Estimation of the size, density, and demographic distribution of the UK pet dog population

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Article

Keywords:

Posted Date: January 23rd, 2024

DOI: https://doi.org/10.21203/rs.3.rs-3772889/v1

Additional Declarations: No competing interests reported.

Abstract

There is limited knowledge about the size of the UK dog population. This makes it difficult to reliably monitor changes in overall population size and characteristics, or the dynamics of dog supply and movement. A repeatable method of measuring the UK dog population would help inform interventions to reduce risks to dog welfare such as poor breeding practices and the illegal import of young or pregnant dogs. However, estimating the total dog population in the UK is not straightforward. Although several estimates of dog numbers have been previously suggested, differing methodologies and limited public access to data sources makes comparison and replication difficult.

In this study, we compiled a comprehensive dataset of UK pet dogs from multiple sources, including breed registries, veterinary corporations, pet insurance companies, animal welfare charities, and academic institutions. Using a hierarchical Bayesian N-mixture model, we estimate 12.64 million (95% CI 8.54-15.16 million) pet dogs within the UK in 2019. Estimates were modelled at the postcode area scale, allowing for aggregation to region or country level, as well as providing associated metrics of uncertainty. Furthermore, we provide spatial demographic estimates, regarding age, breed, cephalic index, and body size.

Establishing a population baseline offers significant analytical benefits to welfare, veterinary, epidemiological, and business stakeholders alike: as it provides the spatial data required to underpin robust canine welfare strategies and campaigns.

Introduction

Dogs are the most popular pet within the United Kingdom (UK), with 31% of households owning at least one dog[1]. Despite this, we have limited knowledge regarding the total canine population size. Accurate estimates of population size, and how dog numbers vary geographically, are vital for understanding total 'market size' within the pet industry, as well as how demand for dogs and/or puppies vary across in both space and time.

Increasing consumer demand for dogs[2,3], and the associated financial benefits for those selling puppies[4,5] has led to several practices that have negative impacts on dog welfare. These include: the sale of puppies bred in large-scale establishments with unsuitable environments with regards to health and behavioural development; legal and illegal international transportation of puppies with associated welfare and disease transmission risks; and sales through online advertising. The latter provides an ideal platform for sellers to prosper from impulse and/or poorly planned purchases, whilst simultaneously accommodating two-way anonymity[4,6–12]. These factors, coupled with a naïve consumer market, has led to experts' warning of a canine welfare crisis[13,14]. To understand the UK pet dog 'market', including factors that influence supply, the first step is to reliably quantify the UK pet dog population.

Estimating the total population size of dogs within any geographical context is not straightforward, in part due to a lack of comparable and accessible datasets[15]. Though several UK estimates have been put forward in recent years, details of methodological approach and data sources are generally not been made publicly available. This makes comparisons across studies difficult, as well as limiting reproducibility of results. Most estimates to date have been survey based. UK Pet Food (previously Pet Food Manufacturing Association) have provided annual rolling population totals from 2011–2023. Between 2019–2020 (comparable timeframe to this research), the UK Pet Food estimate was 9.0 million[16]. Estimates for 2021, 2022, and 2023 have been reported as 12.0, 13.0 and 12.0 million, respectively. However, due to the following methodological changes, it is not possible to compare current data with data sourced prior to 2021: 2011–2020 surveys carried out face-to-face with a sample size of 4,203-8,353 households per year, whilst 2021–2023 surveys were conducted online, with a sample size of ~ 9,000 households[1,16]. Furthermore, evaluating the accuracy of UK Pet Food estimates is difficult, as they lack associated metrics of uncertainty, and exact methodologies are not made publicly available (e.g., sampling, geographic coverage, and estimations). Given the historical knowledge gap, this estimate has been hugely valuable for many industries. Nonetheless, the methods remain limited in scope. For example, the Office for National Statistics estimated 27.8 million UK households in 2019[17], which equates to a UK Pet Food sampling rate of ~ 0.03% of the UK's total households between 2019–2020 (n = 8000), or ~ 0.01% per year.

Based on public surveys, other previous estimates have varied between 10.5–11.5 million[18,19]. However, as surveys are costly initiatives, reliant on active marketing strategies, participant numbers and/or geographic coverage remain limited due to financial constraints. The limited absolute and spatially explicit sample sizes may have led to these surveys resulting in unreliable population estimates. In 2011, Asher et al.[20] approached this challenge from a fresh perspective: by identifying and including three external data sources that enriched public survey data, providing four distinct estimates based on varying combinations of data sources. Despite broadening the data pool, the authors suggested that the most reliable estimate was based on public survey data alone, at 9.4 million. This judgement was based on the potential under- and over-estimate of the population, when incorporating a combination of public survey and insurance records, or public survey and veterinary surveys, respectively[20]. Since then, no further research has built upon this important study (however, see [21]).

To provide an independent and more robust estimate of total dog population size, along with details of spatial demographics, we developed a research infrastructure of 18 project participants, including breed registries, veterinary corporations, pet insurance companies, animal welfare charities, and academic institutions. Data were combined to generate a robust and distinct estimate of the UK pet dog population across multiple spatial scales, to ensure greatest applicability for researchers/stakeholders. We applied a hierarchical Bayesian N-mixture model to estimate population sizes in a mark–recapture framework, using human population density data to improve precision of our estimates (as pet dogs are inherently located with owners). The advantage of this approach is that we model population size at the scale of postcode area, which can then be compiled to provide regional or country level population estimates, as well as associated metrics of uncertainty. Furthermore, spatial demographic details, regarding age, breed, cephalic index (brachycephalic, mesocephalic and dolichocephalic) and body size (large, medium, and small), can be calculated by extracting proportions from the raw data and used to partition the regional and country level population estimates.

Establishing a UK pet dog population baseline offers significant analytical benefits to welfare, veterinary, epidemiological, and business stakeholders alike: as it provides the spatial data required to underpin robust canine welfare strategies and campaigns.

Results

Dogs Trust data were combined with datasets sourced from 17 external project participants. Data sources included breed registries (45.0%), veterinary corporations (26.5%), pet insurance companies (17.1%), animal welfare charities (5.9%), and academic institutions (5.5%). Project participants who provided data to this project include: Battersea Dogs and Cats Home; Blue Cross; SSPCA; Raystede; Wood Green, The Animals Charity; Edinburgh Dog and Cat Home; PDSA; Mayhew; The Insurance Emporium (The Equine and Livestock Insurance Company Limited); NCI Insurance; Cardif Pinnacle; Agria Pet Insurance Ltd; Direct Line; Medivet; Vets4Pets; Savsnet (Small Animal Veterinary Surveillance Network, University of Liverpool); and The Kennel Club (UK). Prior to removal of duplicate individuals and those aged > 18.3 years[22] (see *Methods* for data cleaning and deduplication details), merged data included 12,348,414 million dogs.

Within the raw data, a 1.04:1 male skew was evident (n = 2224732, n = 2139057), along with a 6:1 ratio of pure (n_E = 3694017) to crossbred individuals (n_X = 613079). Following data cleaning and deduplication, the dataset included 4,375,861 million dogs: suggesting that, on average, individual dogs were sampled 2.82 times across data sources. Data represented 332 different purebreds[23,24] and 1071 crossbreds, incorporating: 'Mix Breed' i.e., lineage unknown or > 2 parental breeds; 'Breed X x Breed Y'; or 'Breed X Cross/Type'. Microchip numbers were reported for 50.3% of dogs (n = 2201805), and 0.02% of dogs had > 1 microchip numbers attached to their record (n = 860).

Population estimate

Using a hierarchical Bayesian approach accounting for imperfect detection probability, we estimated 12.64 million (95% CI 8.54–15.16 million) pet dogs within the UK in 2019. Our estimates were compared to two existing datasets: (A) previous dog population per postcode estimate[25] and (B) human population per postcode[26] (Supplementary Fig. 1). Modelled estimates per postcode area agreed with the previous empirical estimate ($p < 0.001$), with estimates both above and below modelled densities, suggesting an absence of bias in the predictions at extreme scales (i.e., small and large populations). This advocates for reliable regional and/or country level estimates, as these represent aggregated small-scale observations (Supplementary Fig. 1A). An asymptotic exponential function was expected and evident between dogs per postcode and human population density (Supplementary Fig. 1B).

Within the 12.64 million, 82.9% (n = 10,486,868) were estimated to reside in England, 2.1% in Northern Ireland (n = 266,367), 9.1% within Scotland (n = 1,155,625) and 5.8% within Wales (n = 733,714). Regional population estimates are listed in Table 1 and visualized in Figs. 1 and 2. Over half of the UK dog population were located within the following 5/24 regions: South East England, North West England, East England, South West England and Yorkshire and The Humber. Predicted densities per postcode are visualized in Fig. 3 (see Supplementary Table 1 and Supplementary Fig. 2, for predicted values). Mean dogs per capita, per postcode, are presented in Fig. 4, with values and 95% credible intervals presented within Supplementary Table 2 and Supplementary Fig. 3. The greatest density of dogs per capita are located within: Telford, Darlington, Swansea, Harrogate, Llandrindod Wells and Sunderland. The lowest densities are located within 6 areas of London (London East, London Western Central, London Northern, London West and Paddington, London South Western and London Southall).

Table 1
Regional population estimates, ranked by population distribution (%).

