Can a regional approach be applied to achieve eradication of bovine tuberculosis in Ireland?

TB Scientific Working Group

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Summary

In view of the lack of progress in recent years, new approaches must be considered in relation to the eradication of bovine tuberculosis (bTB). In that context, the Scientific Working Group (SWG) received a request from the Department of Agriculture, Food and the Marine (DAFM) to examine the potential effectiveness of using a regional approach to facilitate the eradication of bTB in Ireland. In particular, DAFM requested the SWG to address the following objectives:

1. The potential value of using a regional approach for the eradication of bTB

If a regional approach is considered worthwhile:

2. The criteria that should be used to select a geographical area for a regional approach
3. The measures that would be required to achieve freedom from infection. (Such measures could include but not be confined to wildlife, movement controls and diagnostic testing)
4. The measures that would be required to maintain freedom on a long-term basis in the geographical area that is selected

Regionalisation involves establishing subpopulations of animals with defined health statuses within distinct geographical areas of a country for the purposes of international trade, disease prevention or control. In disease eradication programmes, regionalisation is used to create 'risk boundaries', thereby allowing disease control and surveillance to be differentiated based on risk, to prioritise resource allocation, and to protect lower risk areas. Collectively, this approach ensures forward momentum towards an improving national disease situation. The principles of zoning/regionalisation are outlined in the Terrestrial Animal Health Code of the World Organisation for Animal Health. Specific requirements for declaring a country or a part of a country free of bTB are set out in EU legislation, namely, EU Regulation 2020/689. The basic requirement for a country to declare itself free of bTB is to maintain 99.8% of herds free of bTB for at least three years. Legislative freedom should not be confused with biological freedom which requires the complete elimination of the causative organisms, which in the case of Ireland is virtually exclusively *Mycobacterium bovis*, from the territory.

The SWG reviewed the experience of other countries, including the UK, Spain, New Zealand, Australia and Chile, in relation to a regional approach towards bTB eradication. Regionalisation has been central to national bTB control/eradication programmes in all countries, except Ireland, where eradication has been achieved or is progressing. In each of the international examples, regionalisation/zoning is (or in the

case of Australia was) applied across the whole country. In some countries, including Australia and the USA, regionalisation was implemented from the start of the eradication programme, whereas for others, such as Spain, a regional approach emerged over time because of differing rates of progress in different administrative divisions/autonomous communities. In several countries (Australia, Great Britain, New Zealand), regionalisation was first implemented due to large differences in *M. bovis* prevalence in cattle or because of varying risks associated with the presence of recognised wildlife reservoirs of infection. The geographical boundaries and programme actions within each region (such as the intensity of cattle controls and wildlife management) evolve over time in alignment with nationally agreed programme rules, as the country moves towards eradication.

The SWG considered regionalisation in an Irish context.

The SWG noted that the question received from DAFM relates to the application of a regional approach to a single area (a 'case region') within the country, in what is described as a proof of concept for regionalisation. On first assessment, this would seem at odds with the regional approach that has been used in all other countries, where regionalisation is applied across the whole country, rather than in a single area. However, the SWG do not see a major difference between the two, noting that the epidemiological principles for disease eradication (including the creation of 'risk boundaries' and differential eradication efforts in different regions) are equivalent in each case. Further, the definition of a 'case region' by default leads to the establishment of two regions for Ireland: the 'case region' and the rest of the country.

A regional approach was used at the start of the bTB Eradication Programme (BTBEP) in Ireland in 1954. There was a substantial and a rapid reduction in bTB levels to the point where Ireland declared legislative freedom from bTB in 1965. However, this declaration was premature. The reduction in bTB levels did not continue and higher reactor numbers were disclosed in most of the subsequent years.

In an Irish context, there are several potential reasons why a regional approach would be useful and worthwhile. In terms of benefits to the BTBEP itself, a regional approach would provide a proof of concept with respect to the feasibility and impact of additional control measures, particularly those relating to cattle movement controls and wildlife controls, that will be required if Ireland is to achieve its target of eradicating bTB. It would enable planning for the evolution of a regional approach as part of a broader strategic perspective. It should also prompt greater stakeholder engagement as the benefits of bTB freedom become evident.

There would be potential benefits to stakeholders:

- In a region that is free from bTB, farmers will principally benefit from changes in testing requirements, reduction of costs associated with bTB breakdowns and the potential to brand products originating from herds with a higher health status.
- Farmers in a region that is free from bTB would also benefit from a more favourable trading status.
- Currently Ireland benefits from a considerable trade in value-added produce, an example of which is the production of over 10% of global infant milk formula in Ireland. Disease free regions may contribute to improved international market penetration where a high health standard is desirable.

However, there would be several challenges associated with using a regional approach. These include:

- Managing the inward movement of *M. bovis* infection into the selected region through the inward movement of infected cattle between farms, the inward movement of infected cattle between fragments of the same farm, or the inward movement via wildlife (badgers and deer) or other infected farmed species (primarily camelids).
- Effectively addressing all infection sources within the region, including transmission of infection between cattle, transmission of infection from wildlife to cattle and environmental transmission of infection
- Developing a commitment of stakeholders, particularly farmers, towards a regional approach

Host genetics plays a role in the response to infection. A significant amount of research has been carried out in Ireland and elsewhere in developing breeding for reduced bTB susceptibility. Various tools have been produced to assist dairy and beef farmers to select sires with reduced bTB susceptibility.

Potential value of a regional approach for the eradication of bTB (SWG response to ToR 1)

The SWG is supportive of a regional approach within the national BTBEP, but only if certain conditions are met, including the following:

- The proposal for regionalisation is an integral part of a broader strategic approach to bTB eradication in Ireland, including clarity with respect to the planned evolution of the regional approach over time.
- External biosecurity measures are in place to prevent the inward movement of infection into the 'case region'.
- Internal biosecurity measures within the 'case region' are in place to effectively address all infection sources within the region, using approaches that align with best-available national and international scientific information and practice.
- The allocation of additional resources in support of regionalisation is in a manner that does not reduce current efforts at suppression of infection nationally.
- Governance and management structures are in place to facilitate a very high level of farmer and industry commitment to the effective implementation of all relevant BTBEP measures, relating both to external and internal biosecurity.

Ongoing monitoring of progress and the use of specific and measurable targets would be essential. Subject to the successful completion of this first phase, the SWG recommends that the TB Forum support a regional approach to bTB eradication in Ireland that evolves over time, as undertaken in other bTB eradication programmes throughout the world.

The criteria that should be used to select a geographical area for a regional approach (ToR 2)

A number of criteria can be used to determine the suitability of the region. These include:

- *Issues related to the inward movement of M. bovis infection into the region*

- Inward cattle movement relating to the number of moves and the proportion of those moves from higher to lower risk herds. This criterion should be regarded as high priority.
- Geographical boundaries. This criterion should be regarded as medium priority.
- Trade flows. This criterion should be regarded as high priority.
- Land fragmentation. This criterion should be regarded as medium priority.

- *Issues relating to effectively addressing all infection sources within the region*
  - bTB levels in herds and cattle. This criterion should be regarded as medium priority.
  - Administration of the region. This criterion should be regarded as high priority.
  - Effectiveness of the badger programme. This criterion should be regarded as high priority.
  - Stakeholder commitment. This criterion should be regarded as high priority. The SWG consider it as critically important.

The measures that would be required to achieve freedom from infection. (Such measures could include but not be confined to wildlife, movement controls and diagnostic testing) (TOR 3)

The following broad reflections are made:

- In the modern era, all countries that have progressed towards or achieved bTB eradication have applied a regional approach within a national bTB eradication programme.
- A regional approach will be of limited value if only partially implemented. Indeed, the effectiveness of a regional approach will fall rapidly as the risk boundary becomes increasingly permeable to inward movement of infection.
- Many of the required technical measures already form part of the Irish national BTBEP. The main enhancement to achieve and maintain freedom from infection at a regional level relates to cattle trading. This is an essential component if freedom from infection is to be first achieved and maintained.
- An effective verifiable programme to prevent transmission from wildlife, and a commitment to maintaining the necessary resources, is critical if a regional approach is to be successful.
- The full cooperation and participative engagement of stakeholders is an essential requirement to achieve freedom from infection and in maintenance of that freedom once attained. International experience has highlighted the critical link between programme governance and stakeholder collaboration. The agreed model of programme governance, both nationally and at regional level, must clearly define responsibility- and cost-sharing by government and industry.

Further detail is provided in terms of cattle measures, wildlife measures and stakeholder commitment.

In terms of the cattle measures that would be required, the main purpose would be to resolve infection in infected herds within the region and to prevent the ingress of infection into the region. Two broad instruments are available:

- Improved diagnostics, but noting that countries have been successful in achieving or progressing towards bTB eradication using existing diagnostic tools
- Risk-based approaches to animal and herd management, including zoning/regionalisation/area-based management and risk-based approaches to cattle trading

Issues to be considered in identifying and removing infection include frequency and quality of skin testing, interpretation of the skin test, use of auxiliary tests, tracing of disease spread and reactor removal.

Issues to be considered in reducing the potential for the spread of disease include trading considerations – between herd/region cattle movement, dealers, within herd cattle movement including considerations in relation to the renting and leasing of land, other biosecurity considerations and breeding policy.

In terms of the wildlife measures that would be required, the main purpose would be to limit within and between-species transmission of infection within the region and to prevent the ingress of infection into the region. The tools available would be badger culling and vaccination and deer management, including culling. An effective verifiable programme and a commitment to maintaining the necessary resources to prevent transmission from wildlife is an essential component if the regional approach is to be successful.

With respect to stakeholder commitment, key areas of farmer collaboration would relate to the testing of animals (facilities, assistance, time), identifying badgers setts, and adopting and implementing required cattle movement and biosecurity measures. The cooperation of private veterinary practitioners (PVPs) would be required to ensure that testing is carried out at an elevated standard and to advise farmers on effective biosecurity measures suited to their business model.

The measures that would be required to maintain freedom on a long-term basis in the geographical area that is selected (TOR 4)

Experience has shown in Ireland and elsewhere that unless ongoing measures are implemented, an area where eradication of bTB has been achieved will quickly regress to the levels present in surrounding areas. In order to maintain freedom on a long-term basis, continuation of the measures set out in relation to TOR 3 (the measures that would be required to achieve freedom from infection) would be required, particularly those relating to the ingress of infection. In that regard, a key requirement would be to ensure that infection is not introduced through the movement of infected cattle into the region. Identification of infection would be mainly achieved through abattoir surveillance and routine testing of herds. Strict procedures should be put in place for identifying and dealing with any herd infection that may arise. The frequency of testing should be maintained at an appropriate level. Wildlife species would need to be monitored and action taken, where appropriate, to prevent spillover of infection to cattle. This action could include badger culling and/or vaccination and increased frequency of testing in the cattle population.

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1 Introduction

The bovine tuberculosis (bTB) eradication programme (BTBEP) in Ireland has been operating for almost 70 years and, while there has been significant progress in reducing herd incidence during that time period, the level of disease has increased again in recent years. A total of 3,823 new herds were newly restricted for bTB in 2015 representing 3.37% of herds tested (https://data.cso.ie/product/DAAD). The corresponding figures for 2016 were 3,682 herds newly restricted, representing 3.27% of the herds tested. A total 4,613 herds (4.34% of herds tested) and 4,477 herds (4.27% of herds tested) were newly restricted in 2021 and 2022, respectively. During the period 2015 to 2022, there was also an increase in the number of bTB reactor animals.

On 8 May 2018, the Irish government approved a proposal from the Minister for Agriculture, Food and the Marine, Michael Creed TD, to commit to the eradication of TB by 2030. This commitment has been supported by the establishment of a Bovine TB Stakeholder Forum tasked with proposing policies to help achieve eradication within this timeframe.

In 2019, the TB Stakeholders Forum reported to the Minister on a number of initiatives which stakeholders supported. In 2021, the Department of Agriculture, Food and the Marine (DAFM) produced a Bovine TB Eradication Strategy that would build on the progress made to date and drive disease levels down towards the target of eradication by 2030. The strategy document contained several proposals to achieve this target. These included the following:

1. Working in partnership
2. Reducing cattle-to-cattle spread
3. Tackling disease transmission at the wildlife/cattle interface
4. Local area action plans
5. Improving communications about bTB
6. Dealing with legislative changes at EU level
7. Financial aspects
8. Improving programme effectiveness

In view of the lack of progress in recent years, new approaches must be considered in relation to bTB eradication. One possibility is to use a regional approach. This would involve selecting a region of the country and applying the measures necessary to remove infection from herds. It would also involve applying the measures necessary to prevent reinfection of herds from wildlife and from other sources in the selected area, and from sources of *Mycobacterium tuberculosis* complex (MTBC) outside of the area.

Under EU Regulation 2020/689, a Member State or zone can be considered free from infection if 99.8% of herds have been free of bTB for three years and various other conditions are met. In the Irish context, this means that, from a legislative point of view, the disease could be considered to be eradicated from a region, such as one or more counties, if the 99.8% target is achieved and the other conditions are met. The herds in the region could then potentially benefit from more relaxed control measures. However, eradication efforts could cease only when biological freedom is achieved.

The Scientific Working Group (SWG) received a request from DAFM to examine the potential effectiveness of using a regional approach to facilitate the eradication of bTB in Ireland. In particular, DAFM requested the SWG to address the following objectives:

1. The potential value of using a regional approach for the eradication of bTB.

If a regional approach is considered worthwhile:

2. The criteria that should be used to select a geographical area for a regional approach.
3. The measures that would be required to achieve freedom from infection. (Such measures could include but not be confined to wildlife, movement controls and diagnostic testing).
4. The measures that would be required to maintain freedom on a long-term basis in the geographical area that is selected.

A full copy of the request from DAFM to the SWG can be found in Appendix 1.

2 Opinion

2.1 Regionalisation – Definition, regulatory issues and international examples

2.1.1 What is regionalisation?

Establishing and maintaining an infection/disease-free status in the entire territory of a country can be difficult to achieve. However, subpopulations with distinct health statuses can be established within a country for the purposes of international trade, disease prevention, or control. These subpopulations can be established using either:

- Geographical boundaries *(zoning or regionalisation)* or
- Defined management and biosecurity practices *(compartmentalisation)*

The principles of zoning/regionalisation and compartmentalisation are outlined in the Terrestrial Animal Health Code of the World Organisation for Animal Health (WOAH) [1]. For the purposes of the WOAH *Terrestrial Code*, "regionalisation" and "zoning" have the same meaning.

In disease eradication programmes, regionalisation is used to create 'risk boundaries', thereby allowing disease control and surveillance to be differentiated based on risk, to prioritise resource allocation, and to protect lower risk areas. Collectively, this approach ensures momentum towards an improving national disease situation.

2.1.2 Infection/disease eradication in the context of regionalisation

There are two key definitions for *'eradication of infection/disease'* which must be recognised in the context of regionalisation:

- *Legislative* freedom relates to thresholds of disease prevalence as outlined in EU Regulation 2020/689, i.e. a very low level of infection/disease. The requirement for declaring a zone free from *M. tuberculosis* complex (MTBC) infection[1] in bovids and for maintaining freedom is set out in Article 8.11.4 of the WOAH code. The requirements are broadly the same as those set out in Annex IV of EU Regulation 2020/689 as outlined in Appendix 2. There is a need first to achieve legislative freedom, then to maintain freedom below defined levels for herd- and animal-level prevalence. Using this approach, eradication efforts (and resource costs) will continue in perpetuity.
- From a *biological* perspective, eradication is only achieved once the MTBC infectious agent, in Ireland almost exclusively *M. bovis*, has been eliminated from all sources. As a general principle, efforts towards biological eradication becomes more difficult as prevalence approaches (but does not yet reach) zero. Eradication efforts (and resource costs) cease once biological freedom is achieved. However, surveillance (including the need for a rapid response in the event that infection re-emerges) will be ongoing.

2.1.3 A review of international experience

In the modern era, regionalisation has been central to national bTB control/eradication programmes in all countries, except in Ireland, where eradication has been achieved or is progressing.

[1] *M. tuberculosis* complex encompasses *M. bovis* and a number of related mycobacteria. In the following text, where *M. bovis* is referenced, this will include other members of the MTBC, as appropriate.

In each of the international examples below, regionalisation/zoning is (or in the case of Australia, was) applied across the whole country. In some countries, including Australia and the USA, regionalisation was implemented from the start of the eradication programme, whereas in others, such as Spain, a regional approach emerged over time because of differing rates of progress in different administrative divisions/autonomous communities. In several countries (Australia, Great Britain, New Zealand), regionalisation was first implemented due to large differences in bTB prevalence in cattle or because of varying risks associated with the presence of recognised wildlife reservoirs. The geographical boundaries of, and programme actions within, each region (such as the intensity of cattle and wildlife disease management measures) evolve over time in alignment with nationally agreed programme rules, as the country moves towards eradication.

2.1.3.1 United Kingdom

In England, by 1961 disease levels had declined such that the whole of the United Kingdom was declared 'attested' because the incidence of reactors had declined to what was regarded as negligible proportions and, in some areas, testing was reduced to two-yearly or even three-yearly intervals. Disease improvement was, however, not uniform. In TB affected areas, badgers were implicated; controls on badgers were introduced but following on from cessation of gassing of badger setts, there was a further gradual deteriorating disease profile such that Lord Zuckerman recommended resumption of badger controls in 1980 [2]. The deteriorating bTB profile in cattle herds was exacerbated by the diversion of resources from the programme during the BSE crisis in the 1990s and the FMD outbreak in 2001.

Currently there are three designated zones in relation to bTB in England, namely:

- High risk
- Low risk
- Edge

Based on information taken from the tbhub.co.uk website, the High Risk Area (HRA) has a relatively high bTB herd incidence[2] (14.4% in a 12-month period to the end of December 2022) compared with the Edge Area (7.7% in a 12-month period to the end of December 2022) and Low Risk Area (LRA) (1.1% in a 12-month period to the end of December 2022). In comparison to the Edge and LRA areas, there are proportionally more repeat cases among herds in the HRA, and there is a recognised reservoir of infection in wildlife (badgers). Herds in the HRA are subject to six-monthly surveillance bTB testing by default, although herds at lower risk of a bTB breakdown that meet certain criteria are subject to annual surveillance bTB testing. Cattle keepers must also comply with pre-movement testing requirements, i.e. all cattle 42 days old and over moving out of a herd must have tested negative to a tuberculin skin test within 60 days before movement, unless an exemption applies to the animal being moved or the type of movement.

The LRA has a low incidence of bTB and no recognised significant reservoir of infection in wildlife. Most bTB breakdowns are thought to be the result of undetected

[2] Please note that the herd incidence in Great Britain is not directly comparable to that in Ireland because of differences in the methods used for determining this statistic.

infection brought in through cattle movements. Herds in the LRA are generally bTB tested every four years, although there are some exceptions to this. Cattle keepers must also arrange and pay for post-movement tests for any cattle bought in from herds in annual (or more frequent) testing areas of England and Wales. Tests must be completed between 60 and 120 days after an animal has joined the herd. Government-funded bTB tests scheduled to take place within the 60-120 days post-movement testing window can be considered valid post-movement tests. Cattle that are post-movement tested cannot be moved off the premises (other than to slaughter either directly or via a slaughter gathering, a Licensed Finishing Unit, or an Approved Finishing Unit) until the test has been completed with negative results or under a licence issued by an inspector. Based on information taken from the www.gov.uk website, the LRA had five bTB hotspot areas in April 2023 (April 2023: potential TB hotspots in the Low Risk Area of England - GOV.UK (www.gov.uk). These are areas where many bTB breakdowns are clustered and where there are breakdowns of undetermined origin. Increased surveillance on farms and in wildlife are applied in these areas. One such example is the hotspot in Cumbria which has resulted in more than 60 bTB herd breakdowns. Whole genome sequencing of *M. bovis* isolates from this hotspot demonstrated that the infection was introduced by cattle movements from Northern Ireland and had already established and was being maintained in local herds and badgers prior to initial detection [3].

The Edge Area is the buffer zone between the HRA and the LRA which contains local disease fronts advancing from the HRA towards the LRA. The incidence of bTB in most of the Edge Area is lower than in the HRA, however, there is a wide variation between individual Edge Area counties. Herds in the edge area are subject to six-monthly bTB testing or annual testing depending on the bTB status of the geographical area or the individual herd. Cattle keepers must also comply with pre-movement testing requirements, i.e. all cattle 42 days old and over moving out of a herd must have tested negative to a tuberculin skin test within 60 days before movement, unless an exemption applies to the animal being moved or the type of movement.

In Wales, there is now a similar regional approach taken to the application of bTB disease management measures with areas designated Low, Intermediate and High bTB Areas that were established on 1 October 2017 based on disease incidence. Whole herd annual bTB testing still takes place across the whole of Wales. Pre-movement testing is required for cattle 42 days old and over moving out of a herd. These must have tested negative to a bTB test within 60 days before movement, unless an exemption applies to the animal being moved or the type of movement. Cattle moved into the Low bTB Area from the Intermediate or High bTB Areas of Wales, will be required to be post-movement tested between 60 and 120 days after the movement, unless an exemption applies.

Scotland and the Isle of Man are designated as Officially bTB Free. In Scotland, cattle that are or have been in a herd within a high incidence area in Great Britain are required to have a premovement bTB test within 30 days of movement, with this test not being associated with any movement restriction test (Tuberculosis (Scotland) Order 2023). Additionally, such cattle also require a post-movement bTB test 60-120 days after arrival within the receiving herd (unless sent for slaughter prior to the test due date). However, cattle under 42 days of age on date of receipt are exempt from such testing but the herd of origin must be free from any bTB restrictions. Cattle that are or have been in a herd in a low incidence area are also required to have a pre-movement test

within 30 days of movement unless the animal has lived entirely within the LRA. Similar rules apply for cattle imported into Scotland from Northern Ireland (60-120 day post-import bTB test unless slaughtered before the test due date) and those imported from Ireland (60-day post-import bTB test unless slaughtered before the test due date) with animals restricted to the receiving herd until a clear bTB test is demonstrated. Moreover, some herds in Scotland are exempt from the default 48-month bTB testing interval. This was based on analysis of risk-based surveillance carried out by the University of Glasgow [4]. The exemption is applied to herds with less than 50 cattle or herds that slaughter 25% of their stock annually (during previous four years) and have had no more than one consignment of cattle for a high bTB incidence area over the last four years. Additionally, herds that slaughter over 40% of their herd annually during the previous four years are exempt. This is an example of a compartmental approach relating to management and biosecurity practices.

The BTBEP in Northern Ireland commenced on a voluntary basis in 1949 and a compulsory programme commenced in 1959. The initial eradication efforts were focused on Antrim and Derry and subsequently encompassed Down, Armagh, Fermanagh and Tyrone. Northern Ireland was declared an Attested Area on 25th November 1960. However, progress was not maintained. There was a steady increase in herd incidence in the late 1990s with herd incidence reaching a peak of 10% in 2002/2003. This was attributed to disruption caused by the foot-and-mouth disease outbreak in Northern Ireland in 2001. Since then, the bTB levels have fluctuated. Currently, levels are rising with an annual herd incidence of 10.67% being recorded in the 12 month period to April 2023. Annual testing of all herds is mandatory. A herd restricted for bTB is required to have two clear tests at least 60 days apart. Badgers are a recognized source of infection for cattle in Northern Ireland. To-date, most of the work in relation to this source has focused on research and a badger intervention programme has not been implemented. Likewise, a regional approach has not been taken to the application of BTBEP disease management measures.

2.1.3.2 European Union

In the European Union, Spain, Portugal and Italy operated disease-free zones in 2021, as provided for in EU Regulation 2020/689 [5].

Following on from mandatory annual testing of all herds during the initial phases of the Spanish BTBEP conducted in compliance with the rules applicable at the time and in conformity with Directive 64/432/EEC post Spain's accession to the EU, each Autonomous Community (region) is now placed in one of the following categories based on the bTB levels:

- Disease Free Status (DFS)
- Autonomous communities with low prevalence (less than 1%)
- Autonomous communities with prevalence between 1-2%
- Highly prevalent autonomous communities (>2%)

Different testing regimes, including the frequency of testing of herds, are carried out depending on the categorisation of the Autonomous Community [6]. Routinely, all cattle moving between herds in Spain must have a pre-movement test within 30 days prior to movement. Pre-movement tests are also required for within-herd movement in some cases. However, some derogations are applied. For example, animals originating from a region free of bTB do not need to be tested prior to movement. Animals destined for qualified fattening establishments may also be exempt from pre-movement testing

in some cases. In addition, at least 10% of animals that have a pre-movement test and that are destined for a breeding or production establishment must have a post-movement test within 90 days of arriving at the destination premises [6]. Testing frequency is increased if animals move from high risk areas or higher risk herds. In Spain, bTB breakdown periods are risk based and higher-risk restrictions last a minimum of 12 months from when an infected animal is slaughtered. Pozo et al. claim that shorter restrictions with just two herd tests are considered ineffective in terms of clearing the disease on a farm [7].

2.1.3.3 Rest of the World

2.1.3.3.1 New Zealand

Regionalisation was first introduced to New Zealand in the mid-1990s to aid in the management of bTB [8]. Four different disease control areas are now in place, (from lowest risk: (1) surveillance area, (2) special testing area - biennial, (3) special testing area - annual and (4) movement control area) each with different testing frequencies and movement control measures (Disease Control Area (DCA) map | OSPRI). Movement Control Areas (MCAs) were introduced to minimise the risk of bTB spreading through the uncontrolled movement of infected livestock from 'clear' status herds located in areas that are considered to have an elevated risk of infection from local wildlife.

