Seasons and Longevity: Mortality Trajectories among the Oldest Old

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Presented at the Living to 100 and Beyond Symposium
Sponsored by the Society of Actuaries

Orlando, Fla.

January 12-14, 2005

Abstract

Mortality in general, and especially amongst the oldest old, is known to be partially shaped by seasons: winter is classically characterized by excess mortality. We therefore put forward the use of season-related life tables to study the mortality trajectories of the oldest old. This approach can be used to explore the plasticity of longevity, by opposing winter and summer trajectories. Furthermore, summer-related life tables summarize the best conditions of mortality, i.e., the lowest values and the least fluctuating pattern. Results are presented for Switzerland, where season-related life tables have been computed until age 110.

Introduction

The traditional research question when studying human mortality is to determine whether mortality is increasing with age, with which trajectory and at which rate, as well as to which limits. In this paper we examine this question according to season of death: winter or summer. The main hypothesis is that the mortality trajectory, as well as its changes over time, is more obvious in summer, where fluctuations are limited to a minimum. Following the most recent work on the mortality trajectories (Thatcher et al, 1998; Vaupel et al, 1998; Thatcher, 1999), we use a logistic approach to fit the central death rates (mx series) and the probability of deaths (qx series). This work will allow us to further explore the plasticity of longevity to environmental conditions. A second research question, less usual, is to study the distribution of life durations around the central value. Scholars such as Lexis (1878), Greenwood and Irwin (1939), Philips (1954), Benjamin (1959) and Kannisto (2001) already examined this question in the past. This part of the work will allow us to examine whether the individual life durations are more or less concentrated around a central value according to the seasons of death. The usual hypothesis is that deaths are more concentrated when the life expectancy is higher (i.e. when the mortality is lower). Therefore, one can expect individual life durations to be more concentrated under the summer conditions. Following the most recent work by Kannisto (2001) and Cheung et al (2005, submitted and in progress), we use a normal approach to fit the individual life durations (dx series) around and above the modal age at death.

Demographers and actuaries used to fit the death rates when fitting a life table. However, we claim in our approach to human longevity that the life table series to be fitted depend on the research question (Cheung et al, in progress). It is not the same thing to fit the death rates or the ages at death (dx). Whatever the statistical models used, the dx series associated with a fitted qx series cannot replace a directly fitted dx series. Similarly, whatever the models used, the qx series associated with a fitted dx series cannot replace a directly fitted mx and qx series. Such a fit aims to clarify a series of observations by eliminating the fluctuations (statistical errors) while retaining the general pattern. Therefore, when fitting the death rates (mx and qx), it is important to respect the general pattern of the mortality trajectory; that is, the general look of the trajectory, its slope and its points of inflection. It is what the Gompertz (1825) or the logistic models (Perks, 1932), for instance, attempt to do. The goal is to clarify the mortality trajectory at the highest ages where the fluctuations become significant in unfitted data. On the other hand, when fitting a dx series, the goal is to specify the most common length of life and the distribution of individual life durations around it. Therefore, it is essential that the fit respects the general pattern of the dx distribution, accurately locates the modal age at death and properly estimates the number of deaths concentrated at this age. These estimations are extremely important because contrary to life expectancy, which averages out all the observed life durations in one value and provides a robust indication, the modal age at death is just one of these durations, even if it is the most frequently observed. Kannisto underlined the presence of a kind of flatness in the dx distribution around the observed mode, several ages gathering about the same number of deaths (Kannisto, 2001). In this work, we take into account all the dx around and above the unfitted mode to get the best possible estimation of the modal age at death according to a normal model.

1. Data and Methods

1.1 The Swiss Life Tables

Eleven complete life tables have been computed for Switzerland since 1876 (Wanner, 1996). They cover the periods 1876-1880, 1881-1888, 1889-1900, 1910-1911, 1920-1921, 1929-1932, 1939-1944, 1948-1953, 1953-1963, 1968-1973, 1978-1983 and 1988-1993. The first three tables were closed at earlier ages but since 1910-1911 they have been closed at age 100, except the 1988-1993 table, which was closed at age 108. The latest complete life table, which will cover the period 1998-2003, is not yet available. Therefore, we computed a provisional life table for the period 1998-2002 without any graduation and smoothing techniques until the age of 109.

1.2 The Vital Statistics

Since 1969 vital statistics have been computerized in Switzerland, and the statistical bureau provided us with statistics of all the recorded deaths between 1969 and 2002 by year, month of death within the year, sex, and age at death.

1.3 Defining the Seasons

Previous work showed that, in terms of mortality, four winter months (December, January, February and March) clearly contrast in Europe with four summer months (June, July, August and September), with two transitional periods, April/May in spring and October/November in autumn (Jagger and Robine, 2004). This month grouping appears significantly different from the one we obtain with climate indicators such as average temperature, where March appears quite different from the three other winter months and where September appears very similar to May. However, in Geneva, for example, the average temperature varies from about 3°C in our four winter months (average minimum and maximum, 1° and 7°C) to about 17°C in our four summer months (average minimum and maximum, 12° and 23°C).[1]

1.4 The Season-Related Life Tables

To construct the season-related life tables for the years 1968-1973, 1978-1983 and 1988-1993, we weighted the qx series of the complete Swiss life tables, provided by the Federal Statistical Office, by the proportion of deaths occurring in each season. Then, we gave an annual dimension to the new season-related qx by dividing them by the proportion of the days counted in each season (out of 365 days except in leap years). For the winter-related life tables, we weighted the qx series by the proportion (wx) of deaths occurring in the corresponding winter, and for the summer-related life tables, we weighted the qx series by the proportion (sx) of deaths occurring in the corresponding summer[2]. For the last period, 1998-2002, we directly constructed winter and summer life tables from the central death rates (mx) computed in the winter and summer mortality conditions (background report available from the authors).