Country	Region	Predicted Population Estimate	Proportion of UK Population (%)
England	Isle of Man	15520.46	0.1
Wales	Mid Wales	17965.07	0.1
England	Channel Islands	25684.64	0.2
Scotland	West Scotland	59596.50	0.5
Scotland	Highlands and Islands	71937.63	0.6
Scotland	Mid Scotland and Fife	119420.58	0.9
Wales	North Wales	125664.53	1.0
Scotland	Central Scotland	171967.22	1.4
Scotland	Glasgow	176846.42	1.4
Scotland	North East Scotland	177275.57	1.4
Scotland	Lothian	177538.97	1.4
Scotland	South Scotland	201042.12	1.6
Northern Ireland	Northern Ireland	266366.69	2.1
Wales	West Wales	272934.76	2.2
Wales	South Wales	317149.43	2.5
England	East Midlands	712073.71	5.6
England	North East England	757136.28	6.0
England	London	934592.18	7.4
England	West Midlands	1131374.62	8.9
England	Yorkshire and The Humber	1248692.27	9.9
England	South West England	1255197.70	9.9
England	East England	1309538.56	10.4
England	North West England	1480628.38	11.7
England	South East England	1616429.67	12.8

Table 2
Country-level estimates for proportional age demographics (%). Age group (AG) predicted population estimate, per country, and associated proportional age group demographics both within (($N_{AG, country}/N_{country}$)*100) and between countries (($N_{AG, country}/N_{total\ AG}$)*100). Example: 15.9% of England's population is within the geriatric development period ('within country') and 83.3% of the UK geriatric population can be found within England ('between countries').

Country	Age Group	Predicted Population Estimate	Proportion WITHIN Country (%)	Proportion BETWEEN Countries (%)
England	Geriatric	1666510.22	15.9	83.3
Northern Ireland	Geriatric	45087.37	16.9	2.3
Scotland	Geriatric	169554.96	14.7	8.5
Wales	Geriatric	119948.62	16.3	6.0
England	Senior Adults	3464050.08	33.0	82.6
Northern Ireland	Senior Adults	103501.47	38.9	2.5
Scotland	Senior Adults	376283.1	32.6	9.0
Wales	Senior Adults	249816.03	34.0	6.0
England	Mature Adults	4082599.09	38.9	83.1
Northern Ireland	Mature Adults	88025.55	33.0	1.8
Scotland	Mature Adults	466961.86	40.4	9.5
Wales	Mature Adults	277568.4	37.8	5.6
England	Young Adults	890976.62	8.5	82.8
Northern Ireland	Young Adults	20910.21	7.9	1.9
Scotland	Young Adults	101189.27	8.8	9.4
Wales	Young Adults	63228.96	8.6	5.9
England	Juveniles	283332.9	2.7	83.5
Northern Ireland	Juveniles	6908.73	2.6	2.0
Scotland	Juveniles	31094.75	2.7	9.2
Wales	Juveniles	18107.53	2.5	5.3
England	Puppies	99399.54	0.9	85.0
Northern Ireland	Puppies	1933.35	0.7	1.7
Scotland	Puppies	10541.06	0.9	9.0
Wales	Puppies	5044.26	0.7	4.3

Age demographics

The UK canine age distribution in 2019 were: geriatrics 15.8% (n = 1,998,180; ≥12 years), senior adults 33.2% (n = 4,193,073; 7 to < 12 years), mature adults 38.9% (n = 4,917,441; 2 to < 7 years), young adults 8.5% (n = 1,077,512; 12 to < 24 months), juveniles 2.7% (n = 339,548; 6 to < 12 months), and puppies 0.9% (n = 116,821; 0 to < 6 months). Age categories sourced from [27]. Thus, 49% of the UK pet dog population was estimated to be within their senior or geriatric developmental period.

Proportional estimates for age demographics both within and between countries, are listed in Table 2. The greatest national proportion of geriatric and senior adult dogs was observed within Northern Ireland, contributing 16.9% and 38.9% of their total population, respectively. Scotland had the greatest national proportion of mature adult dogs at 40.4%. There was little within-country variation regarding proportional demographics of juveniles (range: 2.5–2.7%), puppies (range: 0.7–0.9%) and young adults (range: 7.9–8.8%). Between countries, England was found to home 82.6–85% of individuals within all age groups, followed by 8.5–9.5% in Scotland, 4.3-6.0% in Wales and 1.7–2.5% in Northern Ireland (Table 2).

Variation in demographics were evident within and between regions (Fig. 2; Supplementary Table 3). Regional demographic proportions varied most for mature adults (range: 33.0-42.8%), with Northern Ireland representing the lowest proportion and West Scotland representing the greatest. Geriatric and senior adult regional proportions also varied, ranging from 11.7% in West Scotland to 19.2% in West Wales, and 31.7% in the Highlands and Islands to 38.9% in Northern Ireland, respectively. Regional proportions of younger age groups did not vary as widely: young adults 7.6–9.9%; juveniles 2.1-3.0%, and puppies 0.4–1.1%. Between regions, South East England was found to home 12.0-13.5% of individuals within all age groups, followed by 10.7–13.2% in North West England, 9.9–10.7% in East England, 9.4–10.5% in South West England and 9.3–10.4% in Yorkshire and The Humber. The remaining 19 regions did not home > 10% of any age group (Supplementary Table 3).

Breed popularity

Across the UK, an estimated 85.8% of the population were listed as purebred[23,24] (n_E = 10843010), whilst 14.2% were listed as crossbred (n_X = 1799564). Estimated ratios between pure and crossbred dogs varied between countries: England = 6.04:1 (n_E = 8997180, n_X = 1489689); Northern Ireland = 8.3:1 (n_E = 237680, n_X = 28687); Scotland = 7.8:1 (n_E = 1024710, n_X = 130915); and Wales = 8.1:1 (n_E = 653360, n_X = 80354). UK proportional breed demographics for purebreds and crossbreds are listed in Supplementary Table 4 and Supplementary Table 5, respectively.

The top 15 purebreds include: Labrador Retriever (10.2%), Cocker Spaniel (6.9%), Staffordshire Bull Terrier (4.7%), English Springer Spaniel (4.3%), German Shepherd (3.5%), French Bulldog (3.4%), Golden Retriever (2.7%), Pug (2.7%), Border Terrier (2.5%), Shih Tzu (2.4%), Cavalier King Charles Spaniel (2.4%), Jack Russell Terrier (2.4%), Bulldog (2.4%), West Highland White Terrier (2.1%) and Boxer (2.1%) (Supplementary Table 4). However, variation in purebred popularity was evident between countries (Supplementary Table 6). England exhibited the greatest diversity of purebreds, representing 98.5% of the available purebred variation within the data (n = 327). Northern Ireland, Scotland and Wales represented 68.1% (n = 226), 79.2% (n = 263) and 75% (n = 249) of purebred variation, respectively.

Population estimates for the top 30 purebreds within the UK, and across countries, are presented in Fig. 5 (Supplementary Table 6). Within this top 30, 16.7% (n = 5) were classified as large breeds, 20% were medium sized, 60% were small breeds and 1 could not be classified due to the combination of multiple sizes into one breed category. Furthermore, 30% of this top 30 were of brachycephalic type, 16.7% dolichocephalic, and 53.3% mesocephalic. This top 30 purebred rankings were in accordance with The Kennel Club (KC) 2019[28] breed registrations: 80% (n = 24) of those listed within their top 30 were also apparent within our top 30. Those missing from the KC list, but apparent within ours included: Jack Russel Terrier (ranked 12/30), Yorkshire Terrier (ranked 16/30), Bichon Frise (ranked 25/30) and Siberian Husky (ranked 27/30). Additions to the KC list, but missing from our top 30, included: Pomeranian, Dobermann, Dogue de Bordeaux and Dachshund Miniature Long Haired[28]. These were ranked 35, 34, 31 and 51 (out of 332), within our data, respectively. Our purebred rankings were also similar to Pets4Homes[29] popularity rankings: 69% (n = 11) of those listed within their top 16 were also present within our top 16. Those excluded from the Pets4Homes top 16 list, but apparent within ours, included: Golden Retriever (ranked 7/16), Pug (ranked 8/30), Border Terrier (ranked 9/16), West Highland White Terrier (ranked 14/16), and Boxer (ranked 15/16). Additions to the Pets4Homes list, but excluded from our top 16, included: Dachshund Smooth Haired, Border Collie, Dachshund Miniature Smooth Haired, Pomeranian and Chihuahua Smooth Coat[29]. These were ranked 61, 18, 22, 35 and 19 (out of 332), within our data, respectively.

Within the UK crossbred population, 39.3% were compiled from 'Mix Breeds' i.e., lineage unknown or > 2 parental breeds. Excluding 'Mix Breeds', the subsequent top 15 crossbreds included: Border Collie cross/type (4.5%), Cockerpoo (i.e., Cocker Spaniel X Poodle; 4.1%), Staffordshire Bull Terrier cross/type (4.0%), Labrador Retriever cross/type (3.7%), Jack Russell Terrier cross/type (3.0%), Labradoodle (i.e., Labrador Retriever x Poodle; 2.5%), Chihuahua Smooth Coat cross/type (2.5%), Rottweiler cross/type (1.9%), Cocker Spaniel cross/type (1.7%), Bulldog cross/type (1.5%), German Shepherd cross/type (1.5%), Shih Tzu cross/type (1.4%), Yorkshire Terrier cross/type (1.3%), Cavapoo (i.e., Cavalier King Charles Spaniel X Poodle; 1.1%) and Sprocker (i.e., Cocker Spaniel x English Springer Spaniel; 1.0%, Supplementary Table 5). However, variation in crossbred popularity was evident between countries (Supplementary Table 7). England represented 99% of the available crossbred variation (n = 1061), whilst Northern Ireland, Scotland and Wales represented 17% (n = 182), 23.7% (n = 254) and 23.1% (n = 248) of crossbred variation, respectively. Population estimates for the top 30 crossbreds (excluding 'Mix Breeds') within the UK, and across countries, are presented in Fig. 6 (Supplementary Table 7).

