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Farm fragmentation in Ireland

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Abstract

Farm fragmentation refers to spatial disaggregation of farms into smaller, often highly separated parcels of land. This can create a number of problems; administrative, economic, environmental and epidemiological. Ireland has a high proportion of fragmented farms, although this an issue not unique to Ireland. From a epidemiological perspective, where a farm is heavily fragmented, there is uncertainty in assigning a location to where livestock have spent time on that farm. We explore techniques to quantify the extent and regional variation in fragmentation and the between-fragment distances of fragmented farms in Ireland with the aim of reducing this uncertainty. The findings, which have made available as an online resource, allow for more precision in spatial analyses of bovine populations and help enhance surveillance and field epidemiology.

Keywords

Ireland, farm fragmentation, spatial epidemiology, GIS, modelling

Introduction

Ireland is an island situated to the west of Great Britain approximately 400km to the nearest point of mainland Europe. The island, with a total area of 84,000 km^2 is comprised of two countries, the Republic of Ireland (also called Ireland and referred to as Ireland in this manuscript) with 70,000 km^2 and Northern Ireland with 14,000 km^2 respectively. Approximately two thirds of Ireland's land area is considered agricultural with 50% of all land area classed as permanent pasture used for farming livestock (https://www.cso.ie/en/releasesandpublications/ep/p-coa/censusofagriculture2020-preliminaryresults/landutilisation/).

For a number of reasons, most Irish farms are comprised of several fragments of land, often separated by considerable distances. It is necessary to briefly describe the historical context to understand the complexity of land ownership in Ireland. Over the centuries, the Irish landscape has been shaped by a variety of factors, including colonization, population growth and rapid population decline, and political instability. The most fundamental changes in land structure and ownership relevant to today, occurred over the last 500 years. From the mid-1500s, there was successive confiscation of Irish land by the English Crown for the formation of Plantations. This period saw substantial changes in land ownership and a shift in the population demographics which sparked the beginning of ethnic and sectarian conflicts which ultimately led to the rebellion of 1641. The rebellion led to the formation of a short-lived Irish ruling party which were dismantled through an offensive known as the Cromwellian Conquest of Ireland leading to Crown control of the island. This conquest brought about a shift in land ownership from predominantly Irish Catholic possession to 90% Protestant ownership with Protestants making up just 10% of the population. The shift of control in Ireland by this small ruling class became known as the "Ascendancy" during which time farming in Ireland evolved to a landlord/tenant system. This remained in place for almost two centuries. Over a period of 50 years from the late 1800s, a number of land reform acts were passed which effectively dissolved the ruling class and repatriated lands to tenants and peasant farmers. There was another huge shift in land ownership over a short period of time. In 1870, only 3% of Irish farmers owned their own land while 97% were tenants. By 1929, this ratio had been reversed with 97.4% of farmers holding their farms in freehold (Bew, 2011; Walsh & Fox O 'Mahony, 2018). In more recent times, land fragmentation has been driven by subdivisions caused by inheritance. The traditional system of inheritance in Ireland, known as gavelkind, where land is divided equally among all sons upon the death of the father, was commonly practiced leading to smaller and smaller land holdings over time. More recently, there has been a steady decline of small farms which are not financially viable and an expansion of large farms taking advantage of economies of scale. The process of land ownership and farmland usage remains a dynamic process driven by market forces and government incentives and penalties. Recent demands to reduce the environmental impact of farming are likely to accelerate these changes in the near future.

To date, there is no description of, or reference to, the extent and regional variation of fragmentation in Ireland with only one published report estimating the national level of fragmentation based on a sample of 54 farms (Saint-Cyr et al., 2017). Many research studies, particularly in epidemiology, elude to the issue of fragmentation (Byrne et al., 2020; Campbell et al., 2020; Casey-Bryars et al., 2022; Chang et al., 2023; Clegg et al., 2013; Collins, 2005; Doyle et al., 2018; Graham et al., 2013, 2016; Madden et al., 2021; McGrath et al., 2009; Milne et al., 2022; More et al., 2007; Tratalos et al., 2023; White et al., 2010; White et al., 2013). Most of these studies describe fragmentation as being a relevant issue but do not attempt to quantify it.

Does fragmentation matter?

As presented, a number of historic events have substantially shaped the spatial arrangement of farmland in Ireland, including the substantial level of fragmentation that is observed today. Given this, it is reasonable to ask whether fragmentation matters? There are a number of disadvantages to having fragmented farms (del Corral et al., 2011; Latruffe & Piet, 2014). Fragmented farms have higher running costs; increased boundary maintenance costs, transportation costs, infrastructural costs (water, electricity, access). These costs make economies of scale hard to achieve across multiple fragments (Orea et al., 2015). Another major consideration for the impact of fragmentation is that of potential spread of animal diseases. The more a farm is fragmented, the greater the boundary distance of the farm. This increases the potential number of neighbouring farms and the associated risk of farm to farm disease transmission. Further, the additional boundary serves as habitat for wildlife species which may harbour infectious diseases. In the case of Ireland, this includes the Eurasian badger (*Meles meles*) a known reservoir host of the bacteria *Mycobacterium bovis* (Griffin et al., 2005), a causative agent of tuberculosis in cattle and humans. Furthermore, where a farm has fragments located long distances apart, livestock that are moved between these fragments will have potential exposure to wildlife from multiple home ranges and neighbouring livestock from different areas facilitating potential introduction of disease both into the livestock and potentially into local naïve wildlife populations. For these reasons, having an understanding of the degree of how fragmented farms are in Ireland and how this relates to the spatial relationship with neighbouring farms, is important. It is also of importance to consider fragmentation in relation to the routine surveillance of infection in livestock and in the management of the outbreak of infectious diseases. The aim of this study therefore, is to describe and quantify the extent and regional variation of farm fragmentation in Ireland. This study will serve as a reference and a resource for future research with an accompanying online interface at https://arcg.is/PGrK with source maps and lookup files at https://github.com/guymcgrath/Fragmentation. Two aspects of fragmentation are described. Firstly, the measure of "fragmentedness" of farms in Ireland, giving an overview of how fragmented farms are, and the distance between same farm fragments and how this varies spatially. Secondly, the "neighbourhoodness" of farms is established giving an overview of the regional differences in potential farm to farm over-the-fence contacts. Further, the relationship between farm fragmentation and farm bovine enterprise type will be investigated. The outputs generated in this study represent the first quantitative baseline reference for farm fragmentation in Ireland and can be used to support future research and surveillance strategies.

