# Mesothelioma mortality in Great Britain: how much longer will dockyards dominate?

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## Abstract

### Objectives

We aimed to investigate whether there has been a geographic shift in the distribution of mesothelioma deaths given the decline of shipbuilding and progressive exposure regulation.

### Methods

We calculated regional standardized mortality rates (SMR) for mesothelioma in men for the period 2002-2015 at local authority district and ward level. We compared spatial autocorrelation statistics (Moran's I) for SMRs at ward level for 2002-2008 and 2009-2015. Subsequently we measured the mean distance of the deceased's postcode to the nearest dockyard at ward level using postcode centroid data provided by HSE and openstreetmap geodata. The coefficient of distance to dockyard for ward SMR was calculated using simple linear regression for men, for 2002-2008 and 2009-2015.

### Results

The top 10 local authority districts for male mesothelioma SMR all contain dockyards. Moran's I changed from 0.13 to 0.09 for men and the coefficient of distance to dockyard for ward SMR changed from to -0.27 (95%CI -0.35 to -0.18) to -0.22 (95%CI -0.29 to -0.16) for men, when comparing 2002-2008 with 2009-2015.

### Conclusion

Moran's I is lower for men in 2009-2015 than 2002-2008 suggesting mesothelioma deaths are becoming more dispersed but dockyards remain strongly spatially associated with mortality.

## Key messages

1. What is already known about this topic?

Regional standardized mortality rates (SMRs) (though not yet crude mortality rates) in areas associated with dockyard exposure such as Plymouth, have been decreasing and regional mortality trends suggest that the relative contribution of traditional asbestos exposure industries, such as shipbuilding, to mesothelioma risk is falling.

2. What are the new findings?

Mesothelioma deaths in Great Britain are becoming more dispersed but dockyards remain strongly spatially associated with mortality.

3. How might this impact on policy or clinical practice in the future?

It is likely that dockyards will no longer dominate UK mesothelioma mortality in the next 10-20 years and the asbestos legacy latent in the built environment may become a more important exposure source.

## Background

Globally, mesothelioma rates have been determined by historic asbestos consumption[1] and rates in many industrialised countries have been steadily rising.[2][3] Great Britain, which now has the highest mesothelioma incidence in the world, pioneered the commercial use of asbestos. For example, Rochdale-based Turner & Newall (T&N) was one of the first companies to industrialise asbestos making products such as Trafford Tile asbestos cement sheets which were widely used in roof construction. The excellent strength, insulation, and fire-resistant properties of asbestos led to it being heavily used in shipbuilding and maintenance. For instance, sprayed limpet asbestos, a T&N product usually containing crocidolite, was used extensively to insulate and fireproof Royal Navy ships for about 30 years (1930-1960).[4]

Dockyard areas have been recognised to be strongly associated with higher rates of mesothelioma, reflecting dockworkers' exposure to asbestos in shipbuilding generally and to amphibole insulation of naval ships in particular.[5][6][7] Cases of asbestosis and mesothelioma in men working at the Royal Naval Dockyard at Devonport in Plymouth were first observed around 1960[8] and have been studied extensively.[9][10][11] An excess of mesothelioma deaths for men living in Plymouth continues; the annual mesothelioma SMR for males 1981-2016 was 804.6 (95% CI 715.5 to 901.7, deaths 296).[12] Working as a docker, in shipbuilding, or on a ship was associated with a raised proportional mortality rate, 135.2, for mesothelioma, as was working in the Navy, 125.6, for men aged 16-74 in Great Britain (1991-2000).[13] A recent mesothelioma case-control study found work in these settings was associated with an odds ratio for mesothelioma of 16.1 (95% CI 8.3-31.3) while working in the Navy was associated with an odds ratio of 20.7 (95% CI 8.9-47.6).[13]

However, regional standardized mortality rates (SMRs) (though not yet crude mortality rates) for areas associated with dockyard exposure such as Plymouth, have been decreasing and regional mesothelioma mortality trends suggest that the relative contribution of traditional asbestos exposure industries, such as shipbuilding, to mesothelioma risk is falling.[2]

British shipbuilding has declined; in 1900 85,000 people were employed to producing 60% of the world's output[14]; by 2004 these figures had shrunk to 24,000[15] and less than 1%.[16]. Over the same period, there has been progressive exposure regulation including voluntary asbestos import bans of crocidolite in 1970, amosite in 1980, and a formal ban of both in 1992 (The Asbestos Prohibition Regulations) and later in 1999 of chrysotile (The Asbestos (Prohibitions) (Amendment) Regulations 1999). On this background, we aimed to investigate, quantitatively, whether there has been a geographic shift in the distribution of mesothelioma deaths in Great Britain. More specifically, we aimed to investigate whether the spatial clustering of mesothelioma deaths around dockyards has reduced over time.