Cephalic index

An estimated 22.5% of the UK purebred population were listed as brachycephalic breeds (n = 2843714), 61.8% mesocephalic (n = 7813435) and 15.7% dolichocephalic (n = 1985426). Cepahlic index categories sourced from [30]. However, variation in proportional cephalic demographics were evident within and between countries (Table 3). Whilst the majority of all country-level populations consisted of mesocephalic breeds (range: 56.6–66.0%), Wales represented the greatest proportion of within-country brachycephalic and dolichocephalic populations at 26.9% and 16.5% respectively, in comparison with England (22.4%, 16.0%), Northern Ireland (23.1%, 11.7%) and Scotland (20.5%, 13.5%). Between countries, England was found to home 82.6–84.5% of individuals within all cephalic index groups, followed by 7.8–9.8% in Scotland, 5.3–6.9% in Wales and 1.6–2.2% in Northern Ireland (Table 3).

Table 3
Country-level estimates for proportional cephalic index (CI) demographics (%). Cephalic index predicted population estimate, per country, and associated proportional cephalic index demographics both within (($N_{CI,\ country}/N_{country}$)*100) and between countries (($N_{CI,\ country}/N_{total\ CI}$)*100). Example: 22.4% of England's population are listed as brachycephlic ('within country') and 82.6% of the UK brachycephalic population can be found within England ('between countries').

Country	Cephalic Index	Predicted Population Estimate	Proportion WITHIN Country (%)	Proportion BETWEEN Countries (%)
England	Brachycephalic	2347705.98	22.4	82.6
Northern Ireland	Brachycephalic	61600.04	23.1	2.2
Scotland	Brachycephalic	237087.93	20.5	8.3
Wales	Brachycephalic	197319.59	26.9	6.9
England	Mesocephalic	6461684.41	61.6	82.7
Northern Ireland	Mesocephalic	173648.6	65.2	2.2
Scotland	Mesocephalic	763099.61	66	9.8
Wales	Mesocephalic	415002.07	56.6	5.3
England	Dolichocephalic	1677478.07	16	84.5
Northern Ireland	Dolichocephalic	31118.05	11.7	1.6
Scotland	Dolichocephalic	155437.46	13.5	7.8
Wales	Dolichocephalic	121392.13	16.5	6.1

Cephalic demographics also varied amongst regions (Fig. 7; Supplementary Table 8). Mesocephalic proportions ranged from 53.5–73.7%, with South Wales representing the lowest proportion and Highlands and Islands representing the greatest. Regional brachycephalic proportions ranged from 11.7–30.5%, with Mid Wales representing the lowest and South Wales representing the highest, whilst Dolichocephalic proportions did not vary as broadly, ranging from 11.7–17.4% (Fig. 7; Supplementary Table 8).

Body size

In 2019, 52.5% of the UK canine population were estimated to be small in body size (n = 6,633,421), with 29.3% (n = 3,711,087) listed as large and the remaining 18.2% as medium sized (n = 2,298,066). Body size categories sourced from [23,24]. Whilst this pattern remained nationally consistent, proportional estimates for size demographics varied within and between countries (Table 4). Scotland presented the lowest national proportion of small dogs, at 51.1% of the total population, in comparison with England = 52.2%, Northern Ireland = 59.2%, and Wales = 56.6%. Scotland also presented the greatest proportion of large dogs, contributing 32.2% of the total population, in comparison to England = 29.4%, Northern Ireland = 26.4% and Wales = 25.3%. England exhibited the greatest proportion of medium sized dogs at 18.4%, followed by Wales = 18.1%, Scotland = 16.7% and Northern Ireland = 14.3% (Table 4). Between countries, England was found to home 82.5–84.2% of individuals within all body size groups, followed by 8.4–10.0% in Scotland, 5.0-6.3% in Wales and 1.7–2.4% in Northern Ireland (Table 4).

Table 4
Country-level estimates for proportional body size (BS) demographics (%). Body size predicted population estimate, per country, and associated proportional body size demographics both within (($N_{BS,\ country}/N_{country}$)*100) and between countries (($N_{BS,\ country}/N_{total\ BS}$)*100). Example: 29.4% of England's population are listed as large breeds ('within country') and 83.1% of the UK large-breed population can be found within England ('between countries').

Country	Body Size	Predicted Population Estimate	Proportion WITHIN Country (%)	Proportion BETWEEN Countries (%)
England	Large	3083122.4	29.4	83.1
Northern Ireland	Large	70419.97	26.4	1.9
Scotland	Large	371951.04	32.2	10.0
Wales	Large	185593.49	25.3	5.0
England	Medium	1934250.91	18.4	84.2
Northern Ireland	Medium	38184.53	14.3	1.7
Scotland	Medium	193014.73	16.7	8.4
Wales	Medium	132616.16	18.1	5.8
England	Small	5469495.16	52.2	82.5
Northern Ireland	Small	157762.19	59.2	2.4
Scotland	Small	590659.24	51.1	8.9
Wales	Small	415504.14	56.6	6.3

Variation in size demographics were also evident amongst regions (Fig. 8; Supplementary Table 9). Regional demographic proportions varied most for the small sized population, ranging from 43.0-59.7%, with Isle of Man representing the lowest and West Wales representing the highest proportions. Large sized populations also varied between regions, ranging from 23.2% (South Wales) to 37.6% (Mid Scotland and Fife). Medium sized populations but did not range as widely, ranging 14.3% in Northern Ireland to 22.6% in Isle of Man (Fig. 8; Supplementary Table 9).

Discussion

We provide an estimate and national description of the density and distribution of pet dogs in 2019, at varying spatial scales across the UK. We estimate that there were 12.64 million (95% CI 8.54–15.16 million) pet dogs, with 85.8% of this total represented by purebreds. We provide details regarding spatial descriptions of demographic factors that directly influence population dynamics, such as breed, age, cephalic index, and body size[21,31,32]. As far as the authors are aware, we have generated the population estimate from the most comprehensive UK pet dog dataset to date, via a collaborative network of breed registries, veterinary corporations, pet insurance companies, animal welfare charities, and academic institutions.

It is important to note that the were 12.64 million (95% CI 8.54–15.16 million) estimate is temporally explicit, i.e., assumes no net migration, death, birth etc. Estimates for the comparable time points include UK Pet Food's 2018–2019 and 2019–2020 statistic of 9.0 million for both periods[16], and PDSA's 2019 statistic of 9.9 million[33]. UK Pet Food also released estimates for 2021, 2022 and 2023, at 12.0, 13.0 and 12.0 million, respectively[1,16]; whilst PDSA suggested 9.6, 10.2 and 11.0 million, respectively[34–36]. These previous and current statistics remain lower, or equivalent to, our 2019 estimate of 12.64 million, suggesting that that the scientific community may have been underestimating the UK dog population. The most prominent consequence is that inaccuracies in these estimates are then propagated forward into extrapolated statistics, such as regional densities, annual population growth and proportional demographics e.g., breed and age demographics. For example, based on previous population and survival estimates[16,37–40], it was commonly accepted that the UK required 750,000-850,000 puppies be born each year, to maintain the population size[11,41]. Applying our population estimate and assuming an unchanged UK median mortality of 12.0[42] or 12.5[22] years, we suggest the number of dogs needed to maintain the population size as 1.01–1.05 million dogs annually. This amplified figure highlights the pressure on the existing puppy 'supply chain'.

Variations in popularity of dog breeds are often evident as large fluctuations, that arise from fashions and fads[43,44]. An acute increase in breed demand and impulse buying[2,3] have resulted in puppies becoming lucrative commodities in an industry driven by profitability, often at the expense of canine welfare[4]. Here, we list UK breed popularity overall, and within England, Northern Ireland, Scotland, and Wales. Our UK purebred rankings were broadly in accordance with the KC 2019 breed registration statistics[28] and Pets4Homes popularity rankings[29]. Thus, we believe our data reliably represents UK breed demographics. However, variation in breed popularity were evident between the three rankings. Small terriers e.g., Border Terriers, Jack Russel Terriers, West Highland White Terriers and Yorkshire Terriers, were more popular within our data; whilst Dachshunds, Pomeranians and Chihuahuas proved more popular within both external rankings. As both external lists are inherently linked to the market supply of dogs, i.e., via breed registry and online sales, these data are likely to include a higher proportion of younger age groups (i.e., young adults, juveniles and puppies). Consequently, this variation may suggest a decline in present day demand for small terriers, and a potential popularity boom for Dachshunds, Pomeranians, and Chihuahuas.

