

Language trees \neq gene trees

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Abstract Darwin saw similarities between the evolution of species and the evolution of languages, and it is now widely accepted that similarities between related languages can often be interpreted in terms of a bifurcating descent history ('phylogenesis'). Such interpretations are supported when the distributions of shared and unshared traits (for example, in terms of etymological roots for elements of basic vocabulary) are analysed using tree-building techniques and found to be well-explained by a phylogenetic model. In this article, we question the demographic assumption which is sometimes made when a tree-building approach has been taken to a set of cultures or languages, namely that the resulting tree is also representative of a bifurcating population history. Using historical census data relating to Gaelic- and English-speaking inhabitants of Sutherland (Highland Scotland), we have explored the dynamics of language death due to language shift, representing the extreme case of lack of congruence between the genetic and the culture–historical processes. Such cases highlight the important role of selective cultural migration (or shifting between branches) in determining the extinction rates of different languages on such trees.

Keywords Cultural transmission · Cultural phylogenetics · Language shift · Scottish Gaelic

Introduction

General issues

It is well-known that Darwin saw similarities between the evolution of species and the evolution of languages (van Wyhe 2005), and that the use of phylogenetic approaches in nineteenth century historical linguistics (e.g. Schleicher 1863) paralleled their use in zoology. Modern theories of cultural dynamics recognise that cultural traditions and innovations are socially transmitted between and within generations (respectively, by vertical or oblique and by horizontal transmission routes; Cavalli-Sforza and Feldman 1981), with learners applying heuristics or rules of thumb in choosing when to engage in independent trial-and-error learning, and in selecting which models to copy when this is the preferred strategy (transmission biases; Boyd and Richerson 1985). Cultural 'macroevolution' refers to the historical processes which explain cultural similarities and differences between human populations arising from such processes (Borgerhoff Mulder et al. 2006). Mesoudi et al. (2006), who propose a multidisciplinary framework for the Darwinian analysis of cultural dynamics, draw an explicit parallel between evolutionary archaeology, cultural anthropology and comparative anthropology (among the cultural sciences), and the macroevolutionary disciplines in biology (respectively, palaeobiology, biogeography and systematic). Historical linguistics should certainly be added to the list of cultural disciplines with a macroevolutionary focus. As Sereno (1991) points out, languages share with biological organisms the properties of heritability (transmission to offspring); mutation; deme-based structuring of transmission pathways; and allopatric (e.g. geographical) and sympatric (e.g. sociolinguistic) divergence mechanisms.

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It is by now widely accepted that similarities between related languages can often be interpreted in terms of a bifurcating descent history ('phylogenesis'; McMahon and McMahon 2005). Such interpretations are supported when the distributions of shared and unshared traits (for example, in terms of etymological roots for elements of basic vocabulary) are analysed using tree-building techniques and found to be well-explained by a phylogenetic model. Mathematically, a tree is an undirected graph that satisfies the requirement for all pairs of nodes to be connected each by a unique path, with no closed loops or cycles. The tree model is the dominant model of biological evolution, although lateral gene transfer in viruses and prokaryotes—and the need for a network model to explain their evolution—is also well-recognised (e.g. Ragan et al. 2009). Lateral transfer of cultural information is also very common within and between human groups, and numerous authors have emphasised the extra information that can be gained about cultural transmission histories if the requirement for a strictly tree-like topology is relaxed (see e.g. the papers in Steele et al. 2010). This relaxation is not, however, the focus of the present article. Rather, our purpose is to question the demographic assumption which is sometimes made when a tree-building approach has been taken to a set of cultures or languages, namely that the resulting tree is also representative of a bifurcating population history.

There is a substantial body of recent scientific literature on the large-scale correlations between genetic and linguistic variation, much of it influenced by the integrative approach of Cavalli-Sforza and his collaborators who see the two systems as coevolving as a result of population expansion and splitting, geographical isolation and parental transmission (the latter being the sole mechanism of genetic inheritance and, they would argue, the predominant mechanism of linguistic inheritance in small-scale societies; e.g. Cavalli-Sforza et al. 1988, 1992). In prehistoric archaeology, such demographic interpretations of cultural macroevolution are familiar from the much-debated farming/language dispersal hypothesis for the spatial spread and diversification of languages such as those of the Bantu, Austronesian or Indo-European groups (Diamond and Bellwood 2003).

However, this is not the whole story, and excessive emphasis on cultural phylogenetic processes will lead us to ignore the important role of selective cultural migration (or shifting between branches) in determining the extinction rates of different branches of such trees. In this article, we will describe our recent work on language competition and language shift, and ask in what circumstances cultural evolutionary processes on trees might reflect analogous underlying demographic events. In particular, when does branch pruning on a linguistic phylogeny (language death) reflect local population extinction, and when does it reflect a purely cultural extinction process with the descendants of its

speakers simply transferring to a different branch of the language tree (language shift)? Some rather fundamental assumptions are implicit in cultural tree-building, and in the interpretation of such trees as reflections of a fully congruent underlying population history. We hope that by asking these questions now, we will contribute to a fuller account of the data which are available to evaluate those assumptions.