# Methods

We obtained data from the British Mesothelioma Register[2], which includes all deaths for which the word "mesothelioma" appears on the death certificate, detailing age, sex, year of death, year of birth, and postcode at time of death, for the years 2002 to 2015.

We merged our data on postcode to add columns corresponding to the postcode centroid latitude and longitude, and the lower layer super output area (LSOA), as of December 2011, from the May 2018 Office of National Statistics (ONS) Postcode Directory for the United Kingdom.[17]

We downloaded from ONS mid-year age and sex stratified population estimates for LSOAs for England and Wales for the years 2002-2015.[18] Wards and local authority district (LAD) areas were added using a lookup provided by ONS.[19] Population data for Northern Ireland and Scotland were not readily available and so we limited our analysis to England and Wales.

We obtained boundary data for England and Wales at country, LAD, ward, and LSOA level, from the ONS Open Geography Portal for December 2016. We found data on the location (centroid longitude and latitude) of dockyards in England and Wales, using Overpass turbo (overpass-turbo.eu), a web based data mining tool for OpenStreetMap.[20] Specifically, we wrote a query in the Overpass Query Language to use the Overpass turbo API to return data on geographic entities with the "waterway=dock" tag within the boundary of Great

Britain and saved the result as an openstreetmap (OSM) xml file. We then converted the OSM file to GeoJSON using the program osmtogeojson. Finally, using country boundaries and Python GeoPandas[21], we discarded docks that were greater than 5km from the coastline of England and Wales and those that were labelled as being Marinas, Weirs, Quays, or Harbours.

We calculated standardized mortality ratios (SMRs) by the indirect method at LAD, ward, and LSOA level by sex, year, and time period(2002-2008; 2009-2015). 95% confidence intervals were created around the rates using Byar's approximation.[22] Statistically significant high, statistically significant low, and non-significant SMRs were plotted as a choropleth for England and Wales using a UK projection (EPSG:27700) and the Python GeoPandas library. We used a spatial lag of SMR defined at ward-level using the python PySal library[23] with Queen's contiguity row-normalized weights and plotted it with GeoPandas[21] to visualise the distribution of mesothelioma deaths at ward level.

To calculate the spatial lag for a given ward, the number of Queen's contiguous wards, that is wards contiguous in any direction, is first taken into account to obtain the row-normalized weights. For example, if a given ward had 5 contiguous wards then the SMR of each of those wards would be multiplied by a weight of 0.2 (i.e 1/5); the mean average of the weighted SMRs is then calculated to give the spatial lag.

Moran's I is a measure of spatial autocorrelation, in other words, how a variable correlates with itself through space. Values of I range -1 to +1 with the distribution of black and white squares on a chessboard corresponding to -1, 0 corresponding a random distribution, and +1 corresponding to a sheet of paper folded in half with one half black and one half white.[24]

We identified and plotted ward-level "hot spots", areas with a high mesothelioma SMR that are adjacent to other areas with a high mesothelioma SMR, by quantitatively measuring local spatial autocorrelation using PySal's local Moran's I[25] with Queen's contiguity row-normalized weights and plotted them with GeoPandas.[21] While

We used PySal's global Moran's I[23] for mesothelioma SMRs at ward level for the period 2002-2015 and for two periods, 2002-2008 and 2009-2015 to test whether spatial autocorrelation reduced over time. We measured the distance of the deceased's postcode to the nearest dockyard and calculated the mean at ward level using postcode centroid data from the British Mesothelioma Register and OpenStreetMap geodata. The association of distance to dockyard with ward SMR was estimated using simple linear regression for men and women, for the whole period, 2002-2008, and 2009-2015 to test whether the magnitude of the association changed over time.

