

How are mortality rates affected by population density?

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Abstract Biologists have found that the death rate of cells in culture depends upon their spatial density. Permanent “Stay alive” signals from their neighbors seem to prevent them from dying. In a previous paper (Wang et al. 2013) we gave evidence for a density effect for ants. In this paper we examine whether there is a similar effect in human demography. We find that although there is no observable relationship between population density and overall death rates, there is a clear relationship between density and the death rates of young age-groups. Basically their death rates decrease with increasing density. However, this relationship breaks down around 300 inhabitants per square kilometer. Above this threshold the death rates remains fairly constant. The same density effect is observed in Canada, France, Japan and the United States. We also observe a striking parallel between the density effect and the so-called marital status effect in the sense that they both lead to higher suicide rates and are both enhanced for younger age-groups. However, it should be noted that the strength of the density effect is only a fraction of the strength of the marital status effect. In spite of the fact that this parallel does not give us an explanation by itself, it invites us to focus on explanations that apply to both effects. In this light the “Stay alive” paradigm set forth by Prof. Martin Raff appears as a natural interpretation. It can be seen as an extension of the “social ties” framework proposed at the end of the 19th century by the sociologist Emile Durkheim in his study about suicide.

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Overview

The “Stay alive” paradigm

It is not unreasonable to assume that for any network of inter-connected living organisms there is an “optimum” density of population. In the present study that “optimum” will be understood in the fairly crude sense of allowing the longest life expectancy. For *in vitro* cell populations biologists have found that life expectancy decreases strongly when the cell-density decreases¹. Prof. Martin Raff described this effect by saying that unless cells permanently receive a “Stay alive” signal from their neighbors, they are bound to die. Is there a similar density effect in human populations?

Evidence at the level of US states

At first sight the answer seems to be negative. This is illustrated by the graph in Fig.1a which gives death rates in fifty US states plus the District of Columbia. The scatter plot does not show any significant trend. As a matter of fact whatever correlation might exist is due to the two points on the left- and right-hand sides, namely Alaska and DC. One may recall in this respect that the population of Alaska is markedly younger than the average US population: 29.4 years as compared to 32.3 years for the whole United States².

Yet, if instead of total death rates one considers the suicide rates of young people, one gets a scatter plot which exhibits a highly significant decrease with growing density, at least within the range of densities covered in the graph of Fig. 1b. Just in order to get a more intuitive idea of what these densities represent it can be mentioned that 10 inhabitant/sq.km corresponds to the case of Nevada, 67 to Michigan, 94 to California, 330 to Massachusetts, 460 to New Jersey and 4,000 to Washington DC. Does this mean that density has an influence on suicide only? Not exactly. Fig. 1c shows a significant connection for “all causes of death” provided one focuses on young people. Yet, this relationship appears weaker than the one for suicide.

Evidence at county level

Many US states have large areas especially in the west. A state like California comprises low density areas as well as large urbanized areas around major cities. The average population density cannot be considered as a faithful indicator in such situations. This is not the only drawback of an analysis that would limit itself to state-level data. Indeed, the graphs in Fig. 1a,b,c show that there are no data points in the density interval between 460 (New Jersey) and 4,000 (Washington DC) inhabitants per

¹Ishizaki et al. (1993 p. 904, 1994 p. 1072), Raff (1998). See also the summary graph in Wang et al (2013, p. 5).

²This example also serves to illustrate the well-known fact that one needs to examine the shape of the scatter plot before drawing hasty conclusions, a methodology to which we will stick subsequently.

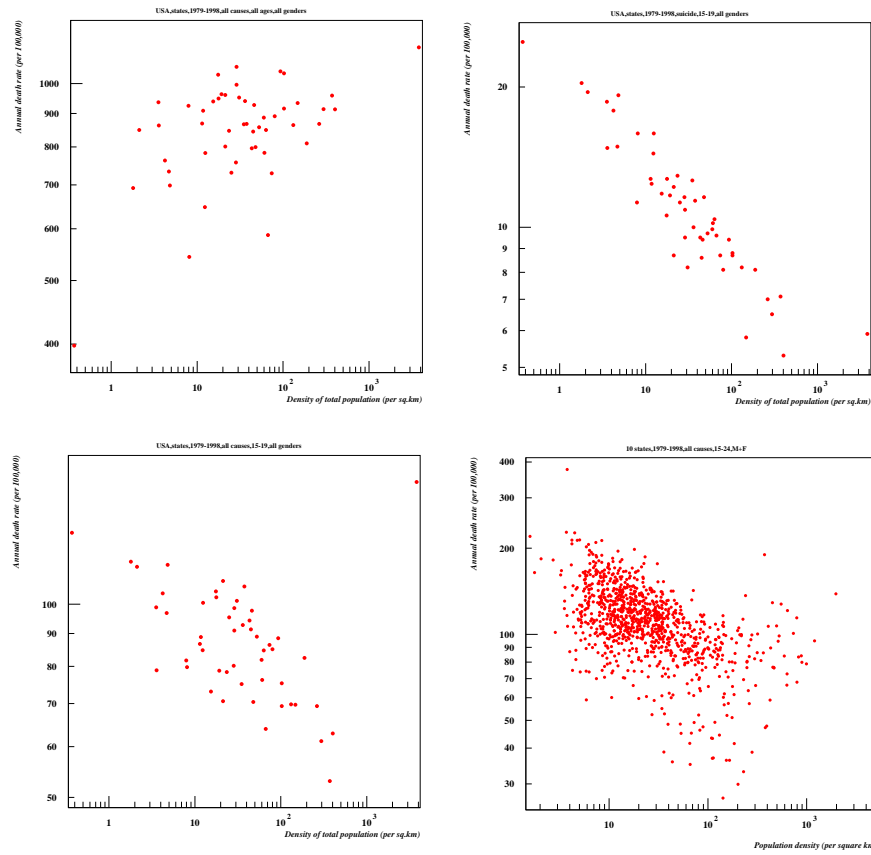


Fig. 1a,b,c,d How does population density affect death rates in the case of the United States, 1979-1998?