Materials and methods

Data

Farms in Ireland are digitally recorded on a Land Parcel Identification System (LPIS) (European Court of Auditors, 2016). LPIS is a series of IT systems based on aerial or satellite photographs recording agricultural parcels in many EU Member States. It is a key control mechanism under the Common Agricultural Policy (CAP) designed to verify eligibility for area-based subsidies, which amounted to approximately €45.5 billion in 2015 (from: ECA 2016). Having land parcel outlines digitized allows for interrogation by Geographical Information Systems (GIS) (Zimmermann et al., 2016). Ireland's LPIS is managed by the Department of Agriculture, Food and the Marine (DAFM) on an Oracle® Spatial database. The data are comprised of a total of 130,385 farms of which a subset were defined as "active" farms registered as having bovine livestock in 2020 or 2021 (101,890). This was exported to ESRI® shapefile format for processing. Data on livestock populations were exported from DAFM's Animal Health Computer System (AHCS). Farm enterprise type was assigned to herds based on the simplest category levels developed by Brock et al, 2022 consisting of; Dairy herds, (milk and calf productions systems), Beef herds, fattening herds (confinement feeding operations where cattle are fed primarily for finishing), Trading herds (characterised primarily on the basis of having a very low proportion of animals that remain in them for more than 30 days), mixed herds (dual purpose operators producing milk, but also having another cattle enterprise focused on beef production), stores (non-breeding herds with a focus on the rearing of young animals from the beef and dairy sectors) and “other” herds (herds falling outside of the aforementioned criteria).

Methods

Several methods were used to describe and quantify spatial representation and relationships of farms and farm fragments, including “fragmentedness” and “neighbourhoodness”.

Method 1: “Fragmentedness”

The simplest and most commonly used spatial representation of a farm is the “centroid”. This is the computed centre of gravity of the largest single farm fragment of land represented as an X, Y coordinate, thus allowing for conventional density and distance point-process spatial analytical techniques to be applied. However, laneways, roads, streams and other physical features intersect farms. When digitized and analysed on a GIS, same-farm fragments in close proximity to one another are not seen as a genuine spatial/epidemiological unit. Alternative spatial representations such as weighted centroid, geographic medians, density based clustering, etc., are useful but often place the estimated computed location outside of the actual farm. This becomes increasingly problematic as fragment separation distances become greater. To get a better spatial and descriptive representation of farms split by small local features, we utilised the Integrate tool (ArcGIS 10.7, ESRI® Redlands CA) to allow same farm boundaries to snap together across these features at a user-defined distance threshold. An integration distance of 3 metres was selected to collapse boundaries across small features such as laneways, access roads, streams, etc. while minimising the change to polygon topology and ensuring fragments separated by real physical barriers remained separate in our analyses. To overcome processing limitations in ArcGIS (~1.4 million land parcels in the raw national LPIS coverage), the coverage was divided into 4 overlapping regions which were integrated separately and then re-joined with duplicated overlaps removed. Following integration, single fragment farms were labelled as such and farms that had more than one fragment had their fragments assigned as “home” for their largest integrated fragment, and “away” for all other fragments. Euclidean distance from the nearest edge of home fragment to all other away fragments were calculated.

Method 2: “Neighbourhoodness”

A methodology to better describe the spatial relationship between neighbouring or contiguous farms was devised. As described in method 1, all farm parcels were integrated, in this instance, at a distance of 20 metres. A greater distance was selected as maintaining topology was less important than ensuring that close neighbours were identified. Integrated farm fragments were placed into 3 categories based on their relative size to total farm size; **A**=fragment size >50% of total farm area, **B**= fragment size 20%-50% of total farm area, **C**= fragment size <20% of total farm area. A scoring matrix, “N score”, was generated to define the relative importance of adjacency between fragments based on their size category; **A-A**=1, **A-B**=2, **B-B**=3, **A-C**=4, **B-C**=5, **C**-**C**=6 (Figure 1). All farm fragments were assigned an “N score” depending on the comparative fragment-size relationship with neighbouring farm’s fragments based on the scoring matrix.

Figure 1 illustrates the principles and methods that underpin the N score. The index farm (in black) is comprised of one “**A**” fragment, one “**B**” fragment and three “**C**” fragments. All farm fragments contiguous to the index farm are coloured based on their computed “N score”. In this example, only one neighbouring farm (in red) scores “1”, an **A** to **A** relationship i.e., only one farm has >50% of its land in a single fragment adjoining the index farms largest fragment (also being >50% of the farm’s total area). A number of neighbouring farm fragments (in blue) score “2”, due to an **A** to **B** (or **B** to **A**) relationship, further (in orange) score “3” due to **B** to **B** relationship etc. In addition, the distance of true shared boundary was computed on the raw LPIS using the 'polygon neighbours' tool (ArcGIS 10.7, ESRI® Redlands CA). As with the fragmentation profile, the “neighbourhoodness” index for each farm can be interpreted directly by farm or can be collapsed into spatial summaries.

