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(Un-) healthy ageing: Geographic inequalities in disability-free life expectancy in England and Wales

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ABSTRACT

Health expectancies are an indicator of healthy ageing that reflect quantity and quality of life. Using limiting long term illness and mortality prevalence, we calculate disability-free life expectancy for small areas in England and Wales between 1991 and 2011 for males and females aged 50–74, the life stage when people may be changing their occupation from main career to retirement or alternative work activities. We find that inequalities in disability-free life expectancy are deeply entrenched, including former coalfield and ex-industrial areas and that areas of persistent (dis-) advantage, worsening or improving deprivation have health change in line with deprivation change. A mixed health picture for rural and coastal areas requires further investigation as do the demographic processes which underpin these area level health differences.

1. Introduction

As society ages, promoting health during the later years of life is paramount for people's health and social care (Welsh et al., 2021). Measures of 'health expectancy' are becoming increasingly important to better understand whether time spent in poor health is expanding or being compressed (Newton, 2021). Compression is characterised by life expectancy increasing faster than years in chronic ill health, resulting in a smaller fraction of life being spent in ill health. Attaining morbidity compression needs health strategies which postpone the onset of ill health through prevention of chronic disease (Fries et al., 2011); this would also be socially and economically beneficial.

Health expectancy measures emerged as tools to ascertain whether increases in life expectancy were accompanied by an increase in years lived in good health, an increase in years spent in poor health, or as an equilibrium between the quantity and quality of years lived (Robine, 2021); with quality being of crucial importance (Lagiewka, 2012). Building on the first calculations of healthy life expectancy by Sullivan (1971), a variety of health measures have been used to investigate inequalities in health expectancies (Pongiglione et al., 2015). The Sullivan method was developed to calculate Disability-Free Life Expectancy (DFLE) using the prevalence of disability by age and sex in the population alongside a standard period life table (Robine, 2021). The method distinguishes between years lived with and without disability, whatever health condition is being used.

Monitoring area trends and inequalities in DFLE is crucial for evaluating the impact of national and local policies aimed at reducing health inequalities which are persistent within the UK (Wohland et al., 2014). For example, the UK Government aimed to increase healthy life expectancy by at least 5 years before 2035 while concurrently reducing the gap in life expectancy between the richest and poorest population groups (Marteau et al., 2019). During 2008–16, the UK's performance relative to the other EU28 countries was poor since there was a period of absolute expansion of unhealthy life in both sexes. These trends suggest that the Government's 'Ageing Society Grand Challenge' target will be difficult to attain (Welsh et al., 2021). The UK policy context now has the 'Levelling Up' agenda (LGA, 2021) which refers to, "… our entrenched health and social inequalities. Health, wellbeing and economic objectives should be explicitly aligned as part of a strategic approach to the local economy."

To improve health expectancies (however defined and measured), there are good reasons for targeting individuals for health improvements (Gonzalez-Freire et al., 2020; Ungvari and Adany, 2021). However, evidence suggests that using personalised information only has a minimal impact on relevant behaviours which tend to be driven by the environments in which people live (Marteau et al., 2019). In any case,

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since most research does not have access to local level individual level information, there is merit in targeting areas for promoting healthy ageing especially as health expectancies correlate with area level measures of prosperity (Newton, 2021).

Relationships between a range of health outcomes and area level characteristics are well established and enduring (e.g. in the UK: Carstairs and Morris, 1989; Pearce et al., 2010; Marmot, 2020). Area characteristics may be the composition of the area (e.g. a deprivation index or geodemographic classification) or the context (e.g. the urban/rural environment) (Macintyre et al., 2002). Areas can change their characteristics over time (Norman, 2010) and there is evidence that at individual level, people experiencing varying levels of area deprivation or urban/rural contexts at different life stages have different health experiences (e.g. Boyle et al., 2004; Riva et al., 2011; Jivraj et al., 2020). There is also evidence of ecological relationships between changing health in relation to both changing and persistent levels of area deprivation/advantage (e.g. Hanlon et al., 2005; Exeter et al., 2011; Norman et al., 2011; Schofield et al., 2016; Exeter et al., 2019; Walsh et al., 2020). These relationships include area-level changes due to regeneration (Timmermans et al., 2020), gentrification (Izenberg et al., 2018; Cole et al., 2021) or to health selective migration (Boyle et al., 2004; Norman et al., 2005).

This paper focuses on geographic variations in disability-free life expectancy for people aged 50 to 74. These ages have been chosen for several reasons:

First, the 50 to 74 age band covers the life stage in which people may be changing their occupation related activities from their main career to retirement or alternative work activities. Since there will be cumulative effects, working conditions throughout one's career play an important role in shaping health at these ages. Nilsen et al. (2021) found that intellectually stimulating work throughout the working life was associated with more successful healthy ageing with the opposite the case for people with a history of stressful, hazardous or physically demanding work. Similarly, there are cumulative effects over the life course of neighbourhood deprivation on health (Jivraj et al., 2021; Salvatore and Grundy, 2021).

Second, the relationship between retirement and health is complex since it could be that poor health may lead to decisions to retire, but retirement itself could have a positive influence, though there is mixed evidence on whether effects are short- or long-term and whether the influences are more likely to impact mental or physical health (Atalay and Barrett, 2014; Gorry and Slavov, 2021). For some people, extending their working life can have health benefits, but this may not be the case for people in highly demanding or low reward jobs (Fleischmann et al., 2020). There is then potential for widening health inequalities between those who are able to reduce their working hours and those who, for financial reasons, need to continue working (Baxter et al., 2021; Hale et al., 2021).