1a: All causes, all ages, US states (including DC); the (low) correlation is entirely due to two outliers, namely Alaska (lower left corner) and Washington DC (upper right corner). **1b:** Suicide, 15-19, US states; notice that the horizontal scale refers to the density of the *total* population, not the density of the 15-19 age group; the correlation is -0.92 and the absolute value of the slope of the log-log regression line is $a = 0.19 \pm 0.02$ (the error bar is for a confidence probability level of 0.95). **1c:** All causes, 15-19, US states; the log-log regression gives $a = 0.052 \pm 0.03$. **1d:** All causes, 15-24, 1025 counties of 10 North-Central states (Georgia, Illinois, Indiana, Iowa, Kentucky, Michigan, Missouri, Ohio, Tennessee, Wisconsin); the log-log regression gives $a = 0.14 \pm 0.01$. The evidence from Fig. 1b,c,d can be summarized by a law of the form $r = r_0/d^a$ where r is the death rate and d the density. However, Fig. 1d suggests that after falling off sharply for densities between $1/\text{sq.km}$ and $d_c = 300/\text{sq.km}$, the death rate levels off for $d > d_c$. A more precise view can only be obtained by observing more high-density counties. This will be done in Fig. 3. All these results are for cumulative death numbers over the 20-year long time interval 1979-1998; similar results are obtained for the periods 1968-1977 or 1999-2010. For instance suicide in the 15-19 age group leads to the following exponents: 1968 – 1977 : $a = 0.15 \pm 0.04$, 1999 – 2010 : $a = 0.25 \pm 0.02$. Altogether over the 3 periods one gets the average exponent: $a = 0.20 \pm 0.015$. Subsequently, for the sake of simplicity and especially when they are under 10% the error bars will sometimes be omitted. *Sources: Population and land area data: “USA Counties” data base from the US Census Bureau; death rates: Centers for Disease Control and Prevention, National Center for Health Statistics, Compressed Mortality File.*

square miles. In other words state-level data do not allow us to explore high density effects on death rates.

These two reasons lead us to consider smaller spatial entities. This was done in Fig. 1d which shows data for some 1,000 of the 3,000 US counties. This graph broadly

confirms the effect suggested by Fig. 1c³.

Why did we draw this graph for North-Central states? The reason is simple. These states hold the largest number of counties and also the smallest counties. Taken together Georgia, Indiana and Kentucky have 366 counties whereas California has 57 and Massachusetts only 6. The median land area of Georgia's counties is 890 square kilometer against 6,200 for those of the state of Utah. With smaller spatial entities the population density becomes a more meaningful indicator. However, the other side of the coin is that together with smaller populations also come smaller numbers of deaths which represents a serious shortcoming for the investigation of specific causes of death⁴.

The evidence presented in Fig. 1 speaks in favor of a relationship of the form:

$$r = \frac{r_0}{d^a}, \quad \text{for } 1/\text{sq.km} \leq d \leq 300/\text{sq.km}, \quad r : \text{death rate}, \quad d : \text{population density}, \quad (1)$$

Incidentally, it can be observed that defining a as a slope in a *log-log plot* has the advantage of making it independent of the measurement units used for the density or the death rate.

However, several questions remain unanswered among which one can list the following:

- Is there a gradual transition between the case of young age groups for which there is a density effect and the case of aged people for which none is expected?
- Does the death rate curve level off above a density d_1 as Fig. 1d seems to suggest.
- Is this effect specific to the United States or can it be observed also in other countries?
- Finally, one may wonder how this effect can be “explained”.

Before considering these questions more closely one can give the following short answers.

- From the 15-19 age group to the 74-84 age group (the last group documented in the Wonder dataset) there is a gradual decline in the exponent a .
- For densities above 300 per sq/km the death rate remains almost constant.
- Apart from the United States the density effect can also be observed in other countries. We will show evidence for the cases of Canada, France and Japan.
- A preliminary answer to the last question will be given in the two sections before the conclusion section.

³Although the mean values of the exponents are not the same their confidence intervals overlap and are not incompatible.

⁴For confidentiality reasons, the WONDER database omits all counties for which there are less than 10 deaths. This limitation represents a major obstacle for the analysis at county level.

Death rate by cause as a function of age

Before going closer into our investigation we wish to recall how death rates increase along with age for different causes of death. We will see that there is a sharp difference between diseases and what the “International Classification of Diseases” calls “external causes of injury”. Typically, as shown in Fig. 2, the death rates of diseases increase exponentially with age (at least after the age of 30). On the contrary, the rates for external causes hardly increase with age.

Why is this distinction important for our investigation? From Fig. 2 we see that the share of deaths by disease or by external causes is not at all the same in young and in old age-groups. In young age-group deaths due to external causes are predominant whereas deaths due to diseases are predominant in old age groups.

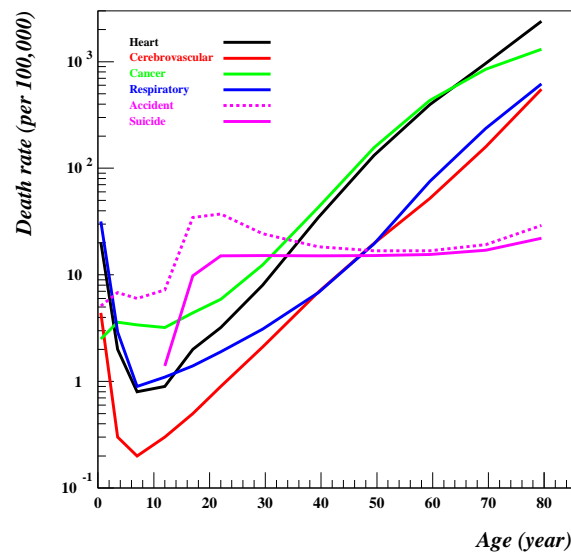


Fig. 2 Age-specific mortality rates for 6 causes of death in the United States, 1979-1998. There are clearly two different groups: rates for cancer and for heart, cerebrovascular, respiratory diseases increase exponentially with age, whereas the rates for suicide and accident remain constant or increase very slowly. *Source: Centers for Disease Control and Prevention, National Center for Health Statistics, Compressed Mortality File.*

Now, it turns out that in contrast to rates for external causes rates for diseases are almost *not* affected by population density. Therefore one expects that in an “all causes” analysis young age-groups will be much more affected by density changes than old age groups. This is indeed what was seen in Fig. 1. In short, young versus old or external causes versus diseases are just two aspects of the same effect.