The popularity of brachycephalic (flat-faced) breeds has been increasing internationally, despite the scientific evidence highlighting significant health and welfare challenges associated with this conformation[45,46]. Fashion (social influence) has been suggested to be more important than function in determining the popularity of dog breeds[47]. Whilst regional and country level variation in brachycephalic popularity is evident within our data: overall, nine of the top thirty UK popular breeds are considered brachycephalic (French Bulldog, Bulldog, Pug, Cavalier King Charles Spaniel, Shih Tzu, Boxer, Chihuahua Smooth Coat, Chihuahua Long Coat and Lhasa Apso[30]). Consequently, it is imperative that we continue to monitor breed popularity patterns[48], in order to ensure the welfare of "fashionable" breeds[49] are not compromised by unscrupulous breeders who are capitalizing on consumer demand[4]. There needs to be a fundamental shift in the way dogs are selected for breeding, refocusing on canine health, welfare, functionality, and behaviour[50,51] and disconnecting from selection pressure towards phenotypic exaggeration to achieve breed standards.

The UK puppy market is vast: we estimated the number of puppies required just to replace the existing ageing population to be around 1 million a year in 2019. The combined sales of puppies in England, Scotland and Wales are estimated to be worth ~£130 million per annum[52]. The estimated 12.64 million dogs in the UK in 2019 are of huge importance in terms of societal influence as well as the economy. Understanding the spatial and temporal distribution of dogs across the UK therefore has numerous benefits, such as informing dog related service and charitable provision.

Rising levels of puppy purchasing was evident throughout the pandemic[8,53–55], with many deciding to purchase a puppy for the first time[56]. In accordance, UK Pet Food reported an unprecedented increase in the demand and acquisition of pets, with 4.7 million households acquired a new pet since the onset of the pandemic[57], and 2.1 million collecting the new pet during lockdown[58]. Sharp increases in web interest regarding the adoption and sale of dogs was also evident[2,59], with online pet supply companies reporting increased sales[60] and dramatic price increases, e.g., 131% average increase for dogs in 2020 versus 2019[29]. However, there is concern for the welfare of these newly acquired pets following changes in the management of COVID-19, e.g., working from home and/or lockdown arrangements to 'Living with Covid' and return to workspaces[61]. Pet owners were found to experience unique hardships related to changes in everyday life from the COVID-19 pandemic[59,62]. A reported 3.4 million UK households have confirmed the relinquishment of a pet since the start of the pandemic, with 60% of that figure represented by pet dogs[57]. Furthermore, 26% of UK dog owners stated the development of at least one behavioural problem as a result of lockdown measures[61], prompting fears of a surge in relinquishment, abandonments and euthanasia. These factors may have altered the density and distribution the UK pet dog population, since the onset of the pandemic. Accordingly, as previously stated, UK Pet Food have reported an increase in the population from 9.0 million in 2019–2020, to 12.0, 13.0 and 12.0 million in 2021, 2022 and 2023, respectively[1,58]. In contrast, PDSA have suggested that there was no been a statistically significant increase in the estimated pet population size[34]. In order to interrogate differences in the UK pet dog population over

time, we plan to repeat the process described in this paper and provide an ongoing estimate. This will allow researchers and stakeholders to better understand any changed patterns in dog ownership pre- and post-onset of the pandemic.

It is vital that we continue to accurately quantify the UK pet dog population size, as the analytical benefits of these outcomes are far reaching, with respect to both human and canine health and welfare. These results provide analytical value to veterinary and epidemiological research, disease control and contingency response, ecological and environmental impact, policy development and implementation, and public health. Furthermore, previous research has attempted to produce national estimates of pet population size by incorporating human-related factors that may influence pet ownership, such as owner age, household size, education/profession, income, rural location etc.[18,19,63–65]. Here, we provide the spatiotemporal dataset required to reverse this approach and elucidate socioeconomic factors that influence pet dog population density and breed popularity, including pure versus crossbred lineage, cephalic index and body size.

The data presented in this paper may contain knowledge gaps or biases, due to human socioeconomic demographics, human reporting error, or poor representation of subpopulations. For example, due to the participants involved, data were unlikely to include laboratory dogs and/or racing greyhounds. Additionally, 49% of the UK pet dog population were estimated to be within their Senior or Geriatric developmental period (≥7 years), with only 0.9%, 2.7% and 8.5% of the population represented by Puppies (0 to < 6 months), Juveniles (6 to < 12 months) and Young Adults (12 to < 24 months), respectively[27]. This suggests a potential under-representation of younger age groups, likely due to delayed registration of young dogs on the compiled data sources. Future studies should consider sourcing datasets which predominantly represent younger age groups, e.g., online advertisements for puppies and registered puppy training classes. It has been estimated that 77% of the UK pet dog population are registered with a veterinary practise, 42–46% of UK pet owners have health insurance for their animals, and 29% are KC registered[20]. Thus, our data set potentially captures a large proportion of the UK pet dog population. However, for a dog to appear within these datasets, a financial contribution is normally required from the owner (in most cases), which some cannot afford. In the hope of representing the remaining subpopulation, the authors incorporated data from animal welfare charities. With regards to the unowned/stray subpopulation, within the UK, there appears to be no consistent UK population of free-living unowned dogs, either as supported strays (i.e., receiving food, even irregularly, and/or occasional veterinary support), or as completely self-sustaining feral packs[8]. Instead, strays are recycled back into the owned sub-population by reunion with their previous owner[25] or via care of an animal welfare charity[8]. As such, we believe the dataset provides a comprehensive proxy for the density and distribution of adult dogs within the UK.

The quantitative model validation undertaken here may be problematic, as it relies upon the accuracy of a previous UK pet dog population estimate. While this previous estimate is based upon survey and extrapolation, subdivided spatially and categorically across ownership classes[25], it remains the best comparable spatial dataset for model validation. As human population density is included within the N-mixture model as a prior, readers must consider the per capita output with caution. Furthermore, we do not provide details regarding proportion of households with dogs or the number of dogs per owner. However, as Asher et al.[20] described geographical variation in both variables, future studies may wish to consider incorporating these measures as potential priors. We recommend that future studies focus on a national-scale overview regarding UK pet dog population dynamics: allowing for the development of a stochastic transitionary state model. By including parameterised compartments and sub-populations, e.g., market sources, emigration/immigration, and birth/death rates, we can start to identify and evaluate unrepresented sub-populations; gaps in data coverage; substandard regulations; and importantly, the potential impact of legislative change.

Methods

Data: sources, cleaning, and deduplication

Dogs Trust data were combined with datasets sourced from 17 project participants (totaling 18 data sources). Participants encompassed a wide variety of industry including breed registries, veterinary corporations, pet insurance companies, animal welfare charities, and academic institutions. Data requested included: breed (free text), crossbred (Y/N/unknown), sex (M/F/unknown), date of birth (DOB; MM/YYYY), postcode area (i.e., first one or two characters), first three characters of dog name (common, not pedigree name), last six characters of microchip number, last six characters of additional microchip number (if more than one known), status (alive/dead) and termination date (death or end of policy due to death; DD/MM/YY). Not all aforementioned canine-centric variables were sent by project participants. Longevity (age of dog in decimal years) reflects the period between the DOB and termination date (if deceased), or date data were received (if assumed alive).

Data cleaning included the removal of non-canids, classifying all individuals into (1) The Kennel Club (KC)[23] and/or Fédération Cynologique Internationale (FCI)[24] recognised 'Purebred' breeds i.e., parental lineage = 1 breed, or (2) 'Crossbred' breeds i.e., parental lineage ≥ 2 breeds, which included 'Mix Breed' i.e., lineage unknown or > 2 parental breeds, 'Breed X x Breed Y', 'Breed X Cross/Type'. Purebreds within the dataset may be included in one or both breed reference lists[23,24]. Due to variation in reporting, alternative breed names were collapsed into one breed category based on known ancestry and/or breed popularity, i.e., historical breed registration statistics[28]. These changes, listed in Supplementary Table 10, were established via majority agreement by canine behaviour and research experts at Dogs Trust. Individuals were grouped into one of six age groups: 'Puppies' aged 0 to < 6 months, 'Juveniles' aged 6 to < 12 months, 'Young Adults' aged 12 to < 24 months, 'Mature Adults' aged 2 to < 7 years, 'Senior' aged 7 to < 12 years and 'Geriatric' aged ≥12 years. These groupings were developed to capture age-related developmental trajectories for the majority of dog breeds[27]. Body size per purebred, i.e., small, medium and large, were obtained from KC[23] and FCI[24] grey literature and cephalic index i.e., the percentage of skull breadth to length, per purebred, were obtained from O'Neill et al.[30] and include brachycephalic (flat-faced), mesocephalic or dolichocephalic (long-faced; Supplementary Table 10).

Postcode area was assigned to one of the following twenty-four regions, determined by the UK National Statistics Postcode Directory[66]: Highlands and Islands, North East Scotland, Central Scotland, Glasgow, Lothian, Mid Scotland and Fife, South Scotland, West Scotland, Northern Ireland, North East England,

North West England, Yorkshire and The Humber, East England, East Midlands, West Midlands, London, South East England, South West England, Isle of Man, Channel Islands, North Wales, Mid Wales, West Wales, South Wales (Supplementary Table 11).

As data were obtained from multiple sources, duplication of an individual across data sources was probable. Deduplication consisted of a four-phase process outlined within Supplementary Note 1. Full implementation of the deduplication workflow is available as Source Code 1 (10.6084/m9.figshare.24534151). For the purposes of this study, deduplicated data were then subset to rows where the following variables were complete: crossbred (Y/N); status (alive/dead) and sex (M/F). Due to the expansive nature of the dataset, DOB was restricted to ≤ 18.3 years, i.e., age where 95% of the UK pure and crossbred pet dog population were deceased[22].