Third, given people with similar life experiences, and therefore similar health exposures, tend to cluster in comparable places (Murray et al., 2021; Brazil, 2021), we would expect there to be distinctive geographic patterns when the data are analysed using compositional measures at different ages. This is the case for both mortality and self-reported health, in which inequalities between areas are found to be greatest in mid-life but become closer to parity for the elderly (Dibben and Popham, 2013; Green, 2013; Norman and Boyle 2014). The 50–74 age-group spans this transition in inequalities and is also a phase in which there are marked upward kinks in rates in some old industrial (Marshall and Norman, 2013) and urban (Allan et al., 2017) areas, rather than the smooth increase in age-specific rates of self-reported health seen for other age bands. Differences in the curve gradients between area types potentially represent geographical differences in healthy ageing between mid-life and older ages. Of relevance to the work we report here, Giri et al. (2021) found an association between increasing rates of retirement by people in ill health living in areas of higher area deprivation among local authorities in England. For Great Britain, and directly relevant to the work here, Wohland et al. (2014) found that less deprived local authorities saw improvements in DFLE at birth between 1991 and 2001 compared with more deprived locations. There also were improvements in DFLE at age 85, but to a lesser extent.

This work investigates small area geographical variations in disability-free life expectancy for males and females aged 50–74 in each of the years 1991, 2001 and 2011 in England and Wales. Specifically, we ask:

- What are the DFLE distributions across subnational areas?
- How consistent are these DFLE distributions over time?
- Are there areas that have improved or worsened their DFLE experiences?
- If so, what are these locations like in their socio-demographic attributes?

2. Data and methods

The study area is England and Wales and the analytical geography is the 2011 definition of the Middle Layer Super Output Areas (MSOAs). This scale provides good geographical detail (7,201 zones with fairly even population sizes: median c. 7,500). The time frame of the disability-free life expectancies and area types will be 1991, 2001 and 2011 but area characteristics will also be from a prior time point, 1971. This is an ecological study using data aggregated to areas.

Calculating disability-free life expectancy using the Sullivan (1971) method requires inputs of mortality rates with age-groups equivalent to an abridged life table and disability rates by the same age-groups (Jagger, 1997; Robine, 2021). The output of interest is the expected number of years of life without disability and can be estimated at birth or at a specific age. In this paper, we focus on DFLE between the ages of 50 and 74. We use age-specific rates (ages 0, 1–4, 5–9 … 75–79, 80–84 and 85+) of mortality and self-reported limiting long-term illness (LLTI) as the disability indicator and undertake separate analyses for males and females (Wohland et al., 2014). The mortality data has been sourced from the Vital Statistics (via ONS) and is pooled (to alleviate small number challenges) for the years 1990–92, 2000–02 and 2010–12. The self-reported LLTI data was sourced from the 1991, 2001 and 2011 Censuses, and we used mid-year population estimates for those years by age and sex. DFLEs have been calculated for all MSOAs in England and Wales except for the City of London and the Isles of Scilly where populations are too small for sufficiently reliable data inputs so there are 7, 199 areas used in this work.

Prior to the calculation of DFLE, adjustments to the raw inputs were needed. First, the original census LLTI data needed to be adjusted to be consistent with the 2011 area delineations, due to census geography boundary changes over time. The raw counts were apportioned from the original geographies to the 2011 geography using address count-weighted postcode locations to represent population distributions in the areas of overlap (Norman et al., 2003). The back series of Vital Statistics obtained from ONS was provided as mortality counts by age and sex and for the three time periods already allocated to the 2011 geography. Second, the age information of the original LLTI data at small area level was not sufficiently detailed for the DFLE calculation. To achieve this, once converted to the MSOA geography, the broader age counts at that level (e.g. LLTI age 0–4 by MSOA) were scaled to agree with more detailed age information (e.g. LLTI ages 0 and 1–4) at larger area, local authority, level (Lomax and Norman, 2016). Further adjustments to the LLTI rates were made to account for minor changes in the LLTI questions between the 1991 and 2001 Censuses (Marshall, 2009; Wohland et al., 2014). (See Supplementary Material Fig. S1 and Table S1 for examples of these adjustments.)

For area characteristics we incorporated a variety of census data. We used the Townsend Index, which has four census input variables (unemployment, home and car ownership and household overcrowding), calculated to be comparable over time to show how deprivation has changed between 1971 and 2011 (Norman, 2016, 2017; Norman and Darlington Pollock, 2017). Additional socio-demographic variables have been extracted from the 2011 Censuses so that further contemporary influences can be investigated (listed in Supplementary Information Table S4). We used MSOA level population density at the 1971, 1991, 2001 and 2011 Census time points to emulate the urban–rural gradient (Smith et al., 2020).

To address the questions posed above, we proceed as follows:

- Headline DFLEs will be reported along with the mapped distribution of the DFLEs which will be illustrated and described;
- Correlations between DFLEs for sex, age-group and year combinations will be summarised as will the correlations of these with area deprivation;
- OLS regression models will be developed with DFLE for males at age 55 in 2011 as the outcome variable and with potential explanatory variables (after Wohland et al., 2014) including the Townsend Index (and its separate input variables) plus social class, in-migration and population density. Models were developed first with explanatory variables obtained from the 1971 Census and then with 2011 Census data;
  - o Males at age 55 in 2011 would have been in the 15–19 age-group in 1971 and therefore just entering the workforce or going on to post-school study;
- The influence of changing deprivation will be explored using DFLEs for all age-sex combinations calculated for areas which became less deprived over time, areas which improved their level of deprivation or which became more deprived or were persistently deprived over time;
- Further variables extracted from the 2011 Census will be presented for the changing deprivation categories to assess the characteristics associated with different DFLE time trends.

