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Quantifying Land Fragmentation in Northern Irish Cattle Enterprises

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Abstract: Farmland fragmentation is considered to be a defining feature of Northern Ireland's (NI) agricultural landscape, influencing agricultural efficiency, productivity, and the spread of livestock diseases. Despite this, the full extent of farmland fragmentation in cattle farms in NI is not well understood, and little is known of how farmland fragmentation either influences, or is influenced by, different animal production types. Here, we describe and quantify farmland fragmentation in cattle farms for all of NI, using GIS processing of land parcel data to associate individual parcels with data on the cattle business associated with the land. We found that 35% of farms consisted of five or more fragments, with dairy farms associated with greater levels of farmland fragmentation, fragment dispersal and contact with contiguous neighbours compared to other production types. The elevated levels of farmland fragmentation in dairy production compared to non-dairy, may be associated with the recent expansion of dairy farms by land acquisition, following the abolition of the milk quota system in 2015. The comparatively high levels of farmland fragmentation observed in NI cattle farms may also have important implications for agricultural productivity and epidemiology alike. Whilst highly connected pastures could facilitate the dissemination of disease, highly fragmented land could also hamper productivity via diseconomies of scale, such as preventing the increase of herd sizes or additionally, adding to farm costs by increasing the complexity of herd management.

Keywords: farmland fragmentation; farm fragmentation; dairy; cattle farming; agricultural productivity; Northern Ireland

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1. Introduction

Farmland fragmentation and dispersal are global phenomena, exhibiting national and international variation [1–4]. Farmland fragmentation can be driven by factors ranging from inheritance traditions, to historical contexts (e.g., land reforms under socialist governments which drove land consolidation, or conversely, the "individualisation" of land parcels to following the disbanding of agricultural collectives) [5,6]. Trends in land use can also influence fragmentation, for example via farm diversification and conservation efforts, or rapid farm expansion which can result in the ownership of multiple parcels [7]. Some of these factors may be intentionally adopted by farmers; for example, farmers may expand the farm through the acquisition of contiguous (adjacent) or non-contiguous parcel in a bid to take advantage of increased demand. Other factors influencing farmland fragmentation include external pressures from nature and society. These could be the growth in farming population given the limited land resources, or the egalitarian based land distribution through partible inheritance and culture [8–11].

Land fragmentation has been conceptualized in different ways, depending on the context in which it is defined. For Bentley [12], land fragmentation is simply the scattering of farmland. Whereas King and Burton [13] defines it as a basic rural spatial issue, whereby farms are imperfectly organized at separate locations across an area. Farmland fragmentation has also been defined as the process whereby farming households possess a number of non-contiguous land plots, scattered over a wide area and defined by spatial characteristics such as farm size, the size and shape of land parcels, the number of land parcels belonging to the farm, the size distribution of plots, and the spatial distribution of plots [6,14–16]. In this respect, farmland fragmentation can be viewed as a multidimensional phenomenon defined in terms of physical fragmentation (use, shape, value, and location), tenure fragmentation (both visible and hidden ownership and usership) and spatial unit fragmentation (parcel, farm and land block or zone) [8,16–18].

Farmland fragmentation can influence agricultural production, biodiversity and ecosystem functions in diverse ways, which may be positive or negative [19]. For example, studies by [19,20] have shown that farmland fragmentation increases production costs which consequently results in a decrease in farm profitability and efficiency. On the other hand, farmland fragmentation has also been found to be associated with increased biodiversity [21,22]. However, the influence of farmland fragmentation also depends on a number of factors including the level of mechanisation or subsistence, the level of development of the factor market, the land tenure systems, the population density and demography of the country, as well as the prevailing agricultural systems and policies [8]. For example, in countries such as the United Kingdom (UK) and other European nations where agriculture is highly mechanised and market-oriented, farmland fragmentation is generally considered detrimental and a major threat to agricultural production, as it has the tendency of limiting economies of scale and centralized management of agricultural production, consequently reducing production efficiency and sustainable land use [8,15,18,23,24]. On the other hand, in countries where agriculture remain highly subsistent in nature, farmland fragmentation may be regarded as beneficial, in that it serves as an adaptive strategy to mitigate production and price fluctuation risks, and provide an opportunity for agricultural production diversification for self-sufficiency in food production and household food security [8,16,25–28].

Livestock farming forms a significant component of NI's commercial output, and cattle farming alone comprises over 50% of the £2.3 billion agri-food sector [29]. Eighty-nine percent of NI's 25,000 farms are associated with cattle. In NI, almost all production systems involve outside grazing and thus, grass availability and quality are key considerations for farmers. Traditionally, farming is a family business in NI, with relatively small herd sizes and head of cattle compared to farms in the rest of the UK, which is considered a competitive disadvantage [30,31]. Farms are usually operated as sole trading businesses (self-employed) or in partnerships, and do not often involve individuals from outside of the family in the management and decision-making processes [32–34]. Also, the majority of the farms in the region are inherited through generational succession, which creates structural difficulties in farming and contributes to farmland fragmentation [33]. This occurs when the number of children (as potential successors) within the farming household increases, and the family farm is to be shared between them. In addition, there is the prevalence of rental agreements based on the traditional "conacre" system, which is a short-term land rental system unique to the island of Ireland. The system (nominally for 11 months or 364 days) permits land to be let to other farmers without the need for either party to enter a long term commitment. As much as a third (about 300,000 hectares) of agricultural land in NI is farmed under the "conacre" agreements, with the consequence that the land owner is not necessarily the farmer [35,36]. Furthermore, dairy herds are becoming increasingly larger, which may be driving demand for suitable grazing land [34].