A very simple and obvious illustration of our general thesis can be obtained from the study of the evolution and transmission of religious beliefs and practise. Stone and Lurquin (2007) illustrate cultural cladogenetic process with the example of Middle Eastern and European monotheistic religions, showing qualitatively that Judaism and the various forms of Islam and Christianity can be resolved into a tree with known historical branching points. Gilbert (2003) has also discussed possible phylogenies of the Judaeo-Christian tradition, and emphasised the usefulness of this example for engaging sceptics with the logic of Darwinian evolutionary theory. However, while the history of the major world religions may well demonstrate branching patterns of this kind, this does not mean that the primary mechanism of cultural reproduction of religious belief during a branching episode is vertical (parent-offspring) transmission. Indeed, in some variants of these religions the priests themselves are not allowed to have children. If one wants to model the transmission dynamics as a demographic phenomenon, one must look to oblique (i.e. between unrelated members of different generations) and horizontal (i.e. within-generation peer-to-peer) transmission processes as well. Hayward (2005) has proposed a useful mathematical model of church growth and extinction dynamics based on an epidemiological analogy, with the population divided into unbelievers, active believers ('enthusiasts') and inactive believers. He shows that with additional terms to allow for a transient period of 'hardened unbelief' in lapsed believers, and for coupled biological and cultural reproduction by believers of new believers (with some defined probability of the child lapsing), a church can only grow if its rate of recruitment (by conversion and by coupled biological/cultural reproduction) exceeds its rate of loss from reversion. Recruitment by conversion, without additional recruitment by coupled biological and cultural reproduction, is sufficient to fuel a short-term growth phase, although it may not be stable as a long-term mechanism of maintenance of a constant organizational size. Thus, a tree-like pattern of diversification of traditions—in this case, church traditions and beliefs—is wholly compatible with a demographic model in which horizontal and oblique transmission determine the success or failure, at critical moments, of the variant found on any one branch.

Boyd and Richerson (2009) ask similar questions to ours in this article, when they model the dynamics of selective migration between groups of varying sizes and with differing internal norms and benefits of membership. They

point out that selective migration into groups that enjoy more favourable returns to membership, with consequent assimilation into the norms of those groups (including their languages), has been a major force in the historical transformation of societal value systems. As they comment,

we are inclined to count migration as a relatively benign force generally favoring improvements in the human condition, especially compared to group-competitive struggles for dominance and power. [...] In the past, immigrants have been attracted to institutions like the great world religions and the tolerant civilizations they were often associated with.

To this we would add that migration between groups need not always happen by physical relocation across group boundaries; it may be that the dynamic occurs by shifting social identities within a larger political entity, by abandoning a smaller, more local or less beneficial set of norms for those of a larger, more spatially extensive or more beneficial alternative set. Of course, such selective migration or shift will not always be beneficial to the migrant (although on average in human history it must have been so): as Boyd and Richerson also point out, when there are very large differences in size of the two groups exchanging members in this way, rates of selective migration can become more driven by this size imbalance than by any asymmetry in benefits of membership.

Language competition and language shift

We begin by asking how appropriate a demographic branching model would be to explain the process involved in generating historical linguistic branching patterns. The basis of the phylogenetic explanation in historical linguistics is that human populations have in the past undergone expansions, with the mechanism of expansion being local population increase, fissioning, and spatial relocation of some fraction of that population. Subsequent divergence from a common linguistic root is driven by the natural tendency of languages to diversify under the combined effects of inherited mutation and isolation by distance, with the diversification accelerated by physical barriers to interaction and by effective population size-related sampling effects (drift). If the fissioning is kin-structured, with sub-populations splitting off who already share idiosyncratic linguistic features by virtue of membership of the same part of the larger interaction network (for instance, due to kinship ties), then these effects will be accelerated (Croft 2003). Some such explanation seems to apply to a number of the major continental language families whose spread has been associated with the spread of farming, and indeed as Bellwood comments, it is hard to imagine how such large-scale phylogenetic patterns could have evolved

purely by adoption–diffusion without ‘population movement or some degree of dispersal by the population carrying the target language’ (Bellwood 2005, p. 182).

However, accepting a role for the dispersal of its speakers in the initial spread of these major linguistic groupings does not preclude contact-induced language change and recruitment into the speaker population by language shift, either at the time of initial spread or subsequently. In fact Campbell suggests (2006, p. 2) that empirically, in terms of the likelihood of finding complete gene–language congruence in language contact situations

All of the following are attested (‘no’ here means ‘little or no’):

- (1) no linguistic admixture—no genetic admixture
- (2) no linguistic admixture—genetic admixture
- (3) linguistic admixture—no genetic admixture
- (4) linguistic admixture—genetic admixture

Where much work in language–gene correlation has tended to privilege (1) [...], linguists expect (1) least, with (4) perhaps the most common.