1.5 Estimation of the Normal Longevity

We used SigmaPlot version 8.0 (SPSS, Inc.) to fit the death rates (mx) and the dx series alternatively. We fitted the death rates using a logistic function with four parameters (Thatcher et al, 1998) and the dx series using a Gaussian function with three parameters, corresponding to the modal age at death (M), the number of deaths gathered at the mode and the standard deviation of the ages at death (SD). We fitted the dx starting five years before the observed mode on the unfitted series, and we used all the unfitted dx above the mode until the extreme tail. This choice meets the theoretical proposal of Lexis-Kannisto about the hypothetical normal distribution of the dx series above the mode, the modern observation of a kind of flatness in the region of the mode (Kannisto, 2001) and the standard methodological requirement for mode determination (Pearson, 1902). We fit the mx using the unfitted death rates from age 55 to age 99 years.

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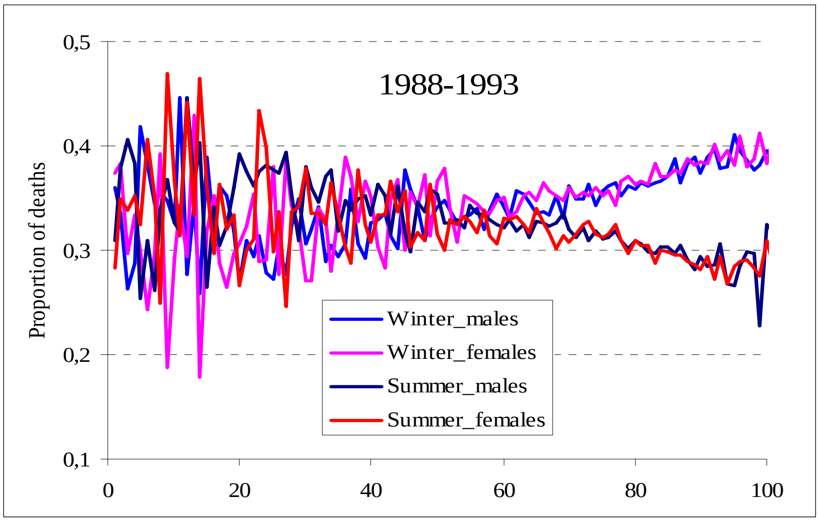
[1] http://www.climate-zone.com/climate/switzerland/celsius/geneva.htm

[2] Winter and summer 1969-1973 for the 1968-1973 life tables.

2. Results

The collection of Swiss life tables shows a fairly regular decline in elderly mortality, between the ages of 60 and 100 years, since the 1920s. On the other hand, the official Swiss vital statistics show a constant excess of mortality in winter for the elderly, at least since 1969. Interestingly, the empirical data present an excess of mortality in summer, increasing from birth to the age range of 15 to 20 years, then slowly declining until the age range of 50 to 60 years. In this age range with no excess or deficit of mortality, about one-third of deaths occur during the four winter months, one-third during the four summer months and one-third during the remaining months, but these proportions steadily diverge after age 60 to reach about 40 percent in winter and less than 30 percent in summer at the age of 100 years. Figure 1 illustrates this persistent pattern for the period 1988-1993.

FIGURE 1
Proportion of Deaths Occurring in Winter and in Summer by Age and Sex, Switzerland, Period 1988-1993



Source: Federal Statistical Office, special tabulation

2.1 The qx Series and the Mortality Trajectories

Figures 2 and 3 display the unfitted qx life table series as well as the series fitted with a logistic model, corresponding to winter and summer mortality regimes, for males and females respectively. The higher panel presents the unfitted series in winter (left) and summer (right), whereas the lower panel presents the fitted series in winter (left) and summer (right).

FIGURE 2

Mortality Trajectory in Winter and Summer for Males: Unfitted and Logistically Fitted qx Series, Switzerland 1968-1973, 1978-1983, 1988-1993, 1998-2002