Outputs

For the “fragmentedness” analysis, summary distance values including average fragment-edge to fragment-edge distance and maximum fragment to fragment distance were calculated for all multi fragment farms. Summary “neighbourhoodness” were similarly collated. A “fragmentation profile” for each farm was created containing the distance values, the number of integrated fragments and the neighbourhood scores. This profile can be interpreted directly giving an indication of the farm structure or can be collapsed into spatial summaries, in this case 10km hexagonal grid and County.

For utility purposes, but not presented in this paper, additional information on fragment address and associated area were provided to DAFM to populate software to support government veterinary field staff in disease surveillance and control operations. As with “fragmentedness”, analyses were performed on all farms and active farms. Enterprise type was assigned to all active farms based on preselected criteria .

Outputs have been generated in two spatial scales: in hexagonal grid squares and at County level. County level values were generated for administrative and descriptive purposes as a spatial unit known to stakeholders in Ireland. Hexagon output allows for more granular visualisation of the values and allows for higher resolution, equally spatially distributed summary data to be downloaded and explored by third parties.

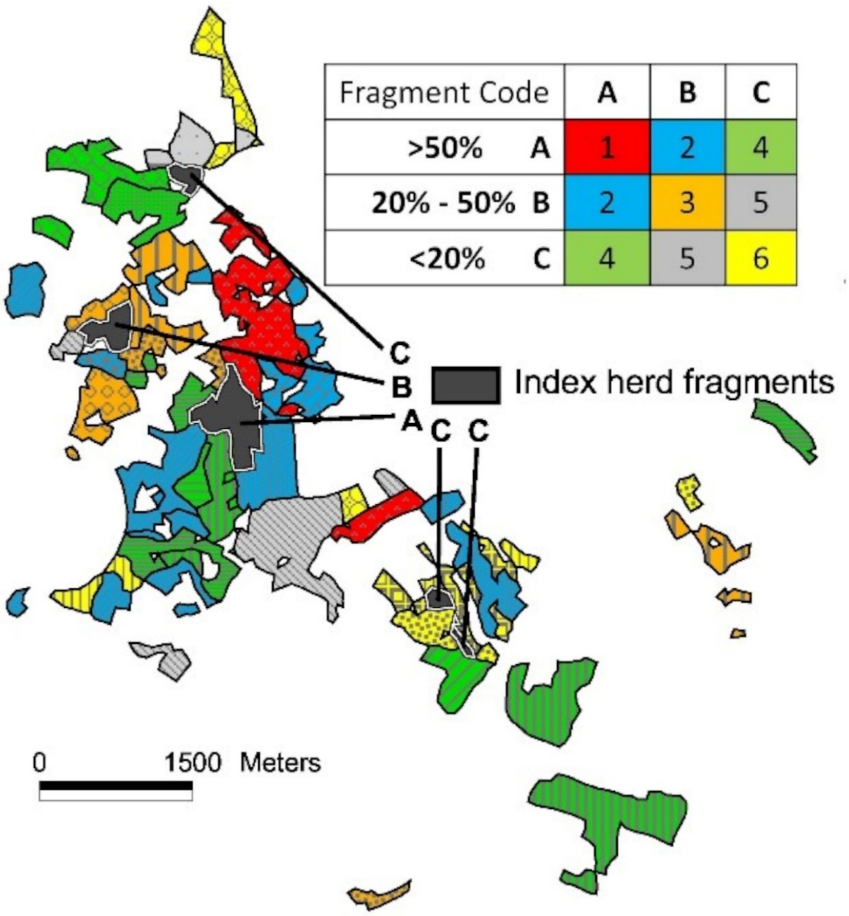

Figure 1. “Neighbourhoodness index” scoring matrix based on relative area of farm with inset real-world example of a farm and it’s fragment to fragment relationship with neighbouring farms (20 neighbouring farms consisting of 411 fragments).

Results

The results of the spatial exploration of farm fragmentation are highly descriptive and are most readily represented in interactive map form. Due to the number of summary categories created, it is not possible to present them all in this paper. However, a selection of key summary categories are presented in figure form to give a sense of the spatial variation and general fragmented structure of farms in Ireland. The figures are presented are at 10km hexagon and county summary level, for all farms and for active farm, depending on context. All summary statistics are available online in both County and Hexagonal grid layers through a map viewer at https://arcg.is/PGrK. The map files are also available in ESRI shapefile format (projected to Irish National Grid) with the accompanying lookup table at https://github.com/guymcgrath/Fragmentation. All summary category definitions are presented in the supplementary materials section. 14 hexagons were removed from the online resource to comply with General Data Protection Regulation (GDPR). Of these, 7 had no herds present and 7 contained a total of 20 herds. These hexagons were partial coastal hexagons too small to see in the figures presented.

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Method 1. "Fragmentedness"

Figure 2 shows the percentage of active farms that are fragmented, that is, the percentage of active farms that have more than one fragment of land after collapsing features of less than 3 metres at both a hexagon level and a country level. Please note, each map has its own legend. Figure 3 shows the mean fragment size of farm fragments in square metres following 3 metre integration. Figure 4 shows the number of active farms, the bovine population, the average number of active neighbours and the average number of farm fragments (also in Table SM I and Figure SM 1) for multi-fragment farms per 10km hexagon. Figure 5 shows the county and hexagon average distances of the mean and maximum distance between same-farm fragments for active farms (computed on closest edge to edge distance – Figure SM 2). Figure 6 shows the percentage of active farms by 10km hexagon with an average maximum farm fragment distance of less than 100 metres, 500 metres, 1km and 5km respectively. The count of farms by enterprise type is presented in Table I along with the breakdown of how many of these farms are single fragment or multi-fragment farms (also shown as a percentage), the average number of fragments per farm, the average distance between fragments (in metres) and the average maximum distance between same-farm fragments (in metres). These values are displayed visually in Figure 7. Figure 8 is a stacked bar chart showing the cumulative percentage of land fragments in fragmented active farms occurring within distance bands of 1km, 5km, 10km and 20km. This is a cumulative calculation, so, for example, all farms in the 20km distance range will also occur by default in the 10km distance, and so on for lesser distances. Figure 9 shows the relationship between the number of fragments a farm has and the area of those farms for active farms. This presents the frequency and area representation of multiple fragments on overall farm fragment composition in Ireland.