Language contact is of course well-known to and well-studied by linguists, and its existence by no means refutes a phylogenetic approach to language relationships. Tree-building methods simply attempt to reconstruct the aspects of similarity and divergence that are due to conservative transmission with mutation-based modification. Other methods focus more on the detection and explanation of linguistic contact phenomena (e.g. wave theory and areal linguistics)—and as Campbell (2006, p. 12) comments, ‘It barely needs to be pointed out that both population genetics, as well as linguistics, has solid methods of dealing with non-cladistic stuff.’ Thomason (2001; cf. McMahon and McMahon 2005, pp. 78–79) has suggested that the effects of language contact can be arranged on a continuum from contact-induced language change (which may involve just non-basic vocabulary elements, or basic vocabulary and structural features, depending on the level of contact and of bilingual interaction); to extreme language mixture (involving pidgins, creoles and mixed languages; cf. Mufwene 2008); to language death, with people abandoning one language outright and shifting to adopt another. The model outlined below emphasises the extreme lack of congruence between genetic and linguistic trees that results from language shift, but we might first reasonably ask how frequently people jump between branches of a language tree in this way. Is it purely a contemporary phenomenon?

Croft (2003) suggests a typological classification of language change, with the first category familiar from phylogenetic classifications and the second category representing contact-induced language change:

1. Language split/divergence
2. Language interference
 - a. Borrowing (loan words and specific grammatical forms)
 - b. Structural borrowing (blending of phonological, syntactic or semantic patterns)
 - c. Creation of contact languages
 - i. Lingua francas
 - ii. Pidgins
 - iii. Creoles
 - iv. Stable mixed languages
 - d. Language shift (language death)

Croft suggests that there are specific social contexts in which the processes of language change in the second category are likely to occur, with the basic mechanisms being marriage, trade, and political integration and the effects of those mechanisms being determined by the scale (and the symmetry or asymmetry in scale) of the speaker populations which are in contact.

Marriage across language boundaries is a mechanism of language change that occurs in small-scale societies, including some ethnographic hunter–gatherer systems, but as the scale and integration of societies increases, so does the likelihood that marriages will occur within linguistic boundaries. The effects on languages are variable (Croft 2003, pp. 18–19): in two cases of extralinguistic exogamous pairings studied by Heath (1978, 1981), both involving one Pama-Nyungan and one non-Pama-Nyungan language-speaking Australian aboriginal band, there is stable bilingualism as well as considerable exchange of vocabulary and of some morphological features, but the languages remain ‘genetically’ distinct. A contrasting case is the upper Vaupes river basin in Amazonia where linguistic exogamy leads to widespread multilingualism, but to relatively little linguistic interference—perhaps because language is a marker of tribal identity (Sorensen 1967; Aikhenvald 2001, 2002).

Trade across language boundaries characteristically produces multilingualism and the emergence of lingua francas and trade pidgins (Croft 2003: 19). Multilingualism is the most common outcome in trade between small-scale societies with limited economic inequality, where trade has a low relative economic significance and takes place in a context of alliance-building. Lingua francas and pidgins are more characteristic outcomes of long-distance trading involving stratified societies or states.

Political integration can take place through segmentary fusion, economic symbiosis, incorporation or assimilation (Croft 2003, pp. 25–26); of these, incorporation in situ into a state society can lead to high levels of borrowing and to stable mixed languages, while state-driven migration (including slavery) can lead to the emergence of creoles.

Finally, full language shift (with the abandonment of the heritage language and adoption of the dominant or majority language) is a characteristic outcome of assimilation into a capitalist or feudalistic state although it can also occur in symbiotic relations among non-state societies (a possible example being a shift to speaking Bantu languages by central African forest pygmies as a result of extensive forager–farmer interaction with neighbouring Bantu chiefdoms; according to Duke (2001), Aka is a typologically mixed language with Bantu structure but with a significant lexical and grammatical substrate residue from the presumed ancestral language).

Spatial expansion by adjacent populations of speakers of competing languages is by no means unique to farming dispersals or to trade and incorporation by state-level societies. McConvell (2001) and Evans and McConvell (1998) propose that the ranges of Australian aboriginal hunter–gatherer groups may have altered with climatic fluctuations, with alternating episodes of ‘upstream’ migration into relatively empty regions as climate improved, and ‘downstream’ migrations into more densely settled areas as climate deteriorated. ‘Downstream’ migration, in this scenario, would have led to social competition and linguistic interference—perhaps even full language shift—by the ‘invaded’ prior occupants, but with some residual influence of the abandoned autochthonous language. Migration-associated language shift occurs in other contexts as well. Where a migration has occurred and where the consequent extralinguistic exogamous marriage involved asymmetric exchanges, then if language transmission was sex-biased it may be possible to find partial genetic and linguistic congruence based on markers of matrilineal (mtDNA) or patrilineal (Y-chromosomal) genetic inheritance. An example is proposed by Nasidze et al. (2006), who studied mtDNA and Y-chromosomal variation in two groups in the South Caspian region of Iran, the Gilaki and the Mazandarani, whose current Iranian languages (like their Y chromosomes) share features with those of populations in the South Caucasus. Their mtDNA, in contrast, is most similar to that of their immediate Iranian neighbours. One possible explanation is a historical migration by a patrilocal population originating in the South Caucasus, who then underwent language shift accelerated by extralinguistic exogamous marriages with local Iranian language-speaking women.