2.1.3.3.2 Australia

In Australia, a system of risk-based herd and area classification was used throughout the national bTB eradication programme that ran from 1970 to 1997. Area classification (either residual, control, eradication, provisionally free, impending free or free) was determined after considering both the apparent disease prevalence across the whole cattle population and the proportion of herds in particular status classifications. In any one location, there was a progressive change in area classification as the programme progressed, until the whole country achieved a free area status. Similarly, a pathway to herd classification was used within each area, both for herds with and without evidence of infection. In herds where infection was found, the herd classification pathway moved from infected to restricted and then provisionally clear. If there was no evidence of infection, the herd classification pathway moved from monitored negative to tested negative and then to confirmed free (CF1, CF2 and CF3). Restrictions on the movement of cattle between herds and between areas was determined according to nationally agreed rules, based on herd and area classifications, to limit the potential for spread of infection to lower-risk herds and areas. There was progressive tightening of movement restrictions as the programme progressed and the last known case of *M. bovis* in cattle in Australia was detected in 2002 [9].

2.1.3.3.3 Chile

In Chile, the national programme for the control and eradication of bTB was launched in 2011. The impacts on economic losses and barriers to exports were among the key drivers for the national programme, which was based on testing and eliminating bTB reactor animals at the producers' expense and without compensation. To deal with differences in prevalence and production systems, regional zoning was applied throughout the country to provide specific and effective strategies to manage and eradicate bTB. The 'eradication zone' was established in both the north and south of the country. It is in the south-midlands where most dairy farming systems are located,

and where the prevalence of infected farms is the lowest in the country. Meanwhile, the region of central Chile was designated as the control zone, which clustered up to 85.5% of infected farms.

In the eradication zone, effective infection control has been achieved, mainly due to bTB-free farm certification, government support to infected farms, and the high level of engagement of farmers involved in export markets. Because of the high costs of the testing and slaughter borne by producers in the control area, the implementation of the programme has experienced difficulties in maintaining surveillance measures and eradicating the disease in infected herds. Within the control zone, there is no evidence of successful disease management as the number of bTB infected herds has increased and the spread of infection has not halted.

2.1.4 Potential models for regionalisation

All of the programmes described above represent potential models for regionalisation.

The common principles running through them include the following:

- Classification of areas, geographical or administrative, based on infection/disease incidence, level of progress towards eradication or threat from wildlife
- The introduction of measures, including but not limited to testing, to prevent transmission of infection from high incidence areas to low incidence areas
- Maximizing and targeting of resources, including appropriate levels of testing
- Conformance with international regulatory requirements
- Ongoing monitoring of progress towards bTB eradication

2.2 Regionalisation in the Irish context

The SWG noted that the question received from DAFM relates to the application of a regional approach to a single area (a 'case region') within the country, in what is described as a proof of concept for regionalisation. On first assessment, this would seem at odds with the regional approach that has been used in all other countries, where regionalisation is applied across the whole country, rather than in a single area. On further reflection, however, the SWG do not see a major difference between the two, noting that the epidemiological principles for disease eradication (including the creation of 'risk boundaries' and differential eradication efforts in different regions) are equivalent in each case. Further, the definition of a 'case region' by default leads to the establishment of two regions for Ireland: the 'case region' and the rest of the country. Therefore, the subsequent sections of this opinion should be viewed in that context.

2.2.1 History of regionalisation in Ireland

A regional approach was used at the start of the BTBEP in Ireland following an initial trial in Tipperary. During the opening phase of the campaign, in September 1954, there was a voluntary scheme in Sligo and Clare. In November 1956, the programme was extended to Donegal, Galway, Leitrim, Mayo, Roscommon and Kerry. The main reasons why counties in the west of Ireland were chosen was that bTB incidence was generally lower in those counties than elsewhere and it was envisaged that less effort would be required for herds and cattle to meet the trading criteria for England (area/animal prevalence criteria) without having to have pre-movement testing (set at 14-days by the UK). The programme was gradually extended to other counties in subsequent years. There was a substantial and a rapid reduction in bTB levels to the

point where Article 3 of Statutory Instrument No. 211/1965 contained a legal declaration that "The State is hereby declared to be an area in which bovine tuberculosis is virtually non-existent". However, this declaration was premature despite the fact that the number of reactors had decreased from approximately 170,000 in 1962 to just over 20,000 in 1965 from a cattle population of approximately 4.5 million. The reduction in bTB levels did not continue and higher reactor numbers were disclosed in most of the subsequent years [10]. Details on the early stages of the eradication programme are provided by Watchhorn [11].

At various timepoints of the programme, policies relating to high bTB incidence areas have been implemented. Unlike the principal concept of this opinion, which focuses on efforts to achieve freedom from disease in lower bTB incidence areas, area-based initiatives have traditionally focused on reducing the prevalence in those high-incidence areas. These efforts included measures such as badger controls, more frequent testing, increased use of severe interpretation of tests, farmer engagement and improving handling facilities. Successful examples include south-west Wicklow and East Offaly in the 1980s and more recently Monaghan and the Burren area of Clare.

Figures 1 to 5 of Appendix 3 contain information on the numbers and densities of cattle and cattle herds in Ireland. This, along with the other information in Appendix 3 was provided by the Centre for Veterinary Epidemiology and Risk Analysis (CVERA), University College Dublin for this opinion.

2.2.2 Potential benefits of a regional approach

In an Irish context, there are several potential reasons why a regional approach would be useful and worthwhile.

2.2.2.1 Benefits to the programme

The following programme benefits are envisaged:

- This initiative would provide a proof of concept with respect to the feasibility and impact of additional measures, particularly those relating to cattle movement and wildlife, that will be required if Ireland is to achieve its target of eradicating bTB. While there has been some level of agreement in the TB Forum in relation to the measures that need to be adopted to eradicate bTB in Ireland, there are significant differences between stakeholders in relation to some measures. In particular, as identified in the Bovine TB Stakeholder Forum Interim Report, there is a lack of agreement on the use of risk-based trading to prevent transmission between herds or areas through cattle movement. With a view to resolving this and other issues and obtaining stakeholder agreement, a programme that includes contentious measures could be trialled in a region. If the programme was shown to be effective and the measures to accelerate bTB eradication were demonstrated to be effective, it would provide a template for achieving eradication in the rest of the country and it would also ensure forward momentum towards bTB eradication.
- This initiative would enable planning for the evolution of a regional approach as part of a broader strategic perspective. As highlighted previously, the evolution of a regionalized approach within a national disease eradication programme allows for a stepwise approach, for effective and efficient use of resources, and for the concentration of resources.
- This should lead to greater overall stakeholder engagement as the benefits outlined above become evident, resulting in enhanced stakeholder commitment.

This would allow a national programme to be put in place with a high level of confidence that bTB eradication could finally be achieved in Ireland.

In order to eradicate bTB from Ireland, additional measures will be required in the short to medium term. These relate primarily to the management of cattle movement to limit disease introduction and spread; see Sections 2.5 and 2.6 for more detail. The SWG notes that additional measures will be required irrespective of whether a regional or national approach is used.

2.2.2.2 Benefits to stakeholders

The successful implementation of a programme in a region should result in reduced costs, reduced disruption with respect to bTB herd breakdowns (less often and less severe), and greater opportunities for farmers and other stakeholders within the region.

The following stakeholder benefits are envisaged:

- In a region that is free from bTB, farmers will principally benefit from changes in testing requirements and reduction of costs and disruption associated with bTB breakdowns. Currently in Ireland, every herd must have at least one annual bTB "round" test. However, in 2022, there were over 35,000 tests completed as a consequence of the presence or the higher risk of disease. Pre- or Post-movement testing is also required on cows and bulls in Ireland and this requirement is likely to expand in the coming years. In addition to these direct costs, farm organisations believe that there are additional costs relating to genetic and production losses. Freedom from disease would result in the potential for lower testing costs. Notably, disruption to farm operations due to disease outbreaks, testing labour requirements and unplanned animal losses would be significantly reduced. Cattle could be freely moved out of the selected region without any restrictions once it is deemed bTB free from a legislative perspective. Indeed, as shown from the current situation in Scotland (section 2.1.3.1), some herds are now exempt from any on-farm testing.
- Farmers in a region that is free from bTB would also benefit from a more favourable trading status. Evidence from the UK has shown that herd owners in low bTB incidence area are more likely to buy cattle from other herds in the low incidence area whereas herds in the high incidence area are less discriminating in this regard [12]. For this benefit to be available, farmers purchasing cattle would need to know which selling herds have a low-risk status.
- Currently Ireland benefits from a considerable international trade in value-added produce, an example of which is the production of over 10% of global infant milk formula in Ireland. Disease-free regions may contribute to improved market penetration in product areas where a high herd health standard is desirable.

2.2.3 Challenges associated with using a regional approach

2.2.3.1 The inward movement of *M. bovis* infection into the selected region

A regional approach relies on measures in place to effectively prevent the inward movement of bTB infection, including the inward movement of cattle from herds of higher to lower bTB risk, the inward movement of cattle across the regional boundary between fragments of the same farm, and the potential inward movement of infection via wildlife. The regional approach will be of limited value with increasing 'permeability' of the 'risk boundary' around the region, noting that this relationship is

likely non-linear, with the effectiveness of a regional approach falling rapidly as the risk boundary becomes increasingly permeable.

2.2.3.1.1 Inward movement of infected cattle between farms

Residual infection (that is, the presence of animals with persistent but undetected infection) is a recognised feature of bTB epidemiology. This phenomenon occurs within test-based eradication programmes throughout the world and is the key rationale for ongoing efforts towards improved diagnostic tests.

In Ireland, the problem of residual infection within the national bTB programme has been demonstrated in several observational studies, including by Berrian et al. who highlighted an increased odds (1.91; 95% confidence interval [CI], 1.76-2.07) for animals sold out from bTB 'exposed' herds compared with animals sold out from bTB 'non-exposed' herds [13]. Similar results were obtained by Wolfe et al. who investigated the future bTB risk in cattle sold from dairy herds with a recent bTB history [14]. In comparison with unexposed herds, animals from herds with 1–7 reactors were 1.23 (95% CI, 0.87–1.74) times more likely to test positive, and animals with 8 or more reactors were 1.77 (95% CI, 1.06–2.96) times more likely to test positive. This is a consequence of the imperfect sensitivity of available diagnostic tests as currently applied in the field.

There is substantial movement of cattle in Ireland. In 2016, there were 1.3 million movement events, this being all journeys travelled by vehicles (such as trailers) to transport cattle to markets, new herds, slaughter plants or export facilities [10,15]. Tratalos et al. found that cattle movement metrics are high throughout the country and movement often involves animals travelling over long distances [16]. In that study, approximately 50% of cattle movements were within the same county with the remainder involving movements between counties. A small number of herds were the origin or destination for a very large number of movements. There is a higher level of cattle movement from southern and western counties, reflecting the movements of animals born in herds in the west of Ireland for fattening in the east of Ireland, as well as movements to herds in the east and north of Ireland prior to export. Therefore, this would suggest that the initial proof-of-concept area may best be located in the south or west so that outward movement from non-restricted herds is least impacted.

Once the two above-mentioned events are combined (that is, residual infection and cattle movement), it is clear that ongoing commerce will result in the movement of some cattle with undetected infection. This is occurring despite ongoing testing of cattle as part of the national BTBEP. This leads to critical questions about the absolute number of animals moving with undetected infection, the relative contribution to this effect to bTB epidemiology in Ireland, and the importance of cattle movement as a constraint to bTB eradication.

<u>Estimates of the absolute number of animals moving with undetected infection</u>

This question has been considered in some detail using a detailed modelling approach and UK bTB data. In a study conducted by the University of Cambridge, Conlan et al. estimated that infected animals will be present in 8% (3-17%, 95% confidence interval) of breakdowns at the time of derestriction, with a median of 1 (1-3, 95% confidence interval) infectious animals remaining in these herds [17]. Under differing modelling assumptions, these figures were 21% (12-33%) of herds, with a median of 1 (1-4) infectious animals [17].

Work is currently underway to repeat these modelling approaches in Ireland using local data, accounting for approaches to BTBEP in Ireland (including the skin and interferon-γ tests) as currently applied in the Irish programme, and some refinement of the methodological approaches. Once this work is complete, it will be possible to estimate the absolute number of animals moving in Ireland with undetected infection.

The relative contribution of cattle movement to the epidemiology of bTB in Ireland and its importance as a constraint to bTB eradication

Here, both direct and indirect contributions of cattle movement to bTB epidemiology are relevant.

The direct contribution of cattle movements to bTB epidemiology in Ireland

This has previously been quantified by Clegg et al. who attributed 6-8% of bTB restrictions to the recent introduction of an infected animal [18,19]. In these studies, source attribution was determined after considering the past movement history (including the potential for bTB exposure) of animals identified as reactors at the start of a bTB restriction. These results must be interpreted with care as there are several potential biases in these estimates. In particular, the 'potential for exposure' was assumed to lead to infection (if not, the risk attributed to cattle movements has been overestimated) and no consideration was made for the potential for latency (if it were important, the risk attributed to cattle movements has been underestimated). A study showed that 6.4% of bTB breakdowns in Northern Ireland were directly attributable to the movement of infected animals [20].

There are further research findings in support of a direct contribution of cattle movements to bTB breakdowns in Ireland.

- Firstly, several studies have consistently associated inward cattle movement with increased herd-level bTB risk [18,21–23]. The measurement of cattle movement has become increasingly sophisticated in later studies, and now utilizes movement network metrics (with the number of herds from which animals are derived being most influential) [23]. In this latter study, with a focus on herd bTB restrictions during 2018 and 2019, Tratalos et al. found that measures of cattle movements directly into the herd were risk factors for subsequent bTB restrictions. A range of movement metrics were investigated with 'the number of herds that animals were coming from' being the most important of these. The authors caution that in many cases bTB infected animals are moving out of herds before being identified through testing, and that risk-based trading approaches, if adopted, should not rely solely on the previous test history of source herds as a proxy for future risk.
- Secondly, although relevant bTB modelling studies are not available, insights can be extrapolated, with care, from modelling studies on Johne's disease in Ireland (noting many shared bacteriological and epidemiological features between these two diseases). In these models, a risk-based approach to animal movements was found to effectively reduce the increase in herd prevalence over a 10-year period in Ireland, but only when levels of herd participation are very high [24].

The indirect contribution of cattle movements to bTB epidemiology in Ireland

Herd bTB breakdowns can also be indirectly attributable to cattle movement, as movement has the potential to 'seed' infection to areas previously non-infected and the subsequent establishment of infection through other transmission routes (in the herd: residual infection; within the locality: wildlife, contiguous cattle, local movement). This is perhaps best demonstrated in the recent study of Rossi et al. where infection was seeded into the local cattle population of Cumbria with the introduction of an infected animal from Northern Ireland [3]. After a subsequent period of cattle-to-cattle transmission, infection subsequently established in the local badger population, with an observed prevalence peaking at 21% in badgers.

To this point, the indirect contribution of cattle movement to bTB epidemiology in Ireland has been difficult to quantify, given the multiple transmission routes that operate when disease is endemic. This knowledge gap may be addressed with the introduction of whole genome sequencing, which, hopefully, will provide important insights into the events that contribute to disease clusters and the relative importance of this and other transmission routes.

The indirect contribution of cattle movement to bTB epidemiology in Ireland will become increasingly important towards the latter phase of eradication, as bTB levels fall and infection-free areas become increasing important. That said, if steps are not taken to address this issue now, during the current endemic phase of infection, it may prove very difficult to establish infection-free areas.

In conclusion

Controls on cattle movement, using risk-based approaches, in addition to ongoing testing, are a central feature of the national programme in all countries where bTB eradication has been successful (Australia, [9]) or progress is currently being made (for example, New Zealand [8]).

Currently, measures to limit infection in cattle in Ireland have mainly relied on a test-based approach, including annual skin testing on all herds, and intensive testing of infected herds using herd-level skin testing as well as the use of the interferon-gamma test in defined high-risk cattle cohorts. To date, there has been an unwillingness within the TB Forum, as there was previously within the ERAD stakeholder Board in the early 1990s, to implement risk-based controls on cattle movement in Ireland similar to those used in other countries as described in Section 2.1.3.

2.2.3.1.2 Inward movement of infected cattle between fragments of the same farm

Farm fragmentation is a common feature of livestock production both in Ireland and Northern Ireland, with the potential for fragments to be separated by considerable distances.

In a study conducted in Northern Ireland, fragmentation was associated with an increase in the risk of a bTB breakdown, with highly fragmented farms almost twice as likely to have a bTB positive neighbour compared to non-fragmented farms [25]. Based on a retrospective observational study, Byrne et al. found that the number of parcels of land on a farm was positively associated with bTB breakdown duration in Ireland though only for herds with four or more parcels relative to herds with one [26]. Studies in the UK found an association between the risk of a bTB breakdown and the number of land parcels on a farm [27–30]. For example, Johnston et al. found that herds that operated

over multiple premises were 1.79 times more likely to have a bTB breakdown than herds that operated from a single premises [29].

In general, the movement of infected cattle or contaminated equipment and/or machinery between fragments facilitates the spread of *M. bovis* to cattle and wildlife in new geographical areas and needs to be properly managed if bTB eradication is to be achieved.

2.2.3.1.3 The potential inward movement of infection via wildlife (badgers and deer)

Badgers live in social groups and only a minority of individuals disperse from their natal social group. However, Gaughran et al. concluded that dispersal may be important for the spread of bTB, as dispersers could act as hubs for *M. bovis* transmission [31]. In that study, 18% of badgers dispersed with only 61% dispersing to adjacent social groups. Moreover, dispersal was an extremely complex process and measurement of straight-line distances between the old and new social groups can severely underestimate how far badgers can travel before settling into a new social group [31]. Overall, based on this and other studies, badger dispersal could potentially facilitate the inward movement of infection into the selected region.

Deer may range over many kilometres and would therefore have the potential to transmit *M. bovis* to the selected region. However, apart from in Co. Wicklow, as outlined in an opinion of SWG in 2021, there is currently no evidence to support deer acting as a maintenance host for *M. bovis*, i.e. a host in which the infection is self-sustaining [32].

2.2.3.2 Effectively address all infection sources within the region

A regional approach relies on measures to effectively and sustainability address all infection sources within the region, including both cattle (with a focus on residual infection and within-region movement) and wildlife (badgers and deer). A regional approach will be of limited value if this cannot be achieved, for whatever reason.

2.2.3.2.1 Transmission of infection between cattle

In an opinion published in 2021, the SWG concluded that cattle-to-cattle transmission is likely to constitute a dominant route of transmission for cattle herds [32]. In the context of a regional approach, transmission of *M. bovis* could occur between herds within the selected region in addition to the transmission of infection from herds outside the region as described in Section 2.2.3.1. Cattle-to-cattle transmission could occur due to movement of cattle between herds in the selected region or due to contact between neighbouring herds. Controls on cattle movement, using a risk-based approach, and the prevention of spread between neighbouring herds would be required to prevent transmission.

In addition, cattle-to-cattle transmission between herds will be compounded by within-herd transmission. In that context, the eradication of bTB from infected herds would be a key requirement in achieving freedom. In 2021, the SWG published an opinion on the diagnostic methods available for detecting *M. bovis* in cattle in Ireland [33]. It highlighted the central role of the Comparative Intradermal Tuberculin Test (CITT) and the utmost importance that it is performed properly. It also highlighted the value of using other approved tests and newly developed tests as ancillary tests.

Currently, Ireland avails of a derogation from Commission Delegated Regulation (EU) 2020/689 whereby bTB restriction/testing periods should last for between 12 -18

months following disclosure of a positive case. Irish restriction periods require a clear test at least 4 months from when the last positive case left the farm having completed 2 negative CITT herd tests. Short restriction periods pose a risk of undetected cattle moving between farms with the concomitant risk of transmission.

2.2.3.2.2 Infection of cattle from wildlife or other farmed species

Since the early/mid 1980s, DAFM has removed badgers through licences issued by the National Parks and Wildlife Service (NPWS) under the Wildlife Act where a serious bTB breakdown had occurred in cattle, which was epidemiologically linked to badgers. This was codified in 2003 into a national programme. Due to Ireland's commitments under the Bern Convention on Wildlife to avoid the eradication of this native wildlife species, the total area under which this programme operated could not exceed 30% of the agricultural land in Ireland [34]. Information on badger abundance and badger captures in Ireland can be found in Figures 24-27, Appendix 3.

In 2018, following successful BCG badger vaccination trials [35–37], the Minister for Agriculture, Food and the Marine announced that badger vaccination would roll out incrementally over time, with vaccination gradually replacing the removal of badgers as the default position in response to bTB in cattle. Information provided by CVERA for this opinion showed that the proportion of the land area in a county that is included in the badger vaccination programme ranges from 1% (Dublin) to 95% (Longford) (Figure 26, Appendix 3). Currently, approximately 50% of the area previously subjected to badger capturing has been switched to badger vaccination with over 60% of the badgers captured in Ireland being captured in vaccination zones. Areas are switched to vaccination when a variety of conditions are met that relate to badger densities, bTB prevalence and resource availability [38,39]. Regardless of whether badger vaccination or culling is employed, the effectiveness of the approach is constrained when there is either insufficient knowledge of local badger habitats or insufficient human resources, particularly in relation to staff that are responsible for implementing this wildlife programme. If a regional approach is adopted, consideration would need to be given as to how *M. bovis* transmission from badgers to cattle herds could be prevented from the badger population within the selected region as well as from the areas surrounding the region. A similar consideration may be required in relation to deer.

A recent study in south-west France, an area with low bTB prevalence but with *M. bovis* infection in local badgers, looked at resurgence of *M. bovis* in cattle and badgers in the period 2007-2019 and projected that "Although eradication of bTB appears possible in the study area (since $R < 1$), the model suggests it is a long-term prospect, because of the prolonged persistence of infection in badger groups (2.9–5.7 years)" [40]. Hence keeping measures in place to prevent recrudescence of bTB in badgers in an area is very important to minimise spread of infection from wildlife into herds in the locality.

The risk from the inward movement of tuberculous New World Camelids (NWCs), Alpaca or Llama, into the region is not negligible. NWCs are extremely sensitive to *M. bovis* infection, generally respiratory in nature and with fatal consequences. This has resulted in TB problems, amongst NWCs in many countries, with potential for spread to cattle directly or as a vector infecting wildlife, the environment or other fomites in an area.

2.2.3.2.3 Environmental transmission of infection

Indirect transmission of bTB in the environment occurs via contact with infectious excreta such as faeces, urine or sputum in the environment. Advancements in methodologies have demonstrated that *M. bovis* persists in the environment of farms affected by bTB [41]. Allen et al. concluded that cattle and other species may contribute to the contamination of the environment and thus be a potential source of infection to any susceptible species which shares the same environment [42]. The presence of cattle at badger-associated locations such as setts and latrines has been found to be a significant risk factor for bTB [43,44].

Akhmetova et al. found that transmission from cattle to badgers is more common than badger to cattle transmission [45]. This reflects the relative numbers of cattle (7 million) and badgers (120,000) in the country where cattle outnumber badgers by approximately 60 to 1. It is the density of both cattle and badgers and/or total density in the environment that determines the risk factor for indirect environmental inter-species transmission.

Environmental contamination and indirect transmission involve transmission from *M. bovis* contaminated fomites such as transport vehicles, farm machinery, farm equipment, soil, pasture, manure, bedding, slurry, excreta, and the built environment either through host animal inhalation or ingestion. Therefore, effective farm biosecurity targeting these pathways would be a fundamental prerequisite for an eradication programme to be successful.

M. bovis tuberculosis can affect all mammals and therefore not only are wildlife of potential concern but other domestic animal species may occasionally be infected and spread infection back to cattle. Thus if bTB is a problem on a farm, consideration should be given to the health of other animals, including sheep, goats, pigs horses, camelids, dogs, cats, and also humans, all of which have been found to be susceptible to *M. bovis*. In particular, camelids can be very susceptible to *M. bovis* infection and can develop quite severe disease with potential for environmental contamination in advanced cases [46].

In general, evidence from Ireland and elsewhere has shown that eradication programmes, and bTB eradication programmes in particular, are only effective when all significant transmission pathways are addressed. Consequently, the constraints that prevent effective measures to be taken against these transmission pathways in Ireland will need to be overcome if bTB eradication is to be achieved in the selected region.

2.2.3.3 Breeding for reduced bTB susceptibility

Host genetics plays a role in the response to infection. Research involving DAFM, UCD, Teagasc and ICBF demonstrated that variability in an animal's response to bTB infection is controlled by its genetics [47–54]. Furthermore, certain family lines of cattle in Ireland were identified with a higher prevalence of bTB reactors than others. Ring et al. also reported that cattle identified as being genetically susceptible to bTB infection (i.e. in the worst 20th percentile of all cattle) had a 1.44 times greater odds of returning a positive bTB result compared to cattle least genetically susceptible to bTB infection (i.e. ranked in the best 20th percentile) [53]. Research has also shown that breeding for reduced bTB susceptibility was possible without negatively impacting on otherwise desirable traits [49–52,55]. Increased understanding of the genetic basis for the host response to bTB will allow us to exploit breeding to complement the existing BTBEP.