Data did not include accompanying information regarding the owner. However, data did include human population density, as pet dogs are inherently where owners are present. The UK 2011 human population census data were obtained from the Office for National Statistics[26], which incorporates censuses undertaken by the ONS in England and Wales[67], National Records of Scotland[68], and the Northern Ireland Statistics and Research Agency[69]. Despite there being previous dog estimates[18–20,25], we did not include these data. However, we applied Aegerter et al.[25] dog population per postcode estimates for model checking, along with human population estimates per postcode[26]. Rankings regarding breed popularity were extracted from: (1) Pets4Homes[29], which details numbers of buyers per puppy, regarding the sale of dogs from their online marketplace; and (2) KC 2019 breed registry statistics[28].

Statistical analyses

All analyses were conducted using the statistical programming software R version 4.0.4 (2021-02-15)[70]. We used an N-mixture model to estimate postcode specific population size using data from all 18 sources. N-mixture models allow estimation of population sizes whilst accounting for imperfect detection, i.e., the fact that the dataset will not include all dogs present in the UK and therefore likely be an underestimate. Therefore, we estimate the true (unobserved) population size at a postcode as a function of (i) the total number of dogs recorded in the dataset and (ii) a postcode-specific detection probability. We modelled postcode-specific detection probability as a function of human population size at that postcode, using random intercepts and slopes. We initially modelled random intercepts and slopes as correlated, arising from a multivariate Normal distribution. However, this led to convergence issues, and so the final model included uncorrelated intercepts and slopes. This model included a 124 row (postcodes) x 18 column (data sources) matrix as a response, representing the individual deduplicated population size estimates for all postcode-data source combinations. Models were run for 100,000 iterations with a thinning interval of 50 following a burnin of 10,000[71]. Flat uniform prior distributions with support from zero to one were chosen for detection probabilities, across the multiple data sources (i.e., breed registries, veterinary corporations, pet insurance companies, animal welfare charities, and academic institutions). This was run in program JAGS[72] via the *R2jags* package[73]. Convergence was assessed by running two parallel chains and calculating the Gelman–Rubin statistic, which was below 1.05 for parameters, indicating convergence. Results are presented as posterior means and 95% credible intervals for all parameters. Full implementation of the model is available as Source Code 2 (10.6084/m9.figshare.24534151).

Posterior estimates of dogs per postcode area were extracted from model and transposed to allow vectorisation with human population data. Each posterior draw was divided by the human population size for that postcode, to allow the calculation of dogs per capita mean and associated 95% credible intervals. To obtain a population estimate per region and country, population estimates per postcode were aggregated to the regional and country level scale, respectively. Estimates for all proportional demographics, including age, parental lineage, breed, cephalic index and body size, both within and between regions and countries, were calculated by extracting proportions from the raw data, which were then used to partition population estimates. Pearson correlation coefficient was used to determine the relationship between our dog population estimate per postcode and (A) previous dog population per postcode estimate[25] and (B) human population per postcode extracted from 2011 census[26].

Declarations

Acknowledgments

We are grateful to the following project participants, who kindly provided data to this project: Battersea Dogs and Cats Home; Blue Cross; SSPCA; Raystede; Wood Green, The Animals Charity; Edinburgh Dog and Cat Home; PDSA; Mayhew; The Insurance Emporium (The Equine and Livestock Insurance Company Limited); NCI Insurance; Cardif Pinnacle; Agria Pet Insurance Ltd; Direct Line; Medivet; Vets4Pets; Savsnet (Small Animal Veterinary Surveillance Network, University of Liverpool); and The Kennel Club (UK). We are grateful to Dr. David Wong and Dr. Zhibin Zhao at the University of Manchester, for developing the deduplication pipeline. Internal to Dogs Trust, we are grateful to Carys L. Williams (Research) for assisting with the breed cleaning, and Kieran Huggan (Operations) for collating Dogs Trust data.

Additional information

Competing interests

The authors declare that no competing interests exist.

Funding

All data collection were supported by Dogs Trust. Dogs Trust and University of Exeter supported the analysis. University of Manchester developed the deduplication pipeline. Open access has been selected.

Author contributions

KMM collected the data; KMM & XAH designed methodology; KMM & XAH analysed the data; KMM led the writing of the manuscript. All authors conceived the ideas, contributed critically to the drafts, and gave final approval for publication.

Ethics

Ethical approval for this study was granted by Dogs Trust Ethical Review Board (Reference Number: ERB038).

Data availability

Raw datasets include commercially sensitive and potentially identifiable information. Consequently, the raw data will not be made available. However, de-duplicated and source/dog anonymized raw data are published on Figshare (10.6084/m9.figshare.24534151), alongside the source code for deduplication workflow ('Source code 1') and model simulations ('Source code 2').

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Figures

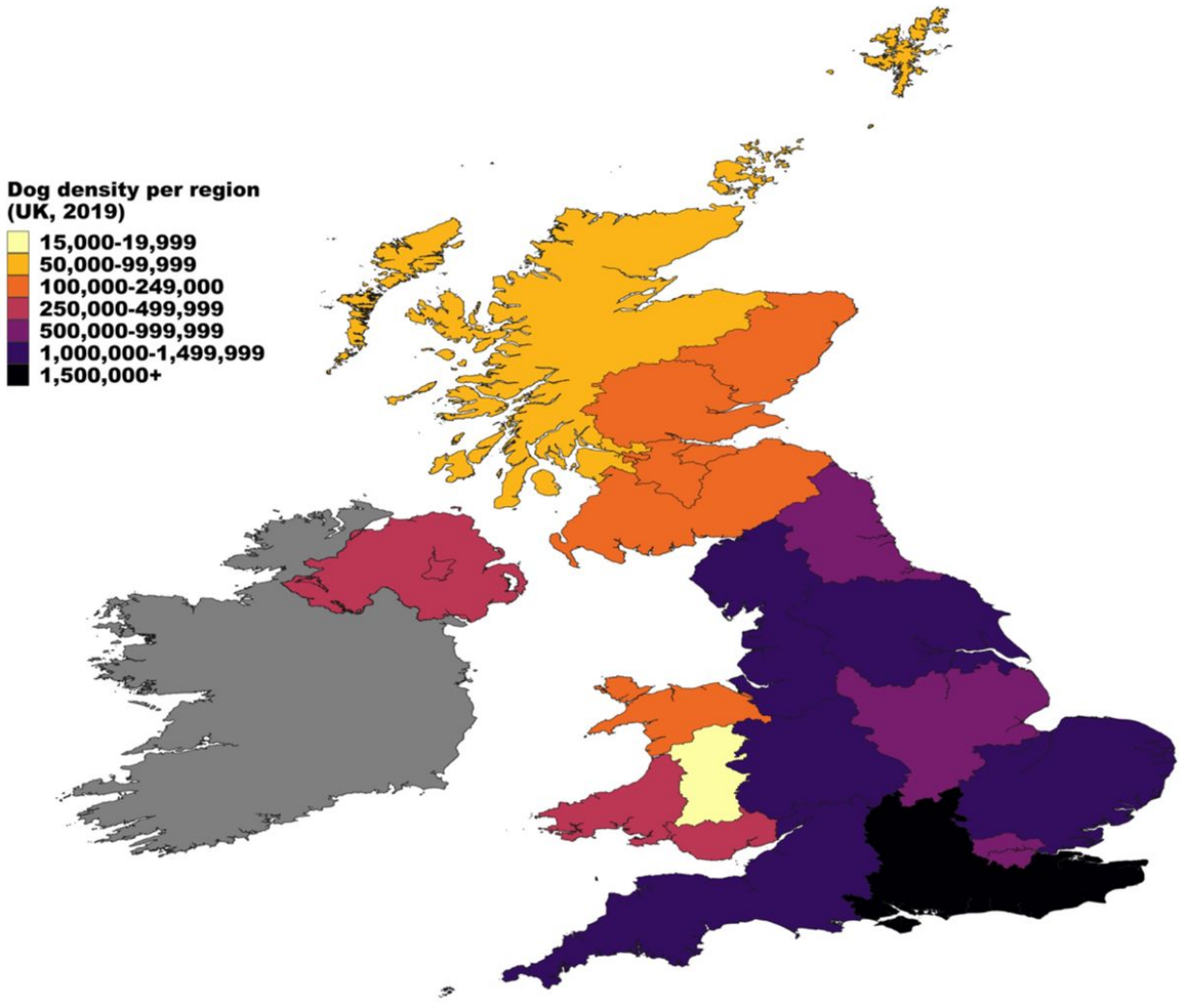

Figure 1

Estimated population mean (i.e., marginal posterior distribution estimate) per region. See Table 1 for further detail.

