-like patterns for this kind of motions (including animal mobility and others) [13–15]. Moreover, the paper of Brown [16] *et al.* applies the Levy flight model basically to a relatively complex society while this article is more focalized on a very simple society basically made by explorer groups. Beside, as pointed by Brown, the Levy statistics is applied to the step length and there is no average travel time between patches, while in this article the time (either traveling or pausing) plays a central role to explain the migration through the continents.

The mean results of this work are listed in table 1. The predictions related to the dispersal time τ for different human migratory processes is in the last file.

Exploitation time, diffusion coefficient and velocity. – After [9] in a two-dimensional problem, with low target density (large separation distance b), and some approximations related to the reaction radius a, the exploitation time could be calculated. Explicitly, for $D/v \ll a \ll b$ the time of exploitation, called time of search in that reference, could be written as $\tau_s = \frac{D}{2v^2}\left(\frac{\ln^2(b/a)}{2\ln(b/a)-1}\right)$. To simplify this expression, and without a relevant error in our calculations, I will assume $\frac{b}{a} \sim 1000$ in accord with the mentioned approximations and consistent with archeological data. The final expression for the exploitation time of a niche becomes, approximately,

$$\tau_s = 2\frac{D}{v^2}. \tag{1}$$

It is a relevant expression for us since it relates fundamental quantities of ancient human migrations. We assume and use (1) as a basic fact (hypothesis) to predict ancient human dispersion. It is a quite reasonable expression (aside of the factor 2) since the problem have only three basic dimensional parameters and it becomes justified through our results which are compared with archeological data.

As a first verification of the above mathematical expression, supporting next calculations, I will consider a well documented agriculture propagation process in Europe. That is, the Neolithic transition some thousand of years before present. This process is related to the replacement of the hunter-gatherer culture by an agricultural culture. After Fort *et al.* [17] the velocity of propagation of the process and the diffusion coefficient D are of the order of 1 [km/yr] and ~ 60 [km^2/yr], respectively. Then from eq. (1) one has $\tau_s \sim 5$ (generations). A quite acceptable estimation for the exploitation time of a determined area.

The total time for dispersal is given by the intermittence between the phase of exploitation and the fast motion. These two phases determine the total dispersal-time over a distance x . In this way, the total diffusion (exploitation) process has a related time τ_D:

$$\tau_D = \frac{x^2}{D}, \tag{2}$$

and the fast phase a total time τ_f given by

$$\tau_f = \frac{x}{v}. \tag{3}$$

Therefore, it seems reasonable to assume that the total dispersion time τ is the superposition of both (2), (3), *i.e.* the total time through the distance x becomes

$$\tau = \alpha\tau_D + (1-\alpha)\tau_f, \tag{4}$$

where α is a number satisfying the condition $0 \leqslant \alpha \leqslant 1$. This parameter has a geographical and climatological sense because for habitats like, for instance, deserts the rapid phase has major weight. The α parameter is difficult to estimate since it is a stochastic quantity depending on random climatological and geographical factors (it could have many alternantions). In this paper we shall use the generic value $\alpha = 2/3$ justified finally through our predictions matching well with archeological data. The meaning of eq. (4) is the superposition of both kind of motion discussed in this work (intermittence).

It is an estimation of the total time of propagation and will be applied directly to ancient migration of human populations. The four examples treated here (see table 1) will be studied according to (4). The reasonable matching with archeological data justifies the above equation.

In terms of the basic exploitation time τ_s, the distance x and the velocity v, the total-dispersion time τ (4) becomes

$$\frac{\tau}{\tau_s} = 2\alpha \left(\frac{x}{\tau_s v}\right)^2 + (1-\alpha)\left(\frac{x}{\tau_s v}\right). \qquad (5)$$

Equation (4) (or (5)) is the main theoretical result of this work. It will be applied to different archeological situations in good agreement with several theories related to ancient migrations in the world. More support of (5) comes from the calculations of the effective colonization velocity of Europe in the last section (Aurignacian).

Finally, since the dispersal motion has two component, it is not correct to assume here the fast velocity phase as related to the population speed. From eq. (5), we can define the effective velocity dispersion v_{eff} by the mathematical expression $v_{eff} = \mathrm{d}x/\mathrm{d}\tau$ being different of v (with $\alpha \neq 0$) and depending on the migration distance x.