However, it should be emphasized that this argument does not tell us anything about how death from external causes are affected by density or how the density effect itself is affected by age. These points will be examined in the next sections.

Density effect for suicide

By focusing on specific causes of death it becomes rapidly apparent that the death rates for diseases are not affected by density, or to say it more correctly, there are other factors which have a stronger influence. This can be seen fairly clearly by looking at the case of heart diseases at the level of US states plus Washington DC. If one discards the two extreme cases of Alaska ($d = 0.5/\text{sq.km}$) and DC ($d = 4,000/\text{sq.km}$) there is no clear correlation among the 49 remaining states. However, the death rate in Alaska is about one-half of the death rate in DC for young as well as for old age-groups. This shows that some ethnic and/or environmental factors are at work which are much stronger than any possible influence of density. In other words if we wish to identify an effect of density we must look either at causes of death that are not due to diseases or at young age-groups for which these causes of death play little role.

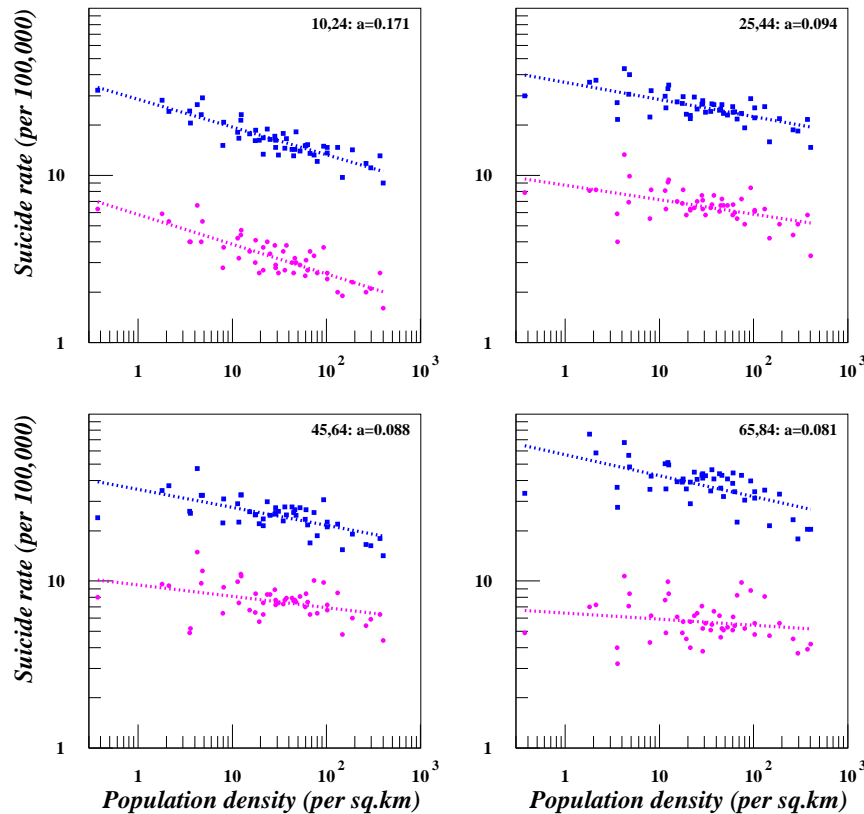


Fig. 3 Suicide rate in function of density for 50 US states, 1979-1998. Blue squares refer to males, magenta dots refer to females. From young to old age-groups one observes a continuous decrease in the slope a of the regression line. The numbers in the upper-right corner are the averages of the male and female slopes. At the same time the correlation becomes weaker: from -0.89 to -0.62 for males and from -0.84 to -0.19 for females. *Source: Centers for Disease Control and Prevention, National Center for Health Statistics, Compressed Mortality File.*

There are mainly three causes of death due to external factors, namely accidents, homicides and suicides. Which of them is the most interesting for us? From the

perspective of the apoptosis paradigm introduced by Prof. Raff ⁵ it is clearly suicide which will be of greatest interest. However, accidents will also be discussed in some detail later on.

As far as suicide is concerned there are two intriguing facts.

- As already seen in Fig. 1 suicide rates are density-dependent
- Secondly, the connection between suicide and density becomes weaker and weaker as individuals become older.

These two facts are documented in Fig. 3 in the case of US states (this time without DC). The rates for males and females were plotted separately because their orders of magnitude are fairly different. However, their dependence with respect to density is almost the same as shown by the fact that the regression lines are nearly parallel.

Weakening in the density-suicide interdependence can best be measured by the decrease in the absolute value of the correlation coefficient; the results are given in the following table.

Table 1: Coefficients of correlation between suicide rate and population density

Age-group	10 – 24	25 – 44	45 – 64	65 – 84
Male	0.89	0.70	0.67	0.62
Female	0.84	0.53	0.41	0.19

Notes: The table gives the absolute values of the coefficients of correlation corresponding to the scatter-plots in Fig. 2. The fall of the correlation for older age-groups occurs in both genders but the reduction is much faster for women than for men.

Evidence for low versus high density

Fig. 1d has the advantage of being based on over 1,000 counties but it has the disadvantage that these counties are mostly in the (10,100) density interval. As a result, it does not give good evidence for very low densities under 10 inh/sq.km or very high densities over 300 inh/sq.km. In order to explore these two ends, we built a special sample which includes states with very low densities such as Arizona, Nevada, Utah or Wyoming as well as states with very high densities such as Maryland, New Jersey, New York⁶.

Fig. 4 shows that the density curve has two distinct parts: one below 300/sq.km and

⁵In Raff (1998) he referred to the phenomenon of cell apoptosis which happens either *in vitro* or *in vivo* as being a kind of “cell suicide”.