These processes will inform the extent of entrenchment in the relationships between area characteristics and health and provide information on whether changing characteristics are paralleled by changes in health.

3. Results

3.1. What are the DFLE distributions across subnational areas?

Disability-free life expectancy is the expected remaining years to be lived without disability at age 50, 55, 60, etc.

Highlighting DFLE at age 55 as an example, DFLE for males across all MSOAs increased from 8.5 to 11.5 between 1991 and 2011 (Table 1). Female DFLEs at the same age were longer and increased from 10.97 to 12.7. There is evidence of a 'North – South' divide with DFLEs in the South consistently increasing over time compared with the North for both males and females. In 1991, DFLE for males at age 55 in the South had 1.86 more years of being disability-free compared with males in the North. By 2011, the difference increased to 1.96 years. For females at age 55, there was a 1.91 year DFLE gap in 1991 which increased to 2.14 years of being disability-free in 2011. (Equivalent data for all ages 50–74 and years are in Supplementary Data Table S1.)

Table 1
Disability-free life expectancy: England & Wales 1991, 2001 and 2011.

	England & Wales	South	North
Males at age 55 in 1991	8.52	9.47	7.61
Males at age 55 in 2001	9.52	10.27	8.80
Males at age 55 in 2011	11.55	12.55	10.59
Females at age 55 in 1991	10.97	11.95	10.04
Females at age 55 in 2001	11.36	12.07	10.67
Females at age 55 in 2011	12.70	13.78	11.65

Note: The 'South' comprises the Government Office Regions, East of England, London, South-East, South-West and the 'North' comprises the North-East, North-West, Yorkshire & Humberside, East Midlands, West Midlands and Wales.

The geographic distribution in 2011 of male DFLEs at age 55 is illustrated in Fig. 1. Longer DFLEs are evident in the South-East of England though there are shorter DFLEs in inner and east London and on the east Kent coast and in the South-West. Shorter DFLEs are widespread across the North of England, particularly in the main urban and old industrial/coalfield areas but also in some coastal areas. In Wales, the shortest DFLEs are in the South, particularly in the old coalfield areas. The geographic variation of DFLEs for females at age 55 is effectively the same as for males (correlation 0.962, Table 2).

3.2. How consistent are these DFLE distributions across time?

There are strong positive correlations for the MSOA DFLE distributions at age 55 across the 1991–2011 period (Table 2). There are also strong correlations between DFLE at age 50 in 1991 and at age 70 in 2011. Taking a longer term perspective, the negative correlations between Townsend deprivation scores in both 1971 and 2011 with males and females at age 55 in 1991 and 2011 indicate that, in more deprived areas, DFLEs will be shorter (Table 3). These relationships persist over time and become marginally stronger. (Cross-sectional correlations between deprivation and DFLEs are in Supplementary Table S2.)

To explore longer-term legacy effects, we investigate the association of area deprivation and other area socio-demographic measures from 1971 with DFLE for males at age 55 in 2011 using OLS regression. Variables on social class, in-migration and population density as well as the separate deprivation indicator variables (as used by Wohland et al., 2014) did not to make a significant contribution to the models, so we report on the influence of the 1971 Townsend deprivation index and dummy variables for whether the MSOA is located in a coalfield area, and if the MSOA is in the 'South' of England or the 'North', including Wales. We then repeat the model with area deprivation data for 2011.

The model with area deprivation for 1971 (Table 4a) shows this has a negative influence on male DFLEs forty years later, so is associated with fewer years of being disability-free. Similarly, areas located in a former coalfield area or in the North/Wales in 1971 are associated with a reduced number of years being disability-free in 2011.

The differences are marginal, but the 2011 Townsend deprivation score (Table 4b) has a somewhat stronger influence on male DFLEs in that year, and also demonstrates the enduring negative effects of being in a coalfield area and persistence of North – South differences. The model fits are reported as being 0.643 and 0.711 respectively for the 1971 and 2011 based information. (Equivalent models for females at age 55 in 2011 are in Supplementary Table S3 and show the same patterns as males.)

Although the regressions reported in Table 4 are a good model fit, there are deviations from the predicted DFLEs. Mapping the residuals can be fruitful in highlighting whether there are geographical patterns in these deviations. Fig. 2 shows the geographic variation in residuals from these 1971 and 2011 based models with the explanatory variables Townsend deprivation, North – South and Coalfields. Many areas are well predicted by the model (white polygons ±1 disability free year). The areas which are red have shorter DFLEs than predicted by the model and those areas in blue have longer DFLEs. The geography of the residuals is similar (correlation between 1971 and 2011 model residuals: 0.73). Compared with using 1971 deprivation, using 2011 deprivation reveals that more coastal areas have somewhat shorter DFLEs than estimated by the model.

