Chapter 2
The Spread of Agriculture: Quantitative Laws in Prehistory?

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2.1 Introduction

Ammerman and Cavalli-Sforza (1971) were the first to estimate the spread rate of a Neolithic front using sound statistical methods. Their linear regression of dates and distances of 53 sites implied an average spread rate of about 1 km/year for the Neolithic in Europe. After almost 50 years, this conclusion remains valid in light of studies with more sites by other authors (e.g., Pinhasi et al., 2005; Fort et al., 2012).

Besides estimating the average speed, it is also of interest to visualize local features. Figure 2.1 shows an example of a spatial interpolation of a database of 918 sites (Fort, 2015). We see very clearly in Fig. 2.1 how the Neolithic wave of advance surrounded the Alps before climbing up those mountains. The slowdown in northern Europe is also seen, because the isochrones become closer to each other as the wave of advance approaches Denmark from the South. Conversely, a fast spread along the Western Mediterranean is easy to recognize because the blue color appears in the Iberian peninsula, which is much further away from Greece than the blue regions in central Europe (just North of the Balkans).

In addition to Europe, several other examples of Neolithic spread have been analyzed in recent years. In this chapter, we will compare those results in order to see if there are any similarities that might point to some general law(s) concerning Neolithic spread.

Admittedly, our knowledge on the Neolithic is different depending on which region of the world we consider. For example, for the Bantu spread in eastern Africa,

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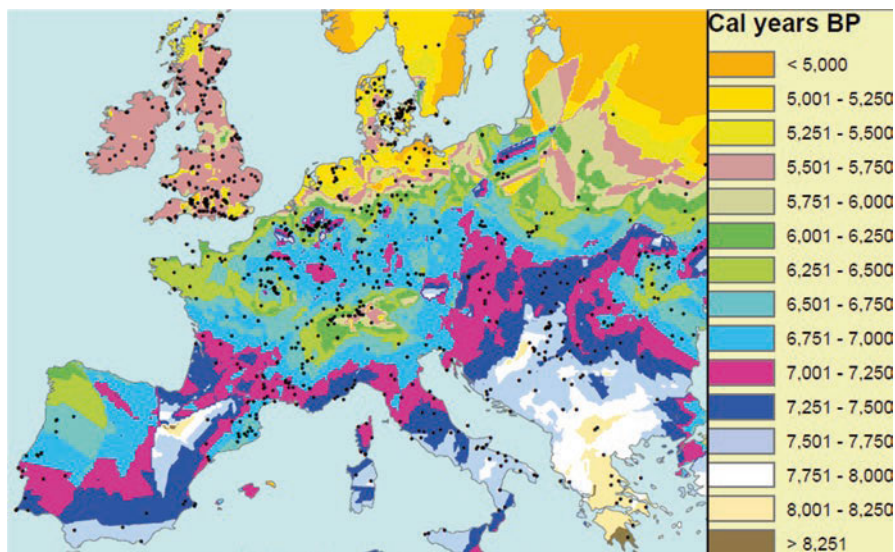e-mail: joaquim.fort@udg.edu

Fig. 2.1 Spatial interpolation of a database of early Neolithic dates in Europe. The slowdowns in the Alps and northern Europe and the fast spread along the Western Mediterranean are visible. (Adapted from Fort, 2015)

we see in Fig. 2.2 that there are substantially less early sites than for Europe. However, clear trends of Neolithic spread can be recognized. Indeed, we see in Fig. 2.2 that the Bantu spread was substantially faster southwards than eastwards, because the distance covered is clearly larger in the first case. As we shall see below, it is possible to estimate the average spread rates for both Bantu expansions (southwards and eastwards).

Spread rates are our main interest in this chapter because if we can estimate a Neolithic spread rate, we can infer the relative importance of cultural and demic diffusion. Local spread rates are still very difficult to estimate in most case studies (leaving outside continental Europe, Fig. 2.1), because of the paucity of early Neolithic dates available.