⁶Altogether there are 13 states: Arizona, California, Delaware, Massachusetts, Maryland, Michigan, Montana, Nevada, New Jersey, New York, Utah, Virginia, Wyoming. These 13 states comprise only 447 counties whereas the 10 states considered in Fig. 1d had twice as many. It can be noted that because of its large land area New York does not have a very high density (only 160/sq.km) but it comprises several top density counties.

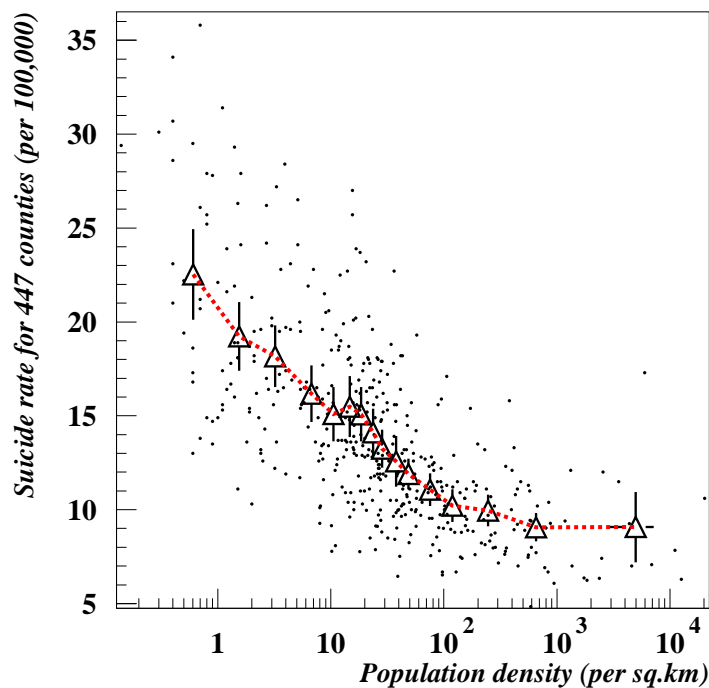


Fig. 4 How population density affects suicide rates in the United States, 1989-1998. The death rates are for suicide at all ages. The broken line connects average for packages of counties of increasing density. We selected either low density states such as Arizona or Utah or states with large metropolitan areas such as New Jersey or New York (the list of the states is given in the text). As a result, one sees fairly clearly that the death rate curve has two distinct parts: a rapid decrease (with a regression coefficient of -0.13) under 200 inhabitants per sq.km followed by a plateau for higher densities. *Sources: Same as for Fig. 1*

a second one above this threshold where the suicide rate remains fairly constant. Fig. 5 and 7 given below show a similar effect for France and Japan.

Evidence for other countries than the United States

France

For a country such as France whose population is about 5 times smaller than that of the United States one faces the difficulty of a smaller number of deaths. France is divided into 95 *départements* and some 20,000 *communes*. Clearly, at the level of the *communes* the number of deaths would be far too small to be useful. Moreover, as the number of *départements* is almost twice the number of US states, the average annual number of deaths per *département* will be some $5 \times 2 = 10$ times smaller than in the US. In other words, one is not in the best conditions to observe a density effect. Nevertheless, a graph (Fig. 5) for death rates in the age-group 15-24 gives a picture that is consistent with Fig. 1c.

Canada

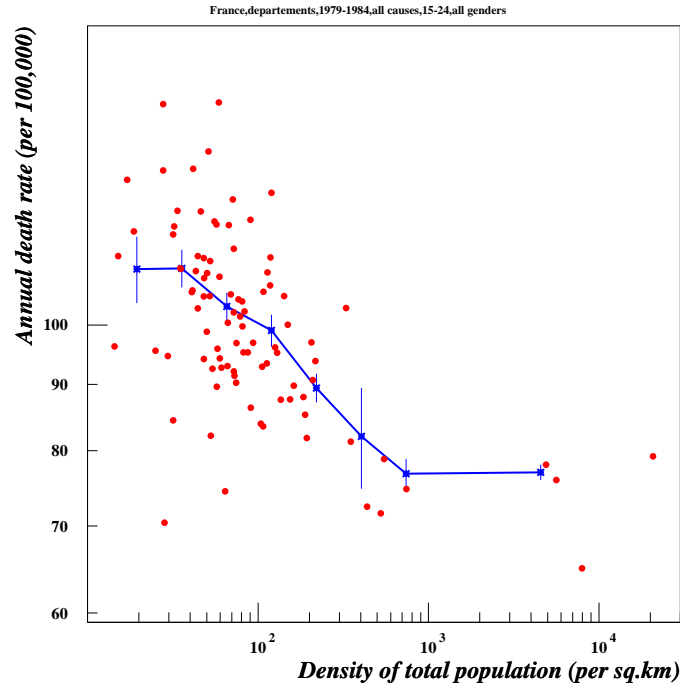


Fig. 5 How does population density affect death rates in the case of France, 1979-1984? The death rates are for all causes of death in the age group 15-24. The slope of the regression line for the data points below a density of 1,000 inhabitants per sq.km has an absolute value of 0.11. It appears that above this value there is a leveling off but in order to get a more precise picture one would need more data points in this interval. *Sources: Population and land area: INSEE; death rates by age: INSERM (“Institut national de la santé et de la recherche médicale” which is the French analogue of the US “National Center for Health Statistics”).*

In the late 20th century Canada had a population of some 30 millions and its territory is divided into 12 provinces and territories.

Compared with the United States the expected annual number of deaths per province will be $(300/30) \times (12/50) \simeq 2$. This makes the situation less unfavorable than in the case of France but at the cost of having but a tiny number of data points. Moreover, all these regions have population densities which are low or very low. There are in fact two distinct groups: (i) a group of 10 provinces whose densities are approximately comprised between 1 and 10 inh/sq.km (ii) a group of two territories, namely the North-West Territories and Yukon, whose densities are below 0.1 inh/sq.km. A report of Health Canada (1994) gives suicide data over a 30-year period from 1961 to 1990.