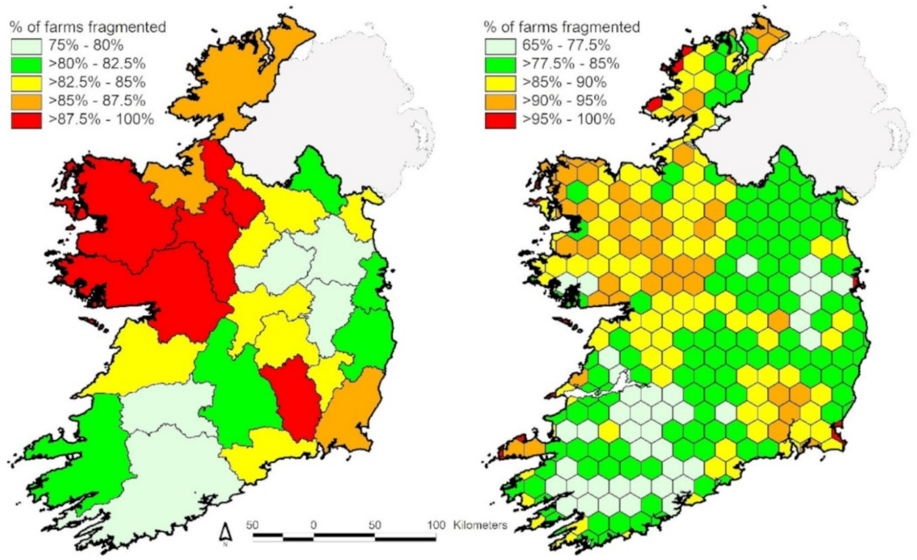

Figure 2. Percentage of active farms that are fragmented at a 10km hexagon and County level.

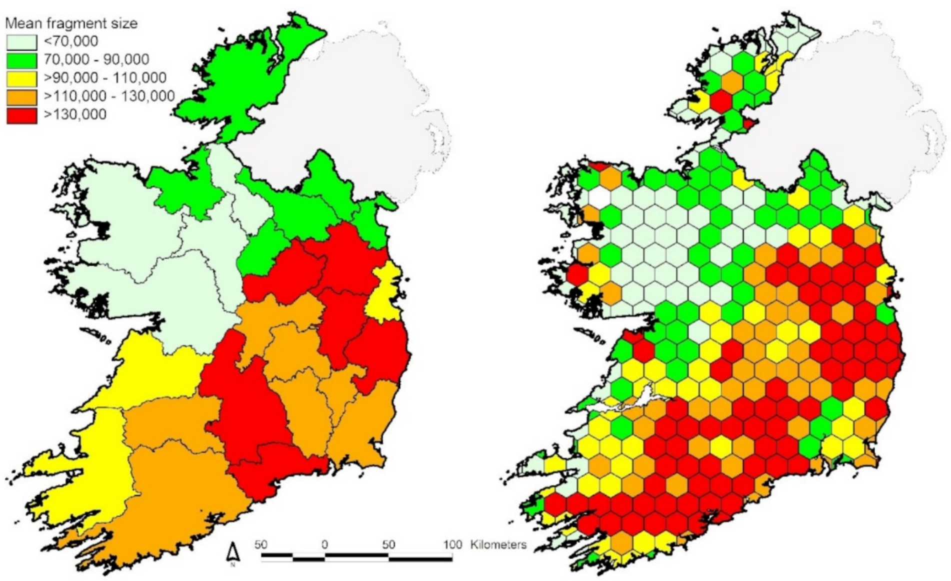

Figure 3. Mean fragment size of active farms (square metres).

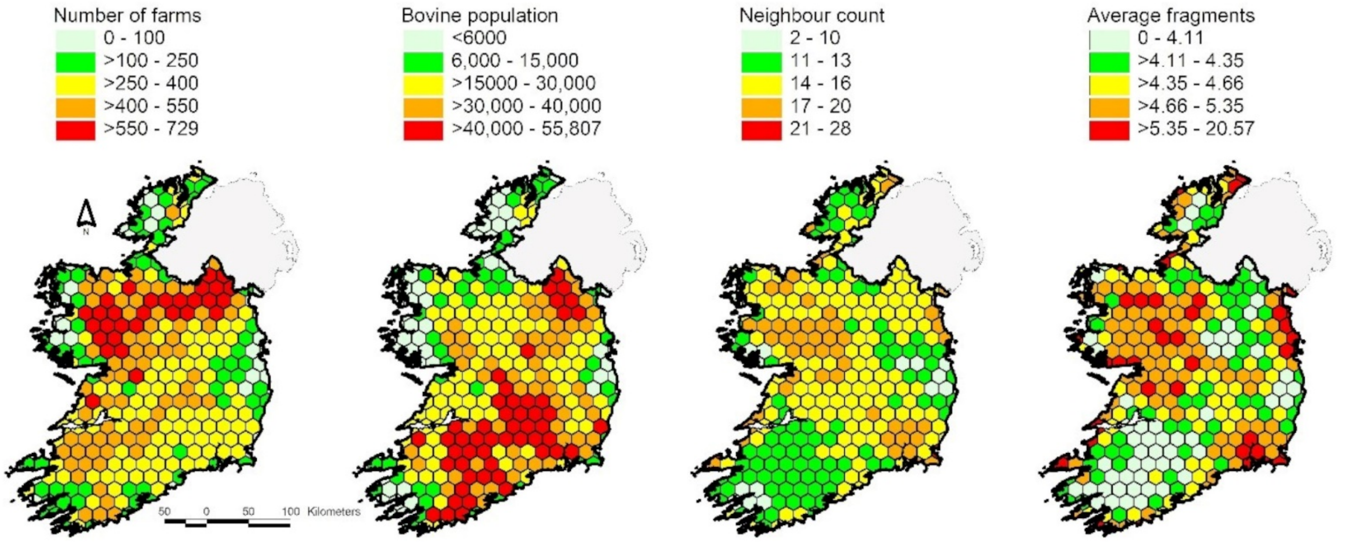

Figure 4. The number of active farms, the bovine population, the average number of (active) neighbours and the average number of farm fragments (for multi-fragment farms) per 10km hexagon.