2.2   Comparison of Neolithic Spread Rates

Figure 2.3 summarizes estimations of Neolithic spread rates in several regions of the world. For each of these case studies, one or several linear time-distance regressions were performed. Time-distance regressions are usually preferred over distance-time regressions, on the basis that errors in the dates of sites are larger than those in their distances (Fort et al., 2004). The number of sites N used is highly variable, because it depends on the archaeological data available for each case study. In the next paragraphs, we summarize the values of N, the spread rates, the correlation coefficients r and their confidence levels (CL) for the case studies the spread rates of which are shown in Fig. 2.3.
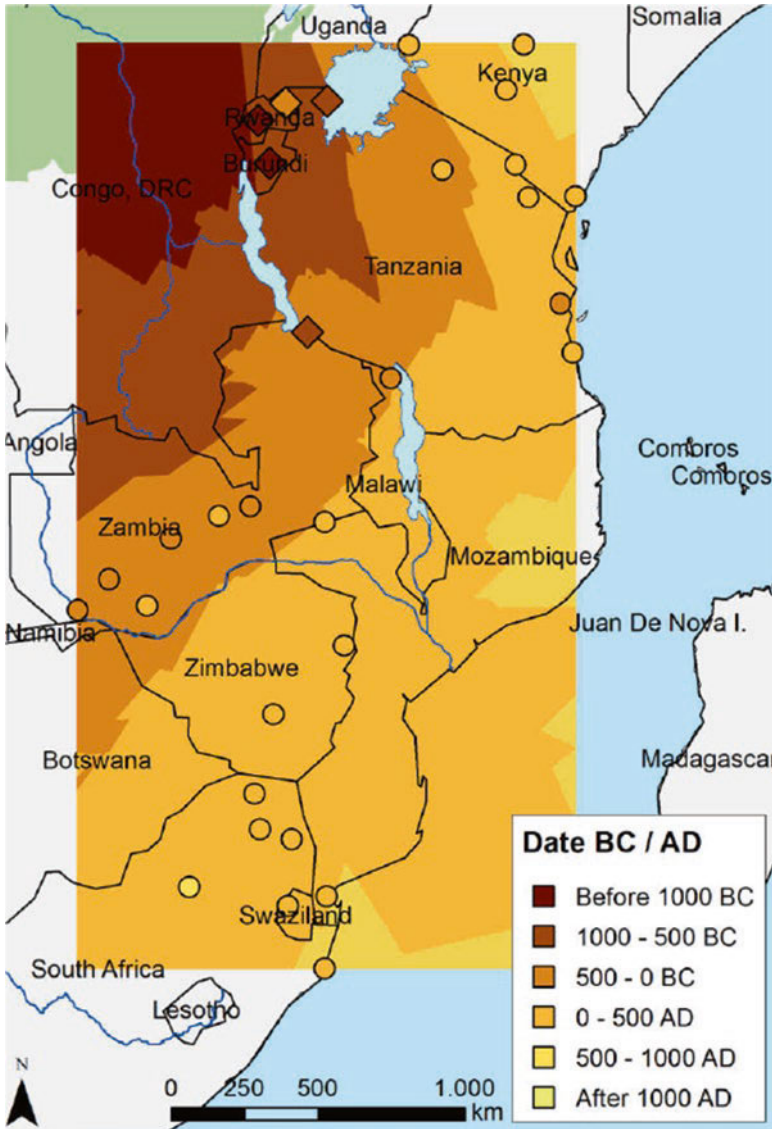
Fig. 2.2 Spatial interpolation of early Bantu dates in Eastern Africa. The spread is clearly faster southwards than eastwards. (Adapted from Isern and Fort (2019). Diamonds are sites that were considered as possible origins)