3.3. Are there areas which have improved or worsened their DFLE experiences?

Transitions between quintiles of deprivation at different time points have been used to analyse health for individuals (Norman et al., 2005) and for areas (Exeter et al., 2011). Similar in approach to a social

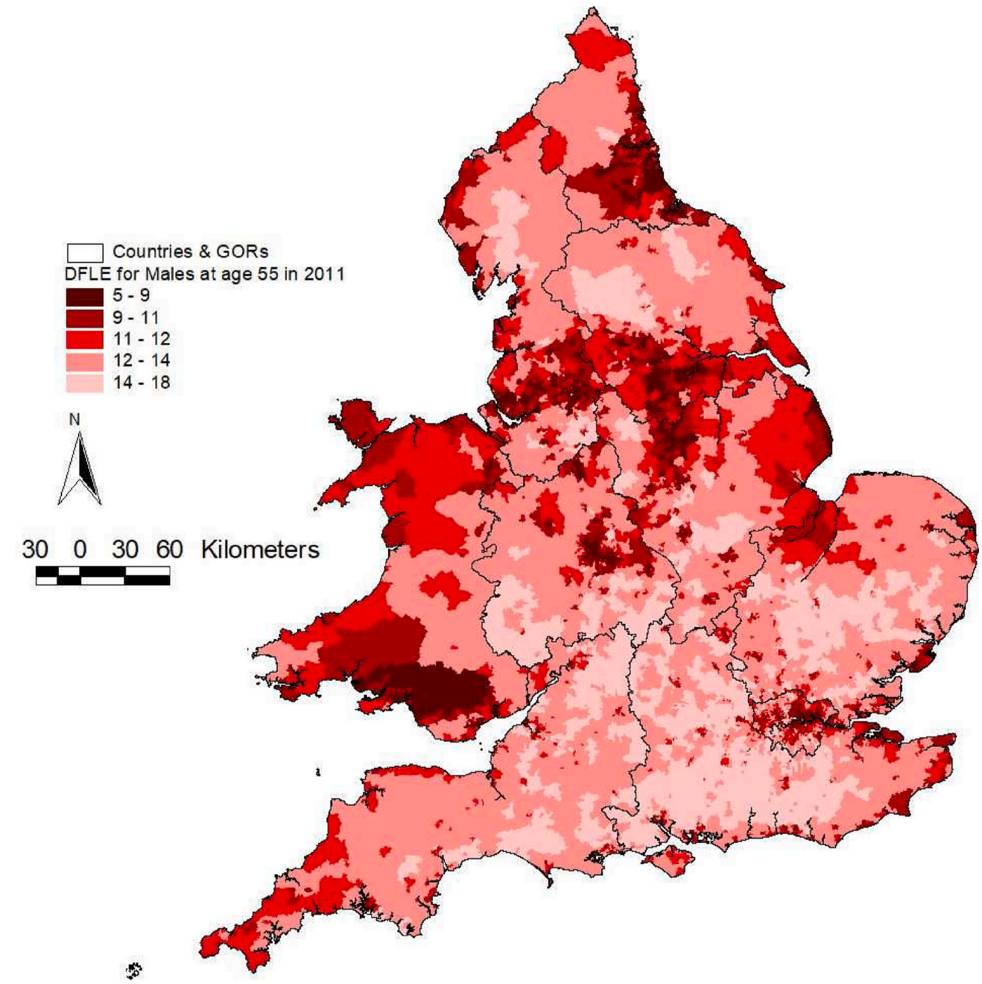

Fig. 1. Disability-Free Life Expectancy Males at age 55 in 2011: MSOAs in England and Wales.

Table 2
Correlations between DFLEs for males and females across years and age-groups: MSOAs in England & Wales, 1991) and 2011.

Males & Females at age 55	Males at age 55 in 2011	Females at age 55 in 1991	Females at age 55 in 2011
Males at age 55 in 1991	0.821	0.955	0.807
Males at age 55 in 2011		0.821	0.962
Females at age 55 in 1991			0.824
Males & Females at ages 50 & 70	Males at age 70 in 2011	Females at age 50 in 1991	Females at age 70 in 2011
Males at age 50 in 1991	0.820	0.959	0.801
Males at age 70 in 2011		0.818	0.918
Females at age 50 in 1991			0.818

Table 3
Correlations between Area Deprivation in 1971 and 2011 with DFLE for Males and Females at age 55: MSOAs in England & Wales, 1991) and 2011.

	Males at age 55 in 1991	Females at age 55 in 1991	Males at age 55 in 2011	Females at age 55 in 2011
Townsend 1971	−0.632	−0.644	−0.735	−0.720
Townsend 2011			−0.701	−0.706

mobility matrix (Boyle et al., 2009), we define transition categories using combinations of 1971 and 2011 Townsend deprivation quintiles (Table 5). These combinations differentiate areas of persistent advantage or deprivation together with categories of improving or worsening circumstances with a focus on the extremes of the area deprivation distribution. The disability-free life expectancies have been stratified across the MSOAs in the different quintile combination categories.

Fig. 3a illustrates trends in DFLE in the deprivation transition categories. The transitions involving the persistently least deprived areas by 2011 have the longest DFLEs and those involving the most persistently deprived category the shortest DFLEs. The other categories have DFLEs between these. By age-group, the largest differences between area types is for DFLE at age 50 with the differences in remaining years of life without disability reducing with increasing age. Female DFLEs are consistently longer than those for males.