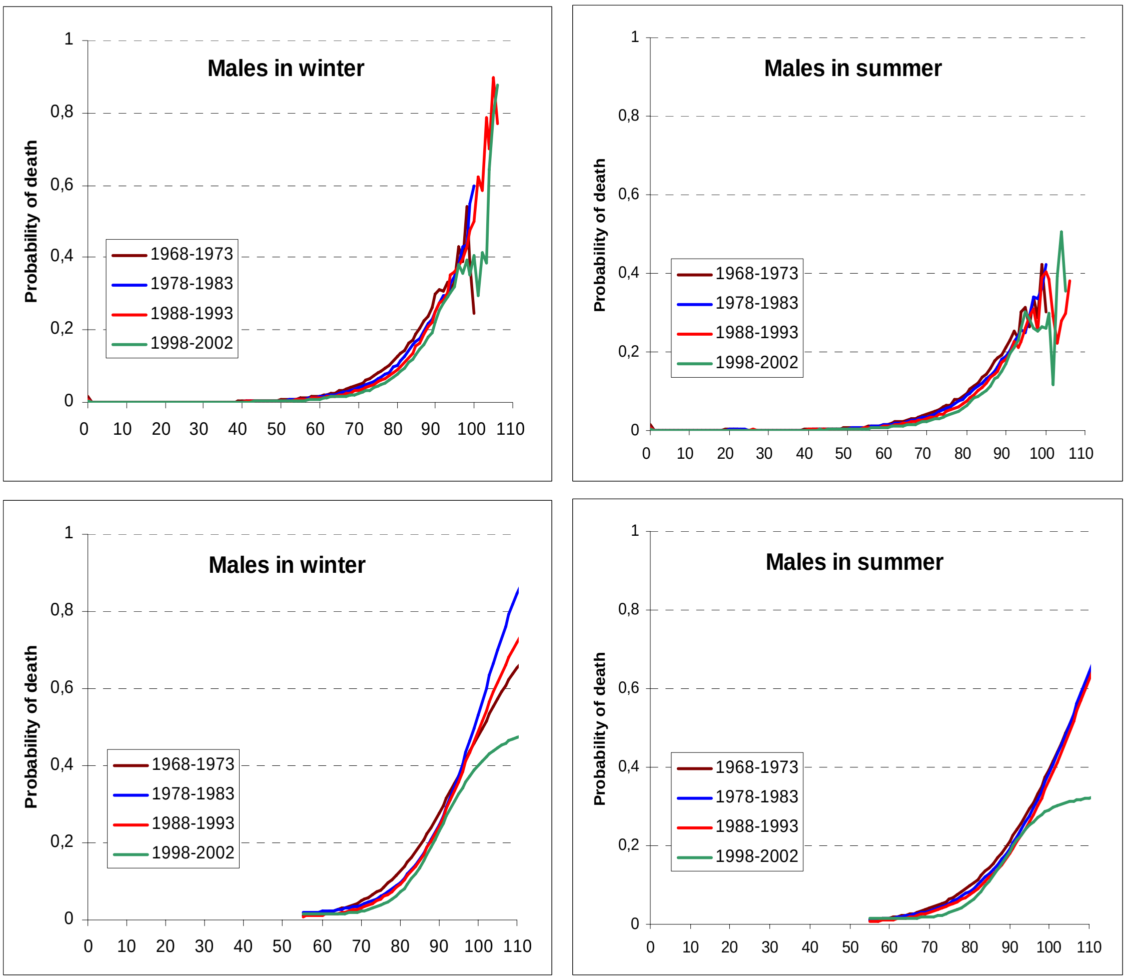


Figure 2 clearly shows that with the unfitted series (higher panel), mortality is lower for the male elderly in summer compared to winter. The fitted series confirm this result but, overall, they suggest that mortality trajectory did not really change before 1998-2002. The logistic trajectories are quite similar for the first three life tables, corresponding to the mortality conditions of 1968-1973, 1978-1983, and 1988-1993 respectively. However, under the 1998-2002 mortality conditions, the trajectories seem to tend to a mortality ceiling below the mark of 0.50 in winter and below that of 0.35 in summer.

FIGURE 3

Mortality Trajectory in Winter and Summer for Females: Unfitted and Logistically Fitted qx Series, Switzerland 1968-1973, 1978-1983, 1988-1993, 1998-2002