Materials and methods

Mathematical models of language competition

As our own contribution to the modelling literature we have explored the dynamics of language death due to

language shift, representing the extreme case of lack of congruence between the genetic and the culture–historical processes. Language competition and language death is a phenomenon that can be observed worldwide. Linguists estimate that there are around 5,000–6,700 languages in the world today but due to an explosive spread of few dominant languages (e.g. English or Chinese), at least half of them will become extinct in the next century (Krauss 1992). The processes leading to the disappearance of languages have greatly accelerated over the past 200 years and this rate of extinction is probably unique to our time (Nettle and Romaine 2000; Grenoble and Whaley 2006).

Abrams and Strogatz (2003) developed a simple deterministic model describing changes in patterns of language usage within a population in which two languages compete. Their aim was to explain historical data on the decline of endangered languages and to quantify indicators of language endangerment so that useful language-preservation programs could be set up at an early stage. An example of historical census data on the loss of speakers of an endangered language is given in Fig. 1, which shows the changing proportion of inhabitants of Sutherland (in northwest Scotland) speaking Scottish Gaelic. The dynamic of the language competition is described by the temporal change of the proportion of speakers of both languages which results in the following formulation

$$\frac{dn_A}{dt} = n_B P_{BA}(n_A, s_A) - n_A P_{AB}(n_B, s_B)$$

The terms n_A and n_B stand for the frequencies of speakers of language A and B and it is assumed $n_A + n_B = 1$. This condition implies a fixed population size. The term P_{BA} models the rate at which an individual shifts from language B to language A per time unit. Abrams and Strogatz assumed that this shift rate is determined by the attractiveness of language A, the target of shifting. They defined attractiveness by the proportion of speakers of language A and its social status s_A and described the shift rate P_{BA} by the power law

$$P_{BA}(n_A, s_A) = cn_A^a s_A.$$

The larger the proportion of speakers of language A and the higher its social status the greater is its attraction and therewith the likelihood that speakers of language B will shift to language A. The exponent a models how the attractiveness of language A scales with the proportion of speakers of A and the coefficient c indicates the peak rate at which speakers of B shift to A. The opposed shift rate P_{AB} is defined analogously by $P_{AB} = cn_B^a s_B$. Abrams and Strogatz fitted this model and estimated the value of s for the case of competition between English and Gaelic in Sutherland during the period ca. 1880–1960 (cf. Fig. 1), implying the status of English (a measure of the relative

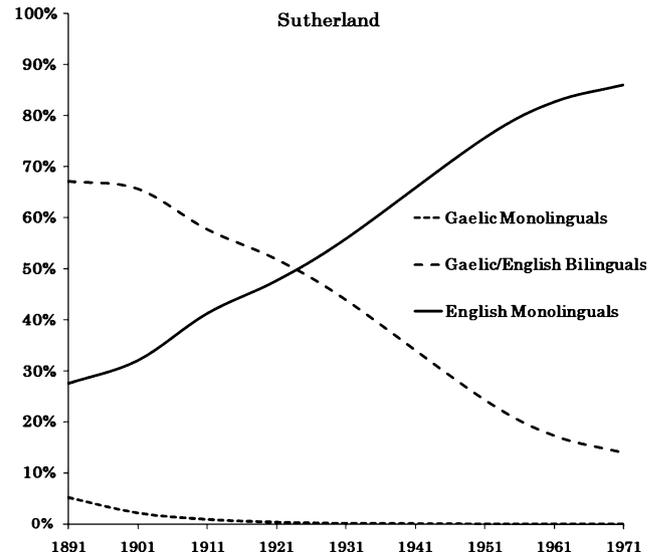


Fig. 1 Frequencies (%) of monolingual Gaelic- and English speakers and of Gaelic–English bilinguals in the county of Sutherland (Scotland), 1891–1971

social or economic opportunities afforded to its speakers) to be approximately twice that of Gaelic ($s_{\text{Gaelic}} = 0.33$; $s_{\text{English}} = 0.67$).

The analysis of dynamical systems such as Abrams and Strogatz's (2003) model encompasses the determination of the stable equilibria expressing the frequencies which do not change over time any more and are robust against small perturbations. The Abrams and Strogatz model predicts that one language (depending on the social status parameters s_A and s_B and on the distribution of the initial frequencies) will always acquire all speakers in the population, causing the language with which it competes to become extinct. They suggested that language maintenance can be achieved by controlling for the social status of the endangered language. However, their model includes the following simplifying assumptions which reduce its explanatory value:

- Languages are assumed to be fixed.
- The population is highly connected with no spatial or social structure.
- All speakers are monolingual.
- The population size is assumed to be constant.