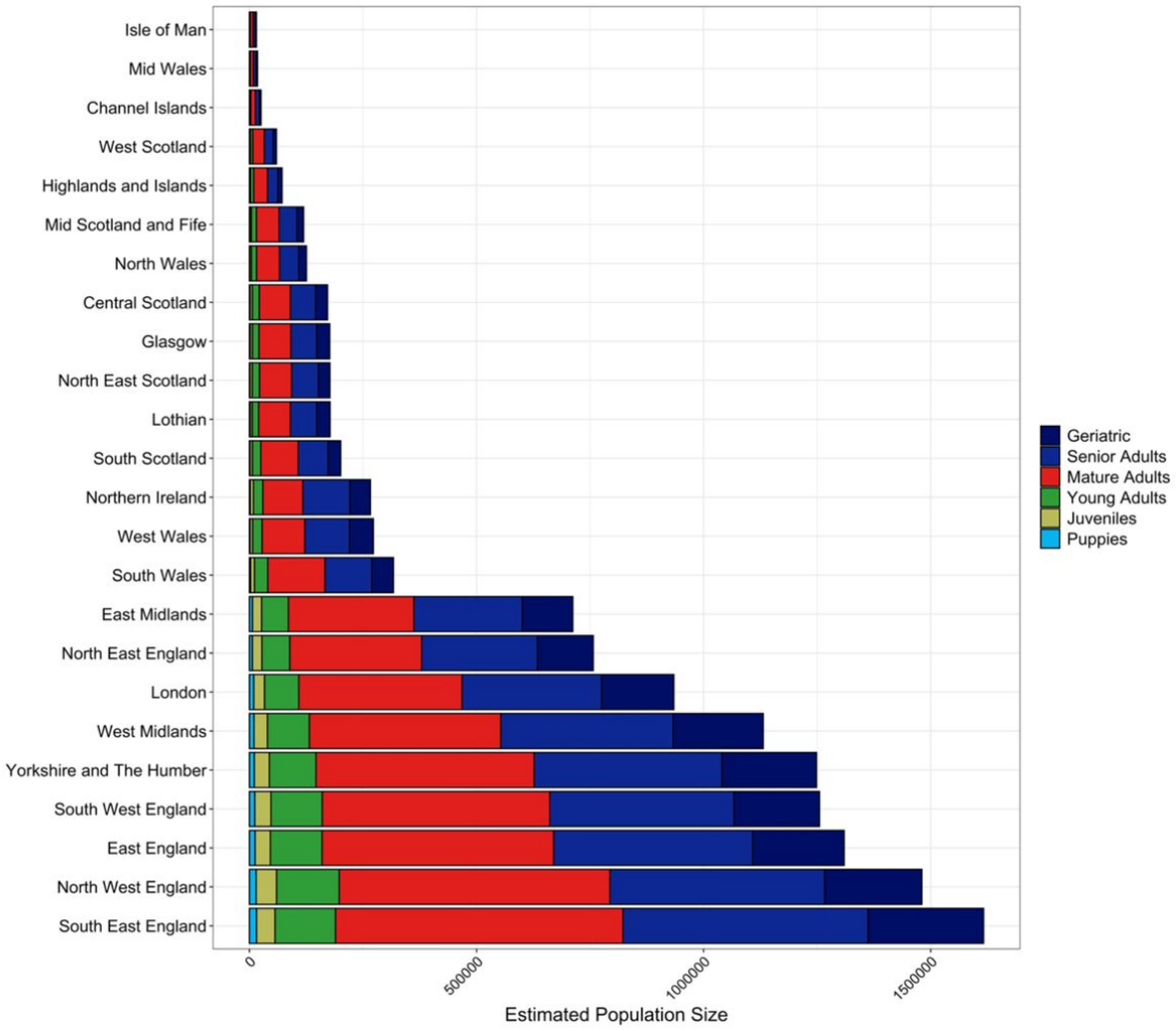

Figure 2

Population estimates per region, with associated regional age demographics. See Table 1 and Supplementary Table 3 for further regional detail, and Table 2 for country-level proportions.

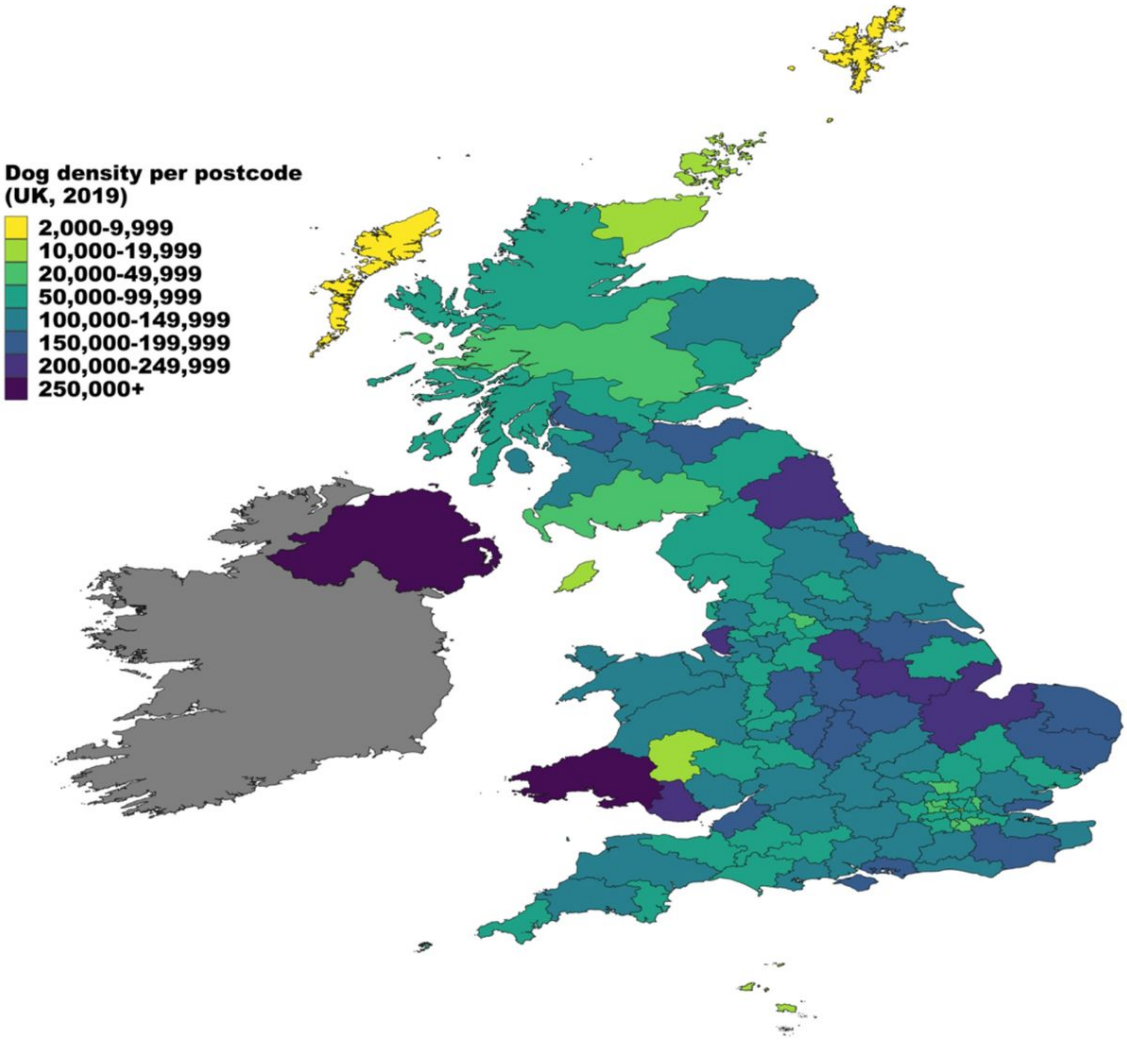

Figure 3

Estimated population mean (i.e., marginal posterior distribution estimate) per postcode. See Supplementary Table 1 and Supplementary Figure 2 for further detail.