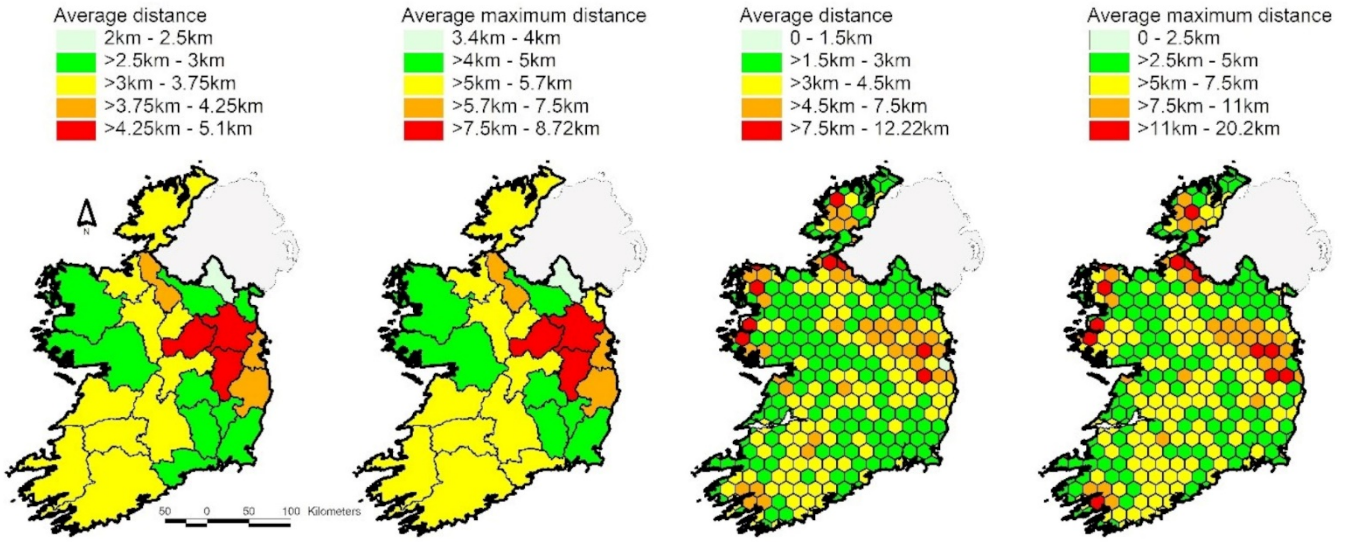

Figure 5. County and 10km Hexagon average of the mean and maximum distance between fragments of multi-fragment active farms.

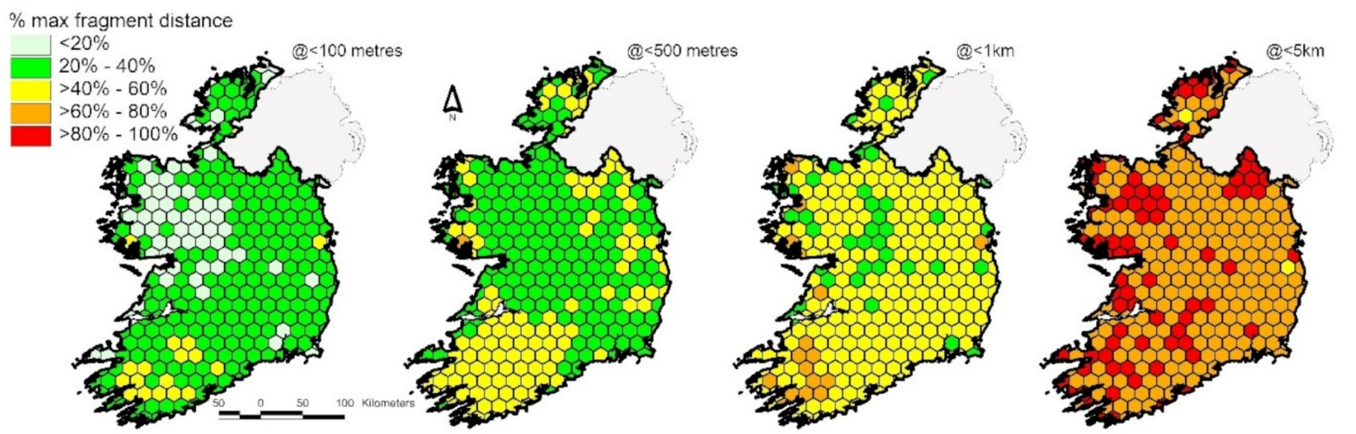

Figure 6. Percentage of farms by 10km hexagon with an average maximum within farm fragment distance of less than 100 metres, 500 metres, 1km and 5km respectively.