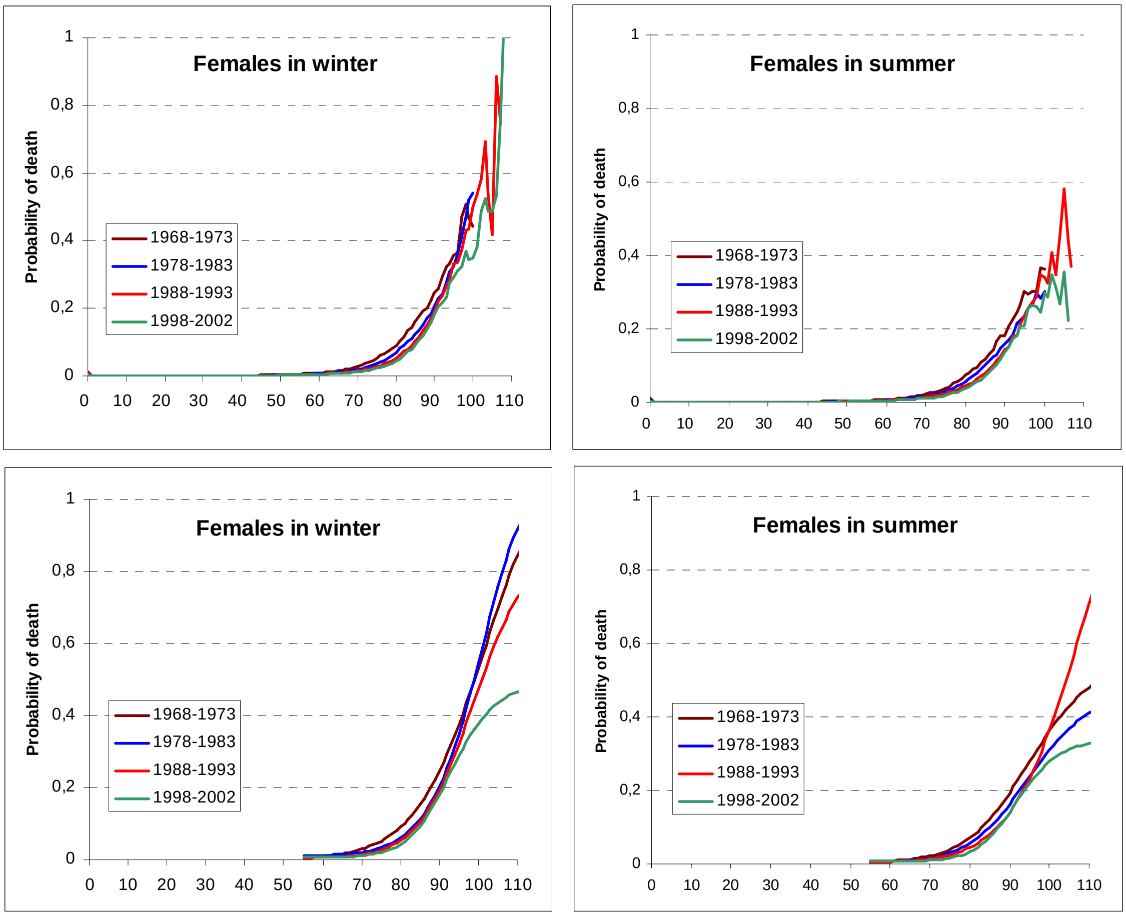
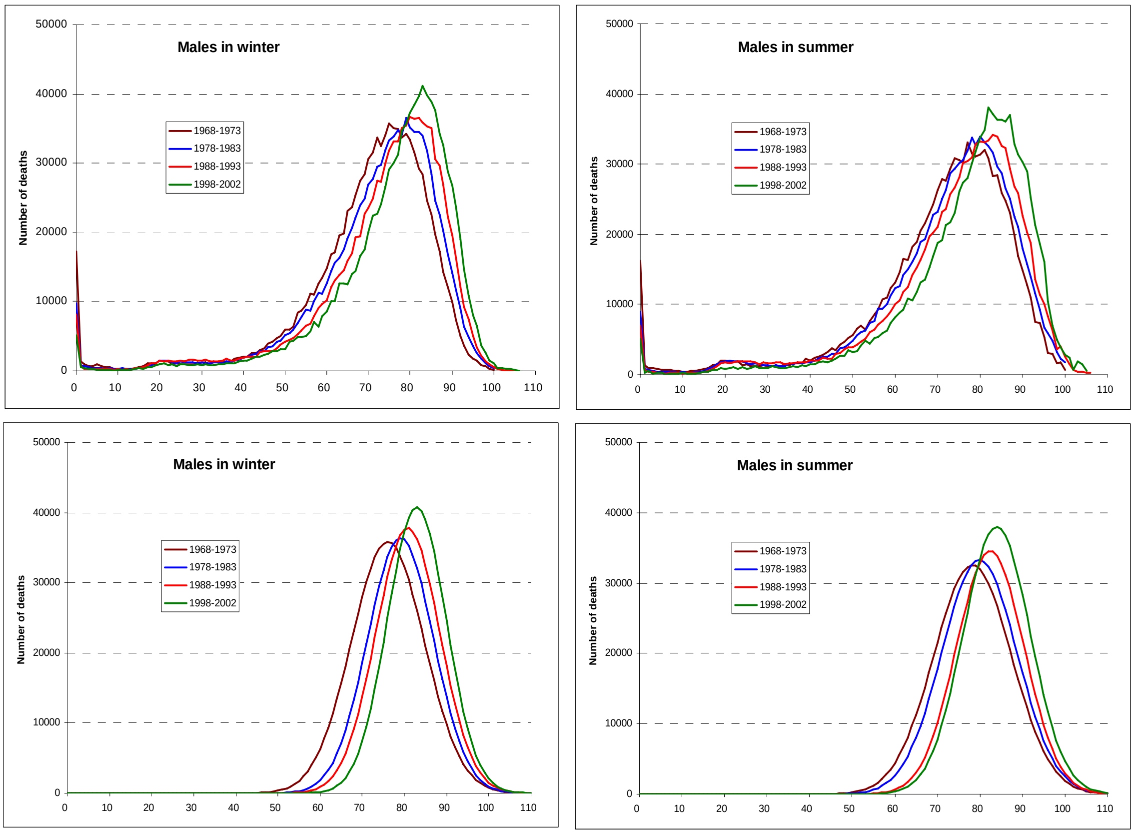


Figure 3 confirms, with the female series, the results presented in Figure 2 for the males. Mortality is clearly lower for the elderly in summer compared to winter (higher panel). The fitted series confirm that mortality did not really change in winter for female before 1998-2002, but the trend is less clear in summer. However, under the 1998-2002 mortality conditions, the female trajectories seem to tend to the same mortality ceilings that male trajectories do, with a ceiling that can be below the mark of 0.50 in winter and below that of 0.35 in summer.