The Irish Cattle Breeding Federation (ICBF) launched a new tool in 2019 (https://www.icbf.com/wp-content/uploads/2019/01/TB_explanation.pdf) using breeding values for bTB genetic susceptibility so that Irish dairy and beef farmers could select sires with reduced bTB susceptibility (Do you know your animal's breeding value for TB? - ICBF). Since 2022, breeding for reduced susceptibility to bTB has been incorporated into the national dairy breeding goal (i.e. the economic breeding index (EBI)) and is expected to be incorporated into the national beef breeding goals during 2023. In the U.K, TB Advantage is a genetic index published by the Agriculture and Horticulture Development Board (AHDB) to help dairy farmers make informed decisions to breed cows which have a reduced susceptibility to bTB. Work is also ongoing in the efforts to determine additional biomarkers of bTB resistance versus susceptibility in cattle to further enhance bovine genetic selection programmes and to support the global efforts to eradicate bTB [56–58].

Breeding for bTB susceptibility/resistance is permanent and cumulative [59,60]. For this reason, further discussion is needed between quantitative geneticists and epidemiologists, immunologists, pathobiologists and other relevant disciplinary specialists, preferably in an international forum, to provide assurance that breeding for bTB susceptibility/resistance in the longer term will not lead to decreased responsiveness in the national herd to current diagnostic methods and/or to establish monitoring and mitigation procedures to ensure such a possibility is not realised.

2.2.3.4 Stakeholder commitment

A high level of stakeholder commitment is an essential component if the BTBEP is to be successful. A bTB stakeholder Forum was set up in 2018 to assist with this issue. At the onset of the TB Forum's deliberations, consultation papers were published to inform the TB Forum of the existing scientific and policy frameworks in Ireland and across the World [61]. Reflecting the National Farmed Animal Health Strategy launched in 2017 [62] the areas on which the papers focused were;

1. Working in Partnership;
2. Additional Policy Measures; and
3. Cost and Benefits.

In relation to the additional policy measures, the TB Forum requested DAFM to collate proposals together on suggestions made in relation to disease and to summarise options [63]. When the TB Forum subsequently reported, it recommended adoption wholly or in part of many of the options but rejected supporting informed purchasing or risk based trading.

Historically, the fact that the implementation of the Irish BTBEP has been overseen by DAFM has given rise to some criticism that bTB is widely considered to be a government problem [10,64]. The issue was partially addressed in 1988 with the creation of an executive agency, Eradication of Animal Disease (ERAD) agency. While, in its four years of existence, it did not achieve its primary disease reduction objective, it did achieve several important objectives including a functional integrated management system and an insistence that national BTBEP policy be advised by good science.

A study by O'Connor examined stakeholder attitudes towards the BTBEP in Ireland [65]. The findings were generally negative and the stakeholder attitudes towards the programme included disengagement, confusion with the purpose, uncertainty about collaboration and a lack of vision. Ciaravino et al. demonstrated that, amongst Spanish

farmers and veterinarians, their BTBEP was perceived as a law enforcement duty without adequate stakeholder motivation [66]. Another Spanish study indicated that different stakeholder groups held differing views on which approaches would be the most effective and practical [67]. Dorn and Mertig noted that stakeholders in Michigan, USA supported the bTB eradication goal but were less supportive of specific measures to achieve eradication [68].

The issue of coordination of bTB eradication has also been addressed in other countries. There was an evolution of governance structures during the Australian BTBEP. The model of shared responsibility and cost-sharing between government and industry, which emerged during the latter part of the programme, is now recognised as a key reason for Australia's success with bTB eradication. Animal Health Australia (https://www.animalhealthaustralia.com.au) was subsequently established with similar governance structures, and now coordinates and facilitates many aspects of national animal health in Australia [69]. In New Zealand, governance of the national BTBEP is overseen by OSPRI (https://www.ospri.co.nz), a non-government organization that manages both TB free New Zealand and NAIT (National Animal Identification and Traceability system).

2.3 Potential value of a regional approach for the eradication of bTB (SWG response to ToR 1)

The SWG is supportive of a regional approach (that is, the establishment of a 'case region') within the national BTBEP, but only with the following provisos:

- This proposal for regionalisation is an integral part of a broader strategic approach to bTB eradication in Ireland, including clarity with respect to the planned evolution of the regional approach over time. As part of both this regional approach and the broader national bTB eradication strategy, there is also a need to clearly define the overall aim of the eradication programme, that is, either legislative or biological freedom, bearing in mind that legislative freedom would come first, in any event, on the way to biological freedom.
- External biosecurity measures are in place to prevent the inward movement of infection into the 'case region'. These measures will need to address each of the following:
    - The inward movement of cattle across the regional boundary from herds of higher to lower bTB risk. To achieve this, risk-based approaches to cattle trade will need to be agreed.
    - The inward movement of cattle across the regional boundary between fragments of the same farm. Rules will need to be agreed to prevent all higher risk movements.
    - The potential inward movement of infection via wildlife, including badgers and deer. The use of geographical boundaries could potentially be explored.
- Internal biosecurity measures within the 'case region' are in place to effectively address all infection sources within the region, using approaches that align with best-available national and international scientific information and practice. These infection sources include:
    - Cattle, with a focus on:
        - Residual infection
        - The movement of cattle, specifically controls to ensure that infection is not spread by cattle moving from higher to lower

risk herds within the region. To achieve this, risk-based approaches to cattle trade will need to be agreed.

    - Wildlife
        - Badgers, with a focus on vaccination, monitoring and population control as necessary
        - Deer with a focus on management, monitoring and population control as necessary

- The allocation of additional resources in support of regionalisation is in a manner that does not reduce current efforts at suppression of infection nationally.
- Governance and management structures are in place to maximise farmer and industry commitment to the effective implementation of all relevant bTB eradication measures, relating both to external and internal biosecurity.

The SWG recommends that there is ongoing monitoring of progress within the 'case region', seeking insights into:

- The effectiveness of external biosecurity measures
- The effectiveness of internal biosecurity measures
- Farmer and industry support for effective external and internal biosecurity measures.

Specific and measurable targets should be identified and put in place. These should be reviewed at regular intervals and appropriate corrective actions should be taken if targets are not met.

Subject to the successful completion of this first phase, the SWG recommends that the TB Forum support a regional approach to bTB eradication in Ireland that evolves over time, as undertaken in other BTBEPs throughout the world. This would allow focus and flexibility with resource allocation whilst also assuring forward momentum in the national programme. In broad terms, a 'ladder-based system' of risk categorisation is needed (say from risk level 1 [lowest] to risk level 5 [highest), which is applied both to regions and to herds within regions. In the initial (proof of concept) stage, therefore, the 'case region' is designed at lower risk (i.e. risk level 4), with the rest of the country designated risk level 5. Technical rules will be required to define these risk levels and to facilitate the safe movement of cattle, both between and within regions. Attention to external biosecurity (the risk boundary around each county) and internal biosecurity (the measures within each county to address bTB), as proposed elsewhere, will be critical. The bTB risk of each county would evolve over time as bTB prevalence changes.

2.4 The criteria that should be used to select a geographical area for a regional approach (ToR 2)

In considering an area as potentially suitable for a regional approach (as outlined above, as a single defined region for the adoption of a 'proof of principle' intensive disease control and protection measures), the main objective should be to use selection criteria that will maximise the possibility of firstly eradicating the disease and then ensuring the region remains protected from re-infection using the resources necessary and appropriate to the task. The second objective is to develop a model that can be incrementally applied to other areas and thence to the whole country. The size of the initial area may be an important consideration given that the smaller the area, the greater

the influence of factors in the surrounding area, in the absence of risk mitigating boundaries.

Several criteria can be used to determine the suitability of the region (as discussed below). Each criterion is categorised as high, medium or low priority. A high priority criterion is one that is deemed essential for the successful implementation of a regional approach, a medium priority criterion should be used if possible, and a low priority criterion should ideally be used but is not essential for the successful implementation of a regional approach. The larger the area the greater the resource requirements, the greater the risk of not getting full cooperation from all within the area. It should also be considered that while success in a high incidence area may be more difficult to achieve than in a low incidence area, it may also be more impactful.

2.4.1 Issues related to the inward movement of M. bovis infection into the region

2.4.1.1 Inward cattle movement relating to the number of moves and the proportion of those moves from higher to lower risk herds

As mentioned in Section 2.2.3.1, there is very substantial movement of cattle in Ireland. Figures 11 to 23 of Appendix 3 provide information on movements of cattle and particularly movements of cattle from higher risk herds to lower risk herds. Figure 11 shows that the proportion of cattle purchased into a herd in 2019 that came from a herd in a different county ranged from 25% (Clare) to 92% (Dublin).

Two different criteria have been used to measure herd risk:

- Based on criteria used by DAFM to designate herds as high bTB risk[3], the number of herds in 2019 that bought animals from herds considered higher risk ranged from 42 (Dublin) to 1,184 (Cork) (Figure 12). The percentage of herds which bought animals from herds considered higher risk ranged from 3.5% (Donegal) to 16.9% (Monaghan) (Figure 14 of Appendix 3). The percentages of cattle purchases that involved movement from herds considered high risk to herds considered lower risk according to the county of the buying herd, ranged from 1.9% (Donegal) to 8% (Wicklow) (Figure 16 of Appendix 3).
- An alternative method to designate the level of bTB risk associated with a herd was calculated using a mathematical model, published by Tratalos et al. [23], (also in Appendix 3). In this model, the bTB risk status of a herd was based not only on its own previous bTB status but also on other factors such as the status of neighbouring herds, herd type, herd size and badger abundance. Overall, using the model criteria, a larger number of herds were designated high risk compared to the criteria used by DAFM. Based on the output from the model, the number of herds which bought animals from herds considered higher risk ranged from 97 (Dublin) to 4,800 in (Cork) (Figure 18 of Appendix 3). The percentage of herds which bought animals from herds considered higher risk ranged from 21% (Dublin) to 42% (Longford, Carlow, Limerick, Waterford) (Figure 20 of Appendix 3). The percentages of cattle purchases that involved movement from high risk herds to herds of lower risk according to the county of the buying herd, ranged from 14% (Dublin) to 53% (Kerry) (Figure 22 of Appendix 3).

[3] High Risk was defined as follows: breeding herd, not a feedlot, had at least one breakdown within the last three years involving at least five animals.

The choice of the appropriate risk metric is important, noting its purpose to prevent the inward movement of cattle from herds of higher to lower bTB risk. The modelling approach reflects our best understanding of bTB risk in Irish herds and was published recently. The DAFM risk designation considers similar principles, but with simplification and compromise. As highlighted previously, a regional approach will be of limited value with increasing 'permeability' of the 'risk boundary' around the region. Furthermore, this relationship is likely non-linear, with the effectiveness of a regional approach falling rapidly as the risk boundary becomes increasingly permeable.

The successful implementation of a regional approach requires farmers within the region to agree and adopt additional cattle movement controls to prevent the inward movement of *M. bovis* infection into their own herd and hence into the region. This will undoubtedly impact commerce in the trade of cattle. Therefore, it would be important to select an area where inward high-risk cattle movements are less common, thereby limiting disruption to trade.

This criterion should be regarded as high priority.

2.4.1.2 Geographical boundaries

Geographical boundaries can be a valuable tool in limiting the spread of animal diseases. These include the coastlines, rivers, forests, mountains, motorways and other main roads. In the case of bTB, such geographical boundaries can be particularly valuable in preventing *M. bovis* transmission from badgers which tend to use linear features like roads as territory boundaries. Indeed, geographical boundaries were used for this purpose in the Four-Area Project [70]. Geographical boundaries will also reduce *M. bovis* transmission by reducing contact between cattle and, depending on the type of boundary, may also reduce transmission by preventing environmental contamination though fomites.

Geographical boundaries may not be in conformity with administrative boundaries. Traditionally, disease control regions have reflected administrative areas. However, modern computer systems relating to land holdings, administration of testing, movements and allocation of tasks allow a more flexible approach to consideration of topographical features.

This criterion should be regarded as medium priority.

2.4.1.3 Trade flows

As highlighted previously, there is substantial movement of cattle in Ireland. In particular, there is a higher level of cattle movement from southern and western counties, reflecting the movements of animals born in herds in the west of Ireland for fattening in more productive grazing areas and feedlots in the east, as well as movements to herds in the east and north of Ireland prior to export.

When selecting a participating region, these trade flows should be carefully considered. Ideally, consideration should be given to the selection of region(s) that experience a net outward movement of cattle. In these areas, restrictions on inward cattle movement (from higher to lower risk herds) would be of lesser impact on ongoing commerce.

This criterion should be regarded as high priority.

2.4.1.4 Land fragmentation

Based on information provided by CVERA for this opinion, the proportion of farms with fragments > 1 km from the county of the home farm varied from 1% (Donegal) to 13% (Dublin) when measured with reference to the county of the home farm (Figure 6, Appendix 3). The proportion of farms with a home farm outside the county and a least one land parcel within the county ranged from 1% (Donegal) to 24% (Dublin) (Figure 7, Appendix 3). In selecting a participating region, preference should be given to areas with a relatively low number of fragments, particularly fragments outside of the region and participating farmers with outside fragments may need assistance (e.g. Teagasc and/or TASAH) to identify and adopt appropriate disease risk mitigation measures to protect their own herd and hence the region from the inward movement of *M. bovis* infection.

This criterion should be regarded as medium priority.

2.4.2 Issues relating to effectively addressing all infection sources within the region

2.4.2.1 bTB levels in herds and cattle

There are variable bTB levels cattle herds in different parts of Ireland, with bTB levels generally lower in western counties than in eastern counties (Table 1). In 2022, seven (Mayo, Donegal, Galway, Clare, Roscommon, Leitrim and Sligo) of the eight counties with the lowest bTB incidence[4] were located along the western seaboard or close to it. Some of these counties have been historically low whereas others, such as Clare, have shown recent improvement. Further information on bTB levels in particular counties can be found in Figures 8 and 9, Appendix 3.

[4] The incidence for a particular year is defined as the number of herds that are newly restricted in that year /total number of herds tested in that year.

Table 1. Incidence of bTB by county, sorted by incidence during 2022

County	Average 2008-2012	Average 2013-2017	Average 2018-2022	2022
Mayo	2.22%	1.71%	2.08%	2.12%
Donegal	3.54%	2.60%	2.22%	2.54%
Galway	3.95%	2.66%	2.75%	2.61%
Clare	5.88%	4.20%	3.70%	2.62%
Roscommon	4.48%	3.41%	2.84%	2.68%
Leitrim	3.21%	2.53%	2.37%	2.90%
Carlow	4.87%	3.00%	3.09%	3.14%
Sligo	3.63%	3.03%	3.58%	3.51%
Cavan	4.58%	4.18%	4.66%	3.89%
Kerry	2.55%	2.61%	3.08%	4.11%
Limerick	3.91%	2.43%	2.76%	4.13%
Wexford	8.62%	6.16%	4.45%	4.25%
Cork South	7.08%	4.15%	4.03%	4.28%
Waterford	5.91%	2.66%	3.48%	4.52%
Longford	4.60%	2.38%	3.23%	4.66%
Kildare	4.44%	3.94%	4.28%	5.07%
Louth	5.62%	4.14%	5.34%	5.35%
Westmeath	7.07%	5.28%	5.79%	5.38%
Tipperary North	6.52%	4.42%	5.39%	5.45%
Tipperary South	5.44%	3.10%	4.14%	5.70%
Laois	5.22%	3.68%	4.85%	5.78%
Monaghan	3.10%	3.55%	6.91%	5.91%
Offaly	6.08%	4.52%	5.39%	6.13%
Kilkenny	6.92%	4.18%	4.37%	6.61%
Cork North	5.42%	4.36%	7.06%	6.72%
Meath	8.15%	5.66%	6.49%	6.75%
Dublin	6.68%	7.03%	7.14%	8.93%
Wicklow East	11.25%	7.27%	9.51%	10.97%
Wicklow West	7.03%	10.48%	13.42%	13.58%

Other things being equal, the initial eradication of bTB would be easier to achieve in low incidence areas/counties, particularly those areas/counties that have had a low incidence over a long period. However, if the will of the participating farmers is sufficiently strong, this criterion is not an obstacle to a region's eligibility for consideration. We note that low incidence may be a proxy for other measures and possibly a good indicator of optimal conditions in the area.

This criterion should be regarded as medium priority.

2.4.2.2 Administration of the region

In Ireland, the BTEBP is administered by the 15 Regional Veterinary Offices. Some of these offices cover several counties while others cover parts of counties (Table 2).

Table 2. Regional Veterinary Offices in Ireland

	Regional Veterinary Office
1	Carlow, Wexford, Wicklow East
2	Cavan, Monaghan
3	Clare, Limerick
4	Cork North
5	Cork South
6	Donegal
7	Dublin, Kildare, Laois, Wicklow West
8	Galway
9	Kerry
10	Kilkenny, Waterford
11	Leitrim, Longford, Sligo
12	Mayo
13	Offaly, Westmeath
14	Roscommon
15	Tipperary

Ideally the region should avoid the involvement of multiple administrative units and should be involve an administrative area with established resources that has demonstrated recent success in terms of bTB trends. The region should involve tight and cohesive professional, technical and administrative participation to advise, liaise and collaborate with the participating farmers and their Private Veterinary Practitioners (PVPs). In particular, it is imperative that sufficient resources are available for implementing the appropriate badger control programme over a sufficiently long period.

This criterion should be regarded as high priority.

2.4.2.3 Effectiveness of badger programme

Both badger culling and badger vaccination have been demonstrated to reduce *M. bovis* prevalence in badgers and the potential for spillback of infection into the bovine herd.

Epidemiological studies in Ireland [71] and Northern Ireland [72] have found significant and positive correlation between metrics of badger density and increased bTB herd breakdown risk indicating that density reduction results in a lower risk of infection. This is because of the immediate direct result of the reduction in infected individuals in the environment and the indirect result of a reduction in badger TB prevalence over time. Badger vaccination is also effective in terms of reducing transmission of *M. bovis* where there is optimal population penetration and resultant vaccinal protection [35,39,73].

Badger abundance in Ireland was estimated by Byrne et al. [74] using a modelling approach. Based on an extrapolation from this model provided by CVERA, the probability of the occurrence of a badger social group was lowest in the north-west of Ireland and highest in the north-east (See Figure 27, Appendix 3).

Prevalence studies, conducted using a detailed post-mortem and bacteriological examination, showed that 36–50% of culled badgers in Ireland were infected with *M. bovis* [75]. Another study showed that *M. bovis* levels in badgers in geographical areas parallels levels in cattle, i.e. in areas with a lower prevalence of bTB in cattle, there is a lower prevalence of *M. bovis* in badgers [76].

Ideally, the selected region should have a low potential for transmission of *M. bovis* from badgers to cattle which has been demonstrable over a prolonged period of time due to:

- A lowered badger density and bTB prevalence due to badger culling. This is measured by the level of badger removal on agricultural land in the past 3-5 years. Typically, this will be higher where there is more bTB in cattle due to the responsiveness of the current wildlife programme.
- An effective badger vaccination programme due to high population vaccinal penetration. Typically, this will also be higher where historically there has been more bTB in cattle. This is measured by the level of badger vaccination in an area in the past 3-5 years. Widespread gap-free spatial coverage is important as varying social group sizes can distort absolute badger vaccination levels in a large area. Effective vaccination is also measured by the proportion of previously vaccinated badgers encountered.
- An area with low bTB levels in cattle. Cattle bTB levels are known to act as a sentinel for *M. bovis* levels in badgers [76]. Therefore, in those areas with a historical low bovine bTB prevalence, even in the absence of culling, low badger *M. bovis* prevalence is probable.

Accordingly, in order to select a suitable region reflecting the above requirements, the key badger-related metric is the recent intensity and spatial coverage of badger capturing per area of agricultural land. This is currently available as an operational tool in DAFM software. Essentially, this is a measurement of both current habitat knowledge of *bona-fide* badger setts and of an effective and widespread application of resources to capturing badgers. As habitat knowledge takes time to improve upon, it would be desirable that there already is widespread baseline knowledge within DAFM databases of the regional approach so that pockets of infection are less likely to have been missed and are less likely to develop in the future.

This criterion should be regarded as high priority.

2.4.3 Stakeholder Commitment

A high level of on-going commitment to bTB eradication by all stakeholders in the region is essential if a regional approach is to be successful. This should be reflected in an agreed model of programme governance, both nationally and at regional level, including those relating to responsibility- and cost-sharing by government and industry. The support of farmers in the region would be essential for the implementation of the different control measures that would be required to prevent *M. bovis* from entering their farm and for removing infection sources, if bTB is already present.

This criterion should be regarded as high priority. The SWG consider it as critically important.

2.5 The measures that would be required to achieve freedom from infection. (Such measures could include but not be confined to wildlife, movement controls and diagnostic testing) (TOR 3)

2.5.1 Cattle measures required – actions and challenges

Purpose

- *Within the region:* to resolve infection in infected herds, to prevent infection and re-infection into non-infected herds
- *Into the region:* to prevent ingress of infection

Challenges given the current programme

- Animals with undiagnosed infection despite ongoing testing (residually infected animals), leading to persistently infected herds and movement of infected animals

Tools available

Two broad instruments are available:

- Improved diagnostics. However, it is important to note that countries have been successful in achieving or progressing towards bTB eradication using existing diagnostic tools.
- Risk-based approaches to animal and herd management, including zoning/regionalisation/area-based management and risk-based approaches to cattle trading.

With each of these instruments, time is an important commodity for programme managers. In herds where infection is present, ongoing spread and disease progression will occur over time, which will increase the utility of available diagnostic tests. In herds where infection is not present, there will be increasing confidence of herd freedom from infection over time as further negative herd-level tests are achieved, coupled – of course – with an ongoing focus on herd biosecurity.

Issues to be considered in identifying and removing infection

- Frequency and quality of skin testing
- Interpretation of the skin test
- Use of auxiliary tests
- Tracing of disease spread
- Reactor removal

Issues to be considered in reducing the potential for the spread of disease

- Trading considerations – between herd/region cattle movement
- Dealers
- Within herd cattle movement including considerations in relation to the renting and leasing of land
- Other Biosecurity Considerations
- Breeding Policy

Reflections

- In the modern era, all countries that have progressed towards or achieved bTB eradication have applied a regional approach within a national BTBEP.
- Risk-based approaches have to be effective in their design but also practical so as to minimise the impact on rural commerce and hence facilitate compliance. That said, the regional approach will be of limited value with only partially implemented. To illustrate, the effectiveness of a regional approach will fall rapidly as the risk boundary becomes increasingly permeable.
- Many of the technical measures described above already form part of the Irish national BTBEP. The main enhancement that would be required to achieve "freedom from infection" and "protecting bTB freedom" at a regional level is that relating to cattle trading. The SWG is of the view that that this is an essential component if "freedom from infection" is to be first achieved and then maintained. This additional measure would also be required to achieve "freedom from infection" at a national level.
- Currently, there are no controls on the movement of cattle and farm equipment between farm fragments, nor are data available on these cattle movements. If a regional approach is to be considered, the main challenge that would arise in relation to fragmentation would be the movement of cattle and equipment between fragments, particularly those that span the regional boundary. Participating farmers would need to agree and adopt measures similar to those agreed for movements between different farms. It is understood that this could have a significant impact on the operation of individual farms.
- Specific indices and targets would need to be included in the BTBEP in the selected area in order to monitor progress towards eradication.
- Bovines more genetically susceptible to bTB are at greater risk of acquiring infection and becoming reactor. Accordingly, farmers in the selected area should adopt the use of bTB resistant sires for breeding purposes as part of the additional appropriate biosecurity measures to prevent *M. bovis* from entering or becoming established on their farm.
- Education and awareness of all stakeholders (including PVPs) of the importance of maintaining high standards and of their responsibilities are essential requirements for the success of a regional approach.

2.5.2 Wildlife measures required – actions and challenges

Purpose

- *Within the region:* to limit within-species and between-species transmission of *M. bovis* infection
- *Into the region:* to prevent ingress of infection through wildlife movements

Challenges given the current programme

- Ongoing optimal resourcing of the badger culling/vaccination programme.
- Quantification of the effectiveness of the national badger vaccination programme is ongoing and incomplete
- Quantification of the epidemiological role of deer
- Population controls on deer and badgers due to protected status under the wildlife act

Tools available

- Conditional licensing from the National Parks and Wildlife Service
- Sett-side testing of badgers prior to vaccination
- Badger culling and vaccination
- Extensive database of badger habitats (setts) in Ireland
- Existent infrastructure, resources and expertise in relation to badger capture
- Expanding Whole Genome Sequencing (WGS) database
- Vaccination buffer zone around a region
- Deer management, including culling

Measures of progress

- High generalized location data on badger setts within a region
- Numbers of badgers vaccinated and/or culled
- Accurate badger density data
- High population penetration of vaccination
- Low levels of TB in culled/tested badgers
- WGS evidence of transmission-levels from wildlife

Reflections

- An effective verifiable programme to prevent transmission from wildlife, and a commitment to maintaining the necessary resources, is an essential component if a regional approach is to be successful.

2.5.3 Collaboration – Key Stakeholders

The cooperation and participative engagement of farmers and PVPs would be an essential requirement to achieve "freedom from infection" and in maintenance of that freedom once attained. The key areas of collaboration from farmers would be in relation to the testing of animals (facilities, assistance, time), identifying badgers setts and adopting and implementing cattle movement, breeding and biosecurity measures. The cooperation of PVPs would be required to ensure that testing is carried out at an elevated standard and to advise farmers on effective biosecurity measures for their business model. To facilitate the necessary level of cooperation, consideration could be given to creating a bTB partnership group in the selected region involving farmer representatives, PVP representatives, DAFM, and other local participants as relevant. This would operate at a local level and would complement the work of the TB Forum at a national level. This partnership group would provide a platform for farmers and PVPs to have an input into the strategy, measures and monitoring regime being applied in their region. In particular, the partnership group would provide a platform to develop an agreed biosecurity plan for the area to be adopted by each of those involved as appropriate. Depending on the size of region being considered, further groupings that include local representation from all or particular bTB stakeholders could be temporally

formed to assist in dealing with emerging bTB hotspots or other developing issues within the region.