Full documented python code for data extraction and analysis are provided (see appendix 2)

# Results

There were 28947 mesothelioma deaths in England and Wales between 2002 and 2015, 23631(84%) in men and 4644(16%) in women. The median year of birth and age for men and women was 1934 and 73 respectively. The top ten LADs for male mesothelioma SMR all have a dockyard (table 1). Figures for female mesothelioma SMR were similar and are included in Appendix 1; we focus on male mesothelioma deaths hereon because they make up the majority of mesothelioma deaths and historically males were more often exposed to asbestos in dockyards than females. Of the 348 LADs in England and Wales, 53(15%) have a raised SMR, 81(23%) a low SMR, and 214(61%) a non-significant SMR. The majority of LADs with raised SMR, 31 of 53(58%), are contiguous with the coast; we suspected that this was because they contained dockyards.

**Table 1: Male mesothelioma deaths in England and Wales 2002-2015 (top 10 LADs all have a dock)**

| lad16nm | observed | expected | SMR (95% CI) |
|---|---|---|---|
| Barrow-in-Furness | 115.0 | 34.0 | 338.0 (279.0-405.7) |
| North Tyneside | 252.0 | 91.6 | 275.0 (242.1-311.2) |
| South Tyneside | 161.0 | 70.4 | 228.6 (194.6-266.7) |
| Portsmouth | 162.0 | 72.8 | 222.5 (189.6-259.5) |
| Medway | 212.0 | 97.9 | 216.5 (188.3-247.6) |
| Hartlepool | 89.0 | 41.2 | 216.0 (173.5-265.8) |
| Plymouth | 225.0 | 108.6 | 207.1 (180.9-236.0) |
| Fareham | 119.0 | 59.2 | 201.1 (166.6-240.6) |
| Newcastle upon Tyne | 208.0 | 105.2 | 197.7 (171.8-226.5) |
| Gosport | 69.0 | 36.4 | 189.4 (147.3-239.7) |

This suspicion, together with consideration of Tobler's first law of Geography which states that "everything is related to everything else, but near things are more related than distant things."[26] motivated us to examine mesothelioma mortality patterns at finer levels of granularity. For reference, there are 348 LADs, 8588 wards, and 34,753 LSOAs in England and Wales and there are about 2000 people or 800 households in an LSOA.

We found an association between raised male mesothelioma SMR and the presence of a dockyard that was visually evident at ward level (figure 1 choropleth and figure 2 hotspot map with dockyards shown).

A similar pattern to that seen at ward level was seen at LSOA level which shows the importance of proximity to dockyard.

We sought to quantify the relationship between proximity to dockyard and

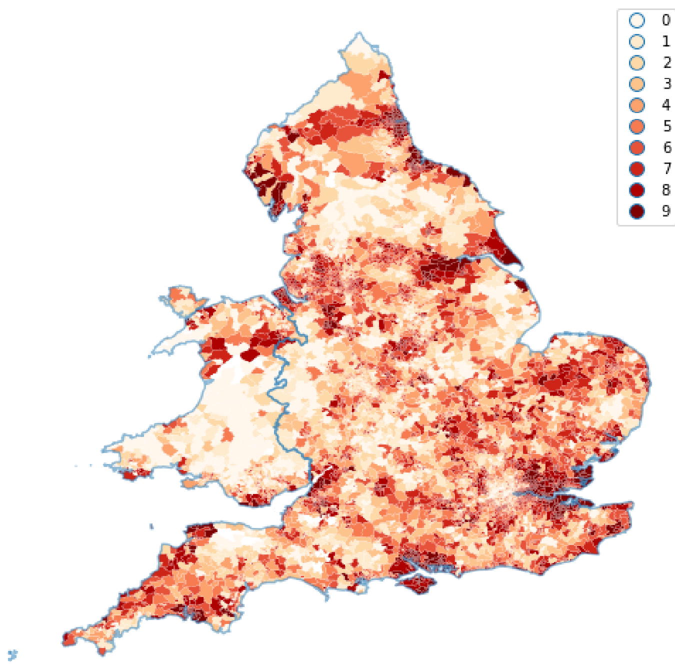


Figure 1: Ward-level male mesothelioma standardised mortality rates 2002-2015, spatial lag deciles.