As with the rest of the UK and ROI, farmland fragmentation is a “considerable feature” of NI’s agricultural landscape [37,38]. Epidemiological investigations in the region allude to highly fragmented and inter-connected farms consisting of at least 2 to 9 land parcels [39,40], where between 66.8% and 79% of surveyed parcels could permit nose-to-nose contact with cattle on neighbouring farms [41–43]. Given the unique nature of farming in NI, it is believed that the different cattle management practices and production systems may be either a feature of, or constrained by, the highly fragmented agricultural landscape in NI. The overall aim of this study is to gain a better understanding of the degree of fragmentation in NI cattle farms. To the best of the authors’ knowledge, this is the first attempt to study fragmentation in NI cattle businesses. The first objective is to firstly describe patterns in farmland fragmentation and farm dispersal in NI cattle farms using the Land Parcel Identification Systems (LPIS). Secondly, we will quantify the extent to which farmland fragmentation differs between different cattle production systems in NI and finally, discuss how local trends in cattle farming may be impacting, or impacted by, farmland fragmentation. An understanding of the spatial arrangement of farmland across the different cattle enterprises will contribute to the development of policy frameworks necessary for the effective management of farms, as well as improving farm efficiency and productivity in NI and other countries of similar farming systems. These findings will also assist policy makers in making informed decisions around farmland fragmentation, and achieving the sustainable development goals relating to land management.

2. Materials and Methods

2.1. Study Area

Northern Ireland is located in the northeast of the island of Ireland. Its climate is classified as temperate marine with both relatively mild summers and winters. The mean annual temperature in the lower areas ranges from 8.5 °C to 10 °C. Rainfall varies with location, but generally NI is considered wet, with annual precipitation ranging between 800 mm and 1660 mm [44]. The climate is highly suitable for growing grass, leading to an agriculture dominated by intensive, grass-based livestock farming with a practical absence of “zero grazing” units. The total area of NI is approx. 13,500 km^2 (Figure 1), with a farmed area exceeding 10,000 km^2 (one million hectares; over 75% of the region). Of this area, about 8087.5 km^2 is utilized for grass. The remaining agricultural land is used for crops, (cereals, vegetables and horticulture; 449 km^2), rough grazing (1436 km^2), and to a smaller extent, forestry (data from 2019 [45]). There are approximately 25,000 farms in NI with some 20,000 enterprises (approximately 80%) associated with cattle, including 2600 dairy farms and 14,000 beef farms, amongst others (e.g., calf rearing, bulls etc.), [25]. There are considerable differences between production types. Almost 40% of beef herds hold fewer than ten animals, whereas 35% of dairy farms hold 100+ animals.

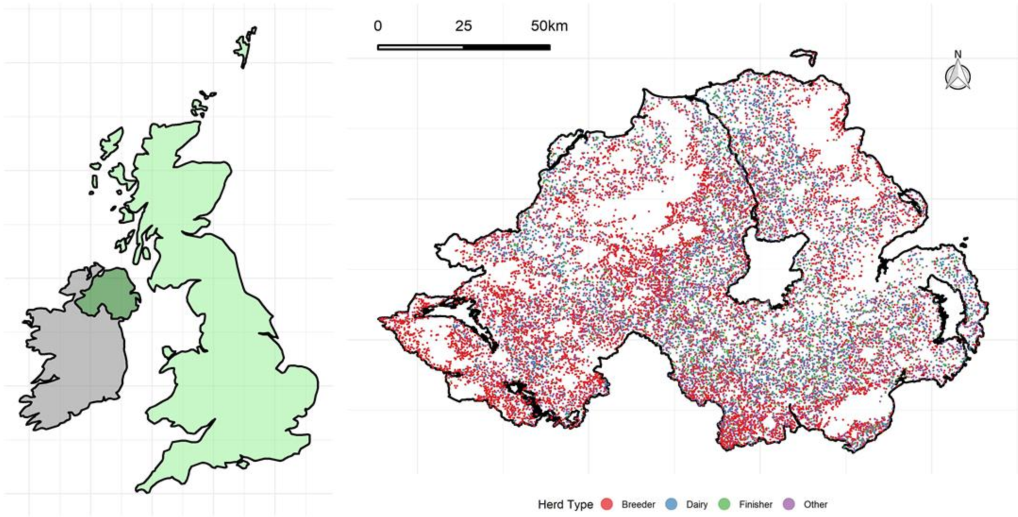

Figure 1. Distribution of cattle herds in Northern Ireland, with point locations representing the registered farmstead latitude and longitude co-ordinates.

2.2. Data Sources

Information on the individual blocks ("land parcels") was obtained from the Northern Irish Land Parcel Identification Systems (LPIS) database. The LPIS are EU mandated geospatial databases employed in the allocation of Common Agricultural Policy (CAP) payments (Council Regulation (EC) 73/2009). They offer the ability to explore land use change on national scales [7,46]. The NI LPIS database is administered by the Department for Agriculture, Environment and Rural Affairs (DAERA). The data were made available in the form of shapefiles consisting of all the land parcels in NI, along with relevant metadata including the field ID, the business owner of the field, and field size (in hectares and km^2). These layers were provided in a per-year basis from 2015 to 2017. Data on cattle enterprises in NI from 2015 to 2017 inclusive were made available from the Animal and Public Health Information System (APHIS), also administered by DAERA [47]. This database records information including business owner, herd identifier, herd size, herd locations, animal breeds, animal sex, disease status, and animal movements, including births, deaths and between-herd purchases. Land cover data for 2015 were purchased from the Centre for Ecology and Hydrology (CEH; https://www.ceh.ac.uk/, accessed 13 August 2019) in raster format at 25 m^2 resolution [48]. This dataset presents the dominant land cover from 21 target habitat classes, per 25 m^2 pixel.