In spite of the few data points the graph in Fig. 6 covers a broad range of population densities. Thanks to the fact that it is an average over a 20-year long period, its suicide rates can be considered as fairly reliable. If one leaves aside Newfoundland, an obvious outlier for some unknown reason, one gets an exponent $a = 0.11$.

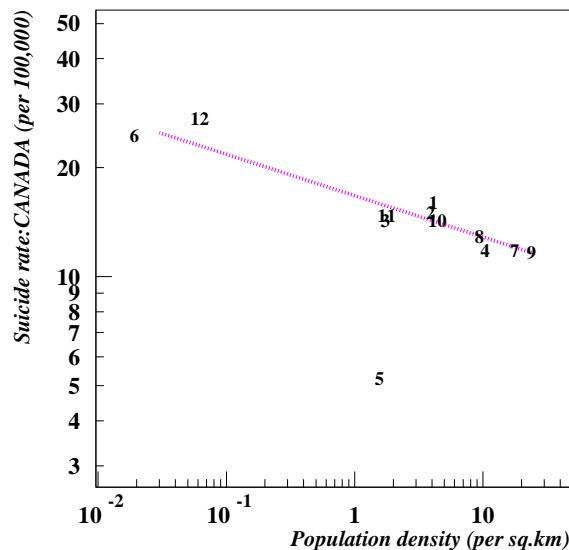


Fig. 6 How population density affects suicide rates in the case of Canada, 1971-1990. Whereas the case of France gave us a glimpse of the incidence of high densities, Canada gives us information about the low density range. The graph suggests that the power law found in previous cases remains valid for the very low densities found in North-West (no 6) and Yukon (no 12) Territories. Newfoundland (no 5) appears to be an obvious outlier (its suicide rates are closer to those which prevail in the UK than to those seen in the rest of Canada). With Newfoundland left apart, the log-log regression gives an exponent $a = 0.11 \pm 0.05$ which is consistent with values found previously. The large error bar does not come from a poor correlation (it is equal to -0.83) but from the small number of data points. *Source: Health Canada (1994).*

As a function of age-group one gets the following results⁷:

$$15 - 24 : a = 0.20 \pm 0.07 \quad 35 - 54 : a = 0.067 \pm 0.09 \quad 65 - 74 : a = 0.12 \pm 0.13$$

Of these three age-groups, it is the first one which has the most significant connection with population density.

The case of Germany

With a population of 80 millions in 2010, Germany may appear as a good candidate for the present investigation. In fact, it is not. There are three main reasons for that.

- The United States has an average population density of 28/sq.km (in 1996) whereas Germany has an average density of 234/sq.km (in 2010). Thus, it is not surprising that of the 16 German *Länder* none has a density under 70/sq.km. As seen above the decrease of death rates as a function of density occurs mainly between 0.1/sq.km and 30/sq.km. Over 70/sq.km one would expect only a small residual decrease.

- The *Länder* which have the lowest densities⁸ are all former East German *Länder*. For that reason their suicide rates are not really comparable to those in former West

⁷As the death rates of the N-W and Yukon Territories become somewhat unstable in separate age-groups (due to small numbers), they were left aside.

⁸Brandenburg (85), Mecklenburg-Vorpommern (86), Saxony-Anhalt (119), Thuringia (143).

German *Länder*.

- The time series of death rates in former East German *Länder* start after the reunification in 1990. Thus, the largest interval over which one can perform averages runs from 1990 to present time.

If, despite such low expectations, one nevertheless draws the curve of average suicide rates over 1990-1997 as a function of density one gets the following results. Though seemingly disappointing, they are in fact consistent with our expectations.

(1) For all ages the slope is slightly (non significantly) negative: $a = 0.012 \pm 0.09$ (the correlation is -0.07).

(2) For the age-group 15-19 the correlation is slightly higher, namely -0.25 (yet still not significant) and $a = 0.040 \pm 0.08$.

Needless to say, even if the correlation had been somewhat higher the fact that there are only 16 *Länder* would still result in giving to a a large confidence interval.

The case of Japan

For Japan the story is very much the same as for Germany in the sense that all 47 prefectures have a population density higher than 70/sq.km. Hokkaido has the lowest (72 in 2005) and there are only two others with a density under 100, namely Iwate (91) and Akita (99). Therefore, if the law $r = f(d)$ is indeed the same as seen above one expects only a small residual decrease of the suicide rate between the densities of Hokkaido at one end and a threshold density d_c which should be around 300/sq.km.

What makes the situation markedly better than for Germany is the fact that we have here 47 prefectures instead of only 16 *Länder*

Actual observation for suicide rates at all ages averaged over the time interval 2009-2011 shows results that are indeed consistent with expectation.

There are two distinct parts: a downward trend under $d_1 = 300$ and an horizontal line above this threshold. For the 26 prefectures whose density is under d_c the correlation is -0.56 with a confidence interval $(-0.78, -0.22)$ which shows that it is significantly negative (despite the fact that there are only 26 data points). The log-log regression estimate of the exponent is $a = 0.19 \pm 0.11$.

It would have been interesting to see if the density effect is amplified by restricting the age to the 15-19 age group. So far, however, we were not able to get the required statistics.

Determinants of the density effect

What kind of explanation?