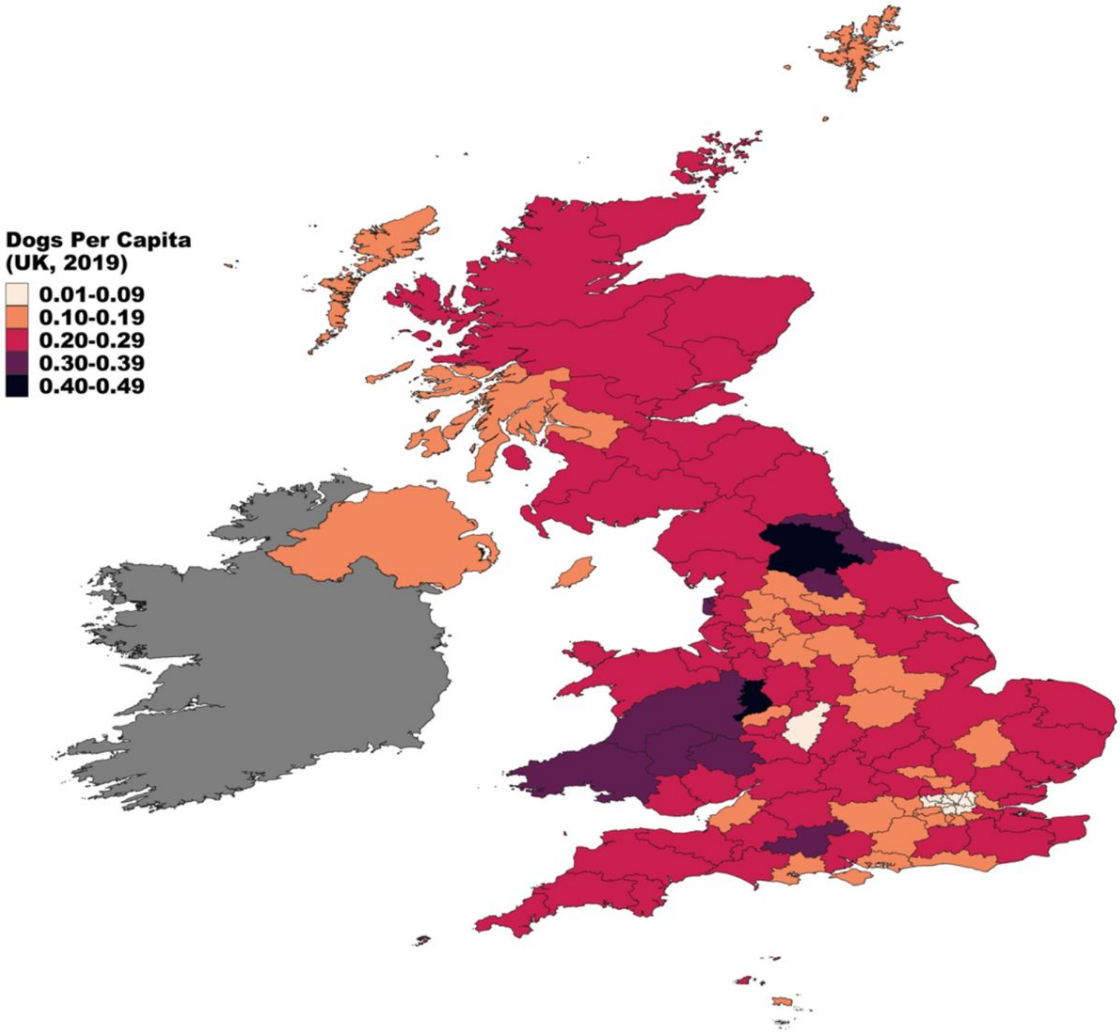

Figure 4

Dogs per capita, per postcode. See Supplementary Table 2 and Supplementary Figure 3 for further detail.

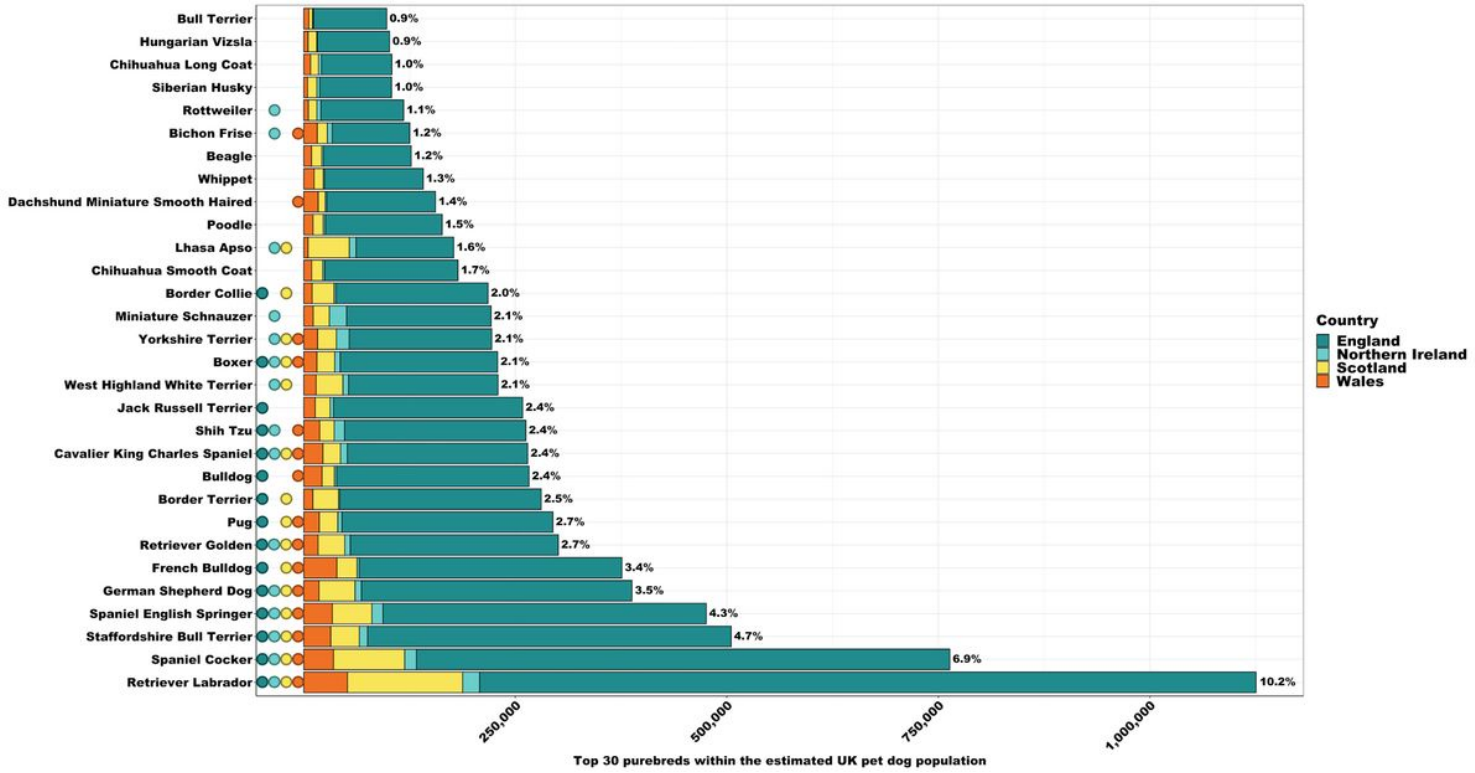

Figure 5

Population estimates for the top 30 purebreds within the UK pet dog population, subdivided by country. Percentage (%) relates to proportion of UK population represented by purebred. Circles represent presence of purebred within country's (England, Northern Ireland, Scotland, and Wales) top 15 rankings. Notable variation in popularity across countries is evident, e.g., Jack Russell Terrier only apparent within England's rankings, West Highland White Terrier apparent within Northern Ireland's and Scotland's rankings only, Miniature Schnauzer and Rottweiler within Northern Ireland's ranking, and Dachshund Miniature Smooth Haired only present within Wales's rankings. See Supplementary Tables 4 and 6 for further detail.

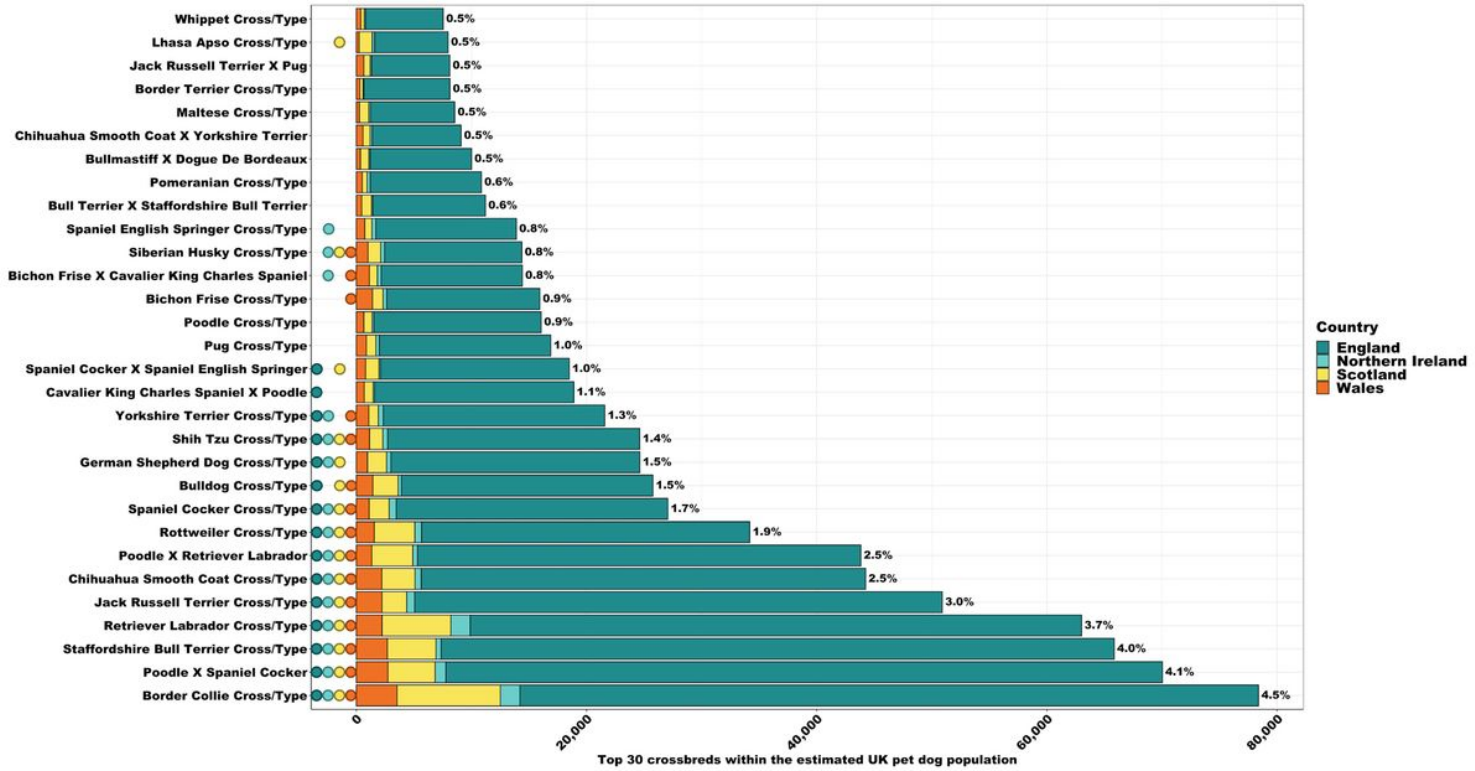

Figure 6

Population estimates for the top 30 crossbreds within the UK pet dog population, subdivided by country. ‘Mix breeds’ was omitted due to unknown lineage (represents 39.3% of the total crossbred population). Percentage (%) relates to proportion of UK population represented by crossbred. Circles represent presence of crossbred within country’s (England, Northern Ireland, Scotland, and Wales) top 15 rankings. Notable variation in popularity across countries is evident e.g., Cavapoo (i.e., Cavalier King Charles Spaniel x Poodle) only apparent within England’s rankings, Sprocker (i.e., Cocker Spaniel x English Springer Spaniel) apparent within England’s and Scotland’s rankings only, Cavachon (i.e., Bichon Frise x Cavalier King Charles Spaniel) within Northern Ireland’s and Wales’s rankings, English Springer Spaniel cross/type only present within Northern Ireland’s ranking, and Lhasa Apso cross/type only present within Scotland’s rankings. See Supplementary Table 5 and 7 for further detail.