Enterprise	Count	Single-frag	Multi-frag	% Single-frag	Av frags	Av dist (m)	Av max dist (m)
Beef	49,555	6,925	42,63	13.97	5.01	3,091	5,211
Dairy	12,101	1,202	10,899	9.93	5.24	2,649	5,281
Fatteners	16,372	3,236	13,136	19.77	4.41	3,372	5,644
Mixed	5,175	455	4,72	8.79	5.46	3,119	5,775
Stores	14,98	3,552	11,428	23.71	3.98	3,108	4,887
Traders	487	107	380	21.97	4.78	7,713	12,162
Unclassified	3,22	961	2,259	29.85	3.88	3,996	6,09

Table I. The number of active single versus multi-fragment farms showing % single fragment farms, average number of fragments, average distance between fragments and the average maximum distance of fragmented farms (see Figure 7).

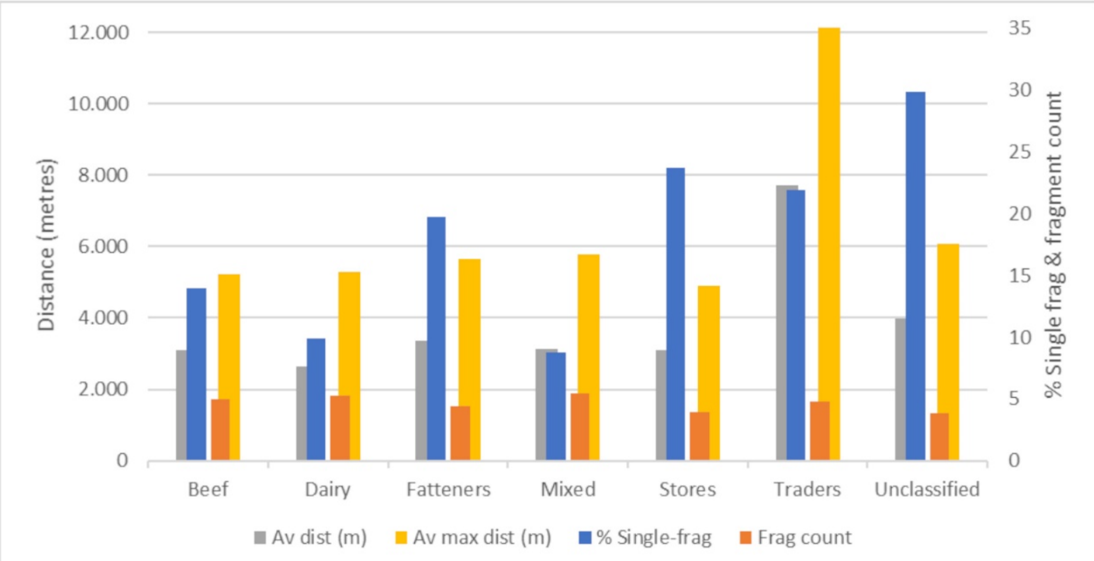

Figure 7. The fragment count (secondary Y axis), average distance and maximum distance (primary Y Axis) of fragmented farms by enterprise type. Also shown, the percentage of single fragment farms (secondary Y axis) by enterprise type.

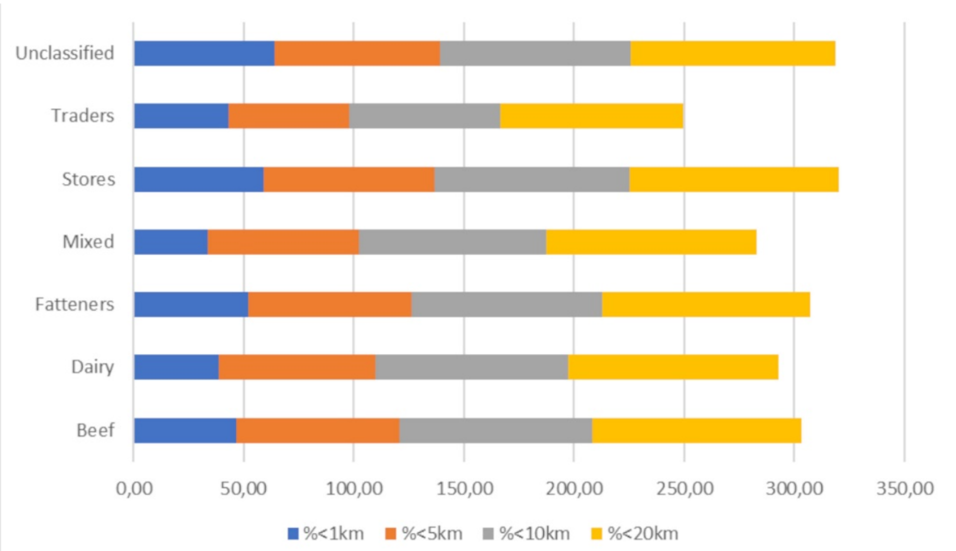

Figure 8. Stacked bar chart showing the cumulative percentage of fragments in fragmented farms occurring within distance bands of 1km, 5km, 10km and 20km by enterprise type. This is a cumulative calculation, so, for example, all farms in the 20km distance range will also occur by default in the 10km distance, and so on for lesser distances.