Subsequent modelling approaches generalised the Abrams and Strogatz model by addressing one or more of these shortcomings (see review, in Kandler 2009; also parts of Steele 2009). To introduce our own approach, we may first consider the case where an invading population comes into contact with (and perhaps into competition with) a second pre-existing population that already occupies the invaded region. The basic equations here are for a Lotka–Volterra competition system:

$$\frac{\partial n_1}{\partial t} = a_1 n_1 \left(1 - \frac{n_1}{K_1} - c_1 \frac{n_2}{K_1} \right)$$

$$\frac{\partial n_2}{\partial t} = a_2 n_2 \left(1 - \frac{n_2}{K_2} - c_2 \frac{n_1}{K_2} \right),$$

where the subscript denotes one or other of the two populations, and c_i is a competition coefficient that represents the influence of its competitor on the growth of each population i . The outcomes of this competition are determined by the carrying capacities and competition terms (Neuhauser 2001): the coexistence condition occurs when $c_1 < K_1/K_2$ and $c_2 < K_2/K_1$, and the competitive exclusion condition occurs when $c_j > K_j/K_i$ and $c_i < K_i/K_j$ (with population j going extinct, $i, j = 1, 2$). If both $c_1 > K_1/K_2$ and $c_2 > K_2/K_1$, then eventually one population will go extinct, but which one depends on the initial densities. Addition of an isotropic diffusion term (e.g. Okubo et al. 1989) produces the reaction–diffusion system: 5

$$\frac{\partial u_1}{\partial t} = d_1 \Delta u_1 + a_1 u_1 \left(1 - \frac{u_1}{K_1} - c_1 \frac{u_2}{K_1} \right)$$

$$\frac{\partial u_2}{\partial t} = d_2 \Delta u_2 + a_2 u_2 \left(1 - \frac{u_2}{K_2} - c_2 \frac{u_1}{K_2} \right)$$

This system has been used in archaeology by Young and Bettinger (1992) to model competition between populations speaking Numic and Pre-Numic languages in the American Great Basin in the second millennium AD.

A closely related system has been studied for the European Neolithic transition by Fort et al. (2008), but with the sign of the interaction term changed for one of the populations (so that the interaction takes the form of one-way conversion, rather than mutual competition-interference):

$$\frac{\partial u_1}{\partial t} = d_1 \Delta u_1 + a_1 u_1 \left(1 - \frac{u_1}{K_1} \right) + \Gamma u_2$$

$$\frac{\partial u_2}{\partial t} = d_2 \Delta u_2 + a_2 u_2 \left(1 - \frac{u_2}{K_2} \right) - \Gamma u_2,$$

where population 1 represents the Neolithic farmers and population 2 represents the Mesolithic hunter–gatherers. The interaction term now represents a switching term, so that the loss to the Mesolithic population is balanced by a symmetrical gain to the Neolithic population. A similar system has been considered in detail in a language competition context by Kandler and Steele (2008), who show that enforcing a single carrying capacity for both populations will inevitably lead to the extinction of the population which is the net source of switchers.

In our own subsequent work we have addressed three of the previously noted deficiencies of the Abrams and Strogatz model. Languages in competition are still assumed to be fixed in character, but we allow the population to vary in

size; we allow the population to be spatially structured; and we impose a requirement that households and individuals shifting between competing languages must first pass through a bilingual phase. We then analyse the dynamics of competition between languages A and B in a reaction–diffusion model of the following form: we examine the dynamics of language shift as a spatially dependent Lotka–Volterra competitive process using the reaction–diffusion system:

$$\frac{\partial u_1}{\partial t} = d_1 \Delta u_1 + a_1 u_1 \left(1 - \frac{u_1}{K - (u_2 - u_3)} \right) - c_{31} u_3 u_1 + c_{12} u_2 u_1$$

$$\frac{\partial u_2}{\partial t} = d_2 \Delta u_2 + a_2 u_2 \left(1 - \frac{u_2}{K - (u_1 - u_3)} \right) + (c_{13} + c_{31}) u_1 u_3 - (c_{12} u_1 + c_{32} u_3) u_2$$

$$\frac{\partial u_3}{\partial t} = d_3 \Delta u_3 + a_3 u_3 \left(1 - \frac{u_3}{K - (u_1 - u_2)} \right) - c_{13} u_1 u_3 + c_{32} u_2 u_3,$$