The region for which there are more dated early Neolithic sites is Europe and the Near East (see Fig. 2.1 for Europe). Pinhasi et al. (2005) used $N = 735$ sites to estimate the average spread rate of this Neolithic wave of advance. They obtained the range 0.9–1.3 km/year (95% CL) for the spread rate (using calibrated dates). The correlation coefficient was $r = 0.82$, both for great-circle distances (0.9–1.1 km/
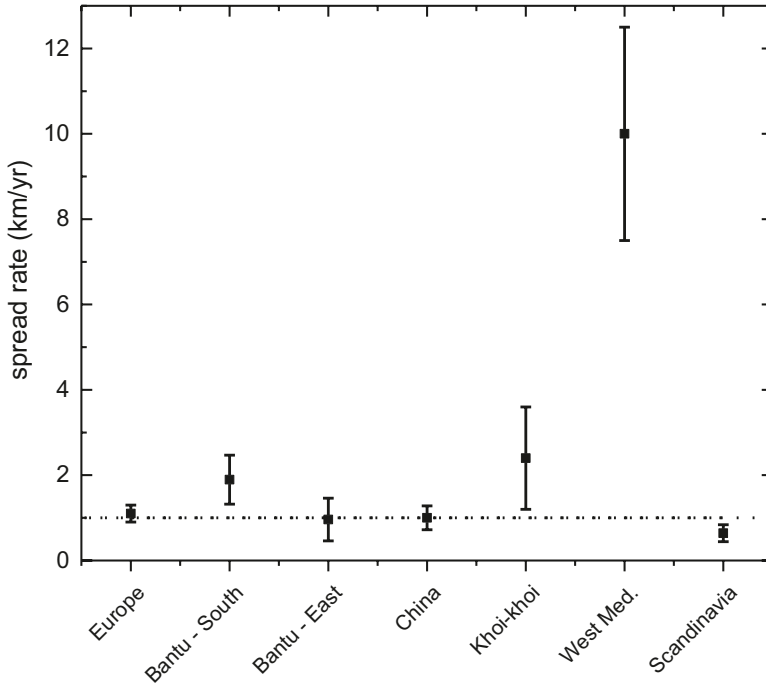
Fig. 2.3 Comparison between Neolithic spread rates for seven regions of the world. The details of each case study are described in the main text. The horizontal dashed line corresponds to a speed of 1 km/year

year) and for shortest-path distances (1.1.–1.3 km/year). Shortest paths take geography into account, in this case by avoiding sea travels of thousands of kilometers across the Mediterranean sea (Pinhasi et al., 2005). Thus in Fig. 2.3 we have used the overall range 0.9–1.3 km/yr for Europe.

The expansion of Bantu languages is considered to have taken place together with the spread of farming across most of subequatorial Africa. For the southern Bantu expansion, it was possible to use only $N = 22$ early sites and the spread rate was 1.32–2.47 km/year (95% CL). This range was estimated by Isern and Fort (2019) by combining the rates from two plausible origins (leading to $r = 0.87$ and $r = 0.86$). For the eastern Bantu expansion, the number of early sites is still lower ($N = 13$) and the rate is 0.46–1.46 km/year (95% CL, $r = 0.84$ and $r = 0.79$). Note that this speed is slower than that of the southern expansion, as expected from Fig. 2.2. In this case study, it was not considered necessary to introduce shortest paths, because their distances would be very similar to those provided by great circles (note that there are not very large obstacles in Fig. 2.2).

Cobo et al. (2019) have recently analyzed $N = 185$ sites to study the spread of domesticated rice in China and southeastern Asia. The range 0.72–1.28 km/year
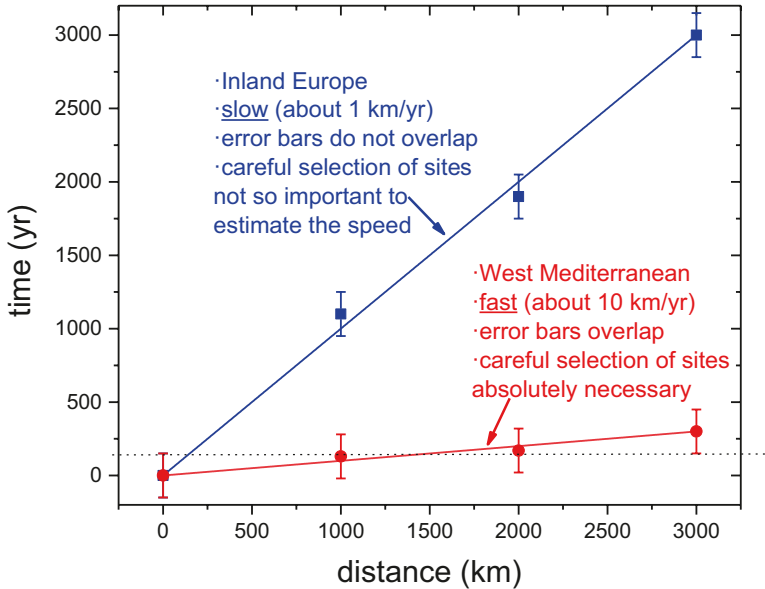
Fig. 2.4 Comparison between a slow Neolithic expansion (blue) and a fast one (red). It is seen that in the latter case the error bars easily overlap (dotted horizontal line). Thus, for fast spread rates, it is very important to use the oldest site for each region if we want to establish a consistent trend by avoiding such overlapping. The symbols and error bars correspond to hypothetical data that are useful for illustration purposes

(95% CL) results from the combination of great circles (0.72–0.92 km/year, 95% CL, $r = 0.78$) and shortest paths (1.02–1.28 km/year, 95% CL, $r = 0.82$).