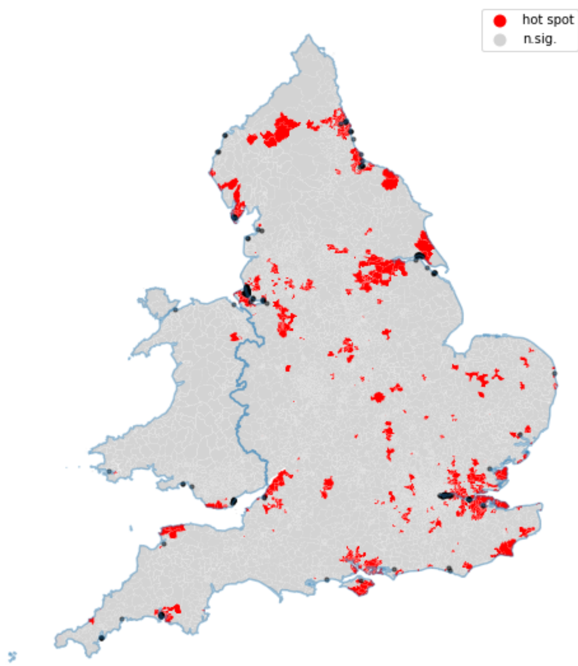


Figure 2: Ward-level male mesothelioma hotspots 2002-2015 data, dockyards shown in black. Hotspots identified using local indicators of spatial association for ward standardised mortality rates.

ward-level mesothelioma SMR, and examine it over time, using a simple linear regression. We found that, in general, the closer to a dockyard the higher the ward-level mesothelioma SMR and that there is a non-statistically significant trend in this relationship becoming weaker over time. The coefficient of association was -0.29 (95% CI -0.34 to -0.25) for all years, and -0.27 (95%CI -0.35 to -0.18) for 2002-2008 and -0.22 (95%CI -0.29 to -0.16) for 2009-2015 (see figures 3).

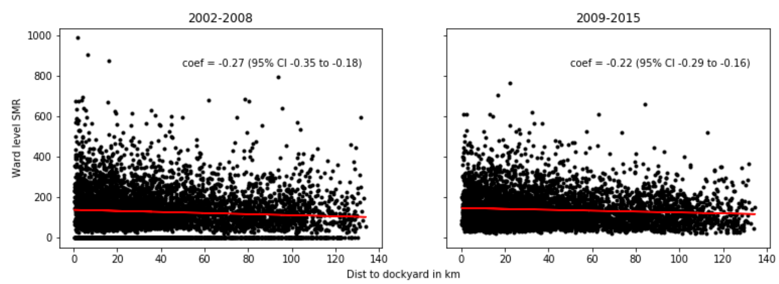


Figure 3: Distance to dockyard and ward-level male mesothelioma standardised mortality rate.

To understand if the relationship between proximity to dockyard and ward-level mesothelioma SMR might be becoming weaker over time because of a shift towards a greater proportion of mesothelioma mortality resulting from more geographically dispersed exposures, such as those arising from asbestos latent in the built environment, we investigated mesothelioma SMR spatial autocorrelation.

We found that mesothelioma SMR is spatially autocorrelated, that is areas of high mesothelioma SMR are associated with other areas of high mesothelioma SMR, and areas of low mesothelioma SMR associated with areas of low mesothelioma SMR, but it is becoming less so, or is becoming more dispersed, over time(figure 4).

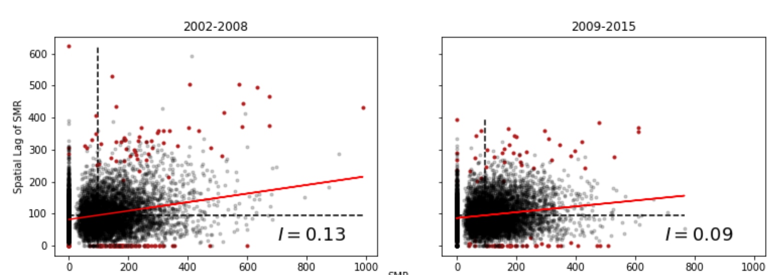


Figure 4: Moran scatter plot of ward-level male mesothelioma standardised mortality rate data. Statistically significant local index of spatial correlation (LISA) values are shown in red.