2.3. Data Processing

Each land parcel polygon in the LPIS shapefile had a unique Field ID, which was mapped to a Business ID to associate individual land parcels with agricultural enterprises. Where the businesses involved cattle husbandry, the Business ID was then linked with one or more Herd ID's, which enabled the spatial data to be enriched with APHIS cattle data. Some businesses were associated with multiple herds, but it was not possible to differentiate which land parcels were used by different herds. The dataset was restricted to only include Business ID(s) and Herd ID(s) present for all three years of the study, as transient enterprises entering or leaving cattle farming may behave differently from established businesses. The analysis was further restricted to those herds populated for all three years of the study, where populated herds had at least 1 head of cattle for each year. We hereby refer to a "farm" as the combination of unique Business ID, Herd ID(s) and Field ID(s) associated with a cattle business. All data were anonymised for analytical purposes.

2.4. Defining Variables and Metrics

2.4.1. Herd Type

Determining herd types computationally is not trivial. Cattle farmers may change their business year on year depending on market conditions, or the herd may consist of several cattle classes which makes differentiation unclear. For example, breeding dairy farms may have a large number of adult female Holsteins, but may also hold adult bulls and male calves all under the one herd identifier. Furthermore, some producers may run different production types under the one herd identifier, which introduces additional complexity when determining the main business type. We therefore opted to define a necessarily broad herd_type variable. This was based on characteristics which generally represent the main specialisations of cattle farming in NI. Dairy herds were defined as those herds with a milk license, which also consisted of a majority of dairy breeds (e.g., Holsteins, Friesians), with at least 60% of the herd consisting of female animals which are at least 12 months old. Finishing herds generally operate by purchasing in stock to fatten animals specifically for slaughter—these are usually beef cattle but increasingly includes dairy animals. We defined these herds as having a minority of the herd derived from within-herd births (≤20%), with a majority of the herd sent directly to an abattoir (≥51%), along with the absence of a milking license. Breeding or suckling herds specialise in producing young animals which are usually sold onwards; these were defined by having a majority (≥51%) of the herd derived from within-herd births, and a minority (≤20%) of the herd sent to an abattoir, and the absence of a milking license. This classification primarily consists of beef suckler herds but can also include operations producing dairy animals. The remaining herds were classed as "Other", and includes mixed production types and rarer herd classifications such as breeding bulls.

2.4.2. Farmland Fragmentation

As we anticipate that the findings from this work will be used to better understand the epidemiology of cattle diseases, alongside farm efficiency and land use, we elected to use farmland fragmentation metrics common to epidemiological investigations in the UK and ROI, namely the number of land parcels/premises [40,49–51], the distance between parcels/premises [52–54], and the extent of shared boundary with contiguous farms [40,41,51]. The number of land parcels (i.e., "fields"; n_fields) associated with each farm was a count of the number of land parcels associated with the business, however a collection of individual land parcels situated together in a single functional unit was defined as a "fragment" (n_fragments). Upon visual inspection, we identified land parcels which initially appeared spatially discontinuous, but were only split by a small feature e.g., a small stream, thick hedgerow, or narrow laneway. In practice, these parcels should be considered part of the same fragment. To address this issue, a 5 m spatial buffer was applied when concatenating parcels into fragments. This distance was chosen as it is the minimum width of a narrow access road in NI and therefore any distance larger than this represents a meaningful boundary between land parcels. The total farm area in hectares (*total_farm_area_ha*) was defined as the sum of all the land parcels associated with the farm (Supplementary Material, Section S2).

2.4.3. Farm Fragment Dispersal

Fragment dispersal was the extent by which land parcel fragments were spatially separated. To measure fragment dispersal, the median distance between the centroids of all fragments was calculated (median_distance_fragments_km), along with the maximum distance between the centroids of the two most distant fragments (max_distance_fragments_km). The first metric is more general representative of general fragment dispersal, whilst the second illustrates the most extreme example of fragment dispersal on the farm. As the registered farmstead is not necessarily representative of where the land parcels are located, we measured the disparity between the registered farmstead address and the associated land parcels using three different location measures. We calculated the distance between the farmstead location from APHIS (Irish Grid reference system; latitude and longitude) and the centroid of all parcels (homestead_farmcentroid_dist_km), the centroid of the biggest land parcel (homestead_field_dist_km), and the centroid of the biggest fragment (homestead_frag_dist_km).

2.4.4. Contact with Contiguous Cattle Farms

Contact with contiguous cattle farms was measured by counting the number of parcels internal to the index farm which were potentially suitable for cattle grazing, which were contiguous to external parcels belonging to a neighbouring farm which were also potentially suitable for cattle grazing. This included only those land parcels classified as LCM 4 (improved grassland) or 5 (neutral grassland), (n_touching_cattle_fields_grazing). The total shared perimeter boundary between these contiguous land parcels was also calculated; (total_shared_boundary_grazing_km).