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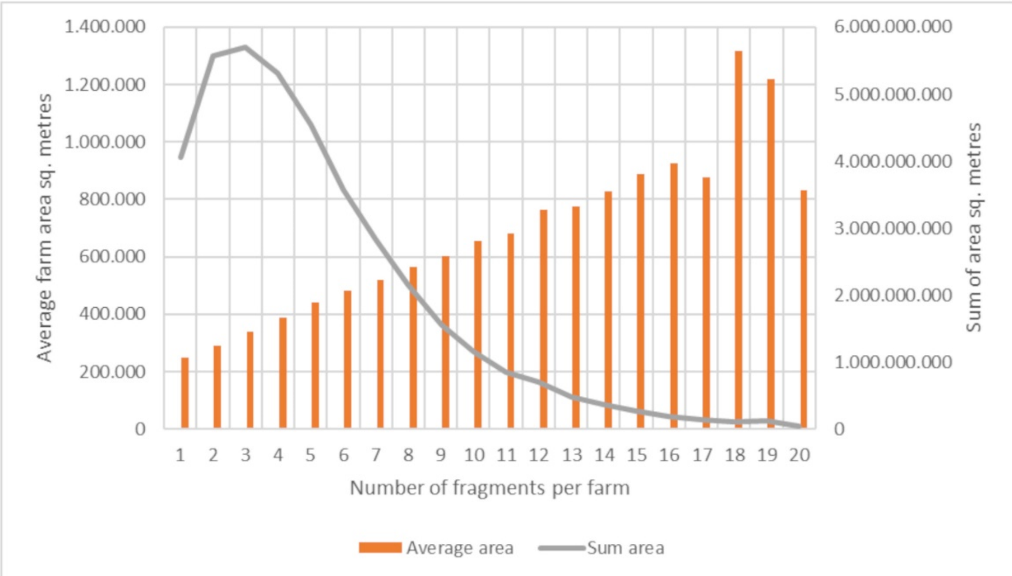

Figure 9. Relationship between the number of fragments a farm has and the area of those farms for active farms.

Method 2. “Neighbourhoodness”

Figure 10 shows the average count of “Neighbourhoodness” score or “N score” relationships between farm fragments for N1, N3, N4 and N6 per 10km hexagon (all categories available in the online resource).

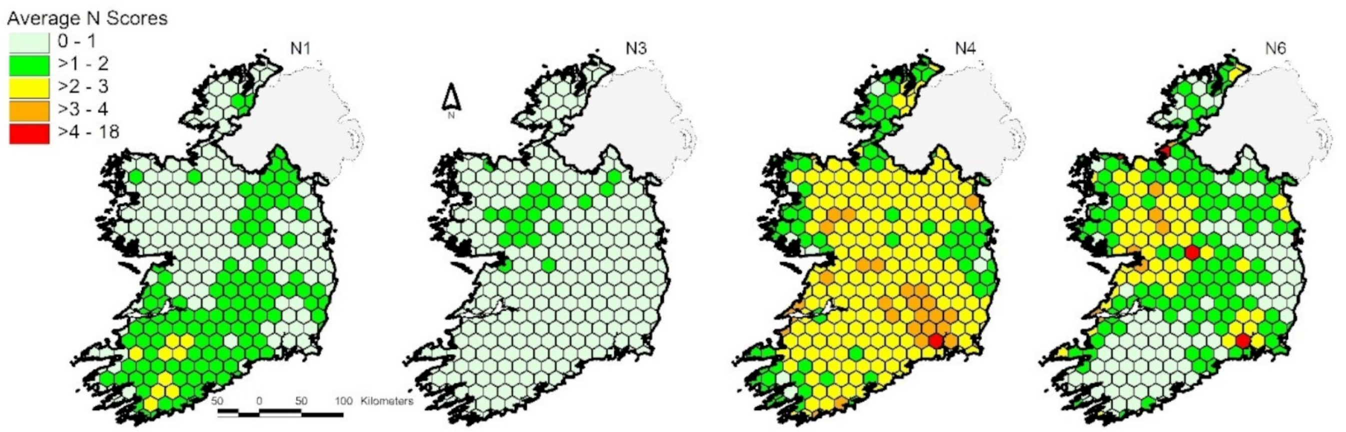

Figure 10. The average count of Neighbourhoodness Score “N score” relationships between farm fragments for N1, N3, N4 and N6 per 10km hexagon (all values available from the online resource).

Discussion

Methodologies employed

As briefly described in the methods section, there are many techniques which can be used to create a spatial representation of a farm which can be a better alternative to using the centroid of the largest integrated fragment. These include Convex Hull, Minimum Bounding Rectangle, Weighted Centroid, Density-Based Clustering, Geometric Median, etc. These are of use in performing point process spatial analyses but fail to accurately reflect the reality that, in Ireland, active farms will generally graze their livestock on almost all, if not all, of their land under pasture at some stage during the grass-growing season (March to October). As such, the techniques presented in this study are based on the principal that all livestock can be on all parcels of land at any or all times. This could be refined by assigning livestock to fragments proportional to the area of land of the fragment compared to the entire farm or by placing a weighting on fragments closest to the farm buildings. This would be useful for non-binary exposure variables such as accumulation of heavy metals from soil and potentially for stochastic exposure variables where increased exposure time reflects increased risk of disease transmission. However, without knowing the management practices of each individual farm, working on such assumptions leads to uncertainty in assigning livestock location. Reducing this uncertainly is becoming increasingly important as models on disease transmission and environmental exposure become more sophisticated.

Collapsing boundaries

Single fragment farms are the most robust when exploring variables relating to transmission from/to the environment/wildlife/neighbouring farms as all livestock are contained in one area for their duration on the farm. Integrating farms at a 3 metre distance effectively increases the number of farms that can be considered single fragment farms from 3,583 to 24,988 (and reduces the overall land fragment count from 1,374,828 to 515,423) giving us much more certainty of livestock location which assists in generating more robust models.

Fragment distances

There are many potential uses for the farm fragment distance summaries generated. Depending on an exposure variable, fragment distance thresholds can be set to select for farms that could be considered single spatial units for the purpose of specific analyses. For example, exposure variables such as soil type, temperature or rainfall would be similar over relatively large areas whereas exploring a putative local exposure source, such as a contaminated river, would only be of significance to livestock with direct access. In the case of the first example, herds could be selected with a maximum fragment distance of several kilometres whereas herds in the second example would need to be integrated single fragment farms to give the most robust spatial attribution of livestock. A working example is a study conducted in Ireland to determine heavy metal exposure to cattle through grazing over time (Canty et al., 2014). Farms were selected manually to ensure homebred livestock grazed in a defined local area ensuring exposure related to local soil parameters. With the methodologies presented in this paper, the farm selection process would have been a desktop exercise without the need for manual selection.