Fig. 3b illustrates the DFLEs but expressed relative to the national level DFLE for each sex and age group. This is calculated as the ratio of each sex and age-group in the deprivation transition category to the national DFLE for that sex and age-group. Unsurprisingly, the less

Table 4
OLS Regression Models of Disability-Free Life Expectancy for Males at age 55 in 2011: MSOAs in England and Wales.

a) 1971 area deprivation	Coefficient	SE	Std. Coefficient	CI Lower	CI Upper
Constant	14.206	0.058		14.091	14.320
North – South	−1.182	0.044	−0.258	−1.268	−1.096
Coalfield	−0.434	0.045	−0.092	−0.523	−0.345
Townsend 1971	−0.599	0.006	−0.676	−0.612	−0.587
Adjusted R Sq.	0.643				
b) 2011 area deprivation	Coefficient	SE	Std. Coefficient	CI Lower	CI Upper
Constant	13.469	0.053		13.366	13.572
North – South	−1.676	0.040	−0.366	−1.753	−1.598
Coalfield	−0.642	0.041	−0.136	−0.722	−0.563
Townsend 2011	−0.572	0.005	−0.714	−0.582	−0.562
Adjusted R Sq.	0.711				

Note: The 'South' comprises the Government Office Regions, East of England, London, South-East, South-West and the 'North' comprises the North-East, North-West, Yorkshire & Humberside, East Midlands, West Midlands and Wales.

deprived transition combinations have DFLEs longer than national with the more deprived combinations having shorter DFLEs. Although the absolute differences in DFLEs in Fig. 3a are reducing with age, the relative inequalities in 3b increase with age and over time. (Alternative age-time layouts of the same data are illustrated in Supplementary Information Fig. S2.)

3.4. *What are these deprivation transition categories like in their socio-demographic attributes?*

Although deprivation trajectories reveal DFLE trends, a better understanding of area types will be aided by determining further socio-demographic attributes of the MSOAs in each trajectory category. Geodemographic classifications can be used to bring out characteristics typical of areas and differences in health (Abbas et al., 2009; Green et al., 2014; Shelton et al., 2006; Norman and Fraser, 2014). We obtained a range of socio-demographic variables from the 2011 Census commonly used in ONS area classifications (e.g. ONS, 2015). These variables have been correlated with DFLE for males at age 55 in 2011 and the 22 variables with the strongest relationships (both positive and negative) have been identified (Supplementary Information Table S4). The observations of these variables in each MSOA have been stratified across the deprivation transition categories and the ratio of each variable to the national level for that variable has been calculated. This brings out the relative presence (and absence) of each attribute for the transition categories.

Table 6 lists the attributes which are positive (i.e. the variable is higher than national) and thereby their presence helps with typifying the area. In the transition categories which are less deprived, the constituent variables are similar and relate to aspects which indicate socio-demographic advantage: large, owner occupied houses and multiple car ownership. 'Dinkys' is an acronym for 'double income, no kids yet'. The difference between these two transition categories is that the 'least to least' category includes degree qualified persons and overall the relative presence of the constituent variables is greater than in 'more to least deprived' areas. Owner occupiers and Dinkys are also present in 'middle deprived' areas alongside terraced housing and lone carers.

In the two trajectory categories which are more deprived, unsurprisingly, there are overlaps with the relative presence of indicator variables used in the Townsend Index: unemployment, rental tenure and no car. There is variation in household size characteristics with multiple children, lone parents and one person households. These areas are also typified by the presence of Black and Asian ethnic groups. The presence of degree qualified persons in the persistently deprived areas seems like an anomaly but these may be postgraduate students or staff in locations close to universities or medical staff located close to hospitals.

Two observations may be telling. First, the occupational social class gradient is aligned with these deprivation trajectory categories with higher social classes and non-manual workers in the less deprived areas while lower social classes are typically in the more deprived areas.

Table 5
Area deprivation transition categories: MSOAs in 1971 and 2011.

1971–2011 Transition	Deprivation Quintile by Year	Frequency	Percent
Least to Least Deprived	Q1 in 1971 & Q1 in 2011	925	12.8
More to Least Deprived	Q2-5 in 1971 & Q1 in 2011	579	8.0
Middling Deprived	Q2-4 in 1971 & Q2-4 in 2011	4,594	63.8
Less to Most Deprived	Q1-4 in 1971 & Q5 in 2011	285	4.0
Most to Most Deprived	Q5 in 1971 & Q5 in 2011	816	11.3
		7,199	100.0

Note: Quintile 1 = least deprived; Quintile 5 = Most Deprived.