2.5. Data Visualisation and Statistical Analysis

2.5.1. Region-Wide Variation in Land Parcellisation and Area

Large-scale spatial variation in the number land parcels associated with cattle enterprises, and the mean land parcel size was visualised on a net of 152 regular hexagonal grid cells, with hexagon centroids 10 km apart. Assessments for changes in these outcomes across Euclidian space (via the explanatory continuous variables hexagon_centroid_lat and hexagon_centroid_long), and through time (via the categorical year_of_study variable), were carried out using Gaussian Generalised Linear Models (GLMs). The model coefficient and the 95% lower and upper confidence intervals (95%CI) were reported.

2.5.2. Farm-Level Variation

Herd-level metrics of farmland fragmentation, fragment dispersal, contact with neighbouring farms, and LCM classifications, were presented as summary data with measures of precision (median and Inter-Quartile Range; IQR). We also tested for associations between production type and farmland fragmentation, fragment dispersal, contact with neighbouring farms, farm area and LCM classifications using linear-by-linear chi-square test for ordered categorical variables [55], and GLMs for continuous outcomes.

All data were managed in MS SQL 2016 and analysed using R version 3.3.4 [56]. All GIS processing was carried out in the R statistical programming environment, using the packages raster [57], rgdal [58] and regeos [59]. Figures were constructed using ggplot2 [60], and Chi-Squared tests were carried out using coin [61]. Due to GDPR concerns, we are unable to make the underlying research data available, however we have included the code and results generated in this analysis as a Supplementary Material R Markdown file (Supplementary Material).

3. Results

3.1. Descriptive Statistics

The total number of land parcels in NI per-year was 736,866 (SD = 355). Approximately 70% of these were associated with cattle businesses (mean per-year = 516,798; SD = 1352). The dataset initially contained 24,495 Business ID's and 26,741 Herd ID's. After the removal of businesses and herds which were not present or populated for the whole of the study period, the final number of Business ID's was 17,744 (72%), and the final number of Herd ID's was 19,008 (71%). As relevant metrics were generated for each of the 19,008 herds for the three years 2015–2017, there were 57,024 total observations. Between year variation was negligible at the farm level for the contact metrics (Supplementary Material, Section S2), and we therefore report most data aggregated across the three years of the study.

3.2. Region-Wide Variation in Land Parcellisation and Area

Figure 2A,B illustrates the region-wide differences in land parcellisation and land parcel area. A negative relationship was detected between the number of land parcels per-cell and latitude (south to north) with 16 fewer land parcels on average for every 1 km increase in latitude (GLM Coef. = −16.04, 95%CI: −19.20, −12.88). There number of land parcels decreased with longitude, with three fewer land parcels per 1 km increase east to west (GLM Coef. = −3.24, 95%CI: −0.45, −6.01). Land parcel size was observed to increase marginally by 0.009 ha per 1 km increase in latitude (GLM Coef. = 0.009, 95%CI: 0.007, 0.01), but there was no observable relationship with longitude (GLM Coef. = 0.0007, 95%CI: −0.005, 0.002). Although there was a small increase in the total number of land parcels recruited into cattle farming through the study period (2015, *n* parcels = 516,060; 2017, *n* parcels = 518,359), there was no evidence of significant variation between years (GLM, compared to null model using ANOVA, F = 0.01, df = 2, $p = 0.99$).

3.3. Farm-Level Variation in Farmland Fragmentation

3.3.1. Herd Characteristics

In 2015, 49.8% of herds were classed as breeding (*n* = 9464), 14.4% (*n* = 2740) were dairy, 10.4% were finishers (*n* = 1970) and 25.4% were classed as "other" (*n* = 4834); this remained broadly consistent in all years of the study (Supplementary Material, Section S1). The vast majority of businesses (93.3%) were associated with a single cattle herd.

3.3.2. Farmland Fragmentation

The median number of land parcels per-farm was 24 (IQR: 14–39; max = 444), organized into 6 fragments (IQR 4–10; max = 81), which dropped to 3 fragments after the application of the 5 m buffer (IQR: 2–6; max = 47). In 2015, over 16% of cattle farms (*n* = 3134) consisted of a single fragment, whilst 35% of farms (*n* = 6755) were comprised of five or more fragments (Table 1); this did not vary notably during the three years of the study. To investigate whether farmland fragmentation varied by farm area, farms were categorised by size on the basis of percentiles. Farms with total areas < 16.4 ha (25th percentile) were classed as "small", farms ≥ 16.4 ha ≤ 59.1 ha (75th percentile) were classed as "medium" and farms larger than 59.1 ha were classed as "large". An ordinal relationship between farmland fragmentation and farm area was detected (Linear-by-Linear Association Test, Z = 118.73.1, $p < 0.001$), with larger farms exhibiting greater fragmentation, Figure 3A. Out of all the non-fragmented farms, some 53% (*n* = 4995) were classified as small, compared to 0.1% (*n* = 17) of farms classed as very highly fragmented. Conversely, 4.3% (*n* = 405) of non-fragmented farms were classified as large, compared to 81% (*n* = 2710) of very highly fragmented farms (Supplementary Material, Section S3.1.1, Table S3). The median distance between the registered homestead and the farm centroid (i.e., all parcels) was 0.67 km (IQR: 0.27 km–1.71 km, max = 112.8 km). Similar values were obtained for the distance between the homestead and largest land parcel only; 0.69 km (IQR: 0.31 km–2.07 km, max = 127.5 km), whilst the distance between the farmstead and the largest fragment was 0.47 km (IQR: 0.22 km–1.58 km, max = 127.5 km).