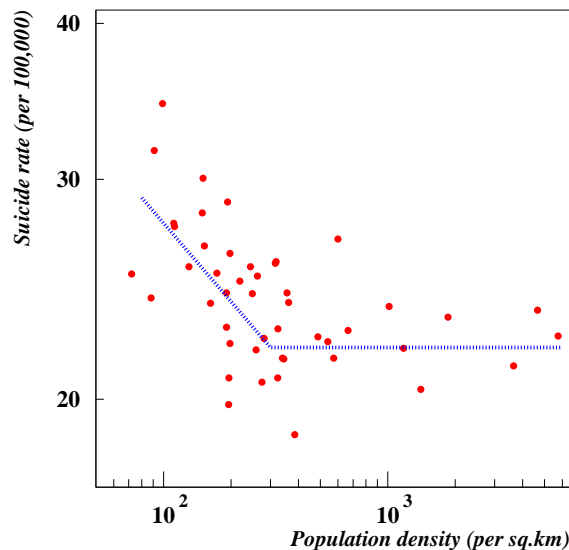


Fig.7 How population density affects suicide rates in the case of Japan, 2009-2011. Because Japan’s 47 prefectures have mainly high or very high densities this graph shows a limited section of the downward curve together with a long level line corresponding to densities over a threshold $d_c = 300/\text{sq.km}$. For the 26 prefectures which have a density under d_c regression analysis gives an exponent $a = 0.19 \pm 0.11$. *Source: Population densities: website entitled “Historical Statistics of Japan”; suicide rates: website entitled “Vital Statistics” of the Ministry of Health, Labour and Welfare.*

There are (at least) three possible kinds of explanations for the density effect described in the previous sections.

- (1) It may be a statistical artifact.
- (2) It may be explained by some fairly obvious anthropomorphic factors.
- (3) The effect may have a deeper (non anthropomorphic) origin, for instance in relation with the “Stay alive” effect mentioned at the beginning of the paper.

Let us examine these possibilities more closely.

Statistical artifact

The best guarantee against possible statistical artifacts is to repeat the observation in different countries in the hope that they do not all use the same statistical methodology. So far, we have considered four countries but in fact we gave a look at quite a few others. These attempts convinced us that it is not easy to find many “good” candidates. This can be illustrated by the following discussion about Sweden as well as by the case of Germany that we already considered.

Sweden is a country which is often useful for statistical investigations because of its excellent statistical system. In 2010 Sweden had a population of some 9 million and a territory divided into 284 municipalities. This means that compared with the United States the annual number of deaths per municipality will be smaller by a factor $(300/9 \times (284/50)) = 189$. In other words, in order to get the same cumulative

number of deaths one would have to consider a time-period that is 189 times longer than in the US. As in the US we have used time-periods of at least 10 years this is clearly impossible.

The previous argument suggests that one should rather turn to countries with large populations. Among them China appears as an obvious choice. That sets a possible objective for a subsequent investigation.

Anthropomorphic factors

One obvious factor comes to mind immediately. For persons who have an accident or a heart attack it will take longer to take them to an hospital if they live in a fairly desert country side than if they live in a city. However, that effect should affect old people as well as young people. It could even be argued that the effect should be stronger for old people because they are less resilient and would therefore be more affected by a long delay to get to the hospital. Yet, for old people one does not observe any clear density effect. In short, there does not seem to be a “distance to hospital” effect.

For deaths through accidents and especially car accidents there is undoubtedly a density effect. In cities the average velocity of cars is low which means that collisions will rarely result in fatal injuries. On the contrary, on countryside roads the high speed reached by cars will transform any collision into a fatal accident. This intuitive argument is indeed confirmed by statistical observation. In all European countries the graph of traffic fatality rates as a function of population density shows the same downward trend (Orselli 2001). For young drivers this countryside road effect may be amplified due to poorly developed driving skills.

Needless to say, the previous argument applies only to road traffic accidents and cannot explain the downward trend of suicide deaths. However, as traffic accidents are the first cause of death in the 15-24 age group, this factor certainly plays a role in this age range, albeit a limited role because in past decades this cause of death represented only between 27% and 35% of all deaths in this age group. Another point which remains unclear is the fact that one does not know which fraction of the downward trend is due to the velocity factor *per se* as compared with other density-dependent factors.

The “Stay alive” effect

The “Stay alive” mechanism easily “explains” the fall of suicide rates when the density increases. However, it does *not* explain why the fall stops around $d_c = 300/\text{sq.km}$; neither does it explain why young age-groups are more affected than

older age groups.

Let us consider these points more closely. One important aspect that will be developed is the parallel between the effects of population density and those of marital status.

Less links means more suicide

We mentioned at the beginning that the death rate of cells in culture increases when their density becomes lower. The results given in Ishizaki (1992, 1993) suggest that the death rate is multiplied by 2 or 3 (depending upon cell type) when the density is divided by 10. In Fig. 1 we have seen that the death rate of young people is multiplied by a factor of about 2 when the density is divided by 100. In any population the frequency of contacts between individuals is proportional to the square of their density. Thus, smaller density means less contacts⁹.

At this point we need to explain why, among various causes of death, suicide plays a special role. It is well known that among the different causes of death it is suicide which is the most sensitive to the lack or severance of social links. This can be seen by looking at how death rates depend on marital status. Whereas for heart disease or cancer the death rate of bachelors or widowers is on average some 1.8 times larger than for married people, in the case of suicide the average excess-death ratios jump to 2.5 for bachelors and 5 for widowers¹⁰.

Amplification of the density effect for young age-groups

For different marital situations age-specific suicide ratios tell us something about the role of age.

They show an amplification of the effect of tie severance for *young* widows or widowers¹¹. This pattern is illustrated in Fig. 8a and Fig. 8b. For Fig. 8a the suicide rates were derived from the regressions on US states performed in Fig. 3. If one denotes the regression line by $\ln s = a_i \ln d + b_i$ where the index i refers to the 4 age-groups, then the suicides rates for the lowest and highest density (along with their ratio) will be given by:

$$S_i = \exp(a_i \ln(0.3) + b_i), \quad s_i = \exp(a_i \ln(300) + b_i), \quad r_i = \frac{S_i}{s_i} \quad i = 1, \dots, 4$$

For Fig. 8b, the death rates were derived directly from an analysis done at county level for the same 1,025 counties already used in Fig 1d. This was made possible because the number of deaths is much larger than the number of suicides. For suicides

⁹Of course, smaller density may also have other effects, but the reduction of contact frequency seems to be a property that is shared by many systems.

¹⁰This can be seen on Fig. 3b of Wang et al. (2013).

¹¹There is no similar pattern in the case of heart disease or cancer; on the contrary, the excess mortality is reduced for young individuals.