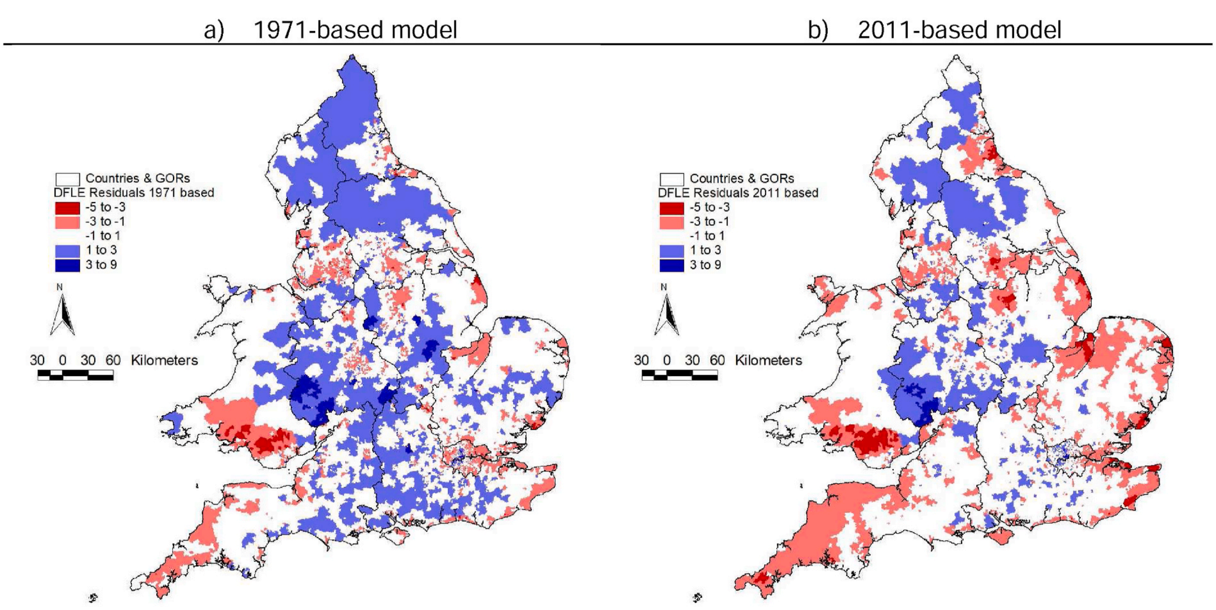

Fig. 2. Disability-Free Life Expectancy males at age 55 in 2011: Model Residuals for MSOAs in England and Wales.

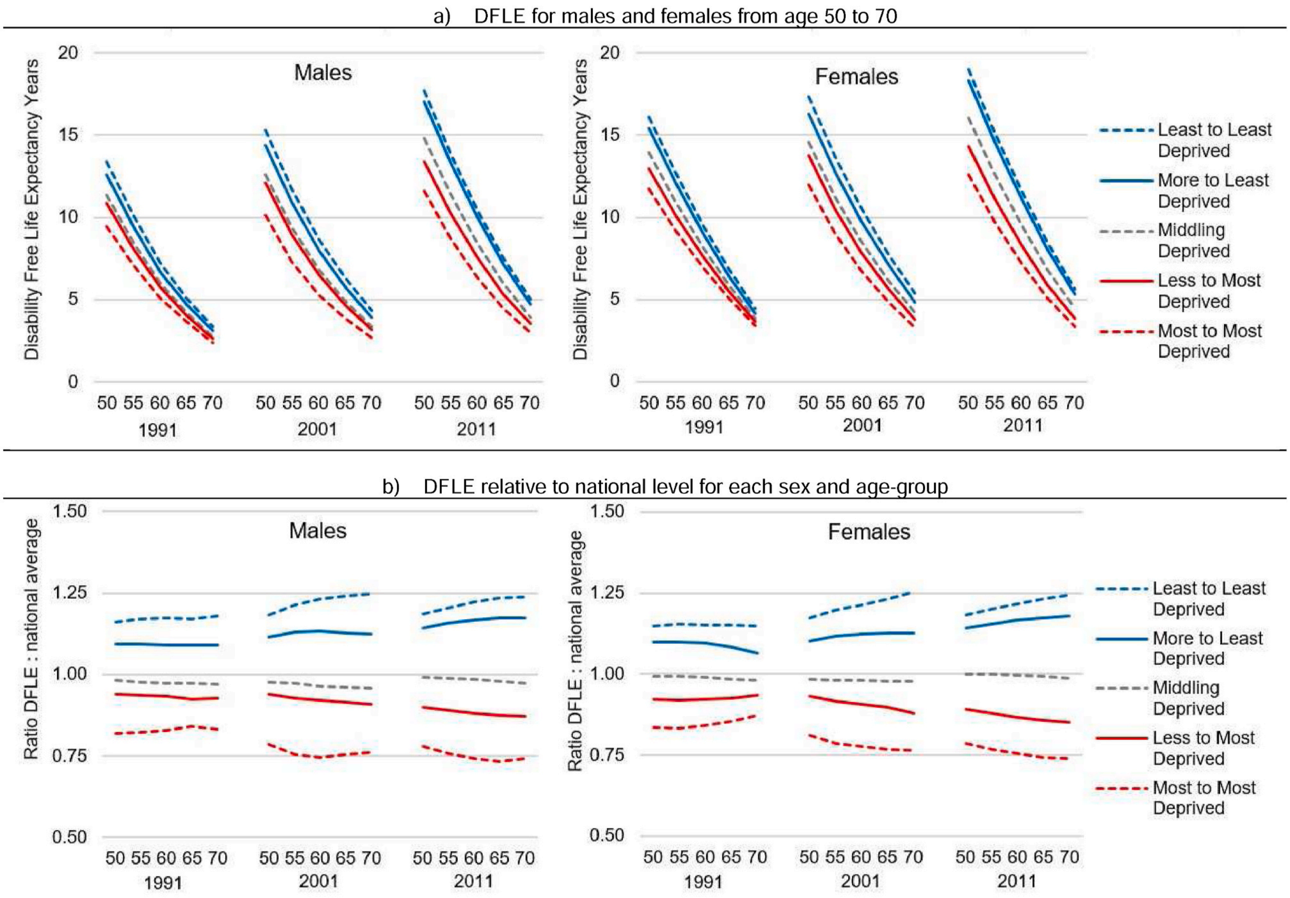

Fig. 3. Disability-free life expectancy by deprivation transition categories: England and Wales 1991, 2001 and 2011.

Table 6
Relative Presence in Rank Order of 2011 Census Variables for MSOAs within each Deprivation Transition Category.