The time- and space-dependent variables u_1 and u_3 stand for the frequencies of monolingual speakers of language A and language B, respectively, whereas u_2 describes the frequency of bilingual speakers of both languages. The terms $\partial u_i / \partial t$, $i = 1, 2, 3$ indicate the rate of change in these frequencies over time. The terms on the right hand side of the equations in this system describe the changes in frequency of speakers in each of the three subpopulations u_1 , u_2 and u_3 . The spatial dispersal behaviour of members of each sub-population is described by the diffusion component $d_i \Delta u_i$ (Δ denotes the Laplace operator); elsewhere we analyse the effects of non-local dispersal behaviour by replacing the diffusion components by an integral formulation, which allows for short- and long-range dispersal. The components $a_i u_i (1 - u_i / (K - (u_j + u_k)))$ define the internal reproductive rates, which represent coupled biological and cultural reproduction within each sub-population. This is usually modelled (as shown here) as a logistic process with intrinsic rate of increase a_i . The variable K stands for the carrying capacity of the environment and defines an upper limit to the size of the whole population regardless of the languages spoken, which imposes the condition $u_1 + u_2 + u_3 \leq K$ for any time t (i.e. we assume that our human sub-populations must compete for a common resource base). For a detailed analysis of the relevance of this self-limiting term see Kandler and Steele (2008). The mobility of speakers of each sub-population in space within the modelled region is modelled by the diffusion terms $d_i \Delta u_i$.

The language shift dynamic is modelled in our system by the frequency-dependent conversion term $c_{ij} u_i u_j$ (see Fig. 2). The coefficients c_{13} and c_{31} represent the

likelihood of language shift causing speakers to become bilingual based on the differential prestige or attractiveness of the two competing languages. Language shift cannot happen by passing directly from being monolingual in one language to being monolingual in the other language, but must involve a bilingual transition state. The bilingual sub-population therefore recruits from both monolingual sub-populations at a rate $(c_{13} + c_{31})u_1u_3$. In turn, bilinguals shift to being monolingual in one or other language at a rate $c_{12}u_1u_2$ (representing the loss to monolingualism in language A) and $c_{32}u_3u_2$ (representing the loss to monolingualism in language B). The coefficients c_{12} and c_{32} represent the likelihood of bilingual speakers then becoming monolingual in each of the two languages. In real life this transition back to monolingualism happens when bilingual parents choose to raise their children monolingually or when speakers reared as bilinguals in bilingual households abandon one of their languages during their lifetime. We define the overall balance of competitive advantage to speaking each language on the base of the conversion rates: for example, fluency in language A can be assumed to be more advantageous if it holds that $c_{31} < c_{13}$ and $c_{12} > c_{32}$. This implies that when the monolingual sub-populations are compared, monolinguals in A are less likely to become bilingual, and bilinguals are more likely to shift to speaking only A.

Data sources

Data for Scottish Gaelic speakers in Sutherland are from the decennial Census of Scotland. The first Census to enumerate Gaelic speakers was that of 1881, but only from 1891 were data gathered separately on numbers of Gaelic monolinguals and Gaelic–English bilinguals (in all cases, among those aged 3 years or older). After 1961 no data were collected on the incidence of Gaelic monolinguals, as

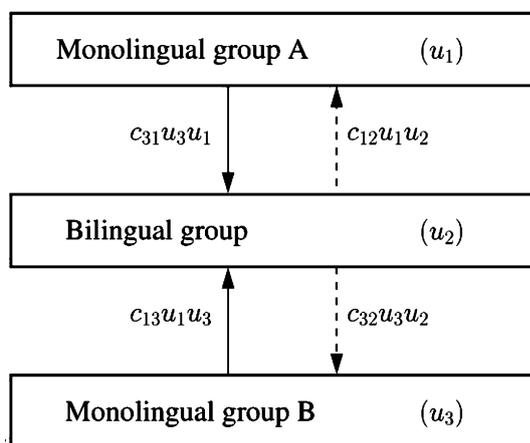


Fig. 2 Chart showing the competition-driven flows between speaker sub-populations in our language shift model

these were assumed by that time to be approaching extinction. From 1891 until 1971 the Census enumerations were collated and analysed on the basis of the old county divisions (the Highland counties of the core Gaelic speaking region, or *Gaidhealtachd*, included Argyll, Inverness, Ross and Cromarty, and Sutherland). From the 1981 census onwards, these counties were subsumed into new administrative units. We compiled our data from the *Vision of Britain* website (<http://vision.edina.ac.uk>), from Withers (1984), and from Mitchell (1988). They are shown in Table 1.

Results

Using our model and the historical Census data, we have estimated the strengths of the competitive advantage driving language shift from Scottish Gaelic to English in Sutherland county, Highland Scotland (1891–1971). In the absence of more detailed data we set $u_1 + u_2 + u_3 = K$ and treat the county’s population as pan-mixing, so that we only consider the competition terms. Historical census data on language use will include some ‘noise’ due to inaccurate answers (for instance, due to the perceived social status implications of self-classification into a particular category), and to changes in the phrasing of the questions in successive censuses. To avoid over-fitting (where the model fits the noise in the data as well as the significant trends), we initially reduced the model’s degrees of freedom by assuming the parameter constellation $c_{31} = c_{32}$ and $c_{13} = c_{12}$. We then derive an estimate of the shift from Gaelic to bilingualism and/or to monolingual English, $c_{13} = c_{12} = 0.035$. The fitted rate of shift from English to bilingualism and/or to monolingual Gaelic was $c_{31} = c_{32} = 0$. The results are shown in Fig. 3 (dotted lines). Our model captures well the general dynamic of the language shift process (the decrease of the Gaelic-monoglot and bilingual sub-populations and the increase of the English-monoglot sub-population). During this period the Gaelic-monoglot sub-population was unable to attract any English speakers or bilinguals, while the shift from the Gaelic-monoglot to the bilingual sub-populations and from the bilingual to the English-monoglot sub-populations happened at high rates due to the competitive advantage of the dominant language.