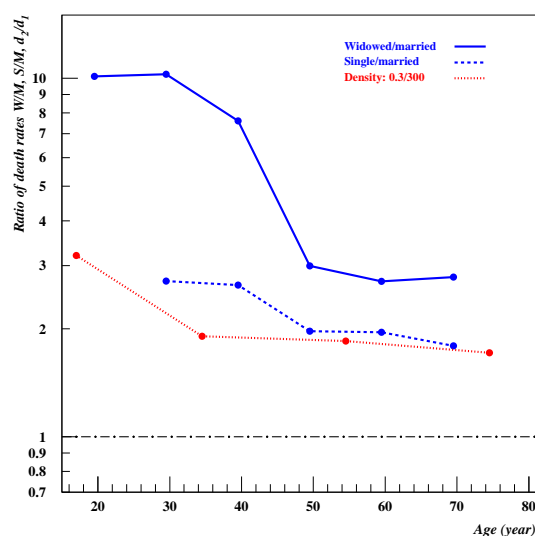


Fig. 8a Parallel between the effect on suicide rates of marital status on the one hand and of density level on the other hand. The marital status ratios are for the United States in 1980. In the density case the ratios were derived from the linear regression performed in Fig. 3; the ratio is the suicide rate for a density of 0.3/sq.km divided by the suicide rate for a density of 300/sq.km. The latter has been selected because it corresponds to the minimum suicide rate in the same way as the suicide rate of married people is the minimum among family situations. What is the practical meaning of the 0.3/300 curve? It means that if 1,000 persons of same age (e.g. 40) move from a place *A* where the density is 300/sq.km to a place *B* where the density is 0.3/sq.m, they will experience *r* times (for age 40, $r = 2$) more suicides than a control group of same age that has remained in *A*. All data in this graph are for males and females together. *Sources: Suicide rates by marital status: Vital Statistics of the United States, 1980, Vol. 2, part A, p. 323; Suicide rates by age and population density: Centers for Disease Control and Prevention, National Center for Health Statistics, Compressed Mortality File.*

as a function of age the analysis is almost impossible at county level just because they are too few.

Of course, by itself the parallel drawn between density and marital status does not offer an explanation. However, it suggests that any explanation that would not apply to both cases may not be satisfactory. In other words, it narrows the range of possible explanations.

Regarding the amplification for young age-groups, we can offer an additional observation. Basically, the argument goes as follows. As suicide rates of young age-groups are driven up by the effect of low density, one would expect that the curves of rates as a function of age are *flatter* in places of low density than in places of high density.

In order to make this point clearer and to see if it is really true, we have drawn a graph (Fig. 9). It shows that age-curves in low density areas are indeed flatter than in high density places. These graphs, once again, underline the parallel with marital status.

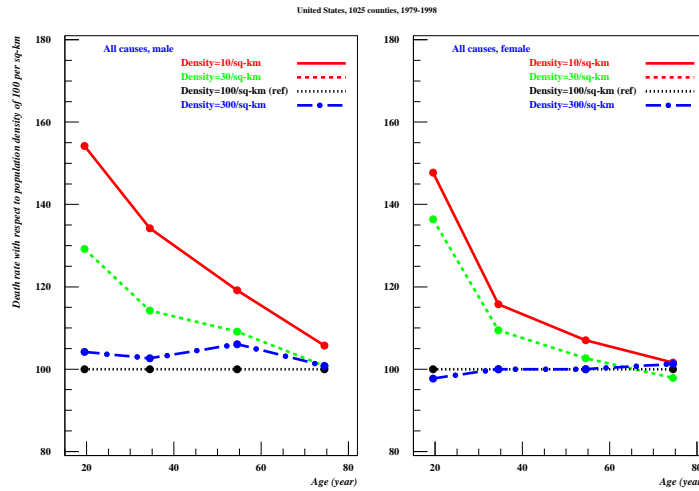


Fig. 8b Effect on death rates of density level and age This graph is similar to the density curve of Fig. 8a but instead of suicide rates it considers death rates from all causes. It is based on an analysis at county level. The different curves give the ratios: density d /density 100 for $d = 10, 30, 300$; the index was normalized to 100 for a ratio equal to 1. It can be seen that the results are almost the same for a density of 100 and for a density of 300. In contrast with Fig. 8a, for age-groups over 60 the ratio tends toward 1 which means that for these age-groups there is no density effect. This is due to the fact that old-age deaths are mostly deaths from diseases. *Sources: Centers for Disease Control and Prevention, National Center for Health Statistics, Compressed Mortality File.*

In the following section we tentatively propose a mechanism which accounts for what one observes in Fig. 9.

An explanation in terms of shock-strength

How can one explain that the suicide rate of young widowers is two or three times higher than the suicide rate of widowers over 50? Was the shock represented by the death of their spouse more painful for young widowers than for widowers over 50? At first sight one would rather expect the opposite. Indeed, it can be argued that a marriage that has lasted for 20 or 30 years creates a stronger link than a marriage that has been in existence for just a few years. This is merely wishful thinking however. A more solid argument is to estimate the propensity for getting married by the marriage rate (defined as the number of annual marriages in a given age group by the number of non-married persons in the same age group) just in the same way as one would measure the rate of a chemical reaction. This calculation shows that the marriage rate is highest at age 28 and decreases sharply thereafter. At age 60 it is about 10 times lower than at 28 (Roehner 2008, p. 72-74). If one accepts that the propensity for getting married provides a measure of the strength of the bond¹², then one comes to a conclusion which is opposite to the previous one. In this perspective the high suicide rate of young widowers is in line with the strength of the shock that they

¹²This is the way of thinking used in chemistry where the strength of a bond is estimated through the energy required to create it or to break it.