For the spread of Khoi-khoi herders in southern Africa, after neglecting clearly late sites and considering only the oldest date per site (as in all other case studies), there were only $N = 10$ sites left (Jerardino et al., 2014). The spread rate is 1.2–3.6 km/year (95% CL) and $r = 0.85$. In this case, great circles were considered unreliable because most sites are near the Ocean; thus it was considered necessary to use shortest paths.

A still smaller number was used for the Western Mediterranean (Isern et al., 2017a). Excluding from the analysis of northern Africa and the interior or Iberia (which have substantially later dates), we have $N = 6$ Neolithic sites, namely, the earliest one in each of six regions from Italy/France to Portugal (Table S1 in Isern et al., 2017a). This yields the spread rate 7.5–12.5 km/year (80% CL) and $r = 0.95$. In this case study, it is particularly difficult to estimate the spread rate because it is extremely fast. This point can be understood by looking at Fig. 2.4, which displays a slow expansion (blue) and a fast one (red). Clearly, in the slow case (blue), the error bars do not overlap, but in the fast one (red) it is necessary to use the oldest site per region (red squares) because otherwise the error bars would overlap so much that no trend would be visible. This need to use the oldest site per is the reason why the number of sites used in the regression is very small. Moreover, even these earliest sites have similar dates (Fig. 2.4, red squares), and this leads to a large error in

the speed (inverse of the regression slope). For this reason, the speed range has been estimated at 80% CL in this single case study.

For Scandinavia, a database of $N = 63$ sites leads to the spread rate 0.44–0.84 km/year by combining again great circles (0.44–0.66 km/year, r = 0.77) and shortest paths (0.56–0.84 km/year, $r = 0.78$) at 95% CL (Fort et al., 2018).

In this chapter, we do not deal with modern range expansions of farmers; but it is worth mentioning that their spread rate across the United States in the nineteenth century is 11.9–14.3 km/year (95% CL, $N = 15$, $r = 0.98$) according to the maps of population density every 10 years from 1790 until 1930 reported by Paulin (1932). An alternative estimation, using the positions of the center of gravity of the population, yields a spread rate consistent with this range (Campos et al., 2006). These regressions are performed for distances versus dates, because the former are less certain than the latter in this specific case study. The fastness of this expansion is presumably due to the fact that distances covered by migrants, which are known from historical records (Fig. 2.3 in Campos et al., 2006), are substantially longer than those used to model inland Neolithic spread, which are estimated from ethnographic data (Eqs. (25–28) in Isern et al., 2008).

Although we focus on Neolithic expansions, for comparison purposes, it is of interest to include the two results that are known for Paleolithic expansions.

Firstly, the spread rate of the post-glacial recolonization of Europe has been estimated (Fort et al., 2004) in the range 0.5–1.1 km/year (95% CL $N = 11$, $r = 0.81$).

Secondly, for the expansion of modern humans out of Africa, a database of calibrated dates across Europe was reported by Mellars (2006). It yields a spread rate of 0.34–0.56 Km/year (95% CL, $N = 32$, $r = 0.83$). In this case study, most sites are located at similar distances from the oldest one. For this reason, it is not sure that a linear fit is adequate over all of the distance considered (about 3000 km). Therefore, it is of importance to date additional sites, which should be distributed more evenly across the landscape, and this may lead to more precise estimations in the future.

An interesting but difficult question is whether there are any general laws on Neolithic spread rates over the world or not. We can try to answer this by looking at Fig. 2.3. The most evident feature is that for sea travel (the Western Mediterranean) the spread rate (about 10 km/year) is substantially faster than in all other case studies (about 1 km/year, horizontal dotted line). This suggests than Neolithic spread rates are faster (by an order of magnitude) for sea travel than for inland travel. Additional support for the validity of this possible law comes from the Western Pacific (Austronesia), the only other case study for which a Neolithic spread rate involving sea travel has been estimated. In this case, it was only possible to infer a lower bound, namely, 8 km/year (Fort, 2003). This definitely indicates a spread much faster than for all of the inland expansions in Fig. 2.3, and is consistent with an increase of about an order of magnitude for sea relative to inland Neolithic expansions.