## Discussion

Between 2002 and 2015, at LAD level, areas with the highest male mesothelioma SMR contain naval dockyards and other sites of naval ship construction and maintenance, a pattern which is repeated at ward and LSOA level. Female mesothelioma SMR is also heavily associated with naval dockyards and other sites of naval ship construction but a contribution from the manufacture of insulation materials, textiles, and cement is evident from London boroughs and adjacent areas (see Appendix 1).[27] This is consistent with French data showing strong geographic correlations between male and female SMR.[28]

Average distance to nearest dockyard and ward-level male mesothelioma showed a small negative linear relationship in which each kilometre distance from a dockyard was associated with an approximate fall in SMR of 0.3. This effect is likely to have been diluted by the inclusive approach used to select dockyards and the fact that all dockyards are given equal weight in the analysis. Though not statistically significant the effect size does appear to be falling over time; it is smaller in 2009-2015 than in 2002-2008.

Measured formally using Moran's I, male mesothelioma SMR correlates with itself through space (I=0.19). This is expected for a rare disease like mesothelioma where there is a strong effect from concentrated environmental exposure sources such as dockyards. Interestingly, Moran's I for male mesothelioma SMR is falling over time which suggests that mesothelioma deaths are becoming more dispersed. This would be consistent with a decline in the proportion of mesothelioma risk arising from concentrated exposure sources. Mesothelioma incidence strongly increases with time since first exposure to asbestos and latencies of 20-30 years from initial exposure are most typical[29][30]; it is thought that some of the highest dockyard exposures occurred between the mid 1940s and 1960s.[4]. The effect of latency was clearly seen in a large case-control study where marine occupational asbestos exposures before age 30 were more important in determining lifetime mesothelioma risk than exposures after age 30, and men born 1925-1939 have higher risk than men born after 1940.[13] Taken together, the latency, peak in dockyard exposures, and importance of exposure before age 30, are compatible with our findings.

A recent study that used lifetime occupational histories and asbestos lung burdens in pneumothorax and lung cancer patients to investigate how mesothelioma risk is changing over time found that the relative contribution from "high risk" occupations such as shipbuilding and carpentry is falling and is absent in those born after 1965. The authors predict that the majority of mesothelioma in persons born after 1965 will be caused by environmental exposures which will presumably mainly come from asbestos in buildings.[31]

Limitations of our work include our use of residence obtained from death certificate data. People residing at variable distances from their place of work and changing their residence, by for example retiring to a different area, would likely tend to dilute the results. Another limitation is that we have not accounted for variation in exposure between dockyards, both in terms of dockyard workforce size and tasks undertaken. Finally, it is possible that non-dockyard asbestos exposure sources which are located close to dockyards, such as certain sites of asbestos manufacture, might confound associations seen. This is likely to be the case for T&N subsidiaries TAC Rhoose (Cardiff, Wales), TAC Erith (north Kent, England), and JWR Leeds for example.

Mesothelioma in Great Britain is known to show a high degree of spatial variability and an association with areas of shipbuilding, however to our knowledge the relationship between regional mesothelioma mortality and dockyard proximity has not previously been quantitated. Our results show that quantitative geospatial methods can be usefully applied to mesothelioma mortality data. Understanding the impact of place on health is a key element of epidemiological investigation, yet spatial methods are underused in occupational epidemiology when compared with areas areas of epidemiological research such as air quality and climate change, resource access studies, and infectious disease outbreaks.[32]

## Conclusion

Mesothelioma deaths are becoming more dispersed; while dockyards remain strongly spatially associated the strength of this association appears to be falling. This is consistent with an earlier reduction in these geographically specific sources while other important sources of exposure which are less clustered spatially - particularly those in the building industry - continued. It is likely that dockyards will no longer dominate UK mesothelioma mortality in the next 10-20 years and the asbestos legacy latent in the built environment may become a more important exposure source.

# Appendix 1 - Male and Female mesothelioma SMR data at LAD and ward level

## Men LAD mesothelioma SMR (top 10)

| LAD16NM | observed | expected | SMR (95% CI) |
|---|---|---|---|
| Barrow-in-Furness | 115.0 | 34.0 | 338.0 (279.0-405.7) |
| North Tyneside | 252.0 | 91.6 | 275.0 (242.1-311.2) |
| South Tyneside | 161.0 | 70.4 | 228.6 (194.6-266.7) |
| Portsmouth | 162.0 | 72.8 | 222.5 (189.6-259.5) |
| Medway | 212.0 | 97.9 | 216.5 (188.3-247.6) |
| Hartlepool | 89.0 | 41.2 | 216.0 (173.5-265.8) |
| Plymouth | 225.0 | 108.6 | 207.1 (180.9-236.0) |
| Fareham | 119.0 | 59.2 | 201.1 (166.6-240.6) |
| Newcastle upon Tyne | 208.0 | 105.2 | 197.7 (171.8-226.5) |
| Gosport | 69.0 | 36.4 | 189.4 (147.3-239.7) |