As mentioned in Section 2.2.2, the successful implementation of a regional approach towards the eradication of bTB would result in benefits to the programme and to farmers. However, in the short term, a regional approach would involve additional controls and additional costs to farmers and to the State. These aspects would need to be considered by the TB Forum, particularly the Finance Working Group and the Implementation Working Group.

2.6 The measures that would be required to maintain freedom on a long-term basis in the geographical area that is selected (TOR 4)

Experience has shown in Ireland and elsewhere that unless ongoing measures are implemented, an area where eradication of bTB has been achieved will over a relatively short time regress to the levels present in surrounding areas. Therefore, it would be vital that a long-term commitment would be given to the necessary eradication measures in the selected area.

To maintain freedom on a long-term basis, continuation of the measures set out in Section 2.5 would be required, particularly those relating to the ingress of *M. bovis*. In that regard, a key requirement would be to ensure that *M. bovis* infection is not introduced through the movement of infected cattle into the region. This could be achieved by the pre-movement and/or post-movement measures like those currently in place in Scotland, as outlined in Section 2.1.3.1 or movement into herds only being allowed from other herds of similar or higher bTB status. Whatever method is used, the key requirement is that the risk boundary must be secure for the regional approach to work.

Strict procedures should be put in place for identifying and dealing with any herd infection that may arise. Identification of infection would be mainly achieved through abattoir surveillance and routine testing of herds. The frequency of testing should be maintained at an appropriate level. Testing intervals in place in other countries that have achieved eradication could be used as a guide for deciding on the surveillance measures that would be needed in the selected region to maintain freedom. Currently, in Scotland, the default bTB testing interval is 48 months. However, it is not believed that wildlife serve as reservoir hosts for *M. bovis* in that country. In Ireland, wildlife species would need to be monitored and action taken, where appropriate, to prevent spillover of infection to cattle. This action could include badger culling and/or vaccination and increased frequency of testing in the cattle population.

2.7 General conclusions

In this opinion, the SWG has reviewed issues relating to the possibility of a regional approach being used to eradicate bTB in Ireland. This review included regulatory issues, international examples, the history of regional approach in Ireland, the potential benefits of using a regional approach and the potential challenges. Based on the review, the SWG is of the view that a regional approach should be adopted as part of Ireland's BTBEP, but only if certain specific conditions are met. These are set out in Section 2.3. In essence, key measures would be required to achieve and maintain freedom from infection in the selected region. These relate to the prevention of inward movement of *M. bovis* to the selected region through infected cattle, wildlife and internal biosecurity measures to effectively address all infection sources within the region.

Several criteria could be used in selecting the area, including those relating to the inward cattle movement, geographical boundaries, land fragmentation, bTB levels in herds and cattle, administration of the region, the effectiveness of the badger programme and stakeholder commitment. The SWG has identified five criteria that are of high priority, namely, inward cattle movement, trade flows, administration of the region, effectiveness of the badger programme and stakeholder commitment with the latter considered the most important criterion.

Many of the measures to achieve eradication in the selected region are already in place in the current national BTBEP. The additional measures that would be required to achieve eradication and to ensure that the bTB freedom of the selected area is protected mainly relate to cattle trading. The SWG is of the view that these additional measures will be required irrespective of whether a regional or national approach is used.

At various timepoints of the bTB eradication programme, area-based programmes have been implemented. Successful examples include south-west Wicklow and east Offaly in the 1980s and more recently Monaghan and the Burren area of Clare. These demonstrate that it is possible to successfully implement area-based programmes. However, the subsequent regression of bTB levels in some of these areas demonstrate that it is essential that an area-based programme be maintained. In that context, it would be vital that a long-term commitment would be given to the necessary eradication measures in the selected area. It would also be essential that the programme in the selected area would be an integral part of a broader strategic approach to bTB eradication in Ireland.

The eradication goal should be clearly set out. The SWG is of the view that the goal should be biological freedom from bTB as this will be a natural step following the achievement of legislative freedom and, in addition, it will bring long-term benefits in terms of reduced eradication efforts and resource costs. Specific and measurable targets should be identified and put in place. These should be reviewed at regular intervals and appropriate corrective actions should be taken if targets are not met. Any allocation of additional resources to the region should not reduce current efforts nationally.

The successful eradication of bTB at a regional level would provide compelling evidence that bTB could be eradicated nationally. With the experience gained and the confidence generated among the farming community, the eradication programme could eventually be extended to the whole country and the eradication of bTB finally achieved.

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Appendix 1. Request from the Department of Agriculture, Food and the Marine for an opinion on applying a regional approach to achieve eradication of bovine tuberculosis in Ireland

Can a regional approach be applied to achieve eradication of bovine tuberculosis in Ireland?

Date of request: 24th January 2023

Deadline for response: 26th May 2023 (next scheduled meeting of TB Forum)

Requested by: Damien Barrett

Context:

The TB eradication programme in Ireland has been going on for almost 70 years and while there has been significant progress in reducing herd incidence, the levels of disease at both herd and animal level have plateaued since 2015. A total of 3,716 herds were restricted for bovine tuberculosis in 2015 representing 3.29% of herds tested. In that year, 15,211 reactor animals were disclosed, the lowest number since the inception of the programme. Since then, there has been a steady increase in the number of herds restricted and in reactor numbers. A total 4,613 herds (4.34% of herds tested) and 4,477 herds (4.27% of herds tested) were restricted in 2021 and 2022, respectively. In those years, there were 22,801 and 23,276 reactors respectively.

In view of the lack of progress in recent years, new approaches need to be considered in relation to the eradication of bTB. One possibility would be to use a regional approach. This would involve selecting a region of the country and applying the measures necessary to remove infection from the herds currently infected. It would also involve the application of the measures necessary to prevent reinfection of herds from wildlife and from other sources in the selected area and from sources of *M. bovis* outside of the area. Once the programme is shown to be effective in the selected area, it could then be implemented in other parts of the country.

Under the EU Regulation 2020/689, a Member State or zone can be considered to be free from infection if 99.8% of herds have been free of TB for three years and various other conditions are met. In the Irish context, this essentially means the disease could be considered to be eradicated from a region, such as one or more counties, if the 99.8% target is achieved and the other conditions are met. The herds in the region could then benefit from more relaxed control measures. As an intermediary step, the EU Regulation allows a decrease in the frequency of testing to once every second year if the herd incidence in a Member State or zone is 1% or less. While the national herd incidence in Ireland is around 4.5%, there are counties where the herd incidence is between 2% and 2.5% . Potentially, these lower incidence counties might be a target for achieving disease freedom particularly if the disease incidence has been relatively low over a prolonged period.

Scope:

The scope of this question relates to an examination of the potential value of using a regional approach to achieve freedom from infection from *Mycobacterium bovis* and related organisms in Ireland as defined in EU Regulation 2020/689 and, in the event that this approach is considered to be potentially useful, the measures and the conditions

that would be required to achieve freedom. In particular, the Scientific Working Group will provide an opinion addressing the following objectives:

- The potential value of using a regional approach for the eradication bTB.
- If a regional approach is considered worthwhile,
    - The criteria that should be used to select a geographical area for a regional approach
    - The measures that would be required to achieve freedom from infection. (Such measures could include but not confined to wildlife, movement controls and diagnostic testing)
    - The measures that would be required to maintain freedom on a long-term basis in the geographical area that is selected.

Purpose:

The opinion of the SWG will be provided to the TB Forum to inform discussions about the potential of regionalisation to assist in the eradication of bTB.

Appendix 2 Legislative requirements relating to zones free from infection with MTBC Annex - IV of EU Regulation 2020/689

Under Section 1. Chapter 2, Part II, Annex IV of EU Regulation 2020/689, a Member State or zone can be considered to be free from infection if the following conditions are met:

(a) during the past 3 years at least 99.8% of the establishments keeping bovine animals, representing at least 99.9% of the bovine population, have maintained their status free from infection with MTBC and the incidence rate of establishments confirmed infected during the year did not exceed 0.1%; and

(b) general surveillance requirements have been carried out for the past 3 years in accordance with point (a) of Article 3(1) for the detection of infection with MTBC in kept bovine animals and included at least:

(i) the systematic research of lesions of infection with MTBC in all bovine animals slaughtered through ante- and post-mortem surveillance;

(ii) the investigations of lesions that could be due to infection with MTBC

The requirements for the maintenance of the status free from infection are set out in Section 2.

1. The status free from infection with MTBC as regards kept bovine animals of a Member State or a zone may only be maintained if:
   - the requirements in point (b) of Section 1 continue to be fulfilled; and
   - for the first 2 consecutive years following granting of the status random annual surveillance based on a representative sampling of all establishments where bovine animals are kept must be carried out to demonstrate with a 95 % level of confidence, that:
     (i) at least 99.8% of the establishments, representing at least 99.9 % of the bovine population are free from infection with MTBC;
     (ii) the incidence rate of establishment confirmed infected during the year does not exceed 0.1%;
   - and if the conditions in point (b) were fulfilled for 2 consecutive years, surveillance is based on:
     (i) random annual surveillance to demonstrate at least with a confidence level of 95%, that the incidence rate of establishments confirmed infected during the year does not exceed 0.1%; or
     (ii) risk-based annual surveillance carried out to detect infection with MTBC, taking into account the systems of production, the risk factors identified, including the spread of infection from other animals than kept bovine animals and increased surveillance in establishments associated with at least one of the specific risks referred to in point 2(d) of Section 2 of Chapter 1.

2. The status of a Member State or a zone free from infection with MTBC is not affected by the confirmation of infection with MTBC in the animal population other than kept bovine animals, provided that effective measures have been implemented,

and are periodically assessed, to prevent transmission of infection with MTBC to kept bovine animals

Appendix 3 Computing metrics to guide area selection as part of a regional approach to bTB eradication.

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The genesis of this analysis was a request made by DAFM about the potential utility in Ireland of a regional approach to the eradication of bovine tuberculosis (bTB), as opposed to the uniform application of disease management practices across the county. Here we compute metrics to guide section of suitable areas as part of such an approach.

As a first step in this process, we chose counties as our candidate areas. This allowed the calculation of a range of metrics for each county which in turn allowed us to examine how each metric varied spatially across Ireland. The insights gained from this step can be used in the future to guide the creation of additional candidate regions for enhanced control measures.

The following metrics were calculated for each county. With the exception of the badger data metrics, 2019 was chosen as the year over which to calculate these metrics, as some of the cattle movement metrics were calculated using a statistical model calibrated for 2018 and 2019 (Tratalos et al., 2023).

A. Geography and cattle population

We generated a series of metrics to give insight into the land area of each county and how many herds and cattle it contains.

1. **Area** (in square kilometers).
2. **Number of herds**. This was calculated using the location of the home farm for each herd. Herds with some land in the area, but not the home farm, were therefore excluded from this calculation.
3. **Number of cattle**. This was calculated in the same way as the number of herds, but in this case the cattle population of each herd was used. For each herd, the bovine population was estimated as an average of the number of animals present in the herd on 1st January 1st May and 1st September.
4. **Density of herds**. The number of herds was divided by the land area of each county, to obtain the number of herds per square km.
5. Density of cattle. The **number of cattle** was divided by the land area of each county, to obtain the number of cattle per square km.

B. Herd Fragmentation Metrics

We calculated two metrics to show the degree to which the land used by a herd was restricted to a single county. We wanted to know this because targeted controls in a given area were likely to be more effective in cases where cattle were not able to move outside the county whilst staying within the same herd. We used data from the land parcel information service (LPIS), which maps each land parcel belonging to each herd. The land parcel for the home farm is attributed to the largest parcel for each herd. Land

parcels less than one KM outside the county were not classified as 'outside'. We calculated two metrics:

6. Percentage of herds with home farm in the county and at least one land parcel outside it.

7. Percentage of herds with home farm outside the county and at least one land parcel within the county.

C. Bovine TB Metrics

These metrics were produced from DAFM bovine TB test and surveillance data for skin, gamma, and lesions for each animal tested in 2019.

8. Bovine TB herd incidence. The bTB herd incidence was calculated in accordance with the definitions laid down in footnote d, e and f of Annex III Table A of Commission Implementing Decision of 2014/288/EU.

9. Animal bTB incidence. Cases consisted of all reactors (for skin and interferon-γ tests) and confirmed slaughterhouse cases. The denominator used to calculate incidence was the cattle population in the county on 31/12/2019.

10. Number of Private Veterinary Practitioners (PVPs). As a proxy for this we used information from the DAFM Bovine TB test data for each herd. In this dataset there are two data columns giving information on the identity of private vets – number of attending PVPs and number of testing PVPs. We used the former measure.

D. Cattle Movement Metrics

Cattle movement metrics were generated from the DAFM AIM dataset, which lists all movements of cattle between herds on an individual animal basis. In the foregoing, when we talk about *moves*, we mean individual animals – e.g. if a herd sells three of its animals to another herd that counts as three moves.

We calculated the percentage of moves which originated in herds located outside of the county, as well as a series of metrics to measure "risky" moves, which might be restricted under enhanced control measures. We measured risky moves in two ways.

The first way to measure risk was in accordance with criteria devised by DAFM: A risky moves involves the sale of cattle from a breeding herd which has had at least one breakdown in the last three years involving at least five animals, and did not have feedlot status at the time of the move, to a herd which does not fulfil these criteria.

The alternative method to designate a risky herd was to use risk of a breakdown in the herd calculated using a mathematical model, published as Tratalos, 2023. This model, named as the 'history and proximity model' in the published paper, determined that the

risk of a breakdown in the years 2018 or 2019 was dependent on the following variables, ordered in terms of their contribution to the model:

a) whether the herd had a breakdown in the five previous years
b) the proportion of herds within 6 km which had had a breakdown within the previous five years.
c) the herd type (dairy, beef, fattener, stores, mixed). Note that dealer herds were not included.
d) the herd size.
e) the number of herds trading into the herd during the previous five years which themselves had experienced a breakdown during that five year period or would go on to experience one during 2018 or 2019.
f) 'betweenness' (a measure of how connected the herd, in terms of cattle movements, to other herds).
g) Altitude of the home farm
h) the number of cattle entering the herd in the previous three years
i) modelled badger abundance (based on Byrne, 2014, described elsewhere in this document)

Whilst using these two ways to measure risk we calculated separate metrics for the county of the buying herd and for the county of the selling herd, although it should be noted that in many cases both buying and selling herd would be in the same county. For these four combinations we calculated separate metrics for i) the number of herds affected, ii) the percentage of herds affected and iii) the number of moves affected. This process resulted in the creation of the following metrics:

11. Percentage of inward moves to herds in the county where the selling herd was in a different county.
12. **Number** of **herds** which **bought** animals from herds considered higher risk according to **DAFM criteria**.
13. **Number** of **herds** which **sold** animals from herds considered higher risk according to **DAFM criteria**.
14. **Percentage** of **herds** which **bought** animals from herds considered higher risk according to **DAFM criteria**.
15. **Percentage** of **herds** which **sold** animals from herds considered higher risk according to **DAFM criteria**.
16. **Percentage** of **moves** from herds considered high risk according to **DAFM criteria** to herds considered lower risk, with reference to the county of the **buying** herd.
17. **Percentage** of **moves** from herds considered high risk according to **DAFM criteria** to herds considered lower risk, with reference to the county of the **selling** herd.
18. **Number** of **herds** which **bought** animals from herds considered higher risk based on **model** of Tratalos (2023).
19. **Number** of **herds** which **sold** animals from herds considered higher risk based on **model** of Tratalos (2023).
20. **Percentage** of **herds** which **bought** animals from herds considered higher risk based on **model** of Tratalos (2023).
21. **Percentage** of **herds** which **sold** animals from herds considered higher risk based on **model** of Tratalos (2023).

22. **Percentage** of **moves** from herds considered high risk based on **model** of Tratalos (2023) to herds considered lower risk, with reference to the county of the **buying** herd.
23. **Percentage** of **moves** from herds considered high risk based on **model** of Tratalos (2023) to herds considered lower risk, with reference to the county of the **selling** herd.

E. Badger metrics

We calculated metrics on badger control and vaccination for each county using data from the DAFM wildlife unit datasets. These data record the sett locations and number of badgers caught and euthanised, as well as vaccinated, under the TB eradication programme. We also had access to information on which areas had been designated for badger vaccination, as of February 28th, 2022. Finally, we used the outputs of Byrne et al., 2014, to calculate the average probably of a badger set being located in each county, based on a broad range of environmental variables. These were the metrics we calculated:

24. Areas were badger vaccination currently takes place. We mapped this not as a county-wide average but instead showing the quartiles given over to vaccination within the county, with county borders overlaid,
25. Total Badgers Culled or Vaccinated, 2018 to 2022. We again mapped this not as a county-wide average but instead showing the number of badgers culled or vaccinated in each badger control quartile, with county borders overlaid,
26. Percentage of the area in the county included within the badger vaccination programme.
27. Average pixel value (1 ha square area) from Byrne (2014) badger abundance model.

Results

The results are shown as a series of maps.

A. Geography and cattle population

The Land area of each county is shown in Figure 1. Note that counties in the West of Ireland are generally larger than those to the East. This is worth bearing in mind for some of the later maps which show the raw number of a particular variable (rather than the density), as larger counties will, all other things being equal, contain a larger number of herds, badgers etc.

The number of herds ranged from 481 (Dublin) to 13, 303 (Cork) and the number of cattle varied from just 22,000 (Dublin) to over a million animals (Cork) (Figures 2 and 3). The larger, western, counties hosted more herds and cattle than those in the eastern half of the country, with a strong correlation between land area and both these variables. Taking account of this relationship with area, by calculating the densities of herds and of cattle, revealed quite different patterns, with northern counties often displaying the highest densities of herds (Figure 4) and those in the southern midlands often having relatively high densities of cattle (Figure 5).

B. Herd Fragmentation Metrics

Values for the percentage of herds which had land patches outside their home counties were similar to those for the percentage of herds with patches in the county which had their home patch in another county (Figures 6 and 7), and was generally larger for smaller counties. These proportions varied from about 1 % (Donegal, both metrics) to 24 % (Dublin, latter metric).

C. Bovine TB Metrics

Bovine TB herd incidence in 2019 was generally highest towards the east of Ireland, with counties Cork and Clare also showing somewhat high values (Figure 8), whereas animal bTB incidence varied from 7.58 per 10,000 animals (Waterford) to 119.05 per 10,000 (Wicklow) (Figure 9). The number of attending PVPs varied from 23 (Louth) to 145 (Cork). (Figure 10).

D. Cattle Movement Metrics

As might be expected, smaller counties had a larger proportion of moves coming from outside the county, with Dublin (92 %) the highest and Donegal (26 %) the lowest (Figure 11). The number of herds which bought animals from herds with a higher risk according to DAFM criteria ranged very widely, from 42 (Dublin) to 1184 (Cork), with larger counties again showing the highest values (Figure 12). Dublin was also the lowest and Cork the highest when these data were calculated with reference to county of the selling herd (Fig. 13), but the values were much lower in both cases (14 and 385 herds, respectively), as might be expected given the low number of high-risk herds. Measuring the same criteria according to the percentage of herds and also the percentage of moves resulted in different patterns being evident, with counties in the northwest, from Mayo to Donegal, generally displaying the lowest values. (Figures 14-17).

When risk was measured using the model of Tratalos et al., 2023, there was a stronger evidence for an West -East trend in the number of herds affected, both when the county of the buying herd and the county of the selling herd was counted (Figs 18 and 19), but the lowest values were again for Dublin (97 buying, 88 selling) and the highest for Cork (4,800 buying, 4,954 selling). Equivalent values for the percentage of herds and percentage of moves showed slightly different patterns to those when the DAFM criteria was used, although there was still a tendency for counties in the southwest to show high values and counties in the east and also county Donegal to display small values (Figures 20-23). It should be noted here that differences between counties was generally modest, with most counties lying between 30 and 50 %. Kerry was highest for number of moves by buying herd (53 %), Limerick, Waterford, Laois and Longford were all tied at 42% for percentage of herds by buying herd, Cork was highest for number of moves by selling herd (48 %) and Clare for the equivalent for number of herds (41%). Lowest values were as follows: Percentage of herds, buying: Dublin, 21%; Percentage of herds, selling: Kildare, 18%; Percentage of moves, buying: Dublin, 14%; Percentage of moves, selling: Leitrim, 26%.

E. Badger metrics

Fig. 24 shows that badger control quartiles have been spread fairly evenly across the country, although the proportion of quartiles in each county varied (see below, commentary on Fig.26). The total number of badgers culled or vaccinated also showed a widely distributed spread of high, low, and zero values across the country, although numerous hotspots of activity were evident (Fig. 25).

The percentage of each county enlisted within the badger vaccination programme varied, from less than 10% in Dublin, Clare, Westmeath and Wicklow to over 70% in Louth, Kilkenny, Carlow and Longford (Figure 26). Conversely, suitability for a badger social group (as modelled by Byrne et al., 2014) did not vary greatly, with a lowest value of 0.2 (County Donegal) and high of 0.46 (Monaghan) (Figure 27).

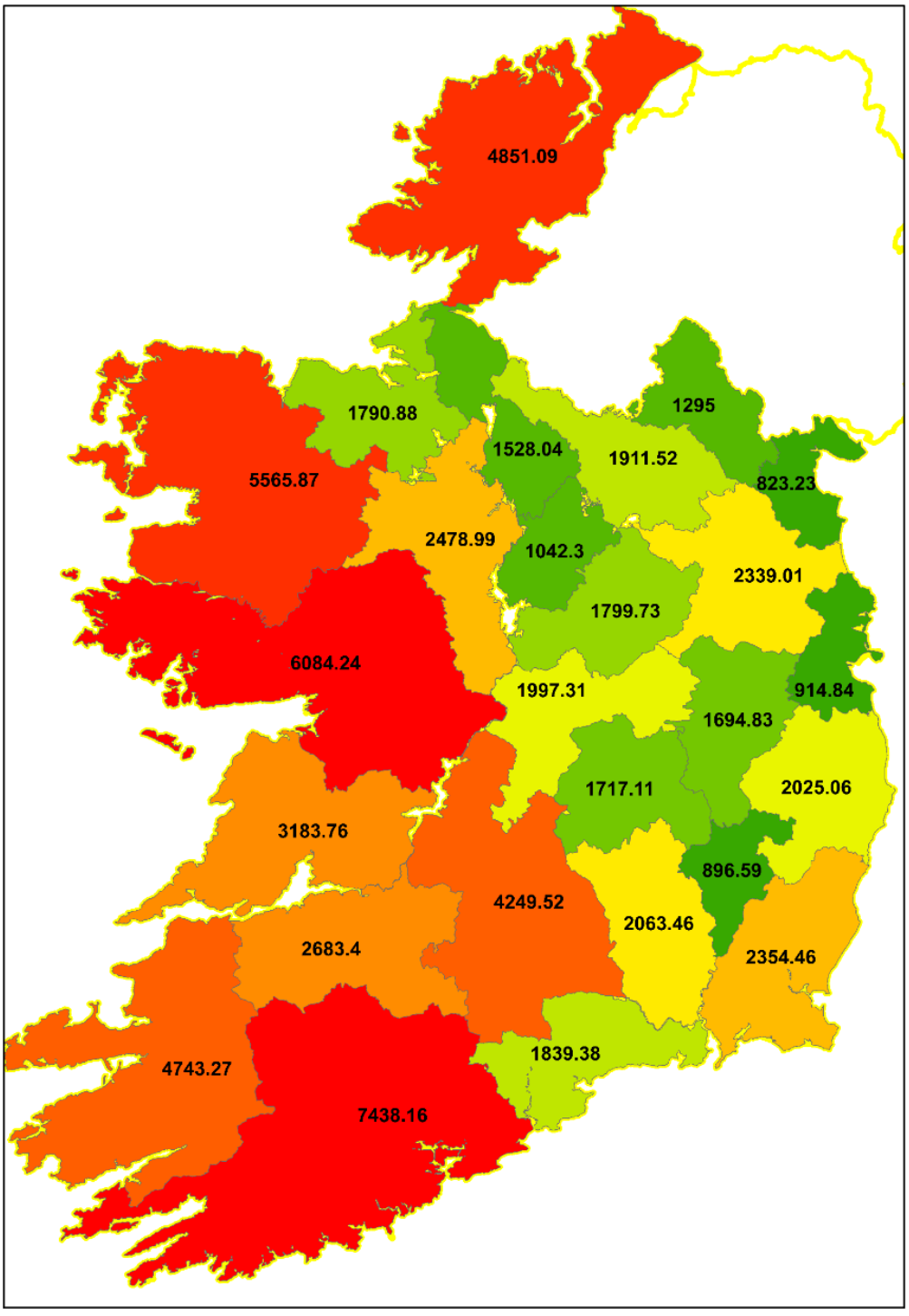

Figure 1. Area of each county in Ireland (Km^2)

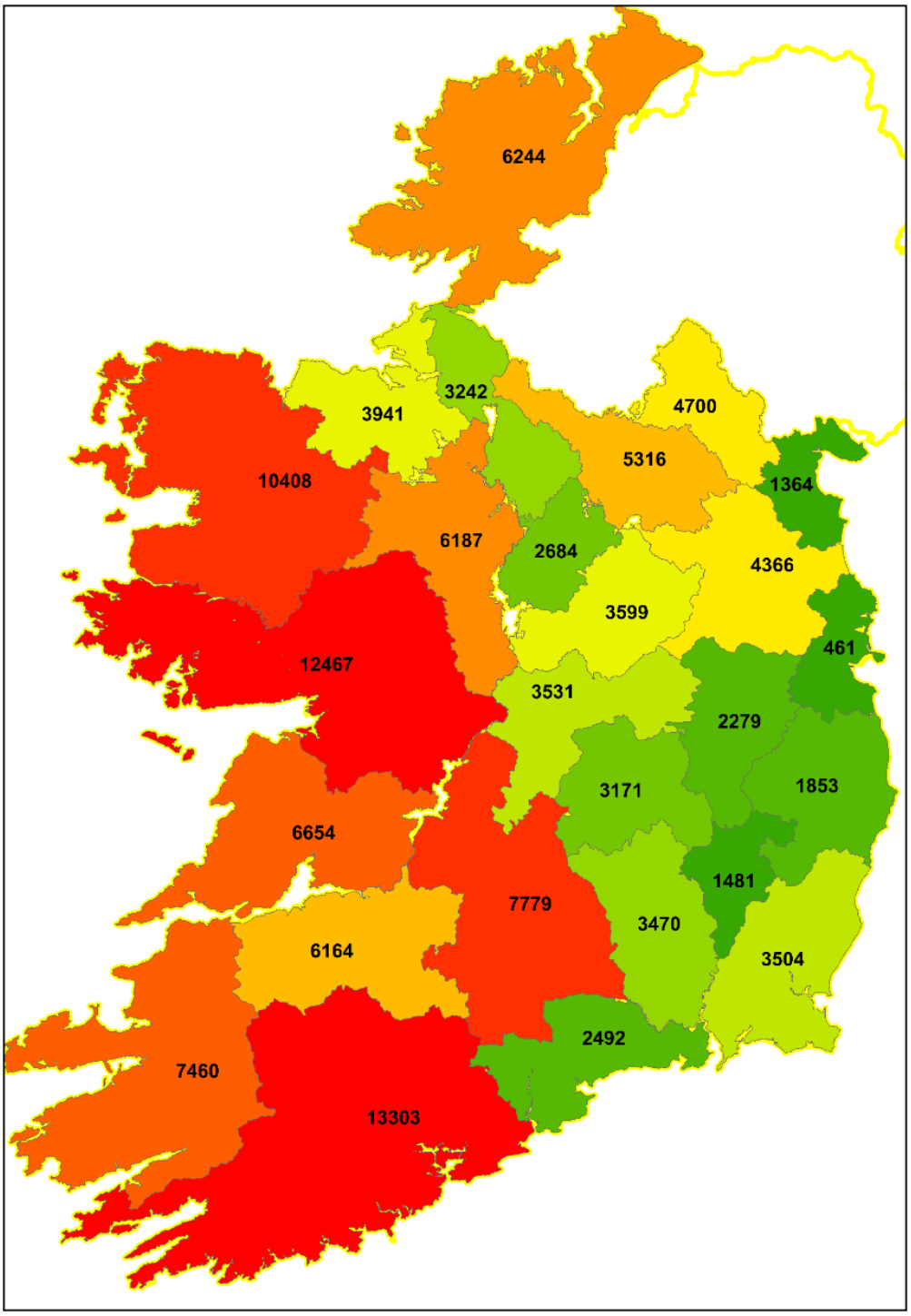

Figure 2. Number of herds by county, calculated as the number of herds containing cattle on 1st January, May or September 2019.