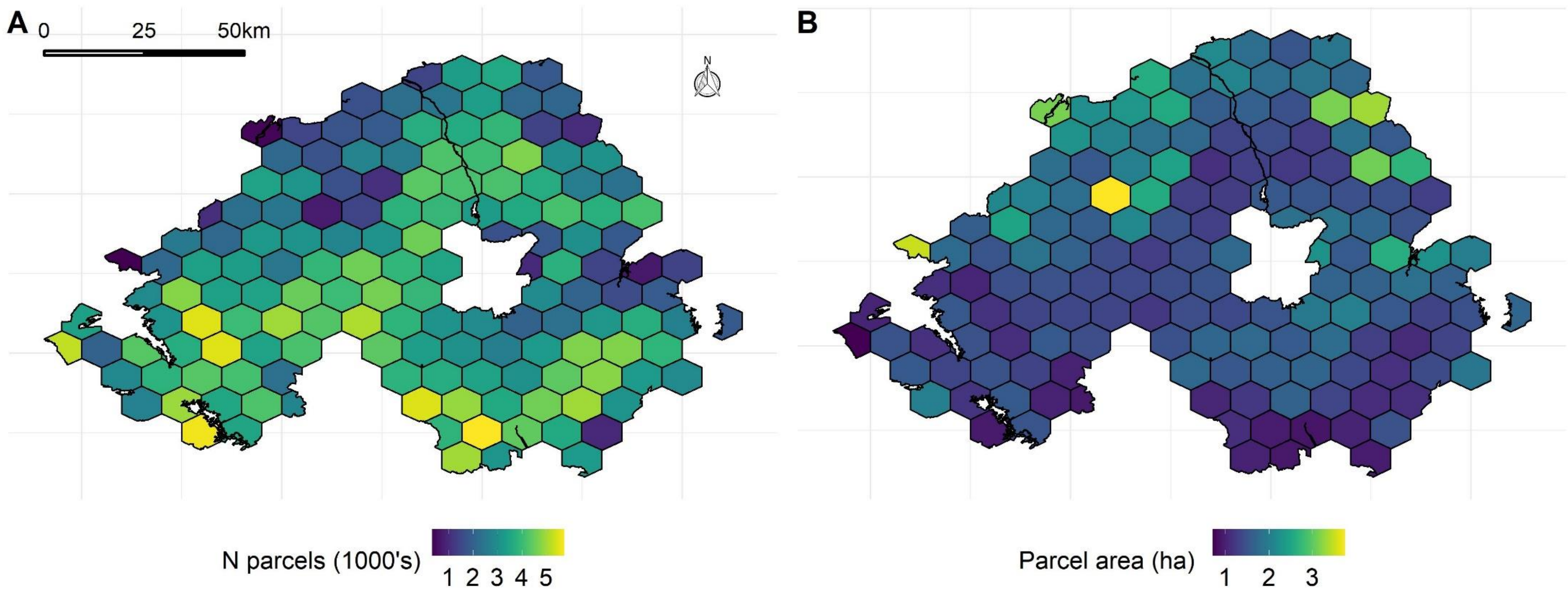

Figure 2. Hexagon plots showing (**A**) the number of land parcels associated with cattle farming per 10 km hexagon cell, and (**B**) the mean area of land parcels associated with cattle farming per 10 km hexagon cell.

Table 1. The degree of farmland fragmentation in Northern Ireland for 19,008 farms throughout the three study years 2015–2017.

N. Fragments Per-Farm	Description	2015	2016	2017	All Years
1	No fragmentation	3134 (16.5%)	3178 (16.7%)	3164 (16.7%)	9476 (16.6%)
2–4	Little fragmentation	9119 (48.0%)	9041 (47.6%)	9004 (47.4%)	27,164 (47.6%)
5–7	Medium fragmentation	4137 (21.8%)	4114 (21.6%)	4102 (21.6%)	12,353 (21.7%)
8–10	High fragmentation	1546 (8.1%)	1574 (8.3%)	1571 (8.3%)	4691 (8.2%)
11+	Very high fragmentation	1072 (5.6%)	1101 (5.8%)	1167 (6.1%)	3340 (5.9%)
Total		19,008	19,008	19,008	57,024

3.3.3. Fragment Dispersal

The median distance between fragments was 1.38 km (IQR: 0.52 km–3.05 km, max = 120.0 km), and was categorised using percentiles, following the approach taken to categorise farm area. Farms with fragments less than 0.52 km apart on average (25th percentile) were classed as "low dispersal"; farms with fragments $\geq$0.52 km and <3.05 km apart were classed as "medium dispersal", and farms with fragments >3.05 km apart (75th percentile) were classed as "high dispersal". Fragment dispersal was positively associated with farmland fragmentation (Linear-by-Linear Association Test, Z = 121.69, $p < 0.001$), (Figure 3B). The maximum distance between fragments differed only marginally to the median distance between fragments, at 2.32 km (IQR: 0.64 km–6.09 km, max = 152.0 km), with a strong, significant positive correlation between both variables (r = 0.93). Whilst 100% (n = 9476) of non-fragmented farms exhibited low dispersal (i.e., no dispersal in this instance), 50% (n = 1683) of very highly fragmented farms where characterised by highly dispersed fragments (Supplementary Material, Section S3.1.2, Table S5).