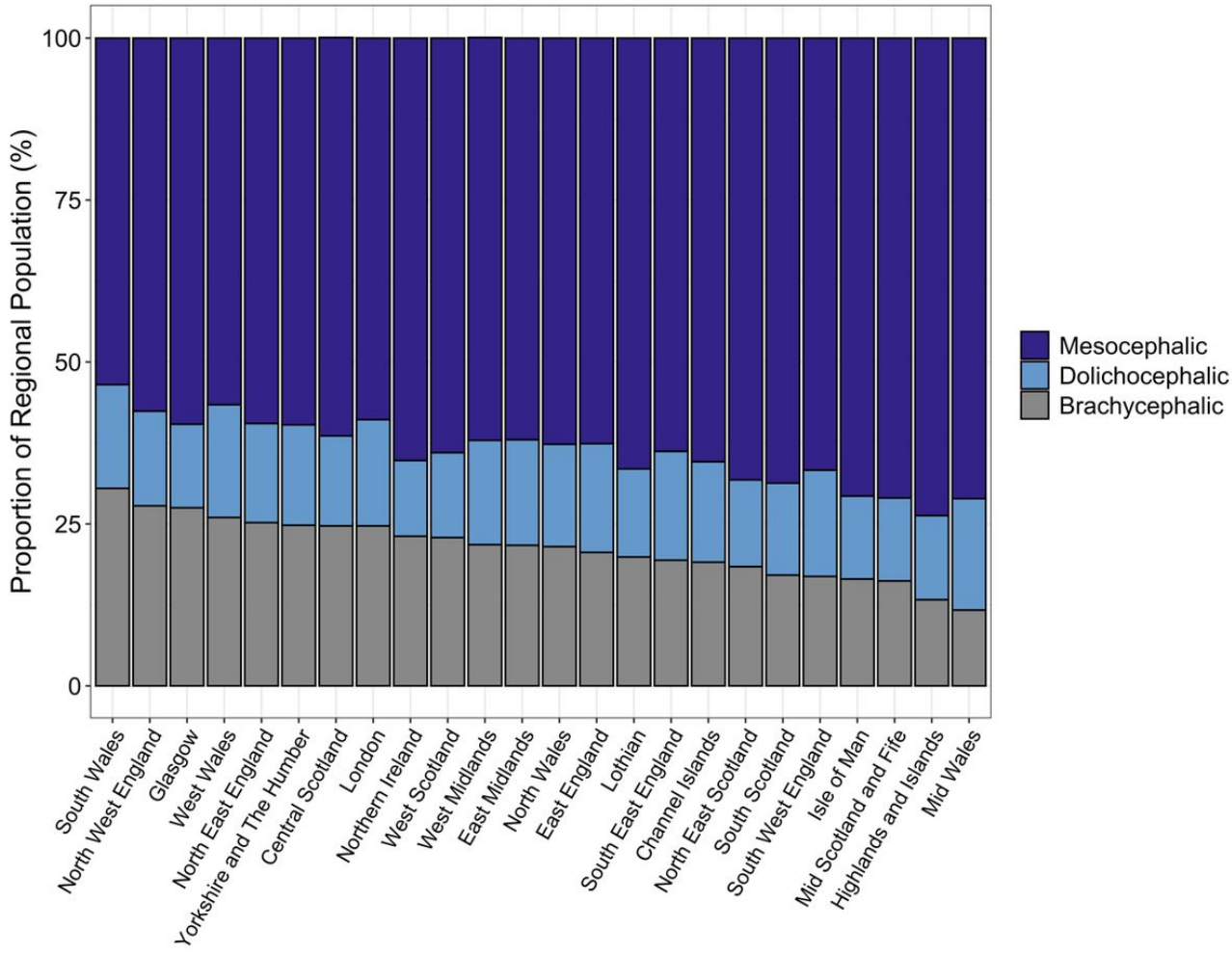

Figure 7

Regional proportional demographics of each cephalic index: mesocephalic, dolichocephalic, and brachycephalic. See Supplementary Table 8 for further regional detail, and Table 3 for country-level proportions

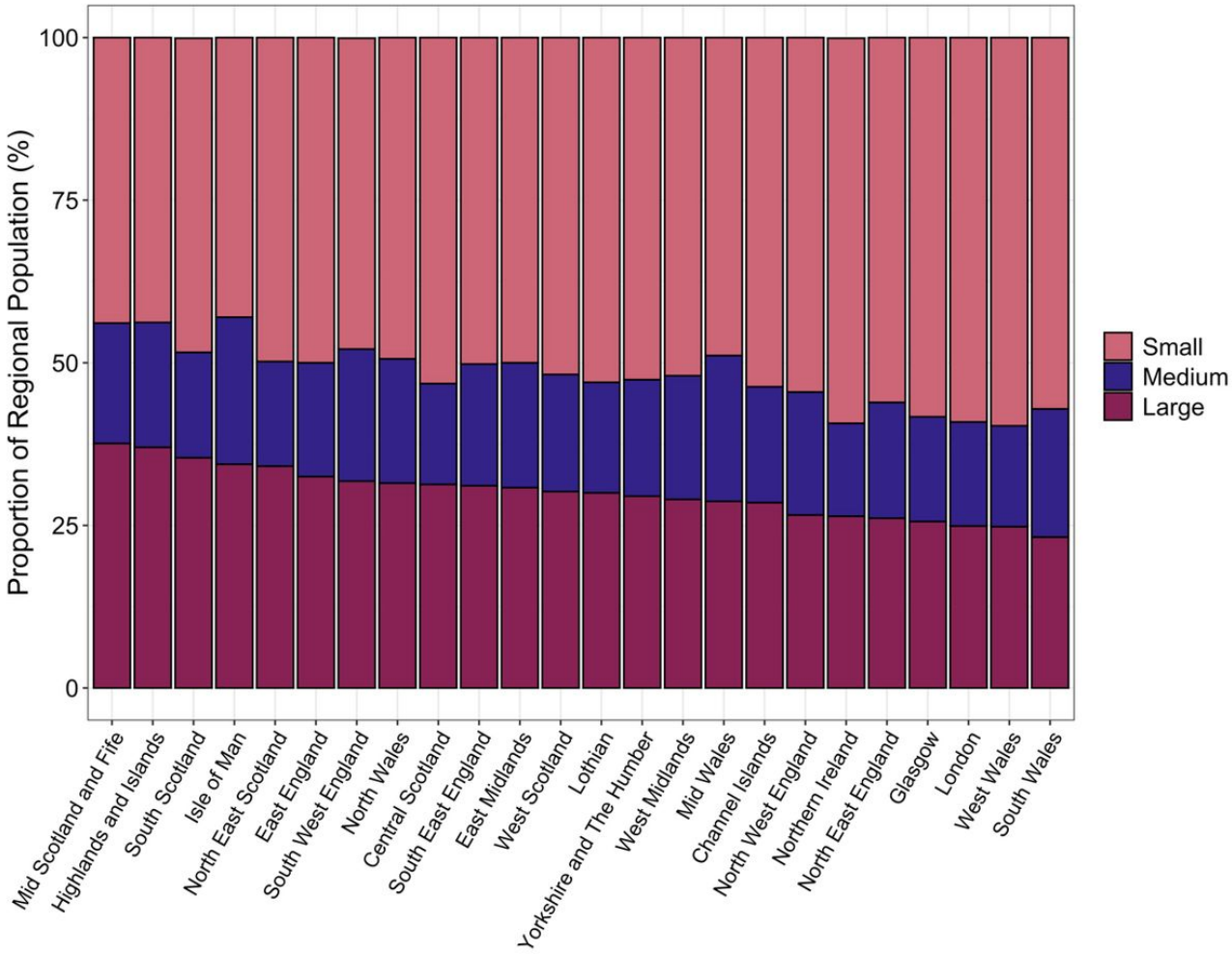

Figure 8

Regional proportional demographics of each body size: small, medium, and large. See Supplementary Table 9 for further regional detail, and Table 4 for country-level proportions.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupplementaryMaterial.pdf