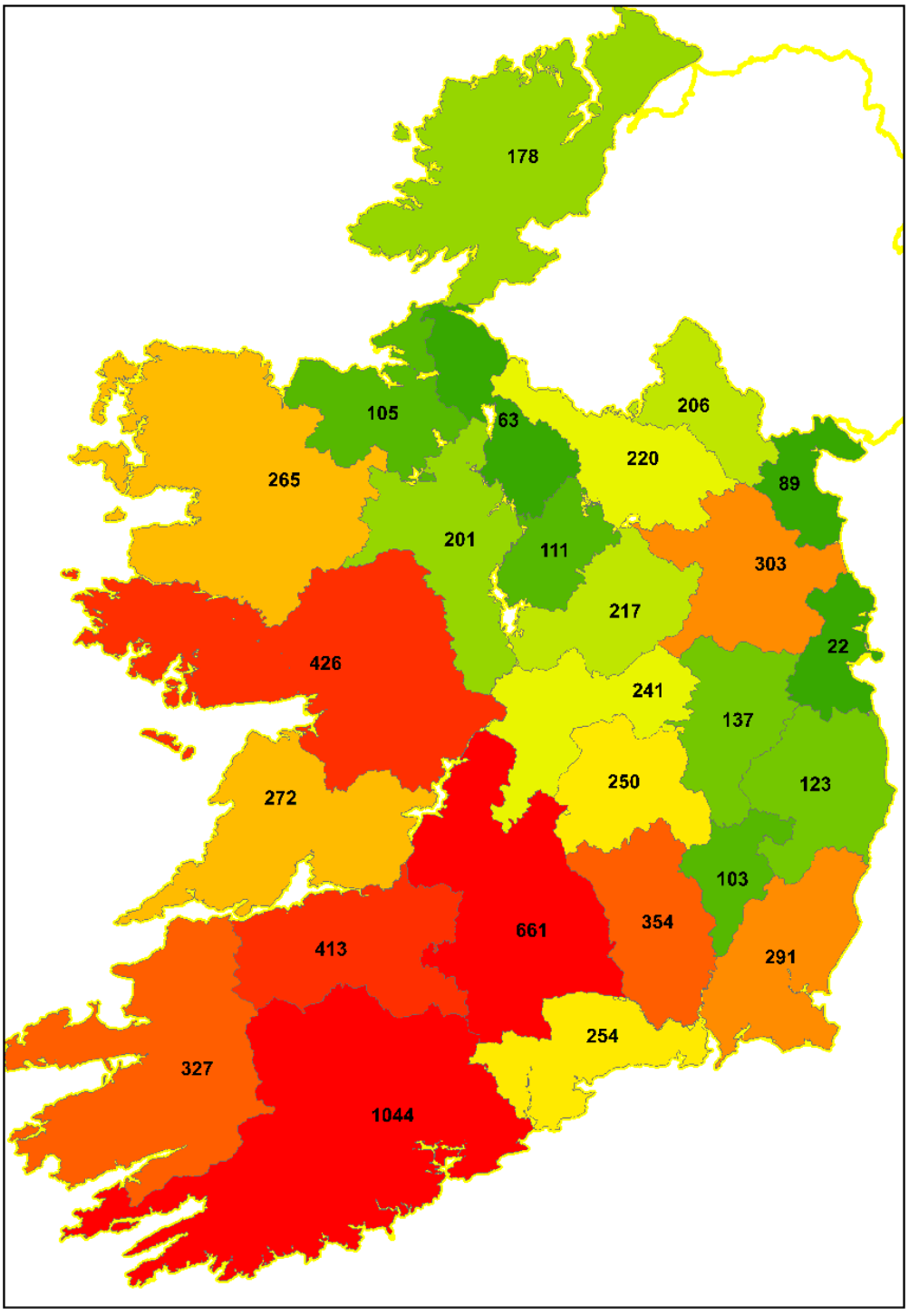

Figure 3. Number of cattle by county, in thousands, based on herd populations calculated at the average of the number of cattle in the herd on January 1st, May 1st and September 1st, 2019.

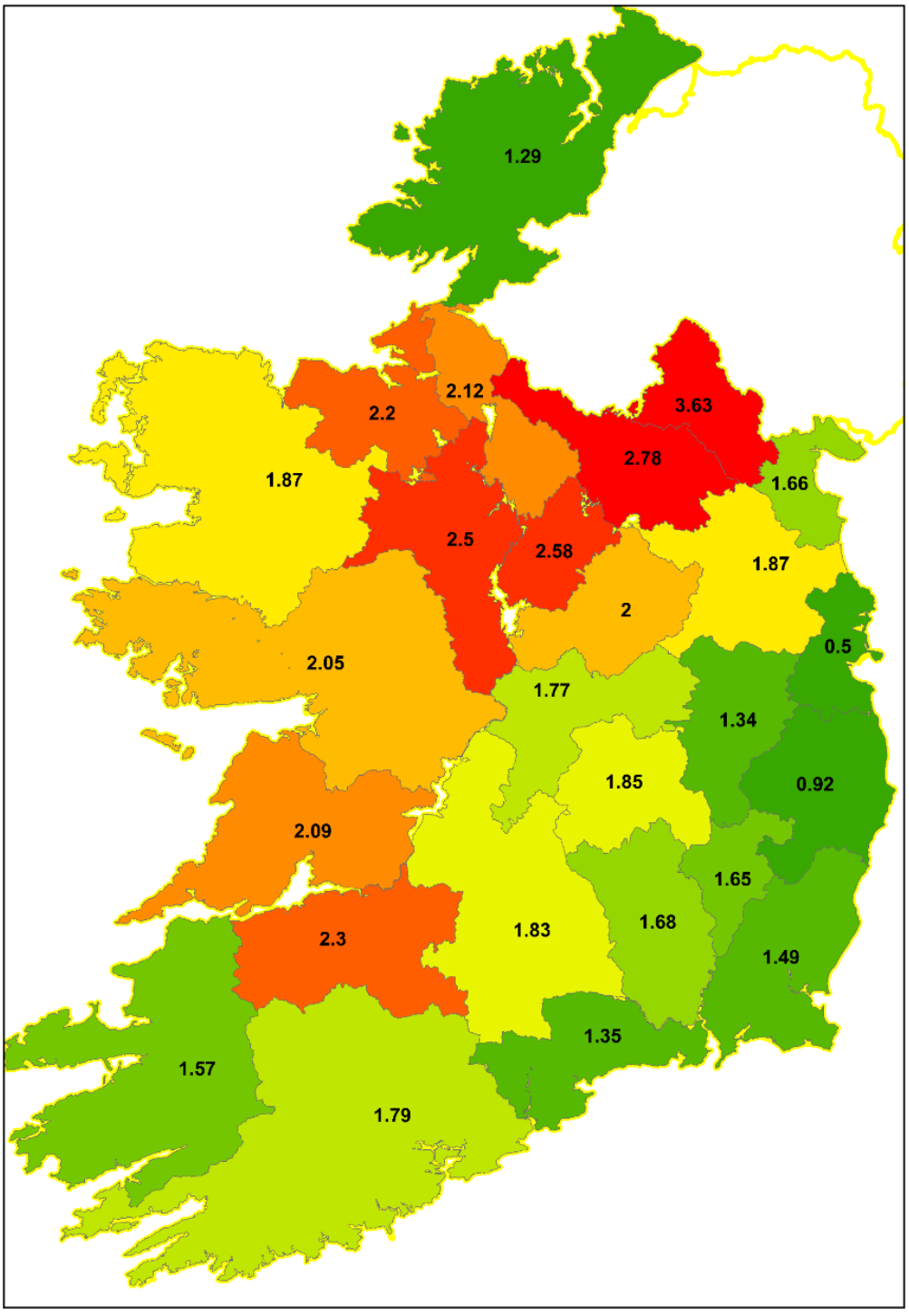

Figure 4. Herd density (per km^2) by county, based on herd populations calculated at the average of the number of cattle in the herd on January 1st, May 1^{st,} and September 1st, 2019.

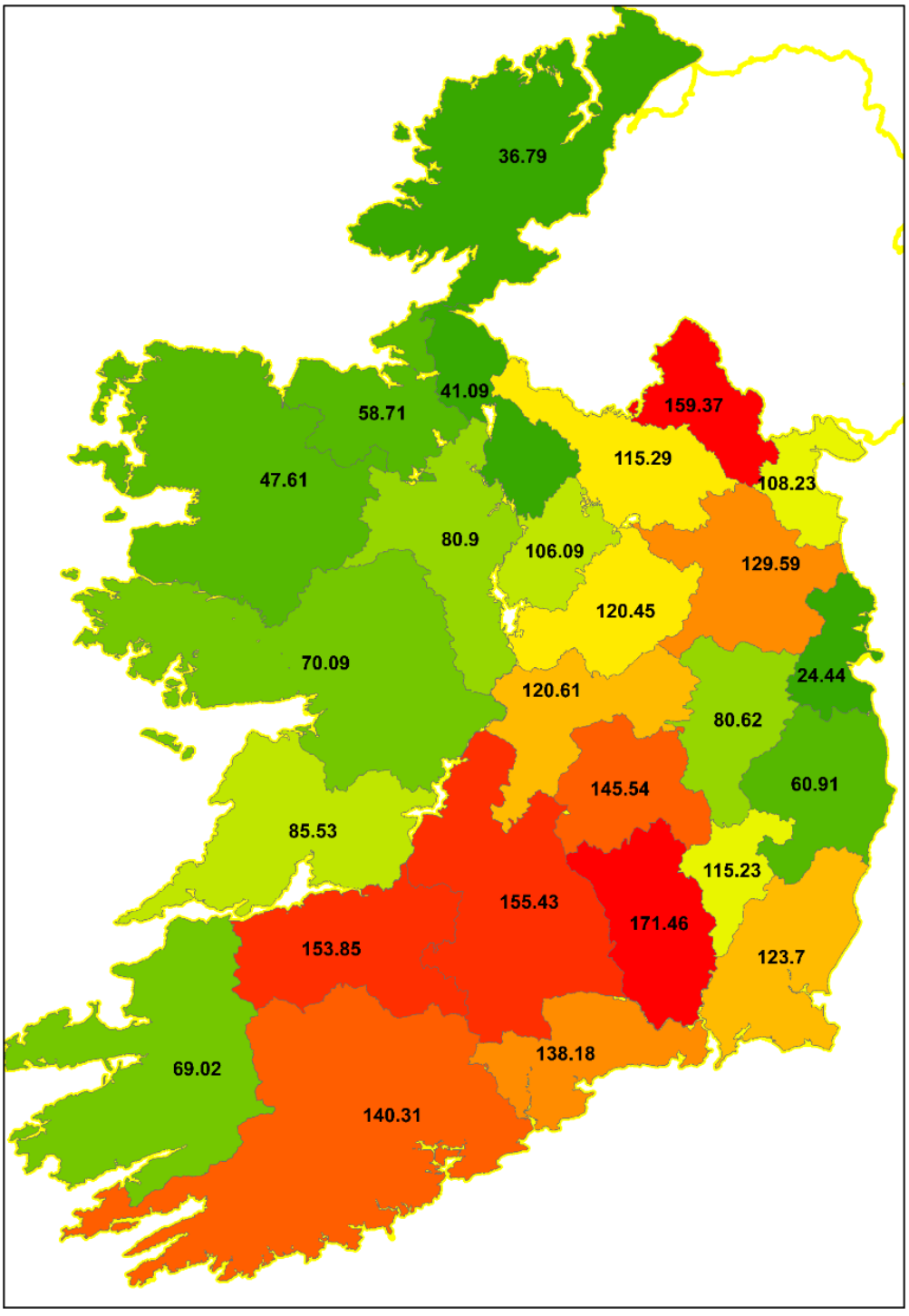

Figure 5. Cattle density (per km^2) by county, based on herd populations calculated at the average of the number of cattle in the herd on January 1st, May 1^{st,} and September 1st, 2019.

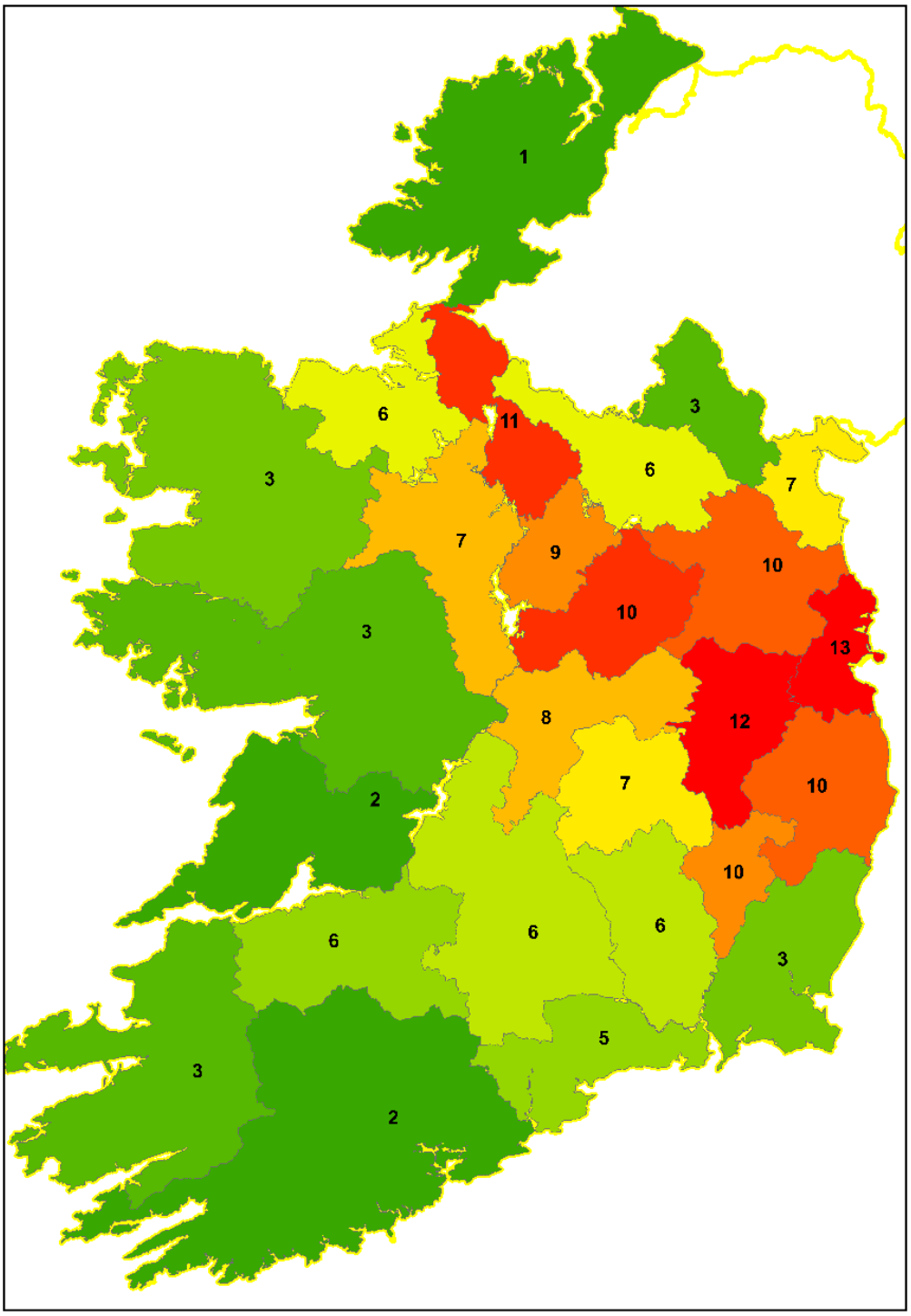

Figure 6. Percentage of herds with home farm in the county and at least one land parcel outside it, in 2019.

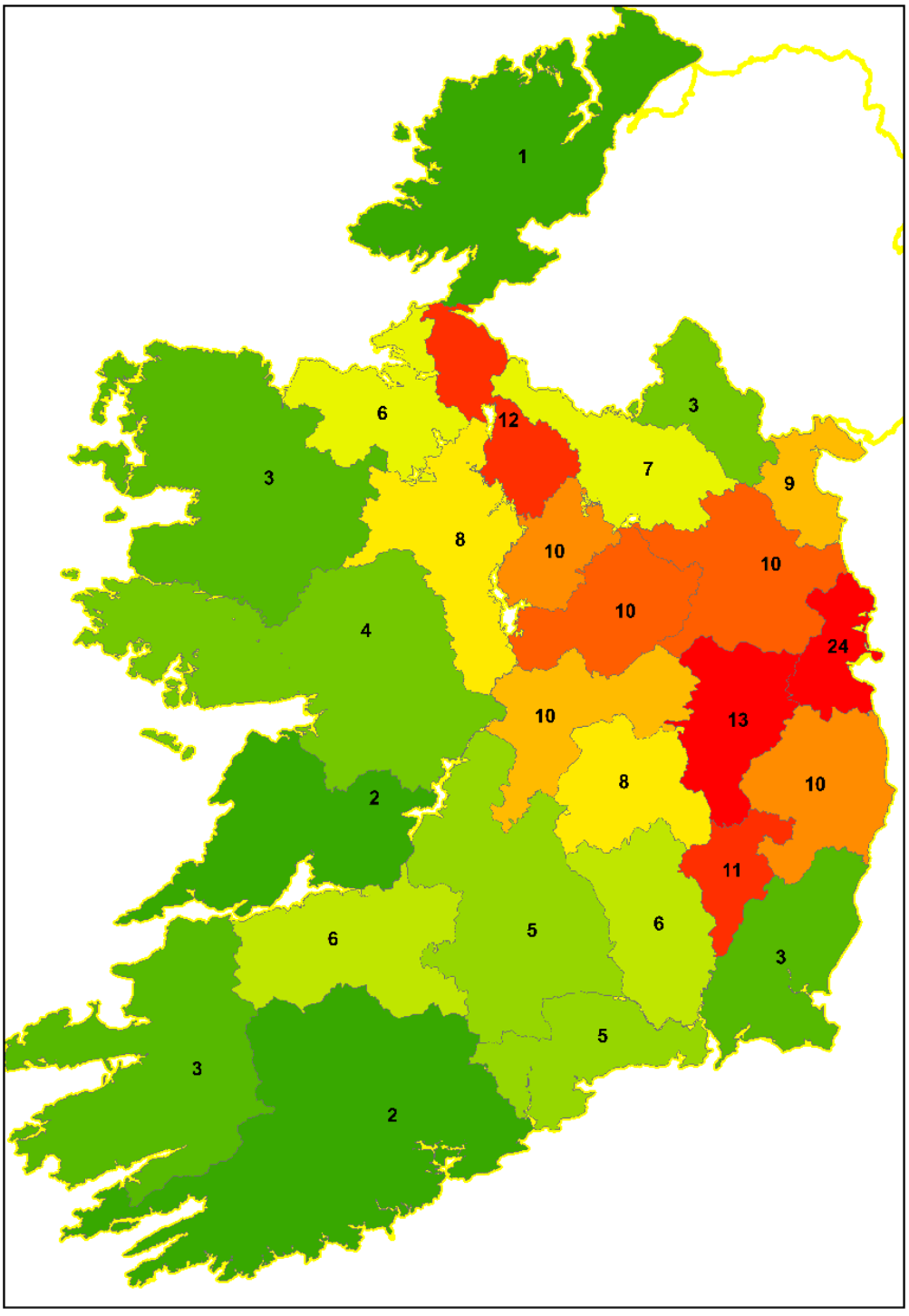

Figure 7. Percentage of herds with home farm outside the county and at least one land parcel within the county, in 2019.

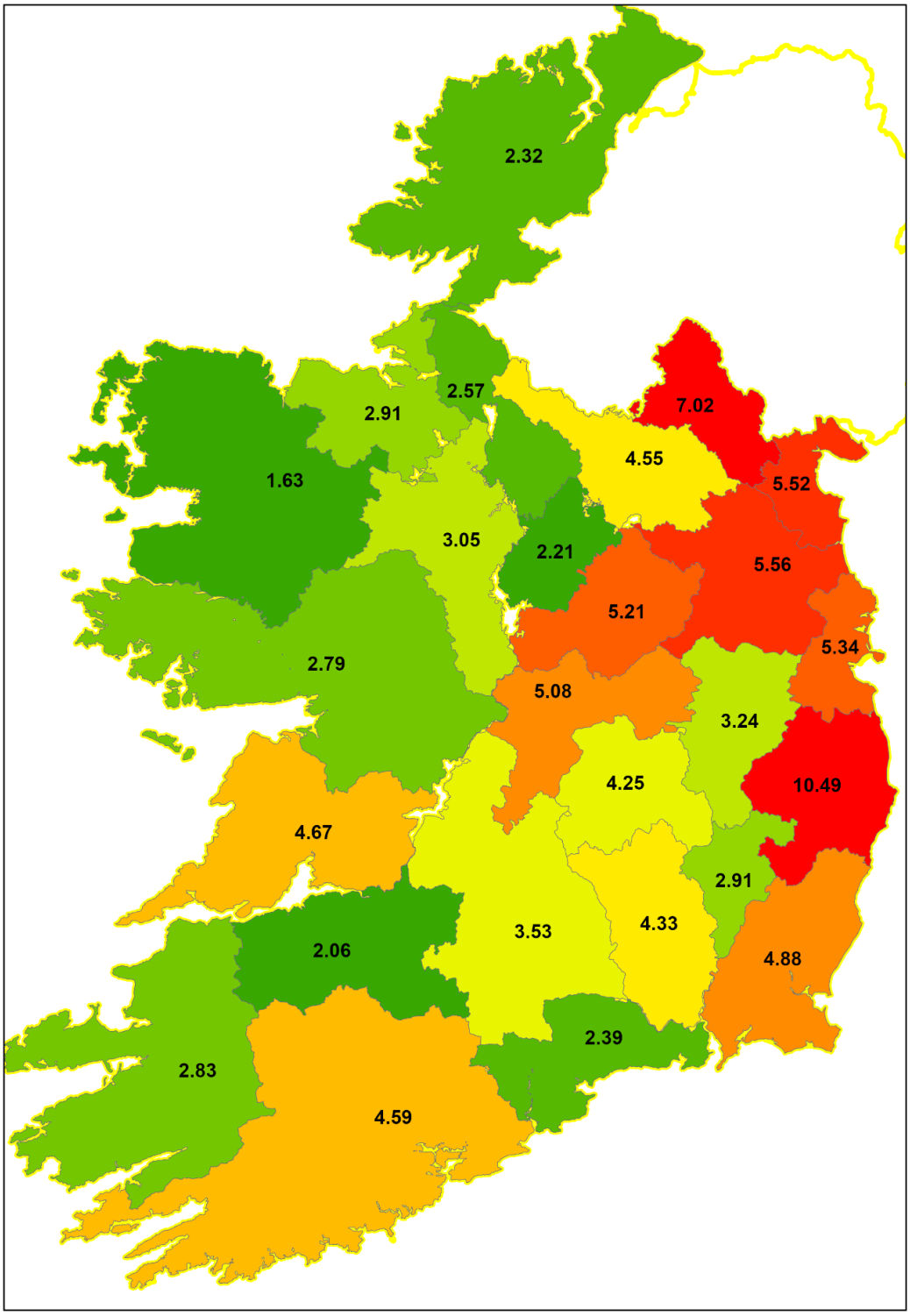

Figure 8. Bovine TB **herd** incidence 2019 expressed as a percentage. The bTB herd incidence was calculated as per the definitions laid down in footnote d, e and f of Annex III Table A of Commission Implementing Decision of 2014/288/EU.