We also observe in Fig. 2.3 that inland Neolithic spread seems to take place usually at a rate of about 1 km/year. Very clear support for this possible law comes from three case studies (at 95% CL): Europe and the Near East, the eastern Bantu expansion, and the spread of domesticated rice in China and southeastern Asia (their error

bars cross the horizontal line, i.e., are consistent with a spread rate of 1 km/yr). However, in two other instances of inland Neolithic spread, namely, the southern Bantu expansion (1.9 ± 0.6 km/year) and the Khoi-khoi expansion of herding (2.4 ± 1.2 km/year), the spread rate is faster (at 95% CL) than 1 km/year (i.e., the corresponding error bars are above the dotted line in Fig. 2.3). It has been proposed that cultural diffusion might have accelerated the spread in both cases. For the southern Bantu expansion, there is indirect support for this proposal, because both herding loanwords (Ehret 1998) and genetic data (Sikora et al., 2011) have led to the suggestion that Bantu farmers incorporated people from local populations, especially in the southern areas (Isern & Fort, 2019). For the Khoi-khoi case (Jerardino et al., 2014), it has been suggested that its fast spread rate could be due to the fact that herding might be simpler to learn than farming, as independently pointed out by Sørensen (2016) and supported by some ethnographic data (Lee, 1979; Isern & Fort, 2019). An alternative explanation is non-isotropic dispersal (Fort, 2020). But it is also reasonable to argue that, after all, the lower bounds of the error bars for the southern Bantu (1.3 km/yr) and Khoi-khoi (1.2 km/yr) are not so far from the dotted line (1 km/yr) in Fig. 2.3; so it seems reasonable to consider that these two case studies also agree (approximately) with the 1 km/year law. This is not inconsistent with the possibility that both of them were somehow faster than the three case studies above (Europe, eastern Bantu and domesticated rice) due to cultural diffusion effects.

Finally, there is a case study (Scandinavia, 0.64 ± 0.20 km/year) in which the spread rate is slower (at 95% CL) than 1 km/year (i.e., its error bar is below the dotted line in Fig. 2.3). It has been suggested that this could be due to lower net reproduction rates of early farmers at high latitudes. Reproduction rates inferred from archaeological data support such lower reproduction rates in Scandinavia (Fort et al., 2018). There is also indirect support from cross-cultural studies of modern populations, which indicate a decrease in fecundity with increasing latitude, a trend that is observed not only in humans but also in other mammals (Barber, 2002). It is worth to note that the upper bound of the Sandinavian rate (0.84 km/yr) is not far from 1 km/yr after all, so in fact this is another example of an inland expansion at a rate of about 1 km/yr. This is not inconsistent with the possibility that it is somehow slower than the three case studies above (Europe, eastern Bantu and domesticated rice) due to a lower growth rate.