Neighbours

In terms of defining the potential influence of neighbouring farms in disease transmission, the “neighbourhoodness” index identifies which neighbouring farm fragments are likely to be of most significance. In the instance of the real-world example displayed Figure 1. The index farm (black), shares a boundary with 20 other farms (411 distinct fragments). However, the index farm’s largest fragment of land only shares a boundary with one other farm’s largest fragment of land (red). Coupled with the shared boundary length, current and historic stocking levels and disease history of the neighbouring farms, surveillance resources can be prioritised for active surveillance of bTB breakdowns and for managing outbreaks of transmissible diseases. The “neighbourhoodness” score can also be used to build relationships between farms for modelling purposes.

The level of fragmentation in Ireland

From the figures presented, it is clear that there is substantial spatial variation in the structure of farms in Ireland. Figure 2 gives a sense of how much fragmentation there is on farms in Ireland, even after applying integration. From Figure 4, it is evident that the number of farms in an area does not reflect the population of bovines (see national herd size distribution in Figure SM 3). The area with the highest farm density (northwest) and smallest mean fragment size (Figure 3) is poorer quality land less suited to intensive farming. The areas of highest bovine population are on the highest quality agricultural land as expressed through the bovine population count and mean fragment size presented in Figures 3 and 4. The number of neighbours per farm is closely related to the number of farms per unit area (correlation value of 0.9732) which is also evident as “neighbour count” in Figure 4. This is exacerbated by these small farms having a tendency to be more heavily fragmented displayed as “average fragments” in Figure 4. The areas with the highest farm density and lower population density have a lower mean maximum fragment distance than areas with higher population density and fragment size such as the east midlands. This is most likely due to historic regional differences where smaller farm holdings on poorer quality land got subdivided through inheritance while larger more profitable holdings on higher quality land purchased additional lands over time. The percentage of fragmented farms by mean maximum distance bands is presented in Figure 6. At 100 metres, most of Ireland falls in the <40% categories. At 1km, this extends to <60%. The relationship between neighbouring farms also varies spatially, as expected, due to the structural differences identified in farms. The average count of N scores presented in Figure 10 shows that the areas associated with most fragmentation and lower population density have the lowest high-significance to high-significance neighbour contacts and the highest low-significance to low-significance neighbour contacts. This is reflective of the high fragment count of these small farms with a high proportion not having a single fragment representing >50% of the farms total area.

Methodological improvements and future work

A number of improvements are intended to follow on from this study.

This study focuses on describing fragmentation on farms in Ireland, particularly farms stocked with bovines. There is great potential for exploring additional parameters. These data could be coupled to DAFM's Animal Identification and Movement (AIM) metrics to build an extended "probability of contact" matrix or connectance index. Contrast metrics could be explored to build maps of neighbourhood diversity based on enterprise types, animal types, arable crop types, other non-agriculture land uses.

Livestock stocking densities per unit area of land can be calculated. Assigning these to consolidated or single fragment farms, coupled with nitrate usage data, aquifer vulnerability and surface water run-off data gives a useful measure of local potential environmental impact on local water quality. This currently a very contentious issue with Ireland receiving EU nitrate derogations due to its reliance on grass-fed cattle rearing systems (Henn et al., 2023; Richards et al., 2015).

Remote sensing can assist in identifying higher productivity grasslands. This could be used to validate DAFM's land parcel usage label. Coupled with machine learning techniques trained with ground truthing, predictions could be made on which fragments of a fragmented farm are likely to be most intensively farmed. This would allow for assigning a relative weighting on estimated time spent by livestock on these fragments (Li et al., 2023; Møller et al., 2021).

Anecdotally, dairy herds are more consolidated than other enterprise types such as beef due to the fact that dairy cows require daily milking. The output however show that dairy herds are very similar in spatial composition to beef herds (Table I, Figures 7-8). This warrants further real-world investigation to see how this is managed practically or whether this is an anomaly in the herd enterprise classifications (only crude classification indices were used).

The outputs presented in this study reflect a snapshot in time. Farming practices change, driven by market forces and shaped by legislation. Computing these metrics over a period of time would be a valuable resource to explore how fragmentation changes in response to these external factors.

Despite the main theme of this study, there are some potential advantages to having fragmented farms. A common winter feed used for feeding bovine livestock in Ireland is sileage; compacted, fermented grass grown and cut in Spring and early Summer. Fragments of land can be set aside for sileage production without having to subdivide large single fragments. Small, fragmented farms are also considered healthier for ecosystems with more crop diversity and a higher density network of hedgerow (Di Falco et al., 2010; Lu et al., 2020; Rundlöf et al., 2008; Sherren & Greenland-Smith, 2019). Another advantage, not so relevant to Ireland, is greater resilience to local climate extremes such as drought, storms and floods (Chatterjee et al., 2022; Ntihinyurwa et al., 2019). Many low lying parts of Ireland are subject to flooding. As these areas are actively farmed, having fragments on more elevated sites offers a degree of redundancy in fodder supply. The techniques used here to assist in quantifying fragmentation from a livestock disease perspective could be utilised to explore the potential benefits of having fragmented farm structures.

Conclusions

Farms in Ireland are highly fragmented. Consolidation of farms is unlikely to happen in a formalised manner so understanding the variation and extent of fragmentation is necessary to better assess the contribution it may make to the cost effectiveness of farming, the impact on the environment and the biosecurity of livestock. This study presents simple methodologies that, in part, reduce the uncertainty arising from how farms are recorded in a LPIS. These methodologies can be employed in a number of settings ranging from field surveillance to estimating exposure estimates in modelling. Presenting these summary data allows for future researchers define and cite the current degree and spatial extent of fragmentation in Ireland which, hitherto, was not possible.

Acknowledgments

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