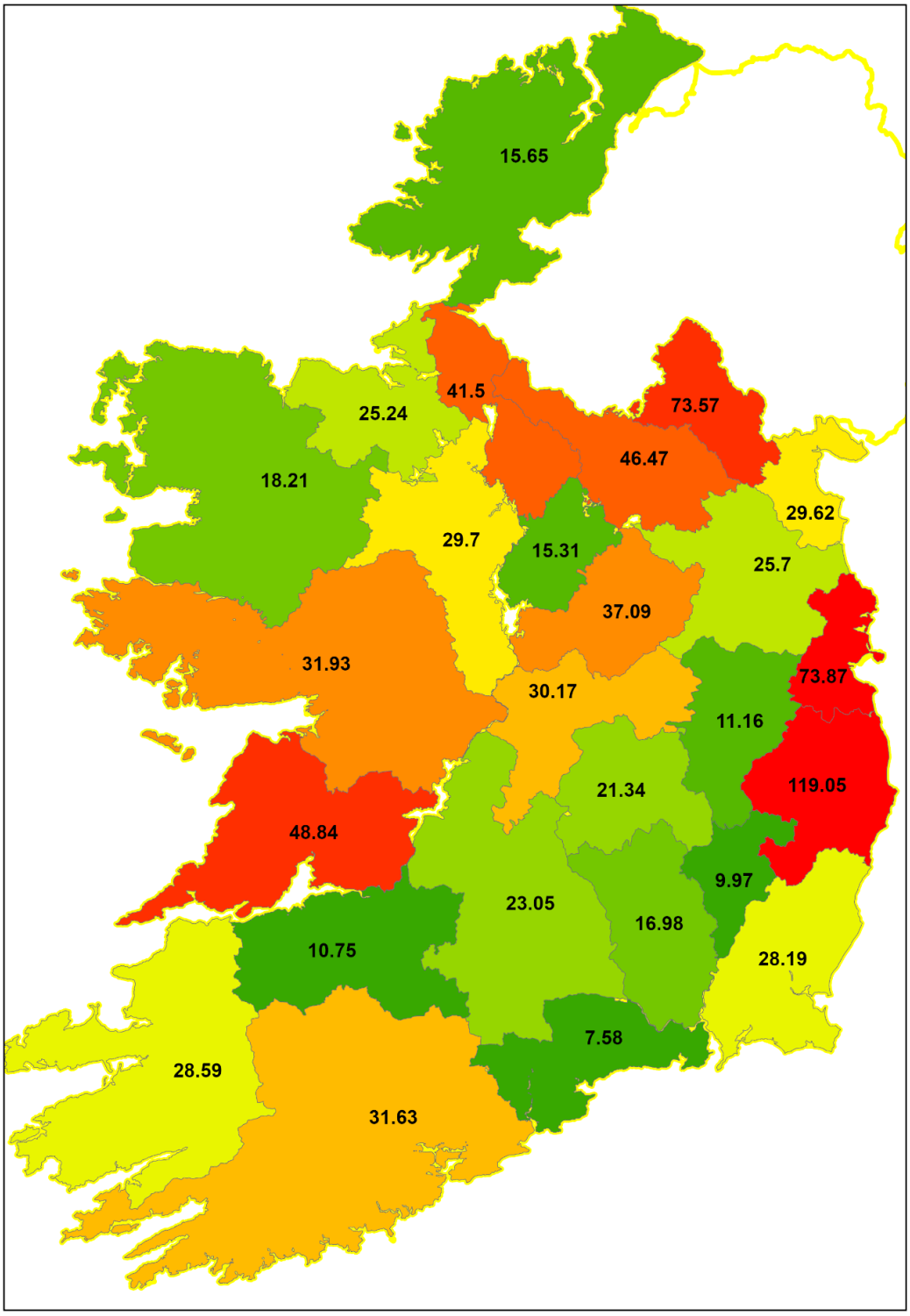

Figure 9. Animal bTB Incidence expressed as number of cases per 10,000 bovines, 2019. Cases included reactors (including the skin and interferon-γ tests) and confirmed slaughterhouse cases. The overall population represented the number of live animals at 31/12/2019.

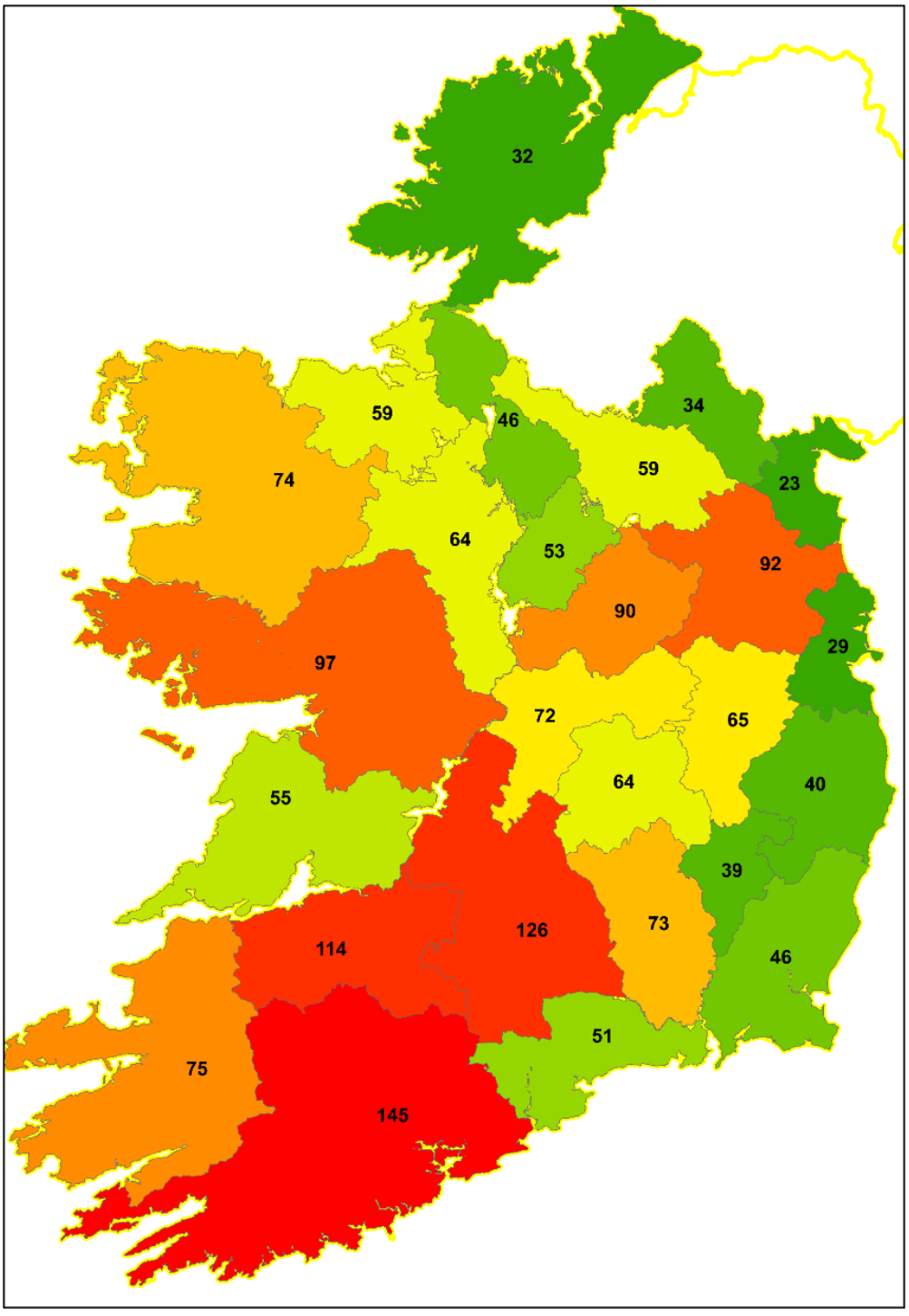

Figure 10. Number of attending Private Veterinary Practitioners by county, taken from 2019 bovine TB testing data.

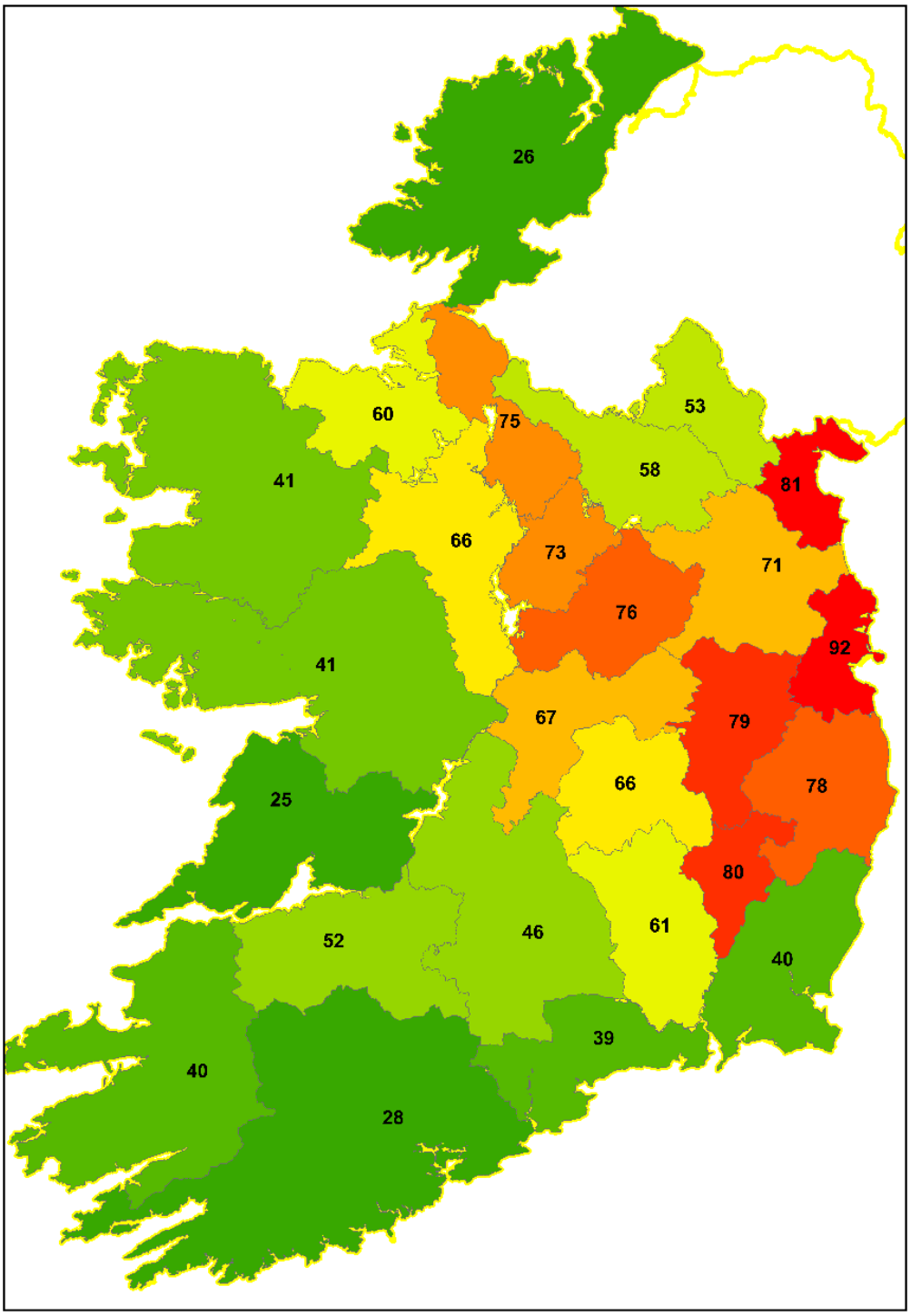

Figure 11. Percentage of inward moves to herds in the county where the selling herd was in a different county, in 2019.

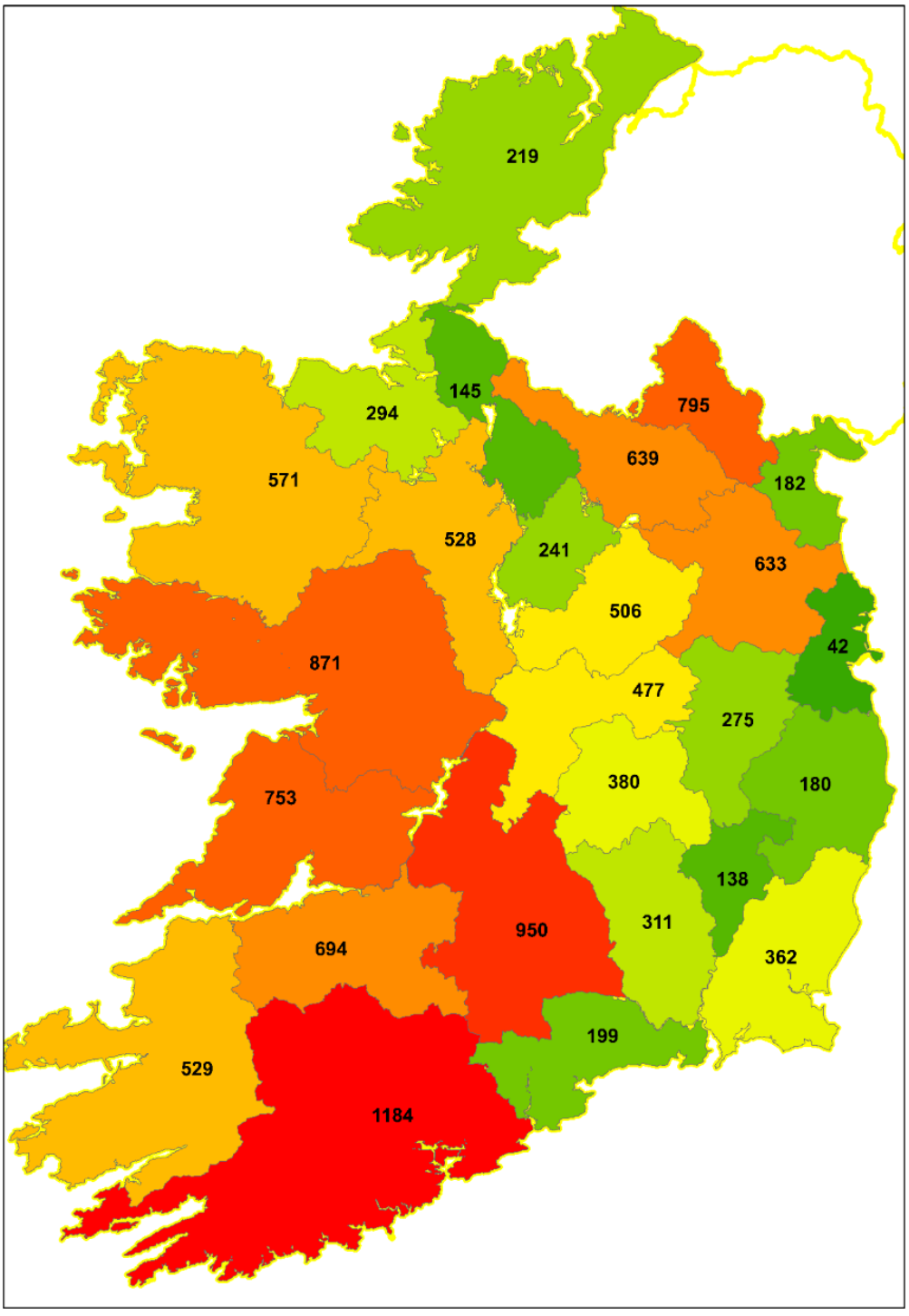

Figure 12. **Number** of **herds** which **bought** animals from herds considered higher risk according to **DAFM criteria**, in 2019. High Risk was defined as follows: breeding herd, not a feedlot, had at least one breakdown within the last three years involving at least five animals.

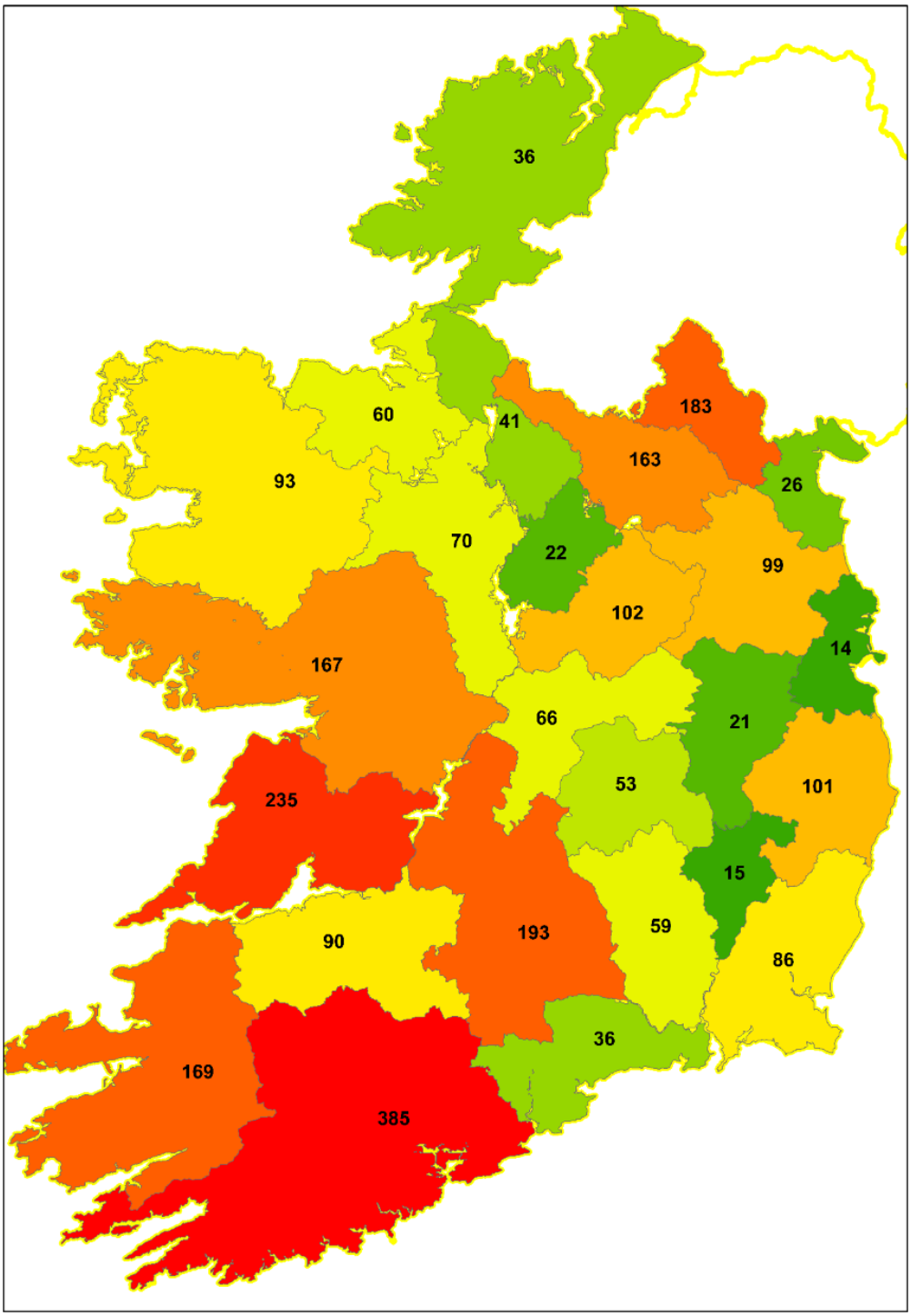

Figure 13. **Number** of **herds** which **sold** animals from herds considered higher risk according to **DAFM criteria,** in 2019. High Risk was defined as follows: breeding herd, not a feedlot, had at least one breakdown within the last three years involving at least five animals.

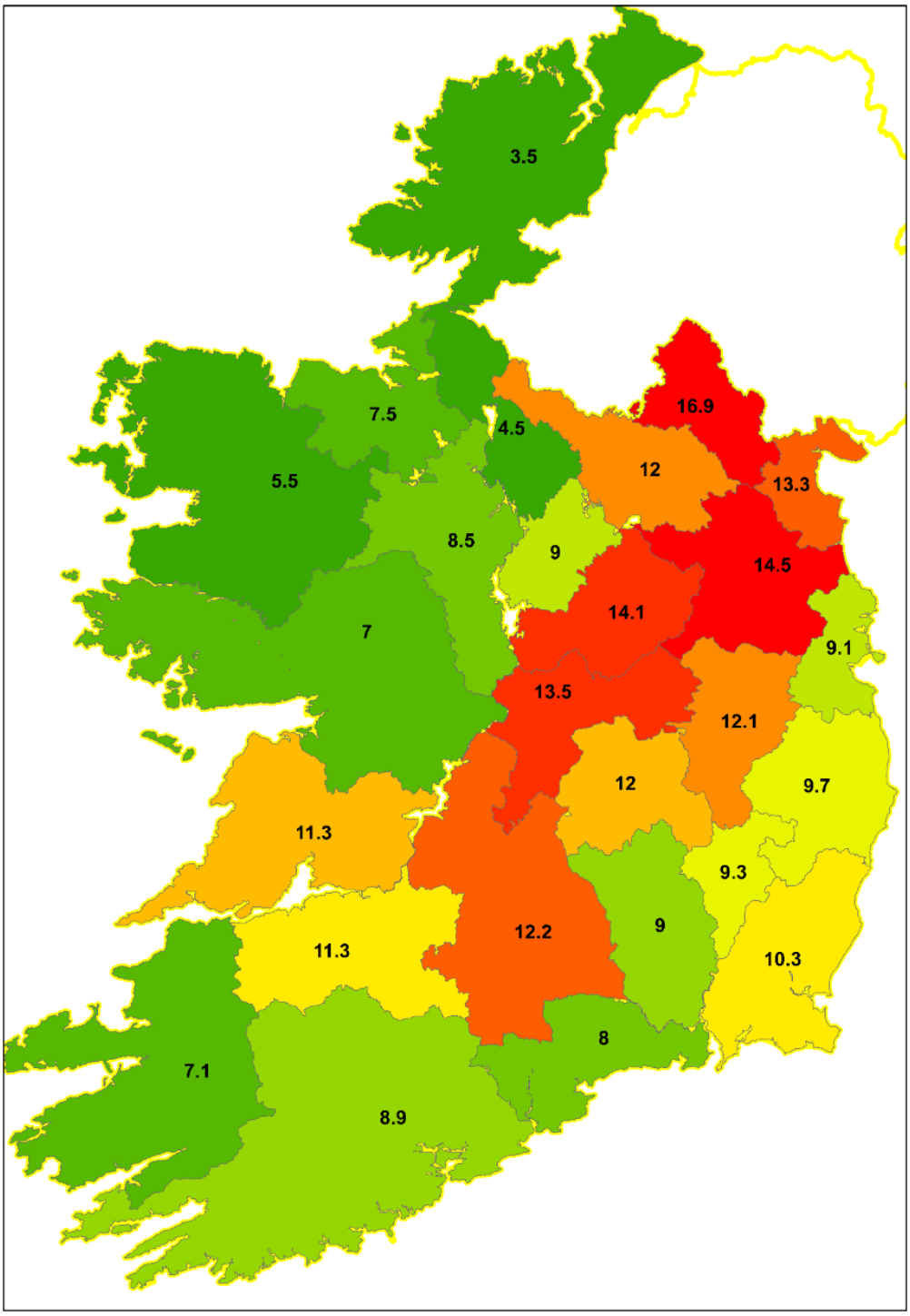

Figure 14. **Percentage** of **herds** which **bought** animals from herds considered higher risk according to **DAFM criteria**, in 2019. High Risk was defined as follows: breeding herd, not a feedlot, had at least one breakdown within the last three years involving at least five animals.