2.2 The dx Series and the Distribution of Individual Life Durations

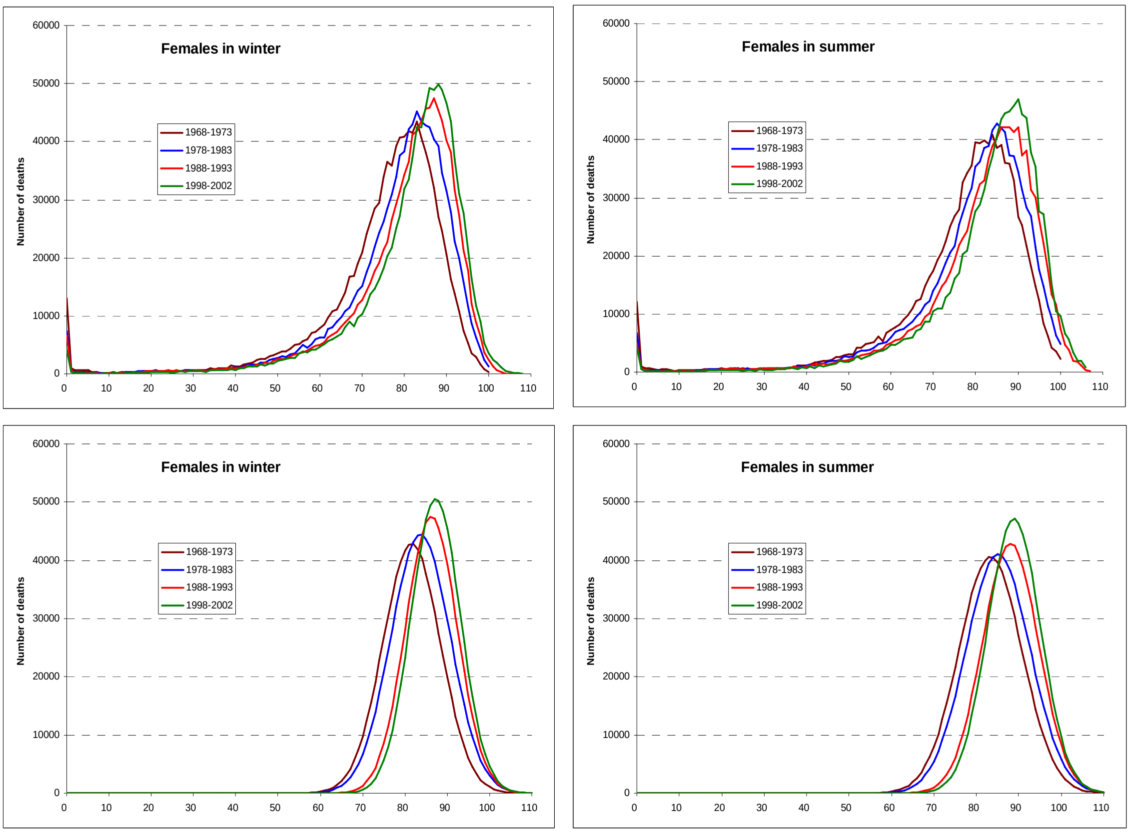
Figures 4 and 5 display the unfitted dx life table series, as well as the series fitted with a normal model, corresponding to winter and summer mortality regimes, for males and females respectively. The higher panel presents the unfitted series in winter (left) and summer (right), whereas the lower panel presents the fitted series in winter (left) and summer (right).

FIGURE 4
Distribution of Individual Life Durations in Winter and Summer for Males: Unfitted and Normally Fitted dx Series, Switzerland
1968-1973, 1978-1983, 1988-1993, 1998-2002



(IDL, version March 2004)

FIGURE 5
Distribution of Individual Life Durations in Winter and Summer for Females: Unfitted and Normally Fitted dx Series, Switzerland
1968-1973, 1978-1983, 1988-1993, 1998-2002



The Rsquare of the normal fitting for the dx series around and above the observed mode (starting 5 years before the unfitted mode) is almost always higher than 0.99. The minimum observed Rsquare is 0.984 for males in winter conditions of 1998-2002. The normal fitting directly provides an estimation of the three parameters summarizing the dx distribution: the mean age of the normal distribution of ages at death (i.e., the modal age at death), the number of deaths occurring at this mean age (i.e., occurring at the modal age at death) and the standard deviation (SD). Two of these three parameters, the modal age at death (M) and the standard deviation (SD) are plotted on Figure 6.

FIGURE 6
Mode (M) and Standard Deviation (SD) of the Individual Life Durations (dx) in Winter and Summer for Males and Females, Switzerland
1968-1973, 1978-1983, 1988-1993, 1998-2002