3.3.4. Contact with Contiguous Farms

The average cattle farm was in contact with 47 land parcels (IQR: 28–76) associated with other cattle farms. Restricting this to only include both internal and external land parcels suitable for cattle grazing (i.e., LCM 4 and 5) resulted in contiguous contact between 13 land parcels (IQR: 7–21), equivalent to a shared perimeter of 2.84 km (IQR: 1.48 km–4.94 km). After categorising this variable using percentiles as "contact level" (low contact < 1.48 km, medium contact $\geq$ 1.48 km $\leq$ 4.94 km, high contact > 4.94 km), a positive relationship between farmland fragmentation and contact category was identified (Linear-by-Linear Association Test, Z = 125.63, p <0.001), Figure 3C. Some 55% of non-fragmented farms (n = 5194) were classified as low contact with external farms, with only 1.8% classed as high contact (n = 170). The opposite was observed for very highly fragmented farms, however, with 1.9% (n = 62) classed low contact and 82% (n = 2741) classed as high contact (Supplementary Material, Section S3.1.3, Table S7).

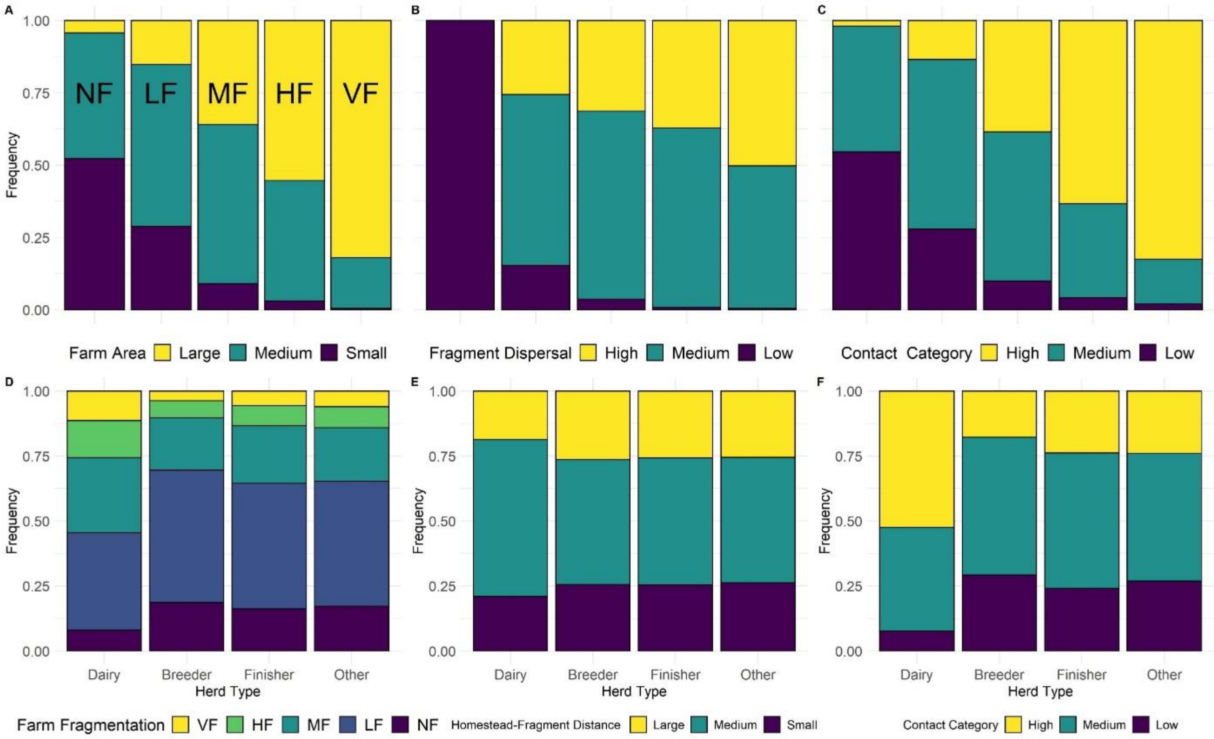

Figure 3. The relationship between (**A**) farmland fragmentation and farm area, (**B**) farmland fragmentation and dispersal, and (**C**) farmland fragmentation and exposure to other farms (via shared perimeter). Farmland fragmentation levels on the *x*-axis are Not Fragmented (NF); Little Fragmentation (LF), Medium Fragmentation (MF); High Fragmentation (HF); Very High Fragmentation (VF). The relationship between (**D**) farmland fragmentation and production type, (**E**) fragment dispersal and production type, and (**F**) exposure to other farms (via shared perimeter) and production type.

3.4. The Variation of Fragmentaton, Dispersal and Contact with Production Type

At 65 ha (IQR: 42 ha–100 ha), dairy farms occupied almost twice the area of finisher farms (32 ha; IQR: 17 ha–58 ha) and almost three times the area of breeder farms (26 ha, IQR: 15 ha–46 ha). Dairy farms also had almost twice as many land parcels (39; IQR: 27–56) as any of the other herd types (Table 2) and indeed, some 11.4% of dairy farms were very highly fragmented, compared to 5.7% of finisher farms and 3.8% of breeder farms (Figure 3D, Supplementary Material Section S3.2.1, Table S8). There was no evidence that the number of fragments varied at the farm level varied through the three years of the study (GLM, compared to null model using ANOVA, F = 2.10, df = 2, p = 0.12; Supplementary Material, Section S2.2.1). When the analysis was restricted to dairy herds, however, a marginal increase was observed in the number of land parcels per farm (2015, median number of parcels = 39; 2017, median number of parcels = 40, Supplementary Material, Section S3.2.2). No other clear trends regarding the number of land parcels and herd-types were observed. The land fragments in dairy farms were more dispersed than in other production types on average, however the maximal distances between fragments was seen in finisher herds, where distances of 152 km between fragments were recorded (Table 2, Supplementary Material, Section S3.2). When comparing the distance between the homestead and the largest fragment, dairy farms were slightly closer than other herd types, although the real differences in the distances involved were small (Table 2, Figure 3E). There were twice as many fields, and twice as much perimeter in contact with contiguous farms in dairy herds than for other production types (Table 2, Figure 3F).