Bering-land-bridge and Pacific-coast theories. – Now I will apply the above concepts and expressions to the colonization of the Americas in the Bering-bridge-crossing theory. For hunter-gatherer populations the motion is related to seasonal (climatological) variations. In this way the elementary measurement of time is *one year* ($\tau_s = 1$ [yr]) and the total estimated distance is $x = 18000$ [km]. Human-beings walk approximately with a speed of 3 [km/hr]. But also they must rest and, moreover, children and old people produce resistance to travel, so that we have an estimation of $v = 400$ [km/yr]. The diffusion parameter is calculated from eq. (1) and its value is $D = 80000$ [km^2/yr]. Using eq. (2), an estimation of the total diffusion (exploitation) time for the Americas is $\tau_D = 4050$ [yr], and the estimation for time related to the fast phase (eq. (3)) is $\tau_f = 45$ [yr]. With a value of $\alpha = \frac{2}{3}$, the total time to colonize the Americas eq. (4) becomes $\tau = 2715$ [yr]. A good estimative prediction in agreement with archeological data. Table 1 shows the value of the parameters in this case and others including the Neolithic transition in Europe, the fisherman-gatherer motion (Pacific-coast theory for the Americas), and an application to the propagation of the Aurignacian culture in Europe around 45000 years ago and, related to the extinction of the Mousterian culture (Neanderthal population).

With respect to the Pacific-coast theory for the Americas colonization, it is a fisherman-gatherer migratory process and the estimations are more difficult because there are not well-documented (quantitative) results. Since boat-travel is faster than walk-travel, we assume a factor of order two respect to the hunter-gatherer process, that is $v = 900$ [km/yr]. On the other hand, the exploitation time in the Pacific coast is widely affected by the so-called El Niño phenomena (ENSO) with an averaged periodicity of four year and producing serious damage in the fishery labors. So, in this case, it is reasonable assume a value of $\tau_s = 4$ [yr]. From eq. (1) we obtain $D = 1620000$ [km^2/yr]. From eq. (2), the total diffusion time in the Americas could be estimated as $\tau_D = 200$ [yr] and the time related to the fast phase eq. (3) as $\tau_f = 20$ [yr]. One obtains the colonization time for the Americas in the Pacific-coast theory as $\tau \simeq 140$ [yr], a quite reasonable value and compatible with the archeological estimation in this case [5] (see table 1).

Aurignacian culture propagation in Europe. – As final application, I will consider briefly the hunter-gatherer culture propagation related to early modern populations around 45000 years ago in Europe. In fact, it was a replacement since Neanderthal population, who occupied the European niche (including also, Israel), was extinct due to this modern migration process coming from Africa [18]. This was a tragic event since Neanderthal specie (*Homo sapiens neanderthalensis*) was extinct together with its culture (Mousterian). Viewed as a competition population problems, Gause's exclusion principle [19] is operative in this case ([20] and [21]). Assuming a culture of hunter-gathering, then we have $\tau_s = 1$ [yr]. Since the propagation was related to competition, the velocity of the rapid phase must decrease with respect to the case of the above section. Consider $v = 100$ [km/yr] in this case, a factor 1/4 respect to the free hunter-gatherer propagation. From (1), the diffusion coefficient becomes $D = 5000$ [km^2/yr]. A travel of $x = 6000$ [km] (next orient, west-Europe) has associated a diffusion time $\tau_D = 7200$ [yr], and for the rapid phase $\tau_f = 60$ [yr]. The total time (4) becomes in this case $\tau = 4820$ [yr], a quite reasonable time for dispersal of modern human across Europe and part of the next orient (Israel). Neanderthal extinction was estimated in a lapse of 6000 [yr] (see ref. [18]) being an upper bound for τ and in good agreement with our prediction.

To support these calculations, let us consider the effective velocity defined as $v_{eff} = \frac{\mathrm{d}x}{\mathrm{d}\tau}$ and eq. (5). With the values assumed in this case a direct calculation gives us an effective velocity $v_{eff} = 0.62$ [km/yr] in reasonable agreement with reference [18] (0.4 [km/yr]).

Conclusions and discussions. – The concept of intermittent was applied to the ancient human migrations, in particular to the colonization of the Americas where the total time for dispersal was calculated, for the Bering-bridge theory (2715 [yr]) and for the Pacific-coast theory (140 [yr]). Also I have calculated the dispersal time of modern human in Europe (approximately, 45000 BP) obtaining 4820 [yr] in good agreement with the estimation for Neanderthal extinction (see table 1). Moreover, in this case the effective velocity of dispersion was calculated as $v_{eff} = 0.62$ [km/yr] in reasonable agreement with the estimation found in [18].

The major source of error in these calculations becomes related to the value of α (4). The choice $\alpha = 2/3$ joins well with the archeological data, nevertheless, it is depending on climatological and geographical random variables. The fact that we use a fixed value, for the different migration processes, makes this choice plausible. The search for the corresponding equation for α is matter of future studies.

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