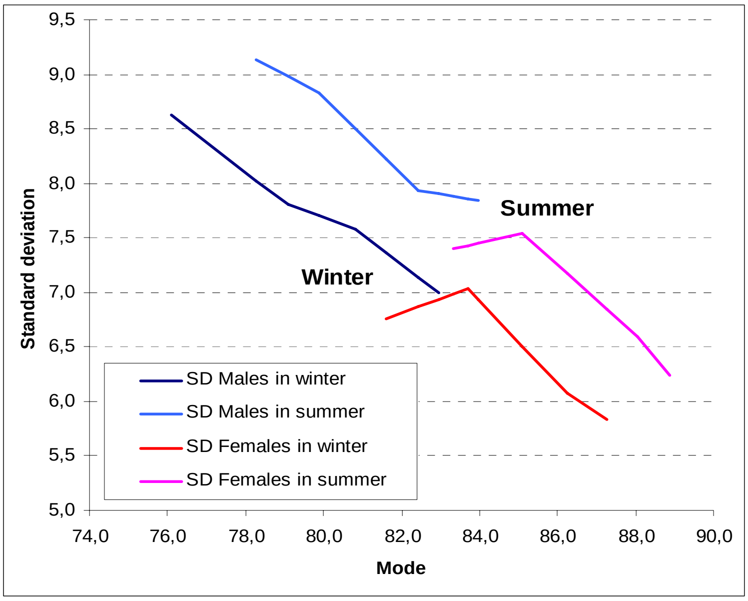
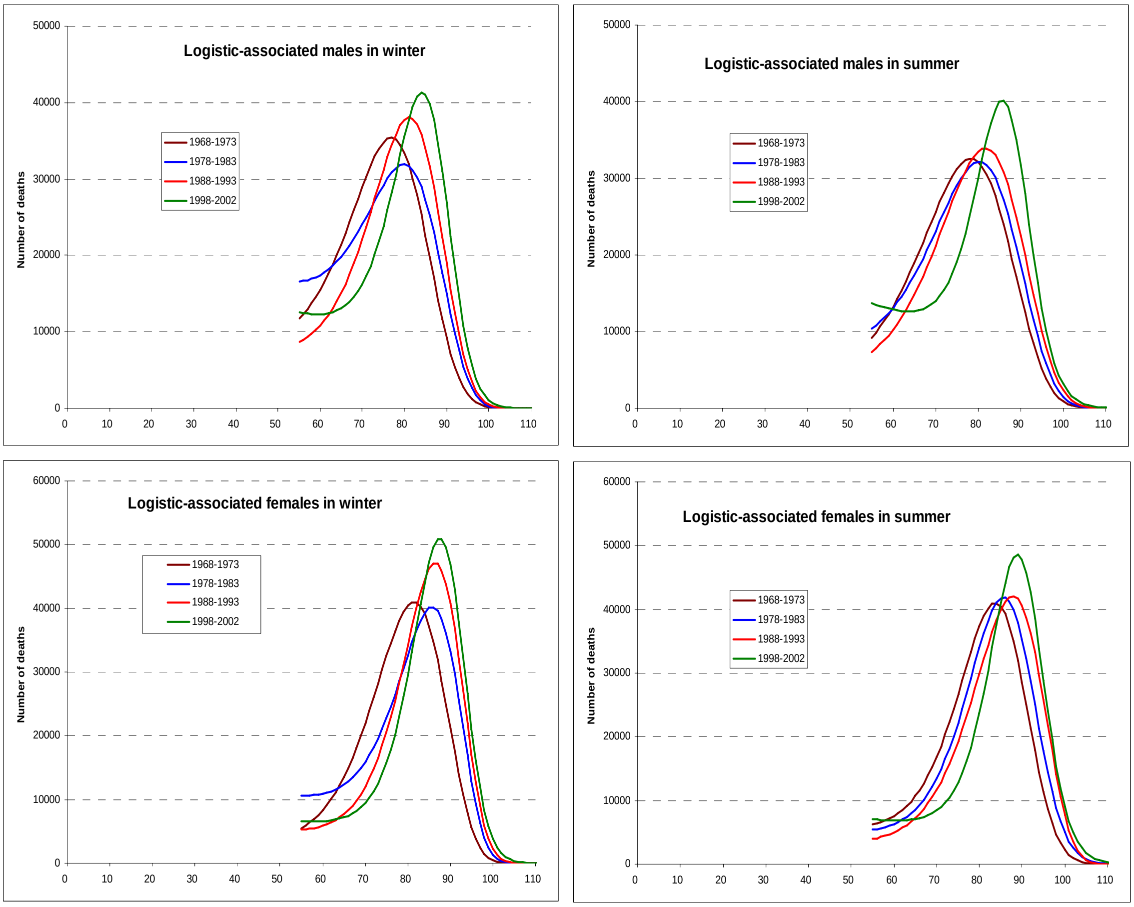


Figure 6 clearly shows two mortality regimes, one in winter and one in summer. In each mortality regime, the higher is the modal age at death (M) and the lower is the standard deviation (SD). For instance, in winter, SD declines from 8.6 years when M reached 76.1 years for males under the 1968-1973 winter conditions, to 5.8 years (-32 percent) when M reached 87.3 years (+15 percent) for females under the 1998-2002 winter conditions. The relationship between M and SD appears to be quite linear, with males lagging 30 years behind females. In summer, SD declines from 9.1 years when M reached 78.3 years for men under the 1968-1973 summer conditions, to 6.2 years (-32 percent) when M reached 88.9 years (+14 percent) for females under the 1998-2002 summer conditions. Like in winter, the relationship between M and SD appears to be quite linear in summer, with males lagging 30 years behind females. These observations strongly suggest that whatever the mortality regime, when the modal age at death increases, the standard deviation above it decreases. However, comparison of the two regimes, paradoxically, shows that in summer, where M is on average higher by 1.5 years compared to winter (2 percent), SD is larger by 0.6 years compared to winter (8 percent). Therefore, the modal age at death and its standard deviation appear to have the same negative relationship over time under the two mortality regimes, when M is increasing SD is decreasing, but they appear to have a positive relationship throughout the season. More specifically, when M is increasing (moving from winter to summer), SD is increasing. Indeed, the ages at death around and above M appear much more dispersed under the summer mortality regime where M is higher.

2.3 Comparing the Two Approaches

Figure 7 displays the dx series associated with logistically fitted death rates, corresponding to winter and summer mortality regimes, for males and females respectively. The higher panel presents the males series in winter (left) and summer (right), whereas the lower panel presents the females series.

FIGURE 7
Distribution of Individual Life Durations in Winter and Summer: dx Series Associated With a Logistic Fitting of the Death Rates, Switzerland
1968-1973, 1978-1983, 1988-1993, 1998-2002



A simple visual inspection of Figure 7 shows, by comparison with the unfitted life table dx series (Figures 4 and 5, upper panels), that the dx series associated with a logistic fitting of the death rates do not provide a fair estimation of M: neither the modal age at death nor the number of deaths gathered at this age are correctly estimated by the logistic fitting. Therefore, the actual pattern of change over time cannot be summarized by the dx series associated with a logistic fitting. However, the two series, the normally and the logistically fitted series, have globally the same Rsquare (see Table 1), underlying the difficulty of testing theoretical models.