Least to Least Deprived	Middle to Least Deprived	Middling Deprived	Middle to Most Deprived	Most to Most Deprived
Large houses	Large houses	Terraced	Asian ethnicity	Black ethnicity
2+ cars	2+ cars	Social Class IV or V	Black ethnicity	Public transport commute
Owner occupiers	Owner occupiers	Owner occupiers	Flats	Public renters
Social Class I or II	Dinkys	Social Class IIIN	Private renters	Flats
Social Class IIIN	Social Class I or II	Dinkys	Terraced	No car
Dinkys	Social Class IIIN	Lone carer	No car	Unemployment
Degree qualified			4+ children household	Asian ethnicity
			Children with single parent	Children with single parent
			Unemployment	Private renters
			No central heating	4+ children household
			Public transport commute	No central heating
			Public renters	Terraced
			One person households	Degree qualified
			Social Class IV or V	Social Class IV or V

Upward social mobility may improve health in areas but not if people move away (Boyle et al., 2009). Second, the less deprived areas are typified by relatively few attributes but the more deprived locations have a very complex mix of circumstances relating to both socio-demographics and housing circumstances.

We explore some further characteristics of these deprivation transition categories and tie in with previous observations. Table 7 shows an increasing population density gradient from less to more deprived areas (a relationship we expect within the UK, Smith et al., 2020). There is a steeper gradient for areas characterised as industrial areas and similarly for MSOAs located in coalfield areas. The somewhat mixed picture we observed above for DFLEs in coastal areas may be because these types of location occur within all deprivation transition categories. This provides further evidence that there are benefits and disbenefits of living near the coast (Asthana and Gibson, 2021; Whitty, 2021).

4. Discussion

Although there are some broad improvements in disability-free life expectancy between 1991 and 2011, inequalities between areas are deeply entrenched, aligned with area deprivation, old industrial areas and the legacy of the coalfields. Relative inequalities in DFLE increase, largely the result of areas persistently deprived or advantaged and where areas became more or less deprived over time. Broad North – South differences have persisted though there is more of a mixed picture for rural and coastal locations many of which do not appear to have the

Table 7
Further characteristics of the MSOAs within each Deprivation Transition Category.

	Least to Least Deprived	More to Least Deprived	Middling Deprived	Less to Most Deprived	Most to Most Deprived
Population Density	12.58	6.12	28.89	62.13	81.45
Industrial Areas	0.76	2.07	15.62	17.54	39.95
Coalfield	2.10	3.76	7.89	5.56	12.55
Coastal	20.44	12.87	19.72	9.62	17.92

Note: Population density is the mean persons per hectare. The other variables are all the percentage of areas with this attribute within the transition category. Industrial Areas are identified using the ONS Supergroups for LSOAs falling within MSOAs.

better DFLEs of other apparently similar area types. Our results are broadly consistent with Wohland et al. (2014), who found deprivation-related inequalities in DFLE at birth for local authority level changes between 1991 and 2001, which were less at age 85. Given that deprivation inequalities in mortality and limiting long-term illness are close to parity by age 85 justifies our investigation of DFLE between 50 and 74 years here and the use of MSOAs adds geographic detail.

The legacies of the past we find here chime with the notion of 'left behind' in the context of former coal mining communities (Abreu and Jones, 2021) and a mixed picture of the past success of coalfield related regeneration policies in relation to unemployment and health (Sinnett and Norman, 2022). To an extent, ex-miners and those directly affected by coal mining will have died and not form part of the DFLE inputs so the legacy effect is largely of long-term deprivation. Time since mine closure could be a useful model input if available.

Equivalent situations have recently been recognised by an All-Party Parliamentary Group (APPG, 2020) committed to improving social and economic outcomes for residents in coastal areas and city suburbs also considered to be 'left behind'. Asthana and Gibson (2021) believe that, just as inner-city deprivation was 'discovered' in the 1970s, the contemporary challenges facing coastal communities in Britain are in urgent need of recognition. Recently, the Chief Medical Officer's report (Whitty, 2021) focuses on coastal health and calls for research on reducing health inequalities with a specific emphasis on population-level interventions. Also noted by the APPG (2020) as being left behind, the suburbanisation of deprivation (Bailey and Minton, 2018; Norman 2016) deserves the same attention since, as we find here, increasing deprivation is related to shorter disability-free health expectancies.

The population level variables associated with less deprived areas are clear, as we noted above. The more complex range of socio-demographic and housing variables associated with more deprived areas indicates there is no clear message to inform which attributes might be targeted as part of deprivation alleviation/health improvement policies. However, the presence of both lack of cars and use of public transport for commuting suggests that improvements in the latter would benefit from being a priority.

In terms of strengths and limitations, the census and vital statistics sources we use here are reliable at MSOA level with limiting long-term illness itself a reliable indicator of self-rated health (Mitchell, 2005). Although there have been changes in the detail of the question wording and categories of answers over time, adjustments to harmonise the LLTI data have been validated (Wohland et al., 2014). However, we do not have measures in the inter-censal years and our study time frame ends in 2011. A perennial challenge is the poor availability of local level publicly available health data which undoubtedly hinders research (Asthana and Gibson, 2021; Murray et al., 2021). There is evidence that since 2011, the UK at national level is not faring well by way of health expectancies at age 65 (Welsh et al., 2021).

In broad chronological order, we need to recognise substantial changes since 2011. There has been the effect of austerity on life expectancies which have been stalling and even decreasing (Hiam et al., 2018; Darlington-Pollock et al., 2021) in part due to rising infant mortality (Robinson et al., 2019; Taylor-Robinson et al., 2019a), the first age-group in a life table. The effects of Brexit with regard to retirement migration are unclear but it is likely that emigration of this age-group will have been suppressed and, given that long distance migrants tend be healthier than non-migrants (Boyle et al., 2002) this would mean that the England and Wales population retains relatively healthy older persons. People already living overseas may return back to the UK due to the uncertainty (Giner-Monfort and Huete, 2021). If there has been emigration of EU residents, these are more likely to be younger working age people and their mobility will only indirectly affect DFLE results for the population aged 50–74. Although updated estimates of international migration are emerging (ONS, 2021), any Brexit related changes to numerators (health events) and denominators (population at risk) at small area level can only be speculative.