Table 2. Measures of farmland fragmentation, fragment dispersal, farm contact and land classification associated with different production types. The test statistics refer to Kruskal–Wallis Chi-squared tests.

Variable	Herd Type	Min	Q1	Med	Q3	Max	X2	(*p*)
total_farm_area_ha	Breeder	0.00	15.00	26.00	46.00	1418	6621	$p < 0.001$
	Dairy	2.00	42.00	65.00	100.00	1973		
	Finisher	2.00	17.00	32.00	58.00	1007		
	Other	0.00	14.00	28.00	57.00	3252		
n_fragments	Breeder	0.00	3.00	6.00	9.00	81.00	4310	$p < 0.001$
	Dairy	1.00	7.00	11.00	15.00	81.00		
	Finisher	1.00	4.00	6.00	10.00	58.00		
	Other	0.00	4.00	6.00	10.00	81.00		
n_fragments_5m	Breeder	0.00	2.00	3.00	5.00	35.00	2117	$p <0.001$
	Dairy	1.00	3.00	5.00	8.00	33.00		
	Finisher	1.00	2.00	3.00	6.00	32.00		
	Other	0.00	2.00	3.00	6.00	47.00		
median_distance_fragments_km	Breeder	0.00	0.43	1.21	2.95	120.00	670	$p < 0.001$
	Dairy	0.00	1.04	1.88	3.21	97.09		
	Finisher	0.00	0.50	1.34	3.04	82.97		
	Other	0.00	0.47	1.36	3.05	105.15		
max_distance_fragments_km	Breeder	0.00	0.50	2.00	5.50	129.10	1129	$p < 0.001$
	Dairy	0.00	1.70	3.80	7.40	117.2		
	Finisher	0.00	0.60	2.20	6.00	152.00		
	Other	0.00	0.60	2.20	6.10	117.50		
homestead_fragment_distance_km	Breeder	0.01	0.22	0.49	1.71	120.83	14.96	$p = 0.002$
	Dairy	0.01	0.25	0.44	1.11	114.34		
	Finisher	0.00	0.22	0.44	1.70	127.54		
	Other	0.00	0.22	0.47	1.64	109.33		
total_shared_boundary_grazing_km	Breeder	0.00	1.29	2.46	4.13	33.30	4702	$p < 0.001$
	Dairy	0.00	3.12	5.14	7.81	44.10		
	Finisher	0.00	1.53	2.85	4.84	33.52		
	Other	0.00	1.39	2.69	4.85	28.57		

4. Discussion

Our results confirm the presence of highly parcellised land, with over 5000 individual land-parcels per 10 km in some areas. We observed a general trend of increased parcellisation in the south of NI compared to the north, concurrent with increasingly smaller land parcels. This is primarily a function of land quality; the land in the south of NI is understood to offer better grazing land than in the north of NI, and farmers can therefore afford to raise cattle on smaller parcels [29]. This pattern also reflected in the greater number of cattle farms in the south of NI compared to the north of the region [29]. Given that the north of NI is less suitable for grazing and conversely, more suited to arable production, the reduced parcellisation in the north of NI could also potentially reflect a historical legacy of hedgerow removal to facilitate efficient crop production.

Until now, our understanding of the degree of fragmentation in Northern Irish cattle farms was largely limited to a few highly localised epidemiological studies and reports [39–42]. We found that fragmentation was extensive, with 35% of herds residing on farms consisting of 5 or more fragments. This is comparable to the Byrne et al. study from the ROI where 32% of herds resided on farms consisting of 5 or more fragments [49], but contrasts against metrics reported in GB. For example, Broughan et al. found that only 5.5% of sampled farms were comprised of five or more fragments [62], whereas Brennan et al. (2008) reported that only 2 out of 56 farms (3.5%) had four or more premises [51]. We also found that only 16% of NI cattle farms exhibited no fragmentation, compared to 53% of GB farms [62]. Our fragment dispersal analysis shows that in 75% of Northern Irish cattle farms, the median distance between fragments was 3 km or less, notwithstanding that maximal distances of up to 152 km were also observed. To place this into the spatial context, this distance is representative of parcels located at the two most distal points in the region. Generally, however, the median distances between parcels were comparatively less than observed in GB, where in 12.4% of farms, the nearest fragment was greater than 8.2 km away [62]. We also find that the average cattle farm in NI has 13 contiguous neighboring fields suitable for cattle farming, compared to data reported by Brennan et al., who reported an average of 7.2 contiguous fields [51]. One possible factor contributing to elevated farmland fragmentation in NI compared to GB may be attributed to the conacre land rental system unique to the island of Ireland, which allows farm businesses to rent grazing land without entering into a long-term agreements.