The modal age at death associated with the logistic fitting can be five or six years higher or lower than the modal age at death observed with the unfitted dx series, whereas the modal age at death estimated with the normally fitted dx differs only by +/- one or two years and clarifies the pattern of change over time (see, for example, males in Table 1).

TABLE 1
Age at Mode: Unfitted dx Series, Normally Fitted dx, and dx Series Associated With a Logistic Fitting, Switzerland 1968-1973, 1978-1983, 1988-1993, 1998-2002

	Unfitted	Normal	Δ	Logistic-Associated	Δ
Males winter					
1968-1973	75	76	1	77	2
1978-1983	79	79	0	80	1
1988-1993	80	81	1	81	1
1998-2002	83	83	0	84	1
Males summer					
1968-1973	83	82	-1	78	-5
1978-1983	83	84	1	80	-3
1988-1993	87	86	-1	82	-5
1998-2002	88	87	-1	86	-2
Females winter					
1968-1973	77	78	1	81	4
1978-1983	80	80	0	86	6
1988-1993	83	82	-1	86	3
1998-2002	82	84	2	88	6
Females summer					
1968-1973	84	83	-1	84	0
1978-1983	85	85	0	86	1
1988-1993	90	88	-2	88	-2
1998-2002	90	89	-1	89	-1

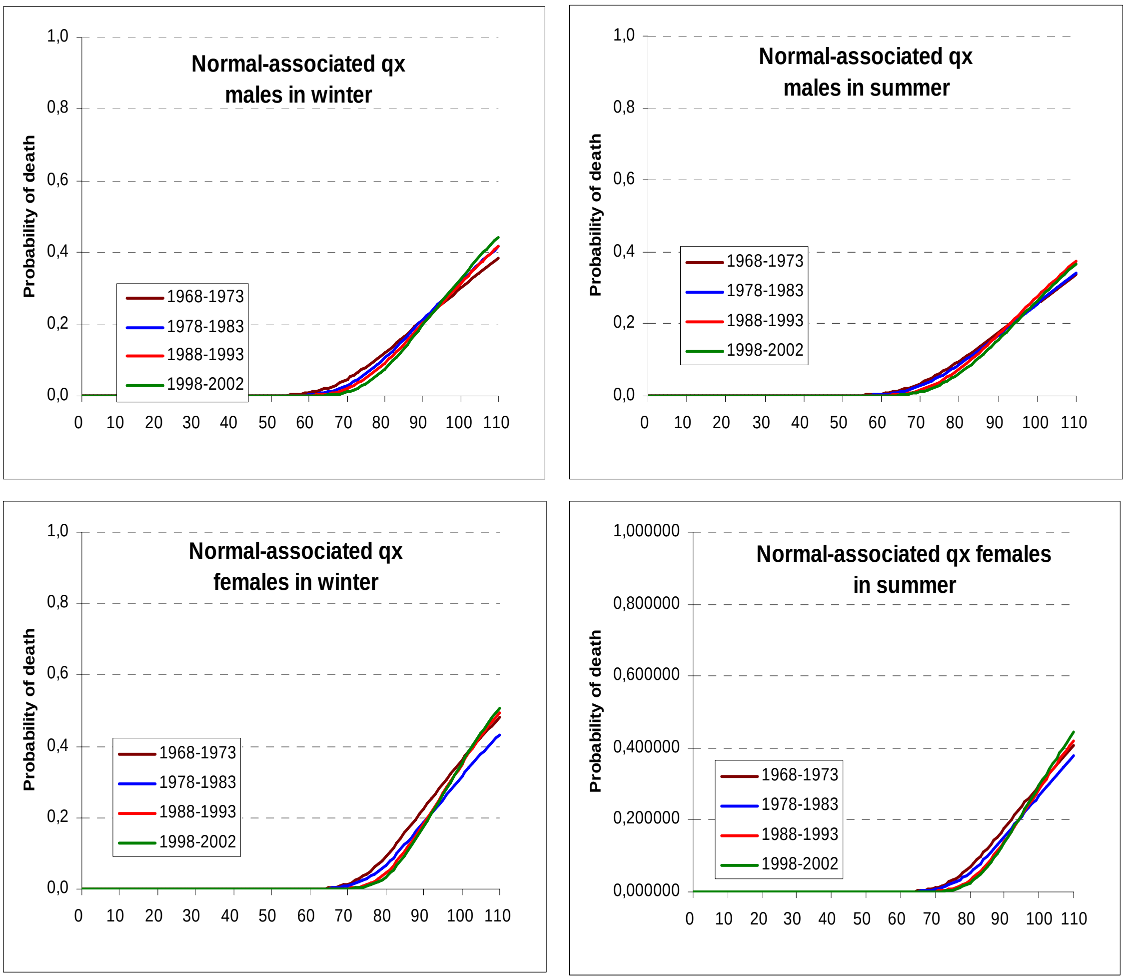
TABLE 2
Number of Deaths Gathered at the Modal Age: Unfitted dx Series, Normally Fitted dx, and dx Series Associated With a Logistic Fitting, Switzerland 1968-1973, 1978-1983, 1988-1993, 1998-2002

	Empirical	**Normal**	**Δ**	**Logistic-Associated**	**Δ**
Males winter					
1968-1973	35762	35838	76	35402	-360
1978-1983	36501	36392	-109	31914	-4586
1988-1993	36664	37766	1103	38036	1373
1998-2002	41162	40746	-416	41271	109
Males summer					
1968-1973	33136	32542	-593	32550	-586
1978-1983	33977	33275	-703	32145	-1833
1988-1993	34234	34490	256	33915	-319
1998-2002	38135	38045	-90	40130	1995
Females winter					
1968-1973	43379	42772	-607	40925	-2454
1978-1983	45146	44400	-746	40176	-4970
1988-1993	47478	47459	-19	47003	-476
1998-2002	49887	50583	696	50840	953
Females summer					
1968-1973	40871	40615	-256	40957	86
1978-1983	42749	41057	-1692	41795	-954
1988-1993	42164	42916	753	42074	-90
1998-2002	47042	47125	83	48624	1582

The number of deaths gathered at the modal age at death associated with the logistic fitting can be significantly different from the number of deaths observed at the mode with the unfitted dx series, whereas the number estimated with the normal fitting differs only little (see, for example, males or females under the winter conditions of 1978-1983 in Table 2).