There will also be effects of the Covid pandemic on local level self-reported health and life expectancies, and therefore disability-free life expectancies. Given greater impacts of the pandemic in disadvantaged areas it is reasonable to presume that less resilient communities will see falls in their years of being disability-free compared with other areas, along with increases in North – South disparities (Hiam and Patel, 2021; Munford et al., 2021) and increased inequalities in disability-adjusted life years between areas experiencing different levels of deprivation (Wyper et al., 2021). In a pre-pandemic study, Guzman-Castillo et al. (2017), estimated that by 2025 the number of older people with care needs will expand by 25% and this would mainly reflect population ageing rather than an increase in disability prevalence. As such, lifespans will increase but a quarter of life expectancy at age 65 will involve a disability. Given the impacts of 'Long Covid', this may be an under-estimate especially in less resilient locations.

We can extend the time-frame used here when the 2021 Census and 2020-22 mortality data become available (though the inevitable boundary changes will need all data inputs to be adjusted to the same geographical units). At that stage too, there will be more clarity on elements relating to changes in life expectancy, international retirement migration and of Covid occurring in the last decade. In the meantime, there will be merit in adopting a similar approach to investigate DFLEs in mid-life (say 30–34 to 40–49) since these are the ages in which health inequalities increase to their greatest for both mortality & self-reported health (Norman and Boyle, 2014) and understanding mid-life variations can help ongoing health as people age (Darlington-Pollock and Norman, 2019). Gietel-Basten (2021) calls for the adoption of an adaptation-mitigation-resilience framework such that a longer-term perspective, from early in life, is taken for policies to ensure that people and institutions 'age better'.

We should also investigate the demographic processes which underpin changes over time in the health – deprivation relationship. Norman et al. (2005) identified the need to account for differences by health status between in and out flows of subnational migrants as well as the health of non-migrants. It was noted that any health changes may be mirrored by changes in other personal attributes which contribute to compositional measures such as area deprivation. Parallel work found that for non-migrants (i.e. those who were ageing in place) health change is affected by change over time in the level of area deprivation (Boyle et al., 2004).

Norman et al. (2005) separated out in and out migrants from non-migrants by health status and age. This showed, for the 1971 to 1991 period, that migration, in the main by younger healthy people at least maintained, if not exaggerated the health – deprivation relationship. This work also explicitly showed that the situation was slightly different for the elderly with a small amount of shift from less to more deprived areas which somewhat ameliorated the inequalities. Darlington (2015) found the same patterns up to 2011. Although without a health dimension, up to 2011, Champion and Ian Shuttleworth (2017) found that the propensity for subnational migration, particularly at older ages was falling. The broad patterns of the types of destination areas (rural and coastal) favoured by retirees continue but the reality is more 'messy' with people moving between and within urban and rural areas (Stockdale, 2016). Although Hoogerbrugge and Burger (2021) find a health advantage for rural migrants, this does not persist over time and the difference in proportions between urban to rural compared with rural to urban migrants does not appear sufficient to change relative difference in health status for these area types (Verheij et al., 1998).

Specifying a suitable approach is complex since the data source needs to have variables over time by age, sex, health and (non-) migrant statuses and linked to area characteristics data which need to be comparable by geographic scale and compositional measure over time. Advice on how to do this is set out by Norman (2018) and Darlington-Pollock and Norman (2020). The ONS Longitudinal Study or Understanding Society are both suitable sources within the UK through which to investigate, for example, the variations in coastal and rural areas and whether there may be 'left behind' non-migrants on old industrial and coalfield locations.

The UK Government aims to increase healthy life expectancy by at least 5 years by 2035 (Marteau et al., 2019) (though this target was set pre-pandemic and since then there has been a drop in life expectancy in the UK and many other countries (Aburto et al., 2021)). This aim is alongside the 'Levelling Up' agenda (LGA, 2021) whereby health, wellbeing and economic objectives should be explicitly aligned as part of a strategic approach to the local economy. In Europe, social spending has had a positive impact on equalising health conditions (Álvarez-Gálvez and Jaime-Castillo, 2018); in simple terms, public investment improves health outcomes, and disinvestment has the opposite effect (Taylor-Robinson et al., 2019b). Prior to the pandemic, cuts in funding for local government especially in the more deprived areas led to widening life expectancy inequalities. Since the pandemic, prioritising reinvestment in local government services, particularly within the most deprived areas of England, would help address adverse trends in life expectancy (Alexiou et al., 2021).

The Health Foundation considers that, "A healthy and productive population will be essential to the country's future prosperity … but ongoing cuts to the public-health grant run counter to this agenda and will ultimately serve to further entrench health inequality (Bibby 2021)." Unfortunately, in the recently announced successful 'Levelling Up' funding bids were focused on local transport projects, town centre regeneration, culture and heritage with very little directly about population health (DLUHC, 2021). More than a third of England's most deprived areas, including deprived coastal and rural areas, will not benefit from the Government's £4.8 billion Levelling Up Fund (Salvation Army, 2021).

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Appendix A. Supplementary data

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