However, the fitted curves in Fig. 3 also suggest that this fitted parameter constellation slightly overestimates the persistence of the Gaelic-monoglot sub-population and slightly underestimates the persistence of the bilingual sub-population. Therefore, we also fitted the model with constellations in which $c_{31} \neq c_{32}$ and $c_{13} \neq c_{12}$ (so that the balance of competitive advantage driving shift from monoglot Gaelic to bilingualism can be different to that

Table 1 *Census of Scotland* data on numbers of Gaelic and English speakers in the county of Sutherland, 1891–1971

Absolute nos. of speakers	1891	1901	1911	1921	1931	1951	1961	1971
Sutherland total population	21,003	21,440	20,179	17,800	16,100	13,670	14,000	13,000
Sutherland Gaelic monolinguals	1,094	469	188	68	24	1	1	0
Sutherland Gaelic/English bilinguals	14,105	14,083	11,652	9,233	7,068	3,324	2,421	1,815
Sutherland English monolinguals	5,804	6,888	8,339	8,499	9,008	10,345	11,578	11,185
% of all speakers	1891	1901	1911	1921	1931	1951	1961	1971
Sutherland Gaelic monolinguals	5.21%	2.19%	0.93%	0.38%	0.15%	0.01%	0.01%	0.00%
Sutherland Gaelic/English bilinguals	67.16%	65.69%	57.74%	51.87%	43.90%	24.32%	17.29%	13.96%
Sutherland English monolinguals	27.63%	32.13%	41.33%	47.75%	55.95%	75.68%	82.70%	86.04%

For sources see main text. Total population numbers for 1961 and 1971 are from Mitchell (1988) and are rounded to the nearest '000

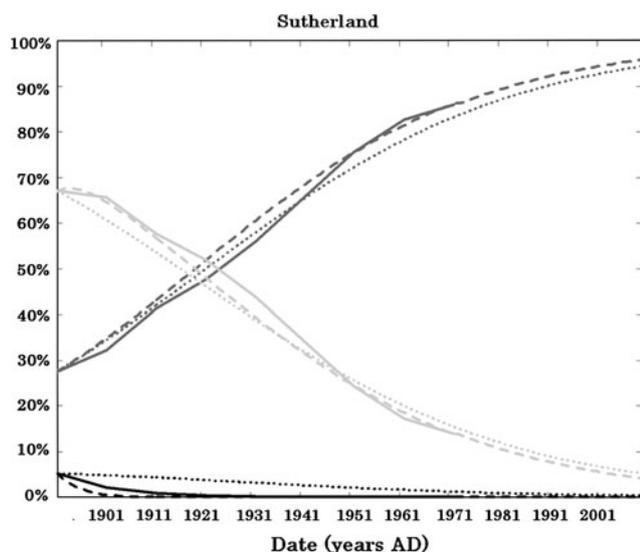


Fig. 3 Frequencies (%) of monolingual Gaelic- and English speakers and of Gaelic–English bilinguals in the county of Sutherland (Scotland), 1891–1971, with curves showing the fitted values from our language shift model (see main text) projected forward into 2010

driving the shift from bilingualism to monoglot English). The results are illustrated by the dashed lines in Fig. 3. The values for the fitted competition coefficients are now $c_{13} = 0.075$ (shift from Gaelic-only to bilingual) and $c_{12} = 0.035$ (shift from bilingual to English-only), with $c_{31} = c_{32} = 0$ for shifts in the opposite direction. The fit is slightly improved and the key to improvement in fit lies in the increase of the shift parameter from Gaelic-only to bilingual (c_{13}). All other coefficients are unchanged. Gaelic monoglots were more affected by the difference in advantages between English and Gaelic. This implies that the priority was to learn the high-status language and not to abandon the disadvantaged language. Bilinguals tended to stay bilingual longer than Gaelic speakers stayed monolingual.

Discussion

In some recent attempts to formulate a theory of cultural dynamics, models were adopted fairly directly from biology, often without much modification to take account of the differences which characterise cultural transmission as an inheritance system (for instance, the non-random nature of human trial-and-error strategies when exploring a technological design space; and the high prevalence of oblique and horizontal transmission, biased by inductive heuristics that increase the likelihood of learners identifying selectively advantageous traits). These differences do not invalidate the application of broader Darwinian principles to cultural transmission systems, but they do require that new models be developed to explore macro-evolutionary dynamics.