On the other hand, Figure 8 clearly shows that when we are looking at the qx series, the qx series associated with a normal fitting of the dx series do not properly respect the actual pattern of change of the mortality trajectories over time; even if, taken separately, the qx trajectory associated with a normal fitting can appear interesting.

FIGURE 8
Mortality Trajectory in Winter and Summer: qx Series Associated With a Normal Fitting for the dx Series, Switzerland 1968-1973, 1978-1983, 1988-1993, 1998-2002



3. Discussion

Our work clearly demonstrates the plasticity of longevity to environmental conditions. In summer, the mortality trajectory is much lower than in winter but, in both cases, we should wait until the 1998-2002 mortality conditions to observe a clear lowering in the ceiling of mortality. Contrary to our initial hypothesis, the background mortality trajectory is not more obvious in summer when the yearly fluctuations are reduced to their minimum. However, this study demonstrates a cross-sectional plasticity of the mortality trajectory to seasonal conditions.

Our study equally confirms, with the dx series, that two different mortality regimes prevail in winter and summer. On the one hand, they are very similar. The modal age at death and its standard deviation have the same negative relationship over time under the two mortality regimes, when M increases SD decreases. But, on the other hand, M and SD appear to have a positive relationship through the season. When M increases, moving from winter conditions to summer conditions, SD increases. Our work shows that the ages at death around and above M are more dispersed under the summer mortality regime.

Comparing the two approaches, the mortality-trajectory approach (with mx and qx) or the distribution-of-ages-at-death approach (dx), it is quite difficult to use statistical testing to pick the "best" or the "right" approach. Since the work of Lexis (1878), several fellows confirmed that a normal distribution fits the dx series quite well beyond the modal age at death (Freudenberg, 1934; Greenwood and Irwin, 1939). Already Greenwood and Irwin noted in 1939 that "neither method has an overwhelming advantage over the other" (Greenwood and Irwin, 1939). The question was at this time based on opposing the method of Gompertz to that of Lexis, i.e., the exponential approach on the qx to the normal approach on the dx. According to Greenwood and Irwin, a possible advantage of the method of Lexis over that of Gompertz is that "the rate of mortality increases with age more slowly than the 'law' of Gompertz requires." We claim in our approach to human longevity that the choice of a qx approach or a dx approach depends on the research question and not on the Rsquares or maximum likelihood obtained with the different models. This claim was eloquently defended several years ago by Clarke (Clarke, 1950).

Contrary to the usual hypothesis that deaths are more concentrated when the life expectancy is higher (i.e., when the mortality is lower), our study shows that the ages at death are more concentrated in winter where the mortality conditions are worse than in summer. Our ongoing work on Japanese mortality confirms this result. In the most recent periods, improvement in mortality conditions is no longer accompanied by a further concentration of the ages at death. On the contrary, the most recent data suggest an increase in the dispersion of the ages at death for females (Cheung et al, in progress).

Previous academic seminal work in biology demonstrated that the rectangular survival curve, corresponding to a strong concentration of the deaths around the mode, can be approached, though not precisely realized, by starved *Drosophila* (Pearl and John Miner, 1935; Comfort, 1964).

For a long time throughout human history, high mortality was accompanied with a high dispersion of the ages at death, at all ages of the life cycle. With the fall in mortality (especially infant mortality), increased life expectancy at birth and then later increased modal age at death were accompanied with an increase in the concentration of the ages at death around the mode (Kannisto, 2001; Cheung et al, in press). On the one hand, this relationship may end as the most common length of life reaches extremely high values like in Japan today, while on the other hand, deleterious mortality conditions can artificially concentrate the ages at death of the oldest old in winter, confirming that secular change in human longevity should be studied in summer, when the yearly fluctuations are reduced to their minimum.

Acknowledgment

The authors want to acknowledge Carol Jagger (University of Leicester) and Yasuhiko Saito (Nihon University) for their contribution in discussing the seasonality of mortality at the University of Lausanne.

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Annex

TABLE 1

Rsquare of the Normally Fitted dx Series (Normal dx) and Logistically Fitted mx Series (Logistic mx)

	Normal dx	Logistic mx
Males winter		
1968-1973	0,992	0,950
1978-1983	0,994	0,985
1988-1993	0,991	0,998
1998-2002	0,995	0,990
Males summer		
1968-1973	0,990	0,968
1978-1983	0,997	0,996
1988-1993	0,996	0,974
1998-2002	0,986	0,978
Females winter		
1968-1973	0,997	0,987
1978-1983	0,994	0,995
1988-1993	0,995	0,998
1998-2002	0,997	0,996
Females summer		
1968-1973	0,992	0,994
1978-1983	0,994	0,997
1988-1993	0,995	0,997
1998-2002	0,995	0,992