4.1. The Variation of Fragmentaton, Dispersal and Contact with Production Type

Our principal finding was that farmland fragmentation varied considerably with production type; higher levels of farmland fragmentation, fragment dispersal and contact with contiguous neighbours were observed in dairy production than in non-dairy cattle farms. This was an unexpected finding because animals used for milking are expected to be kept in close proximity to the home farm. We propose that the presence of highly fragmented dairy farms may be associated with a rapid expansion of the dairy sector, linked to the abolition of the milk quota system in 2015, to allow dairy farmers in the EU to produce as much milk as they can after 31 years of quota restriction [63]. Although the quota was not binding in NI towards the end of the quota years, the study by Adenuga and Davis [63] has shown that the abolition of the milk quota system has varying effects on different farm types, so that the larger farm types have greater tendency to expand compared to the smaller farm types. This may provide an explanation for our results, where we found that larger farms tended to be more fragmented than smaller farms. Specifically for dairy farms, the drive to take advantage of the milk quota abolition may have resulted in greater fragmentation of land. Thus, the largest fragment is the original land near the premises, but as the farm has expanded, more distal parcels are assimilated as they become available, despite their distance from the original holding. Our results are in line with those previous studies where it was found that the level and type of farmland fragmentation can be influenced by the type of enterprise, and the level of market activity in the sector [11,64]. An alternative explanation for the high levels of fragmentation in dairy farms lies in how the herd is distributed across land parcels. Many dairy herds consist of different groups of animals including calves, heifers, or bulls, and not just milking cows. A localised study in the South East of NI found that milking dairy cows were only grazed on land parcels connected to the main premises throughout the grazing season, however, dairy calves, heifers, and bullocks were grazed on the fragmented land parcels, possibly because those life stages would not require as many interventions as milking cows [40]. Indeed, our present study found that despite overall higher levels of fragment dispersal in dairy farms, the distance between the homestead and the largest fragment was smaller for dairy herds than all herd types, suggesting a nucleus of land parcels in the proximity of the main premises. This study by Campbell et al. also identified a statistically significant difference in the amount of time beef and dairy herds spent grazing on fragmented land (47% and 41% of grazing days, respectively). Thus, whilst dairy farms themselves are more fragmented than beef farms, the main milking herd may not necessarily be routinely grazed on distal fragments.

4.2. Farmland Fragmentaton and Efficiency

Highly fragmented land may limit increases in herd size; it is already noted that herd sizes in NI are generally smaller than those in GB, and larger producers may have more bargaining power than smaller ones. Thus, in 2012, only 24% of slaughtered finishing cattle in NI originated in herds with more than 501 animals. In GB, the equivalent figure was 29% [65]. Farmlands in NI are already small in size compared to farms in other regions of the UK, and further parcellisation resulting from extreme farmland fragmentation may make the land less accessible for mechanization, which could consequently have a limiting effect on agricultural productivity and sustainable farm management. Specifically, farmland fragmentation could reduce both labour and land productivity through change in the marginal output of agricultural inputs, as well as increase agricultural production costs, for example, through additional transport cost in moving between parcels, time taken to move cattle between parcels, and increasing the logistical complexities of herd management across multiple fragments of land (e.g., rounding up animals for routine disease testing). These can all directly affect agricultural production and farm profitability. The fragmentation of farmland can also have consequences for the social fabric of the rural landscape and the environment, especially in relation to loss of biodiversity [6,23]. Already, sixty-nine percent of the total agricultural area farmed in the region is categorised as "less favoured", compared to 51 percent for the rest of the UK, and 61 percent for the EU15. Further farmland fragmentation in the region without adequate structural adjustments may therefore present a significant challenge for the long- term sustainability of the cattle industry. This therefore supports the need for the development of an appropriate rural area strategy that focuses on efficient land use patterns among dairy farmers.

It is important to stress that this study is not without its limitations. Whilst every effort was made to ensure that herd types were appropriately classified based on production practices, the potential for classification bias still remains. This is most likely to impact non-dairy herds, however given that the general findings were similar for all non-dairy herd types, the impact on the conclusions are minimal. Another limitation of the study is that it is impossible to know which land parcels are actually utilised for cattle grazing. Whilst we have some understanding of this at a small scale [40], it is not possible to assess whether these findings can be generalised to the entirety of NI. Undoubtedly, there are expansive farms in this study which utilise only a small component of their holdings for cattle grazing. Furthermore, it is not possible to assess what land has been rented out as conacre. Further research is needed to explore ways by which farmland fragmentation can be reduced, and to better understand the role of the land rental market in farmland fragmentation. Future studies may also include exploring the structural causes underlying the process of farmland fragmentation.

5. Conclusions

An explicit understanding of the degree of farmland fragmentation is essential for promoting sustainable farmland utilization by optimizing farmland use structure, and improving land use efficiency. Our data reveals high levels of farmland fragmentation that correspond to observations in the ROI, but are higher than observed in GB. Our study also shows that notable differences exist in the degree of farmland fragmentation across the various types of cattle enterprise. Specifically, we found that dairy farms are more fragmented when compared to the other cattle enterprise types. We propose that this may be in part due to the abolition of the milk quota in 2015, which has contributed to the recent expansion of the dairy sector in NI. Our findings have implication for land use policy development, and we argue that these results will be useful in designing appropriate policy to promote economic viability of rural areas through maintaining efficient use and distribution of farmlands, to ensure farm productivity improvement as well as maintaining biodiversity and habitat heterogeneity in rural areas of NI. This study presents a farmland fragmentation dataset for the entirety NI, which will be particularly useful for further exploring the impact of farmland fragmentation and pasture connectivity on livestock disease, agricultural efficiency and productivity.

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