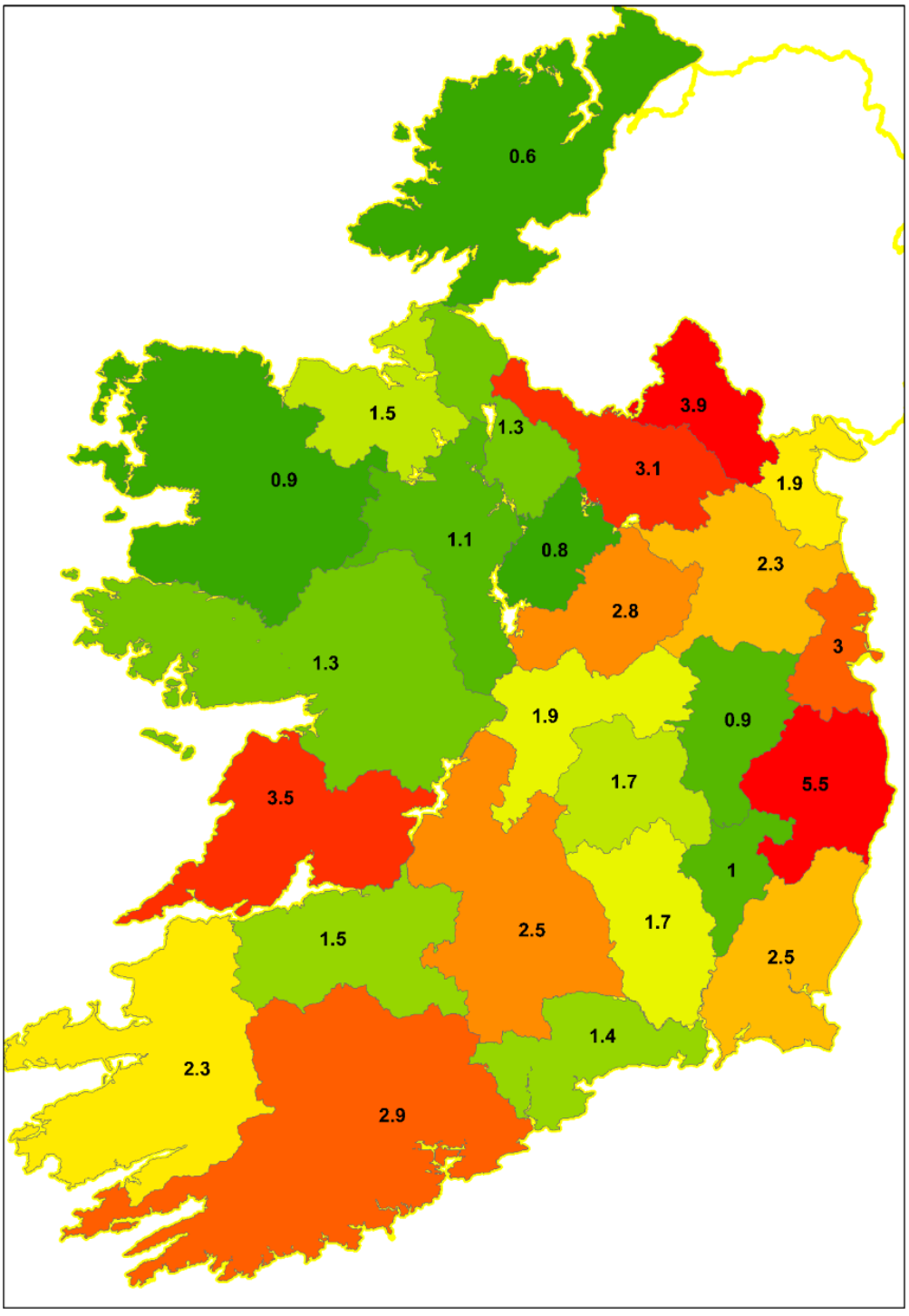

Figure 15. **Percentage** of **herds** which **sold** animals from herds considered higher risk according to **DAFM criteria**, in 2019. High Risk was defined as follows: breeding herd, not a feedlot, had at least one breakdown within the last three years involving at least five animals.

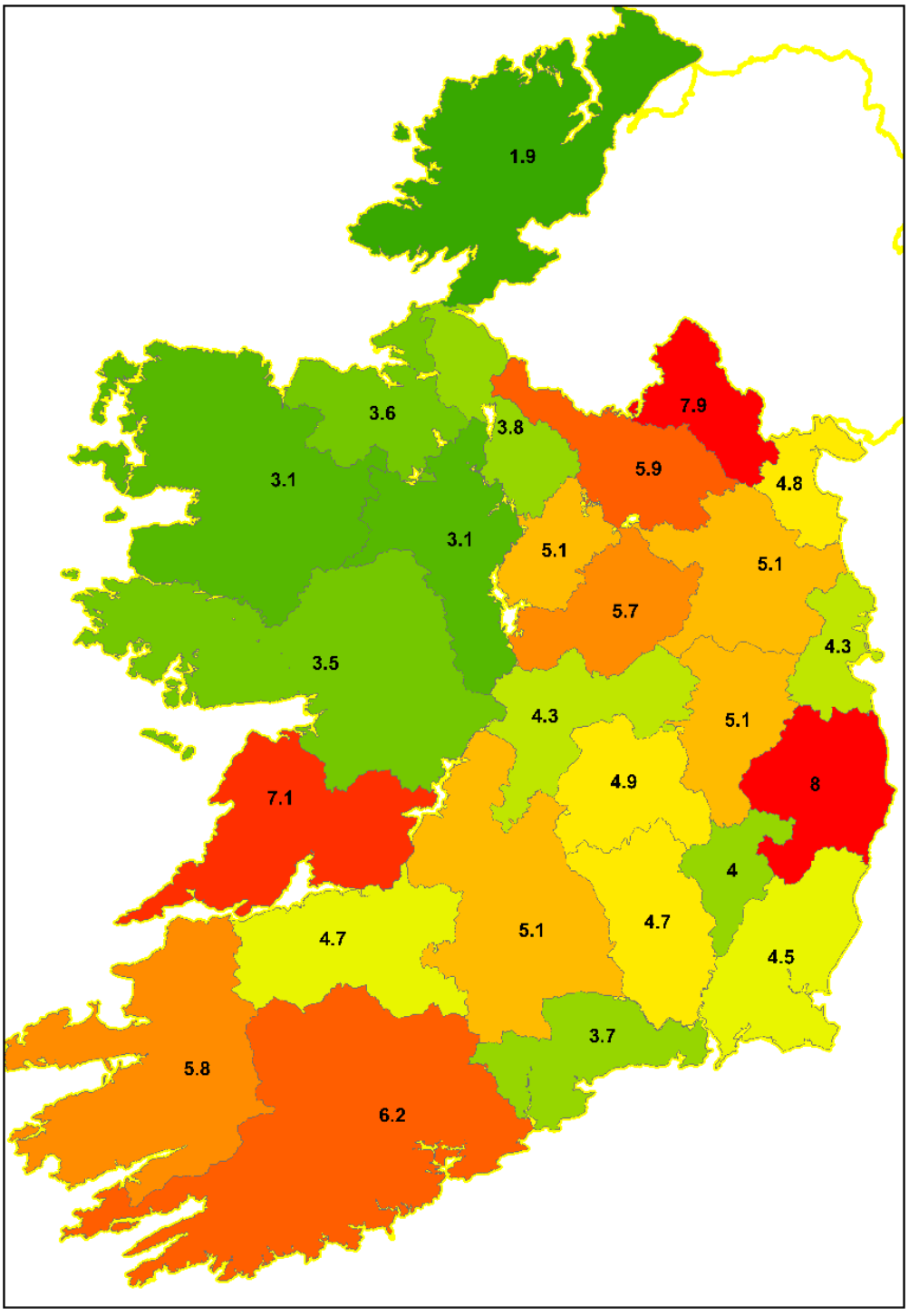

Figure 16. **Percentage** of **moves** from herds considered high risk according to **DAFM criteria** to herds considered lower risk, with reference to the county of the **buying** herd, in 2019. High Risk was defined as follows: breeding herd, not a feedlot, had at least one breakdown within the last three years involving at least five animals.

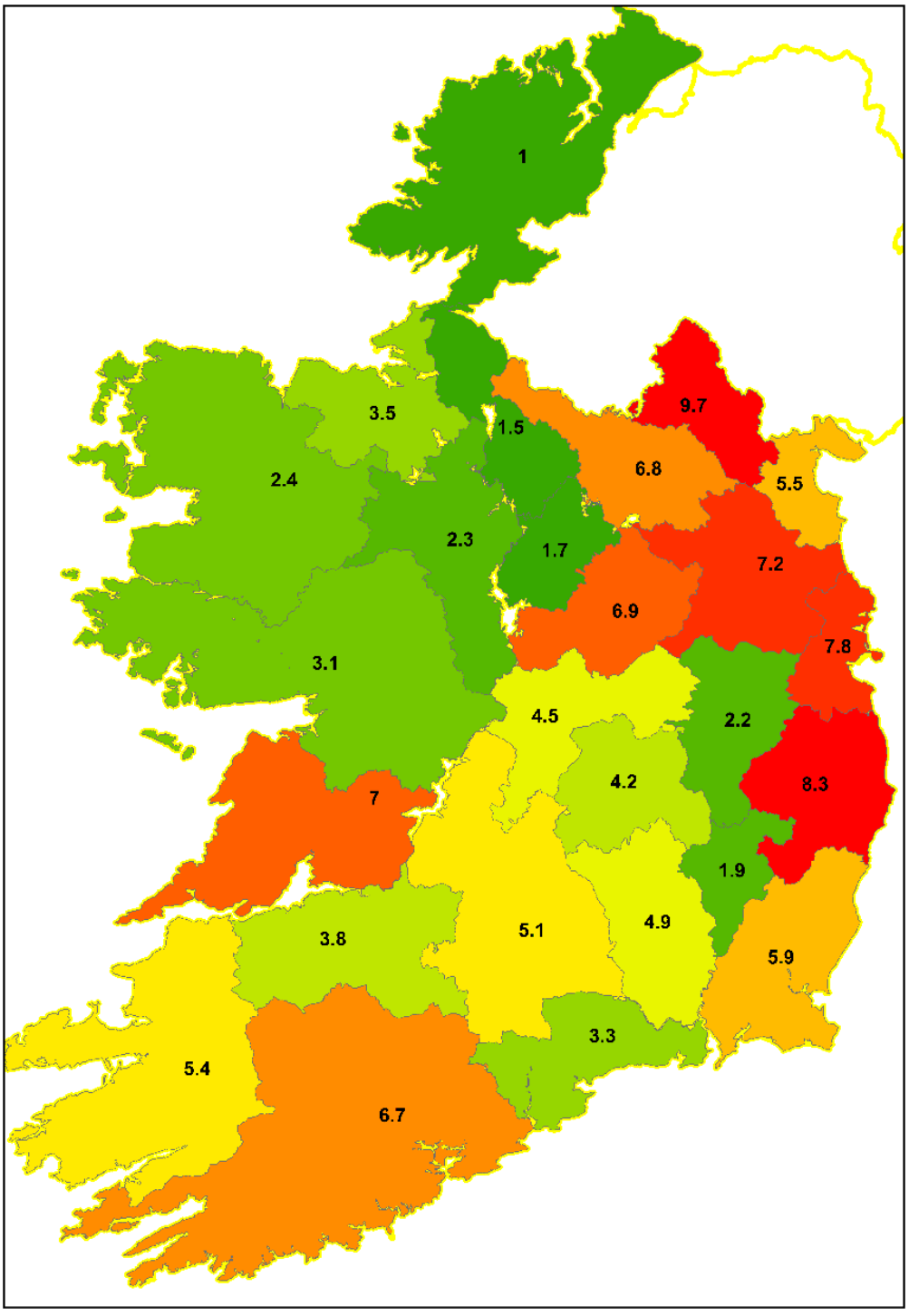

Figure 17. **Percentage** of **moves** from herds considered high risk according to **DAFM criteria** to herds considered lower risk, with reference to the county of the **selling** herd, in 2019. High Risk was defined as follows: breeding herd, not a feedlot, had at least one breakdown within the last three years involving at least five animals.

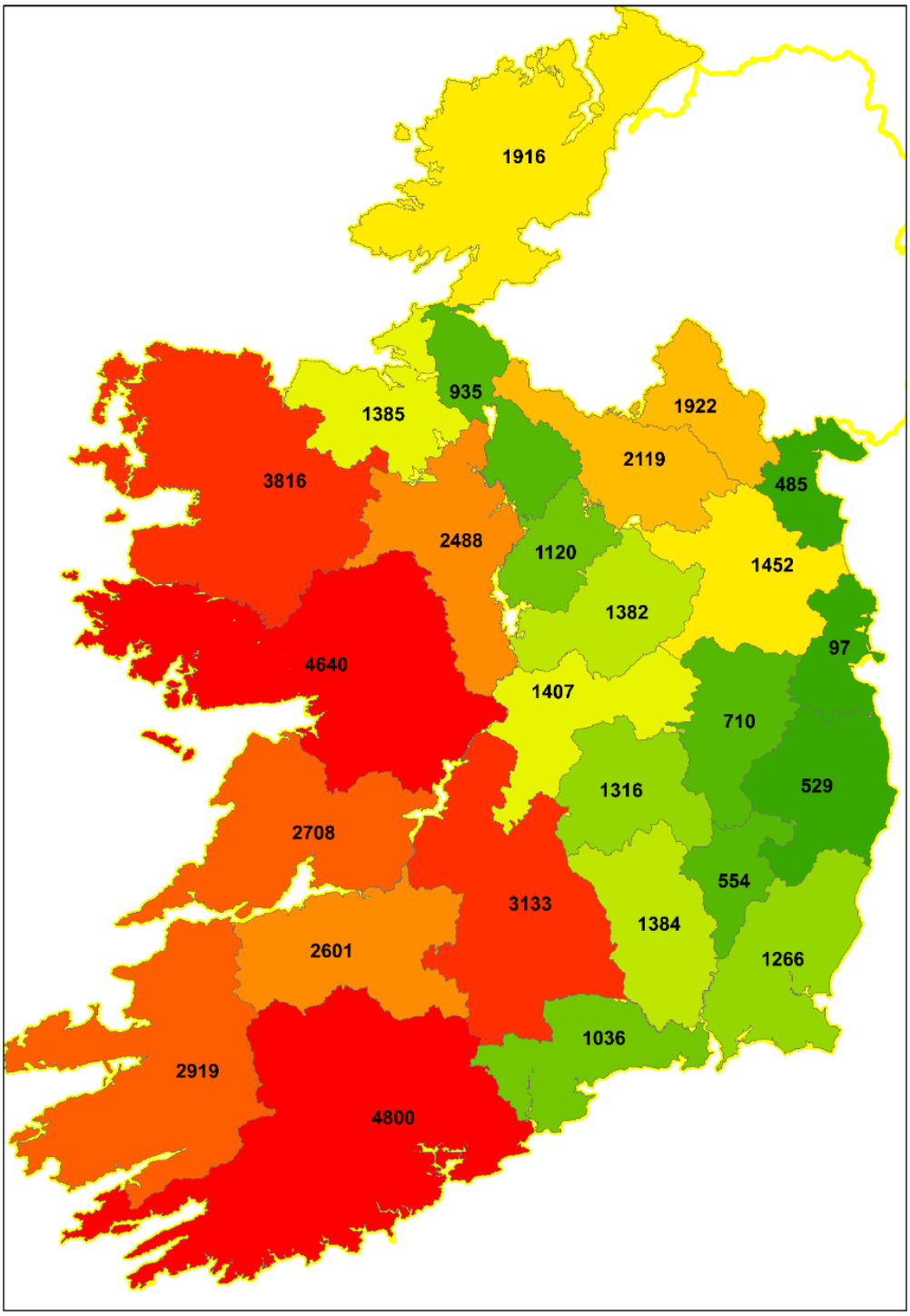

Figure 18. **Number** of herds, by county, which in 2019 **bought** animals from herds with a higher risk of breakdown, 2018-19, in the 'history and proximity model' **model** of Tratalos (2023).

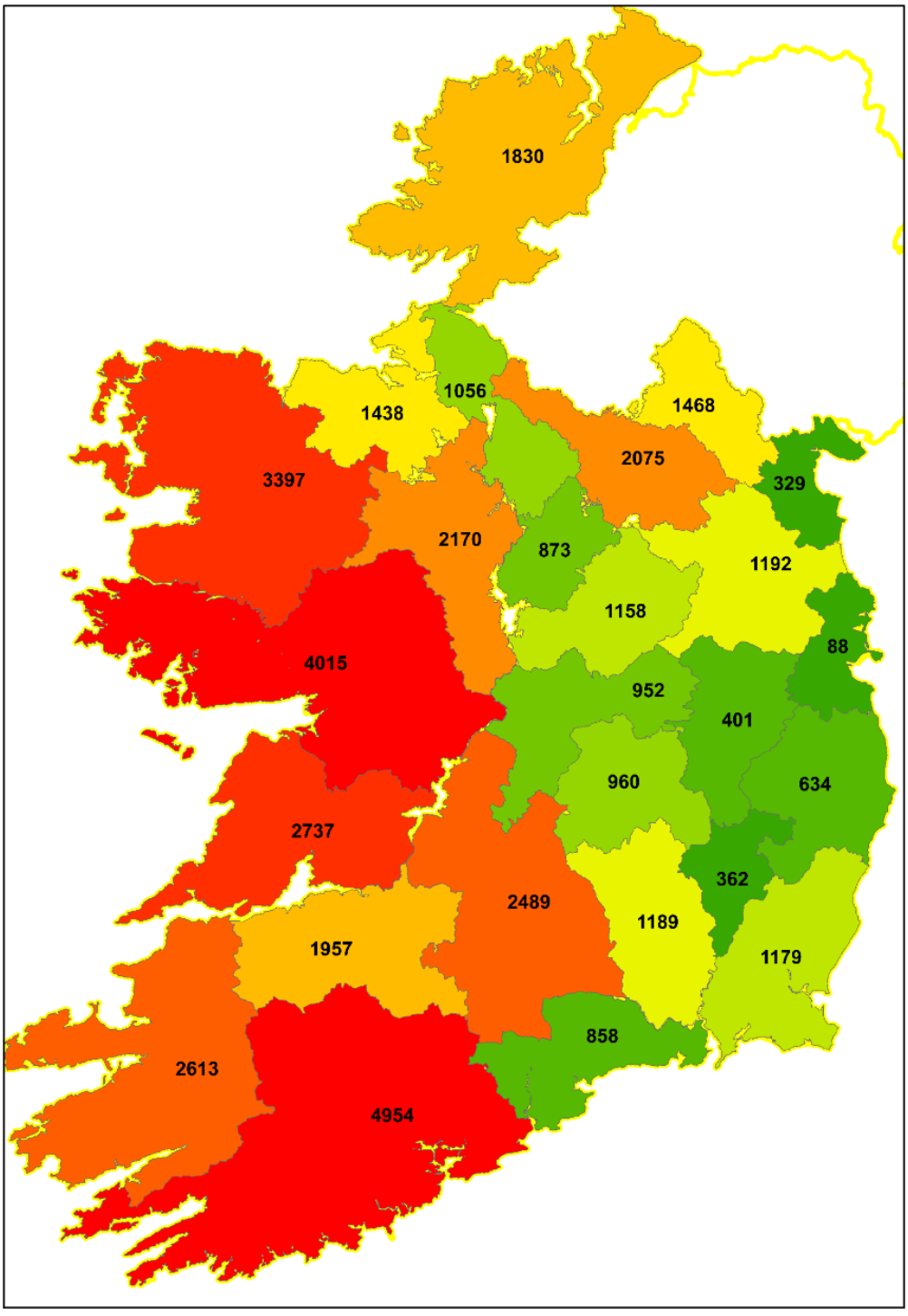

Figure 19. **Number** of **herds**, by county, which in 2019 **sold** animals from herds with a higher risk of breakdown, 2018-19, in the 'history and proximity model' **model** of Tratalos (2023).

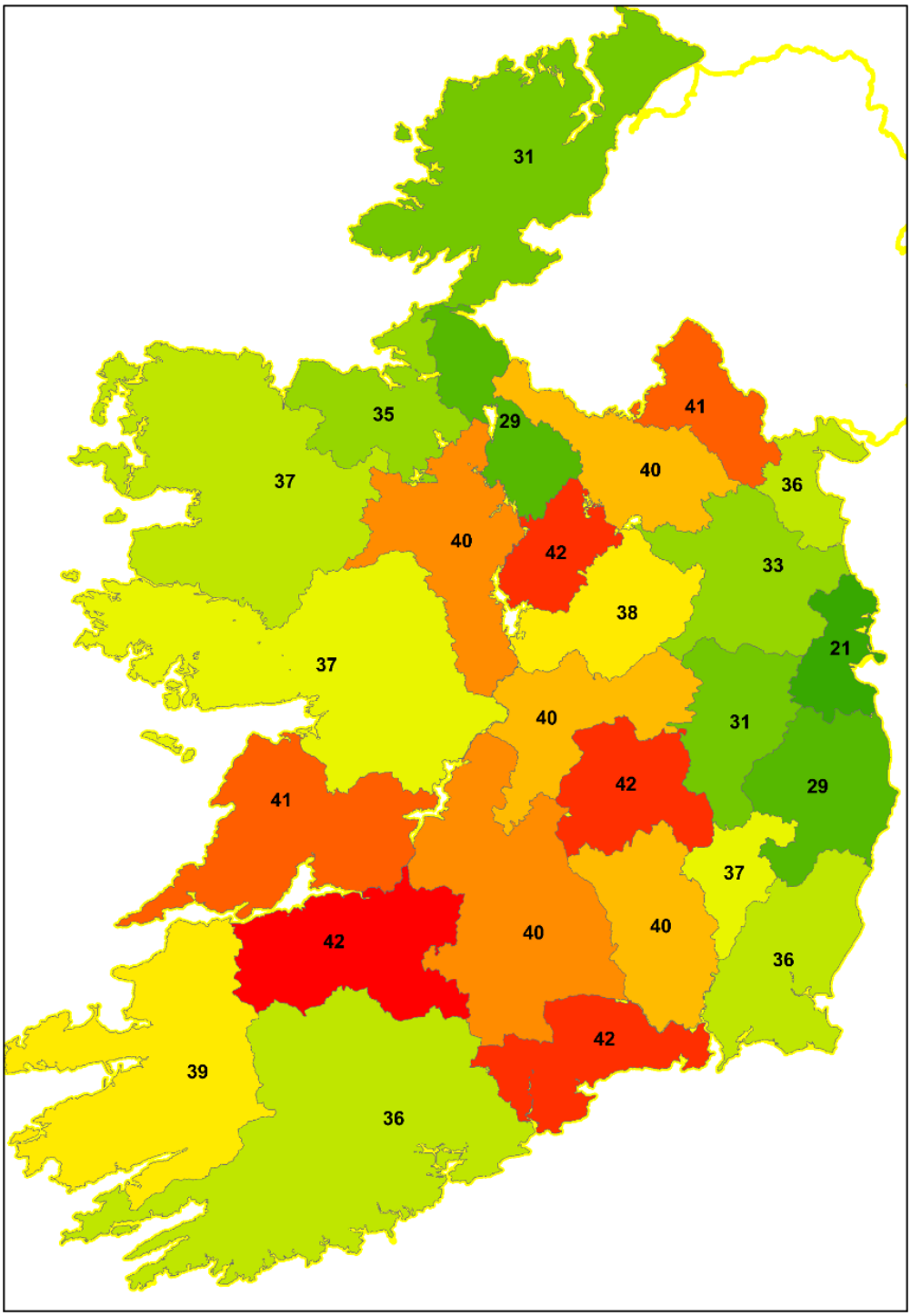

Figure 20. **Percentage** of **herds**, by county, which in 2019 **bought** animals from herds with a higher risk of breakdown, 2018-19, in the 'history and proximity model' **model** of Tratalos (2023).

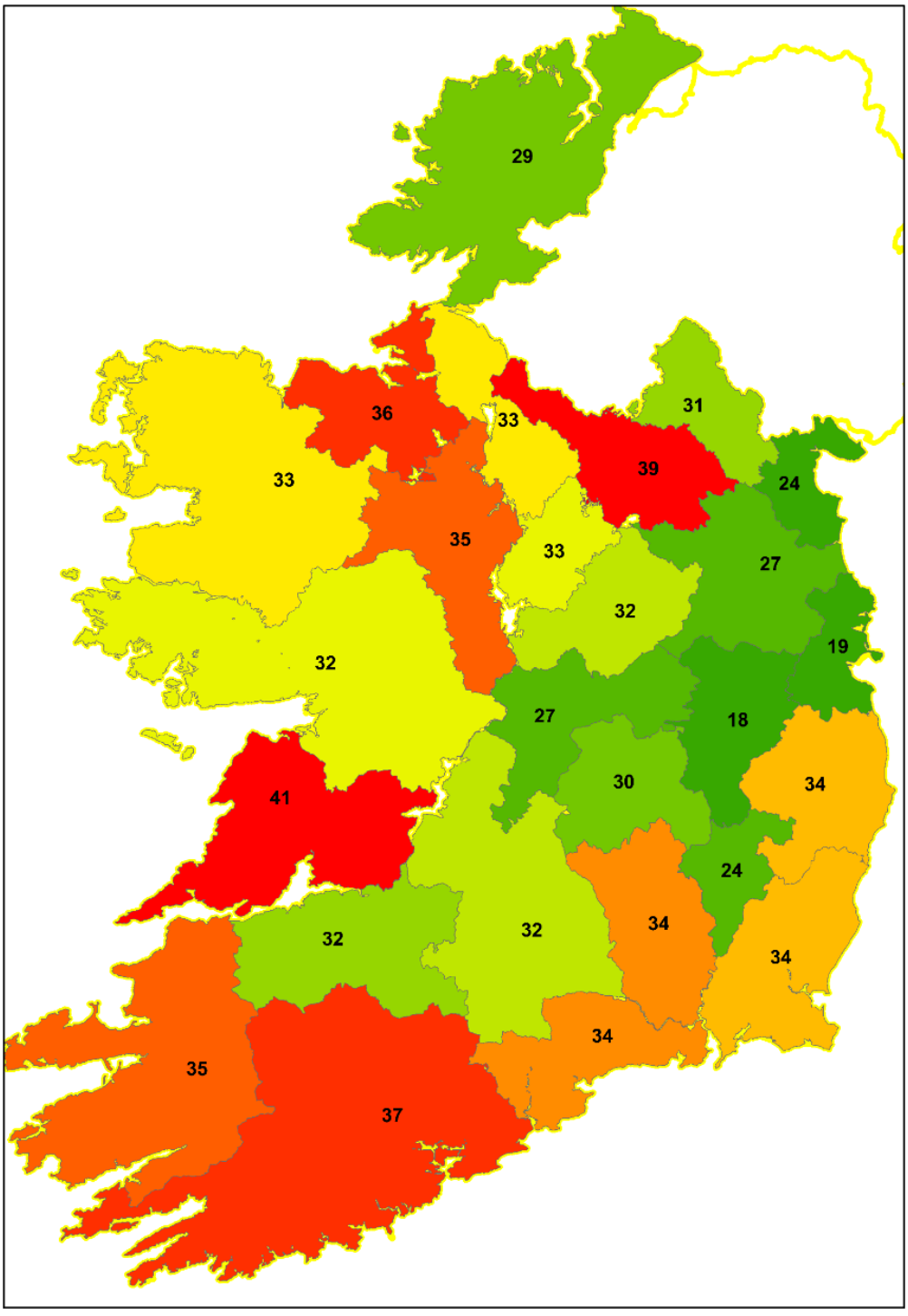

Figure 21. **Percentage** of **herds**, by county, which in 2019 **sold** animals from herds with a higher risk of breakdown, 2018-19, in the 'history and proximity model' **model** of Tratalos (2023).