2.3   Relative Importance of Demic and Cultural Diffusion

Ammerman and Cavalli-Sforza (1973) applied a purely demic model (i.e., without cultural diffusion). Later, a demic-cultural model was proposed (Fort, 2012). In the latter model, the spread rate of Neolithic waves of advance is obtained as a function of the intensity C of cultural diffusion. Then, comparing the range of the spread rate predicted by the demic-cultural model (for realistic parameter values) to that
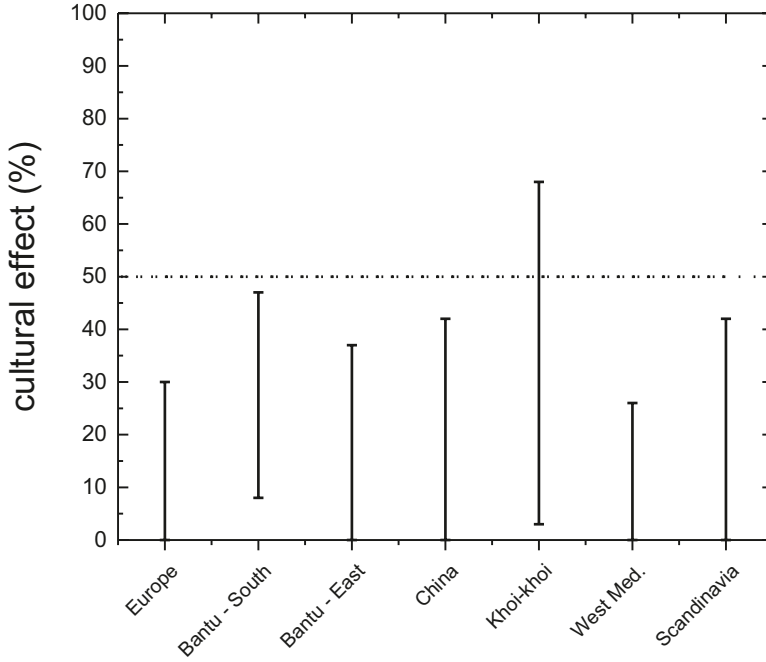
Fig. 2.5 Estimated percentages of cultural diffusion for inland Neolithic expansions. The percentage of demic diffusion is 100% minus the percentage of cultural diffusion. The horizontal dashed line corresponds to the case in which cultural and demic diffusion are equally important. Above this line, cultural diffusion is more important than demic diffusion. Below it, demic diffusion is more important than cultural diffusion. We have used the model by Fort et al. (2012) and the technical procedure is explained in the main text

estimated from archaeological data (Fig. 2.3), we can estimate the effects of cultural and demic diffusion as (Fort, 2012):

$$\text{cultural effect}\,(\%) = \frac{s - s_{C=0}}{s} \cdot 100$$

$$\text{demic effect}\,(\%) = \frac{s_{C=0}}{s} \cdot 100$$

where s is the spread rate from the cultural-demic model (which must agree with that from the archaeological data) and $s_{C=0}$ is the spread rate without cultural diffusion ($C = 0$). Note that the sum of the cultural and the demic effects is always 100%.

This approach has been applied to estimate lower and upper bounds on the percentage of the cultural effect for the seven case studies the speed of which has been plotted in Fig. 2.3. The results are a cultural effect of 0–30% for the spread of the Neolithic in Europe (Fort, 2012), 0–26% for the Western Mediterranean (or 0–22% using more accurate equations derived by the author very recently), 0–42% for

Scandinavia (Fort et al., 2018), 8–47% for the southern and 0–37% for the eastern Bantu expansions (Isern & Fort, 2019), 0–42% for the spread of domestic rice in China and southeastern Asia (Cobo et al., 2019) and 3–68% for the range expansion of Khoi-khoi herders in southern Africa (Jerardino et al., 2014). The results are shown in Fig. 2.5. We see that there is substantial uncertainty, but in all cases demic diffusion is more important than cultural diffusion (except perhaps for the expansion of Khoi-khoi herders, which as mentioned above could be due to the fact that herding may be easier to learn than farming).

It is worth stressing that in the future, genetic data could substantially reduce the uncertainty (i.e., the length of the error bars in Fig. 2.5). Unfortunately, only one such study has been published until now (Isern et al., 2017b) due to the paucity of ancient genetic data. However, the results are very promising because they show that, when comparing the cline of a genetic marker for early Neolithic farmers in Europe (mitochondrial haplogroup K) with simulations based on the same model as that used to produce Fig. 2.5 (Fort, 2012), the percentage of cultural diffusion can be estimated with much more precision and it turns out to be only about 2% (Isern et al., 2017b). For consistency with other case studies (see the next paragraph), this cultural effect can be estimated as 0.6–2.9% if we use, as in Fig. 2.5, the Gilishi 25 dispersal kernel (Fig. S1b in Fort, 2012) with the range $0.01 \leq C \leq 0.03$ from the genetic analysis by Isern et al. (2017b). This is perfectly consistent with the left bar in Fig. 2.5, but much narrower. In other words, it is a genetic estimation of the relative importance of cultural and demic diffusion which agrees with the archaeological one (Fig. 2.5, left bar) and is substantially more precise. However, it is only a first step. Studies for other genetic markers and more realistic simulation models will be probably published during the next years, leading possibly to more complete results. And hopefully, in the next decades, many more ancient genetic data will become available, making it possible to perform similar studies for the other regions in Fig. 2.5.