## Women LAD mesotheliomia SMR (top 10)

| LAD16NM | observed | expected | SMR (95% CI) |
|---|---|---|---|
| Barrow-in-Furness | 21.0 | 6.5 | 323.8 (200.4-495.0) |
| Newham | 35.0 | 11.4 | 306.7 (213.6-426.6) |
| Barking and Dagenham | 29.0 | 11.2 | 258.4 (173.0-371.2) |
| Sunderland | 63.0 | 24.6 | 256.6 (197.2-328.3) |
| Newcastle upon Tyne | 47.0 | 21.0 | 224.2 (164.7-298.2) |
| Medway | 41.0 | 19.0 | 216.2 (155.1-293.3) |
| Guildford | 22.0 | 10.9 | 201.3 (126.1-304.8) |
| Thurrock | 21.0 | 10.7 | 195.4 (120.9-298.7) |
| Dacorum | 23.0 | 11.8 | 194.7 (123.4-292.2) |
| Basildon | 28.0 | 14.5 | 193.7 (128.7-280.0) |

## Men ward mesothelioma SMR (top 10)

| WD16NM | LAD16NM | observed | expected | SMR (95% CI) |
|---|---|---|---|---|
| Farmborough | Bath and North East Somerset | 10.0 | 1.6 | 607.2 (290.7-1116.7) |
| Wallsend | North Tyneside | 19.0 | 3.2 | 598.4 (360.1-934.5) |
| Lambourne | Epping Forest | 7.0 | 1.2 | 588.3 (236.5-1212.0) |
| Newbarns | Barrow-in-Furness | 12.0 | 2.2 | 545.7 (281.6-953.2) |
| St. Athan | Vale of Glamorgan | 7.0 | 1.3 | 535.8 (215.4-1104.0) |

| WD16NM | LAD16NM | observed | expected | SMR (95% CI) |
|---|---|---|---|---|
| Walkergate | Newcastle upon Tyne | 25.0 | 4.7 | 527.0 (341.0-778.0) |
| Lydden and Temple Ewell | Dover | 7.0 | 1.4 | 509.3 (204.8-1049.4) |
| Risedale | Barrow-in-Furness | 17.0 | 3.4 | 499.7 (290.9-800.1) |
| Hindpool | Barrow-in-Furness | 14.0 | 2.8 | 495.9 (270.9-832.0) |
| Totton Central | New Forest | 11.0 | 2.3 | 485.6 (242.1-869.0) |

### Women ward mesothelioma SMR (top 10)

| WD16NM | LAD16NM | observed | expected | SMR (95% CI) |
|---|---|---|---|---|
| Wateringbury | Tonbridge and Malling | 3.0 | 0.2 | 1638.5 (337.9-4788.5) |
| Tintwistle | High Peak | 2.0 | 0.1 | 1356.6 (164.3-4900.6) |
| Waldon | Torridge | 2.0 | 0.2 | 1235.8 (149.7-4464.2) |
| Northgate | St Edmundsbury | 3.0 | 0.3 | 1155.7 (238.3-3377.4) |
| Larkfield South | Tonbridge and Malling | 4.0 | 0.3 | 1155.0 (314.7-2957.2) |
| Carr Bank | Mansfield | 2.0 | 0.2 | 1151.8 (139.5-4160.9) |
| Ash and New Ash Green | Sevenoaks | 5.0 | 0.4 | 1140.3 (370.3-2661.1) |
| Pontlottyn | Caerphilly | 2.0 | 0.2 | 1114.1 (134.9-4024.4) |
| Toller | South Kesteven | 3.0 | 0.3 | 1104.6 (227.8-3228.1) |
| Derwent Valley | Allerdale | 2.0 | 0.2 | 1063.1 (128.7-3840.3) |

## Appendix 2 / data sharing statement

Full documented python code for data extraction and analysis are available as supplementary material on Figshare (carl to add reference)

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