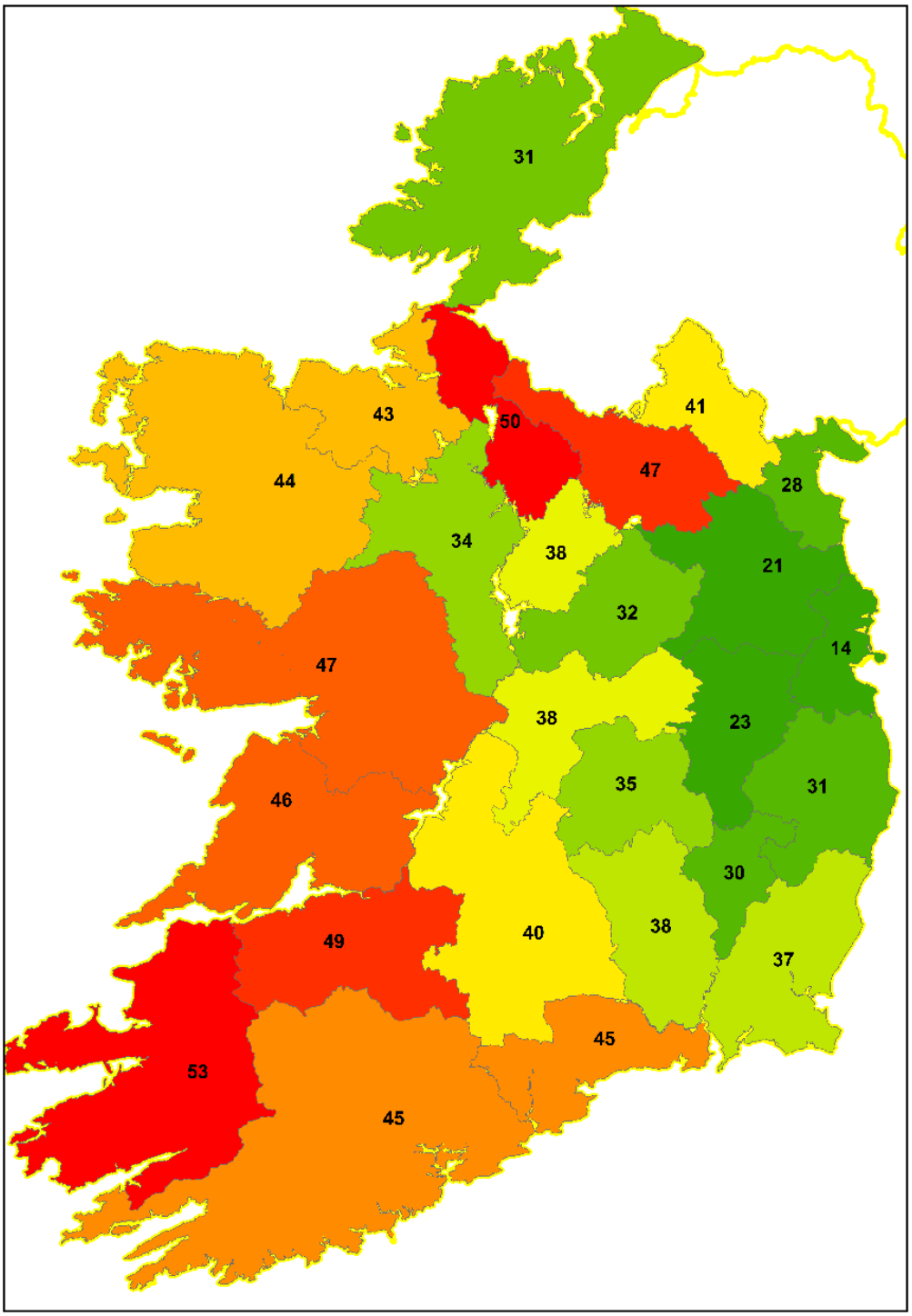

Figure 22. **Percentage** of **moves** from higher to lower risk herds, 2019, with risk calculated from the 'history and proximity model' **model** of Tratalos (2023), with reference to the county of the **buying** herd.

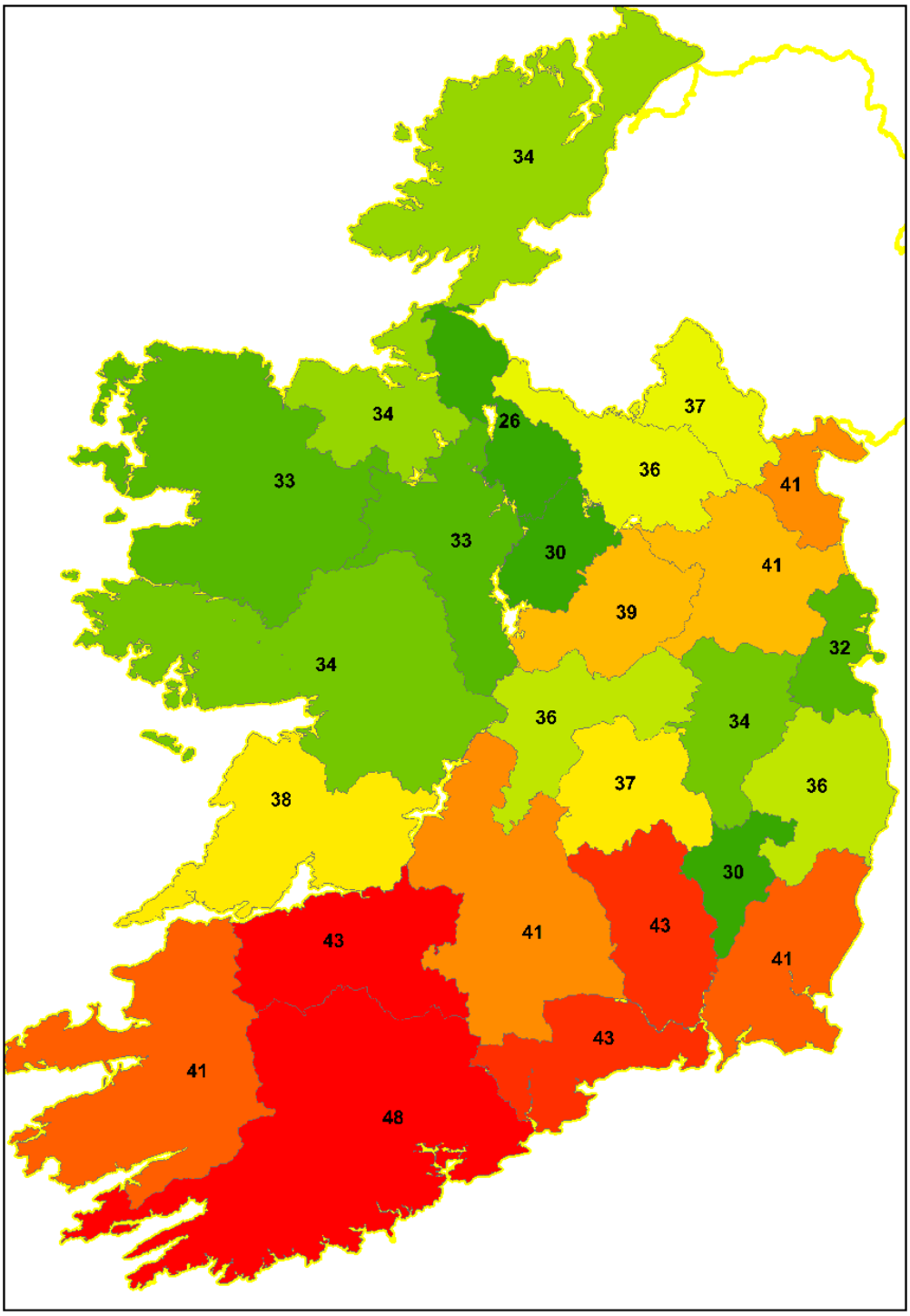

Figure 23. **Percentage** of **moves** deemed risky based on the 'history and proximity model' **model** of Tratalos (2023), with reference to the county of the **selling** herd.

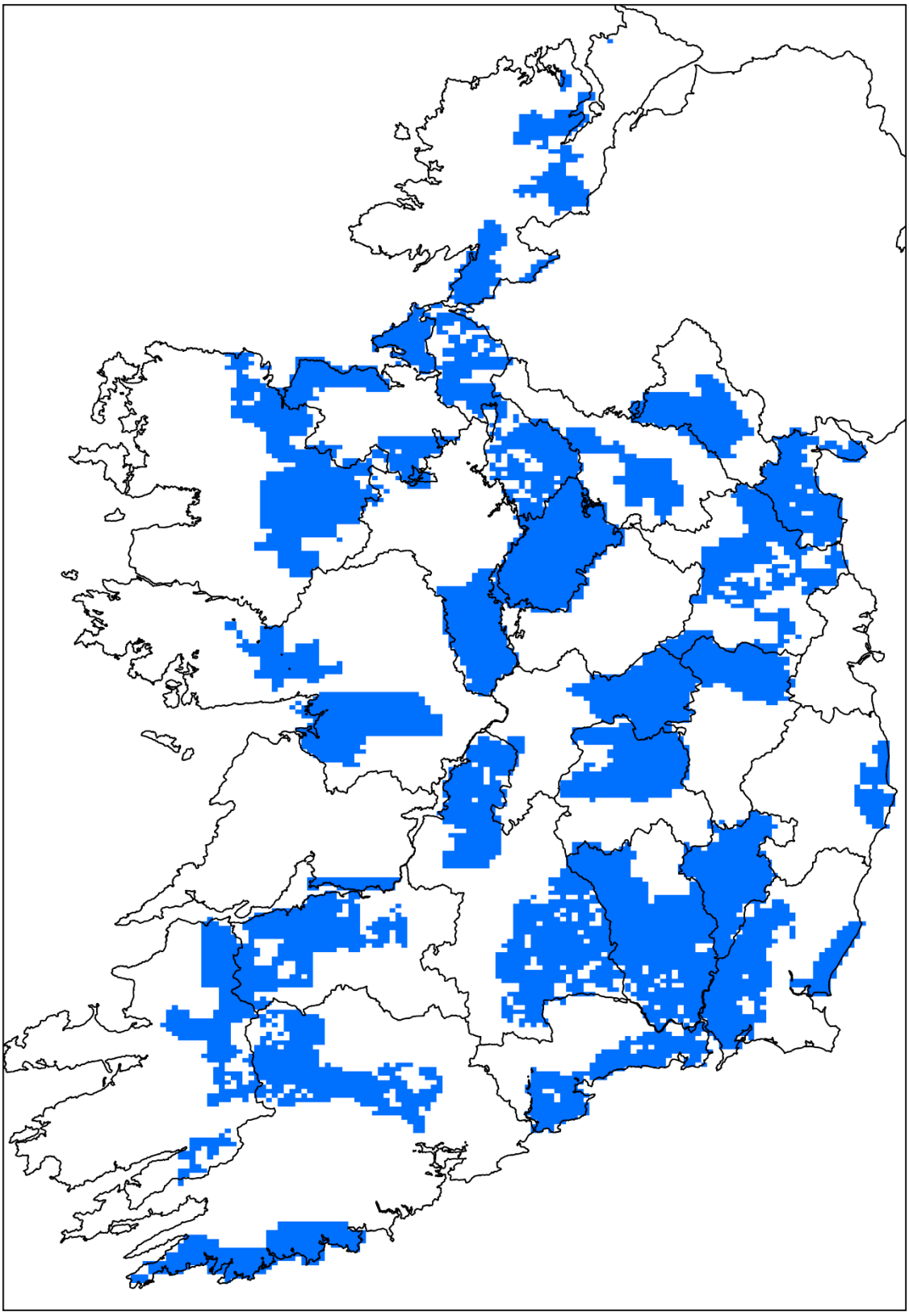

Figure 24. Areas where badger vaccination currently takes place.

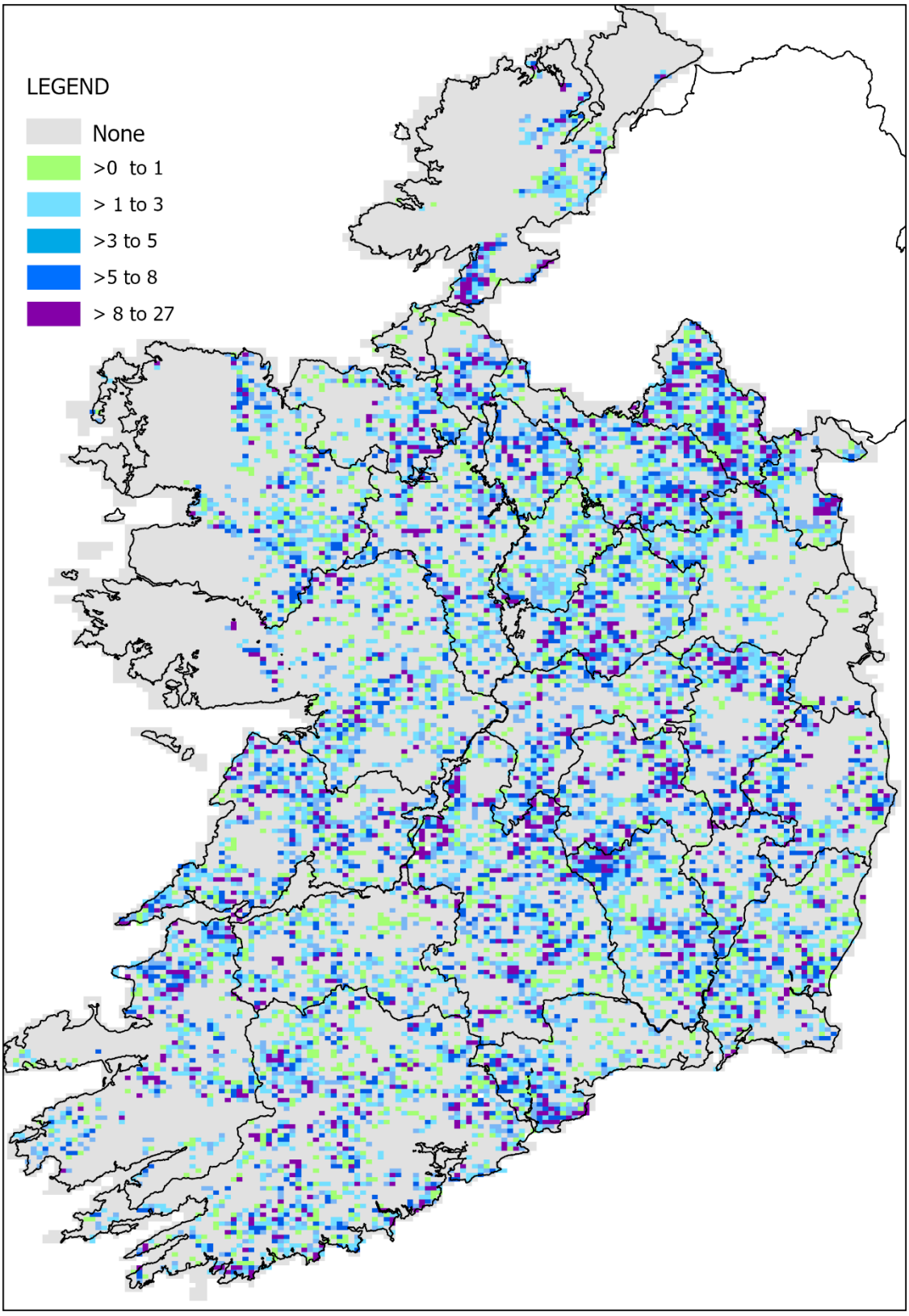

Figure 25. Total Badgers Culled or Vaccinated, 2018 to 2022

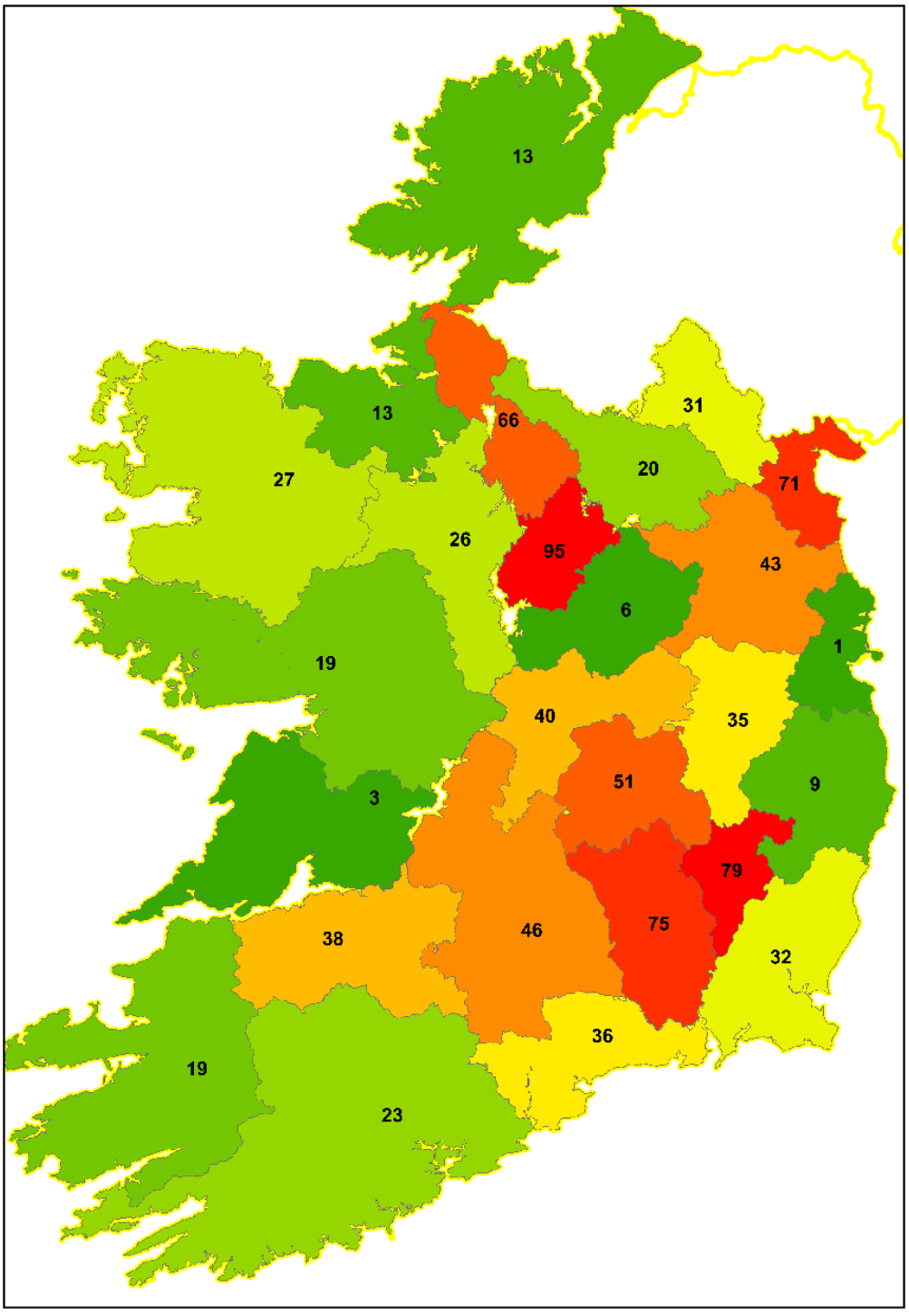

Figure 26. Percentage of the area in the county included within the badger vaccination programme, as of 28.02.2022.

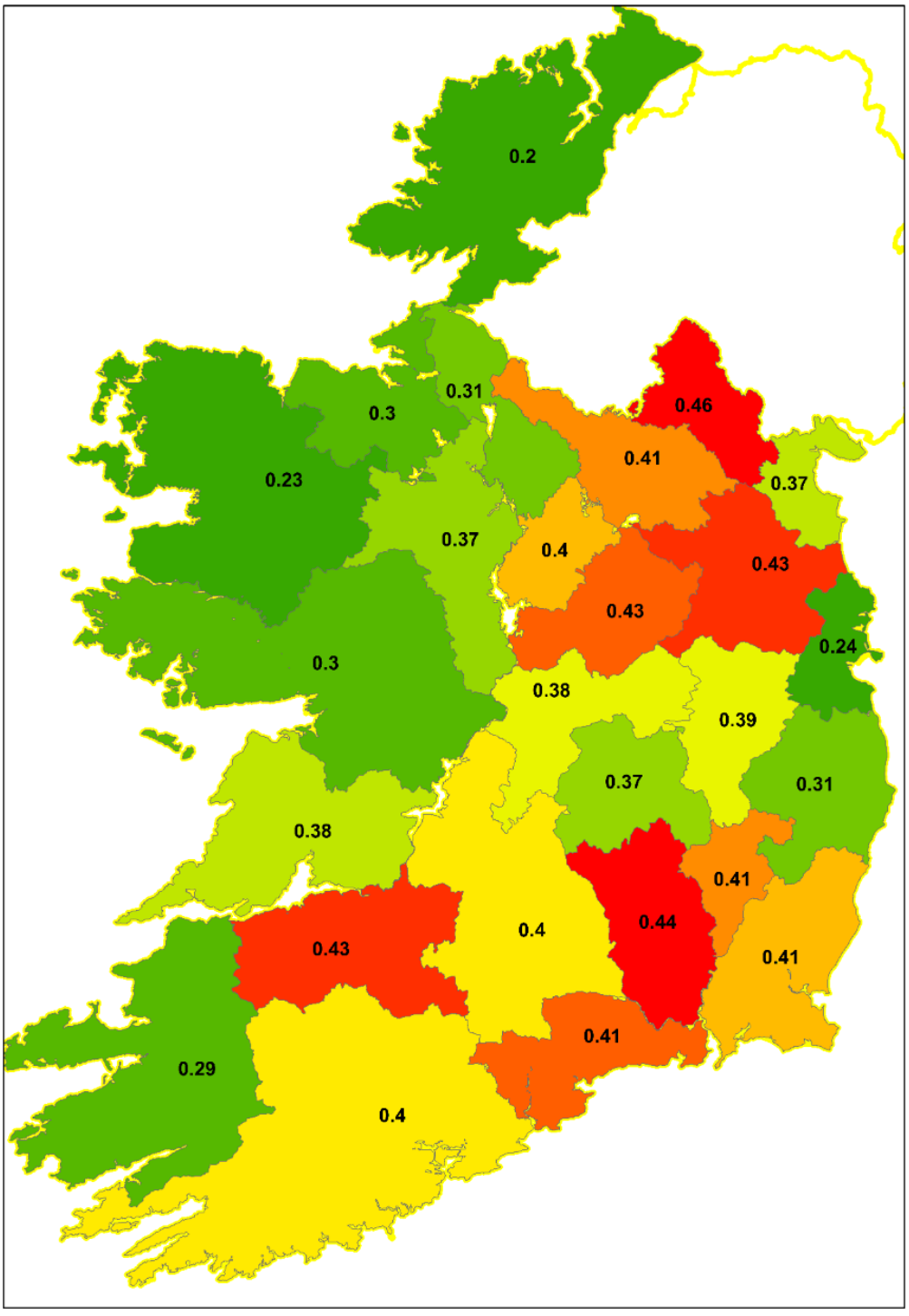

Figure 27. Average pixel value (1 ha square area) from Byrne (2014) badger abundance model, by county (Byrne, A.W., Acevedo, P., Green, S., O'Keeffe, J., 2014a. Estimating badger social-group abundance in the Republic of Ireland using cross-validated species distribution modelling. Ecological Indicators 43, 94-102. https://doi.org/10.1016/j.ecolind.2014.02.024.