Finally, we give some details on the technical procedure followed to obtain Fig. 2.5. For Europe, the two Bantu expansions and Scandinavia, we have applied the dispersal kernel from ethnographic data of pre-industrial farmers Gilishi 25 (see Isern & Fort, 2019 for details). A kernel of herders reported by Mehrai (1984) has been used for the expansion of Khoi-khoi herders (Jerardino et al., 2014). A kernel of rice cultivators also reported by Mehrai (1984) has been used for the spread of domesticated rice in China and southeastern Asia (Cobo et al., 2019). Upper bounds correspond to the lower bound of the initial growth rate ($a = 2.3\%$ except $a = 0.69\%$ for Scandinavia) and the upper bound for the generation time ($T = 35$ years). Other realistic values of a and T lead to faster speeds and, therefore, smaller percentages of the cultural effect. The Western Mediterranean has the special feature that no ethnographic kernels for sea travel of pre-industrial populations are known. Its upper bound has been computed by using, e.g., the observed speed of 10.0 km/year (Fig. 2.3 here), the minimum jump length necessary to obtain this speed (10 km/year · 32 year = 320 km) and, as in Isern et al. (2017a), $T = 32$ year, $a = 2.8\%$ and 62% of the population moving each generation (from ethnographic data). Longer

distances of sea travel (i.e., above 320 km per generation) lead to faster fronts and, therefore, smaller percentages of the cultural effect.

2.4   Conclusions

In Sec. 2.2 we have tentatively suggested several possible laws of Neolithic spread in prehistory, as follows.

First law. Inland Neolithic spread rates take place at about 1 km/year but there is substantial variation (0.44–3.6 km/year).

Second law. When in addition to demic diffusion there is substantial cultural diffusion, Neolithic spread rates are faster.

Third law. Neolithic spread rates over the sea take place at about 10 km/year Therefore, they are substantially faster than inland spread rates (even if there is substantial cultural diffusion in the latter case).

Fourth law. Most inland and coastal Neolithic spread rates are mainly demic.

Fifth law. Neolithic spread rates tend to become slower at higher latitudes.

The first law is that for which there is most empirical support, with six case studies now backing its validity. Three very clear ones are Europe, the Eastern Bantu expansion, and the spread or domesticated rice in China and southeastern Asia. (Fig. 2.3). In my opinion, the southern Bantu spread, the expansion of Khoi-khoi herders and the spread of the Neolithic in Scandinavia (Fig. 2.3) also support this law (this is perfectly consistent with the fact that they also agree with the second and fourth laws).

The second law is mildly suggested by two case studies (the southern Bantu spread and the expansion of Khoi-khoi herders), for which the spread rate was about 2 km/yr but with ranges (1.3–2.5 km/yr and 1.2–3.6 km/yr) with lower bounds close to 1 km/yr. The second law has strong support from mathematical models (Fort, 2012).

I think it is fair to say that the third law is relatively well-established at present, due to the very large observed differences in rates between sea and inland expansions (about an order of magnitude) although only two Neolithic sea expansions have been analyzed quantitatively so far (the Western Mediterranean and Austronesia).

Concerning the fourth law, the Khoi-khoi herder expansion (Fig. 2.5) and the spread of maize in America [Fort, Kohler & Blake, in preparation] are the only examples known so far in which the cultural effect might have been larger than 50%. In any case, the fourth law (i.e., a cultural effect below 50%) is compatible with all seven case studies in Fig. 2.5.

In contrast, there are only two case studies known so far in support of the fifth law, namely northern Europe (Fig. 2.1) and Scandinavia (the latter with a spread rate of 0.44–0.84 km/yr). Thus this is a rather tentative law according to present knowledge (hopefully in the future additional case studies will be found to test or

rule out his law). The upper bound for Scandinavia is close to 1 km/yr, so in fact it also backs the first law. We have mentioned in Sec. 2.2 that one possible reason for the fifth law is that reproductive rates could have been lower at higher latitudes, but this is a rather hypothetical explanation given the present state of knowledge (so it has not been included above the fifth law).

The example of the spread of farmers across the United States during the nineteenth century suggests that these laws do not hold for modern populations of farmers.

There are still too few and uncertain estimations of Paleolithic spread rates to suggest whether some of these laws hold also for such populations or not.

Additional case studies (and more accurate archaeological and genetic data) should be used to determine which (if any) of these four laws are valid and how they should be modified if they are not.

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