In the present article, we have illustrated this point by exploring the processes that determine the success or failure of particular branches of a linguistic phylogenetic tree. We have not considered here the reasons why a phylogenetic model might explain the historical evolution of languages in terms of their basic vocabularies; rather, we have shown that language shift (seen as selective migration between branches of a language tree) is a significant force in cultural evolution, one which may also—in some circumstances—serve as a mechanism of cultural selection acting on alternative systems of economic practices and social norms.

Is it naive to adapt models from biology (in this case, Lotka-Volterra models from competition ecology) to explain cultural change? Some linguists have warned against interpreting language death in terms of a revived social Darwinism: as May (2000, p. 36) puts it,

one could view the loss or death of a language as simply a failure on its part, or its speakers, to compete adequately in the modern world where, of course, only the fittest languages can (and should) survive. This form of linguistic social Darwinism is widely

articulated by majority language speakers—conveniently secure in their own linguistic and cultural heritage—but it is by no means limited to them. Many minority language speakers likewise see their social, cultural and economic advancement, or evolution, in the guise of a majority language.

Dorian (1998, pp. 10–11) has rightly cautioned against any expectation that a language that gains speakers through language shift must in some way differ from its competitors in its adaptive and expressive capacity. She reminds us of the fates of the languages of vanished empires of the Near East and pre-Hispanic New World. Sumerian, Akkadian and Hittite are all now extinct, while Quechua and Nahuatl are now endangered. What causes shift is not cultural selection acting on grammatical or prosodic potential, but people shifting between two competing languages because of their associated social ecologies. There may of course be some associated variation in expressive potential relating to those ecologies (for example, in terms of specialised vocabulary); in the case of the Gaelic speaking fishing communities of East Sutherland, the death of whose language was studied closely by Dorian, problems arose when their niche was irrevocably altered:

Now I should stress here that fisherfolk Gaelic was *not* lexically impoverished. The trouble was, that like any other strictly local speech form deeply associated with a traditional life style, the richness of the lexicon was chiefly connected with their own specialized way of life. There wasn't much connected with the sea or with boats that they didn't have a word for, and they had a lot of weather terms that reflected the importance of decisions about whether to put to sea or not. When I acquired the dialect I learned the names of more varieties of seaweed than I had ever known existed, the names for parts of a rabbit snare, and the term for an egg that emerged from the hen without an exterior shell. But, not surprisingly, there were no local words for the parts of a car or for the national health service (Dorian 2006, p. 7).

The solution used by Gaelic speakers was to adopt the English words as loanwords; what drives the shift process is not the available specialised lexicon, but the wider contrast in social and economic potential which participation in one or other linguistic community opens up.

In this article, we have analysed some data from the late phase of a historical case of Gaelic to English language shift, and have favoured an explanation in which speakers were exercising in some sense a 'free vote' when they and their households shifted to speaking English. We think this is the right approach for late phase language shift.

However, it is less clear to us that a simple voting model is enough to initiate language shift in the early phase, where speakers of what is ultimately the losing language make up the local majority. Even from a purely mathematical perspective, the competition coefficients fitted to census data by Abrams and Strogatz (2003) are insufficient to make the invading language prevail at an earlier phase, when its speakers were much less numerous than in the censused periods. Our own spatially explicit model is more robust in that we can predict the eventual successful outcome for the invading language in cases where its speakers maintain a dense local concentration at the invading front, particularly if their numbers can be augmented by a steady stream of continuing immigration into the regions behind that front. Nonetheless, many historically minded sociolinguists correctly intuit that in the earlier phase of language shift, there was often a more aggressive interference competition between the two groups of speakers as they competed to control resource flows; and it is for this reason that language shift reversal and contemporary language maintenance policies are often promoted politically by invoking the memory of past historical injustices dating from the earliest phases of the language shift.

In Scotland in late mediaeval times Gaelic was the main language of the Highlands and western islands, with Scots (descended from the Old Northumbrian dialect of Old English) and English prevailing in the Lowlands. This division appears to have been reinforced by a contrast between these two regions in their social structure, marriage and migration patterns (with the clan system predominating in the Highlands): the subsequent breakdown of the geographical 'niche' for Scottish Gaelic is closely linked to the political and economic dominance of actors to the south, and their interference with the Highlands' political and economic systems. The establishment of English as the language of education and advancement and drastic demographic changes (the 'Highland clearance') were associated with increasing rates of Gaelic-to-English language shift (Murdoch 1996). The census data we have examined represent the late phase of this process. Recent Gaelic language revitalisation efforts in Scotland have included the establishing of Gaelic medium primary school units and Gaelic pre-school playgroups, and the foundation of the Gaelic Television Committee which ensures the incorporation of Gaelic programs into the Scottish television programming (Murdoch 1996). In 2005 the Gaelic Language (Scotland) Act was passed by the Scottish Parliament, providing a planning framework for a number of additional shift reversal measures, while Comhairle nan Eilean Siar, the Western Isles Council, has adopted Gaelic as its primary language. The effectiveness of these initiatives can be assessed when the results become available for the next decennial Scottish census in 2011.

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