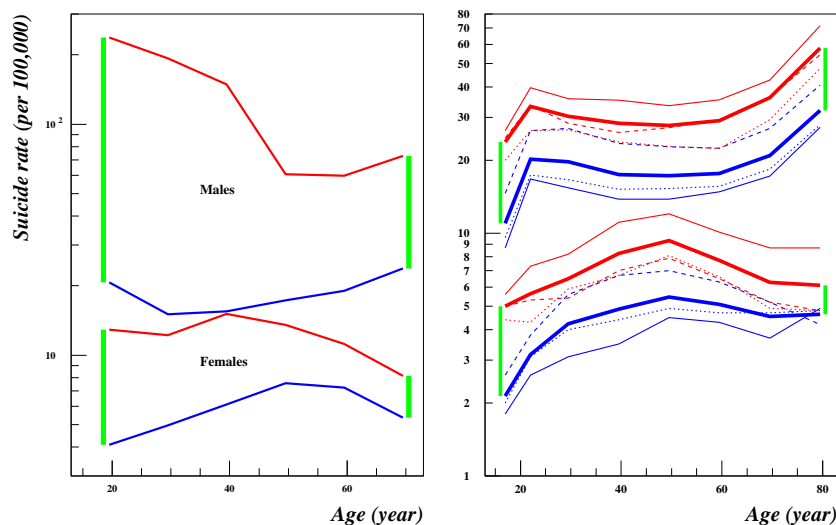


Fig.9 Graph showing the way in which lower density (or severed marital ties) affect age-curves. The curves for males are on top of the curves for females. The red curves show cases characterized by reduced links: widows and widowers on the left, low density areas on the right. The blue curves show networks characterized by higher interactions: married individuals on the left, high density areas on the right. For the density case, it would have been fairly arbitrary to select just one state of each kind. Instead we have selected 3 areas of each kind. The low density areas are the following. A (solid line)=(AZ,CO,NE,NV,NM,WY), B (broken line)=(ID,MT,ND,SD), C (dotted line)=KS. The high density areas consist in the following states: A (solid line)=NJ, B (broken line)=PA, C (dotted line)=NY. The thick solid lines are averages of the A,B,C cases. Overall, the curves for low density areas are flatter than those for high density areas. As a result, the ratios at 20 year of age are larger than the ratios at 80. These ratios are represented by the green vertical bars. On the marital status graph the same effect can be observed but in much stronger form. The upper curves which correspond to widowers and widows are not only flatter, they are in fact inverted in the sense that instead of going up with age they fall off. Basically, this figure is equivalent to Fig. 8. but it is seen from a different, more basic, angle. *Sources: Suicide rates by marital status: Vital Statistics of the United States, 1980, Vol. 2, part A, p. 323; Suicide rates by age and population density: Centers for Disease Control and Prevention, National Center for Health Statistics, Compressed Mortality File.*

experience.

Is it possible to transpose this argument to the density case? The analog of the widowhood shock would be the transfer from an urban environment that corresponds to a density of over 500/sq.km to a countryside environment. How can one estimate the strength of the links that connect residents to their social environment? Obviously, one cannot use the same method as for marriage. Another indicator that can be used is the suicide rate itself. For a given density individuals in old age-groups have a higher suicide rate than young people. If one agrees with the perspective set forth by Emile Durkheim (1888, 1897), this suggests that their connection with their familial and social environment is weaker than that of younger people¹³. Now comes the

¹³Intuitively, this seems of course very plausible because of the strong link that an occupational activity represents for individuals until they retire. Incidentally, Fig. 9 shows that the suicide rate of men begins to climb up after the age of 60 whereas for women the curve remains fairly flat.

last step in our argument. If young persons are more connected to their social environment, then the shock of moving out to a countryside environment will be more painful to them and, just as in the case of widowhood but with smaller magnitude, it will result in inflated suicide rates.

A word of caution is perhaps in order with respect to the previous argument. Once one has identified a possible mechanism (here the parallel with marital status), it is generally difficult to prove that it is indeed the right one. In this respect, our proposal should be seen rather as a working hypothesis. If, in the course of time, it appears that it is able to explain an ever growing set of observations (rather than just some isolated facts) this will make it more convincing and better accepted.

Conclusions

This paper gave statistical evidence for the following effects.

(1) Whereas there is usually no clear connection between *overall* death rates and population density (d), a significant relationship turns up between d and the death rates (r) in young age groups.

(2) Whereas overall death rates are dominated by the deaths of people over 60, the death rates for suicide or for accidents are rather dominated by the deaths of young or middle-aged people¹⁴. Therefore it is not surprising that suicide or accident rates exhibit a strong connection with density even if all ages are included.

(3) In those cases (defined above) where the death rate falls off with increasing density, the decrease slows down for densities over 300 inh/sq.km and is followed by a plateau.

(4) The pattern described by the previous rules is observed in very similar ways in Canada, France Japan and the United States. It can be summarized by a power-law of the form: $r = r_0/d^a$ where a is of the order of 0.12 for suicide rates and somewhat lower for all-causes death rates among young individuals.

(5) The “Stay alive” paradigm¹⁵ establishes a connection between death rates and strength of inter-individual interactions. Fig. 8 and 9 establish a parallel between the effects of marital status on the one hand and population density on the other hand which suggests that the strength of intra-family contacts is similar to the strength of social (non-familial) interactions.

At this point we do not wish to claim that this pattern holds in a general way and in all times. Whereas family links have remained fairly unchanged in recent time, big

¹⁴This is true even when the suicide rate increases with age because the age-groups over 60 represent a smaller share of the total population than the groups of young or middle-aged people.

¹⁵It can be seen as an extension of the framework set forth by Emile Durkheim (1888, 1897). That point of view was also developed in Roehner (2007, part 3)

changes have affected social life in villages and towns of industrialized countries. Back in the 19th century, countryside villages and small towns were still vibrant places of living characterized by a broad spectrum of activities, from farmers to craftsmen or clerks. With the advent of very large mechanized farms, the social network of the countryside has lost much of its diversity and interactions. In the United States this transformation mostly occurred during the first half of the 20th century. In western Europe it occurred mainly during the second half of the 20th century. In many developing countries, and in particular in China, it is currently occurring at great speed under our eyes.

The purpose of the present article was not to explain everything but rather to describe the empirical pattern and to state as clearly as possible the interrogations which remain. Once we get a clearer understanding of the factors which control this effect, we will be able to predict the situations in which it should occur as well as those in which it will not be expected.

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