Hill sheep breed genetic improvement strategy

Prepared for:
Sheep Ireland

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DISCLAIMER

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Executive Summary

Genetic improvement is a well-established technology that provides cumulative and permanent improvements in animal performance, leading to increased profitability all along the supply chain. The Irish hill sheep sector has the potential to contribute significant value to the Irish sheep industry through genetic improvement. This report provides an actionable strategic development plan to enable the Irish hill sheep sector to engage in, and benefit from, the genetic improvement services offered by Sheep Ireland.

From a baseline assessment of the hill sheep sector, learnings from the development of a genetic improvement program in the lowland breeds and combining the unique features of the hill sheep sector, the critical factors for success of the hill sheep genetic improvement program are outlined below.

- Engage hill sheep ram breeders and commercial farmers to ensure long-term buy-in,
- Utilise flocks already engaged with Sheep Ireland for initial data collection,
- Increase data volumes by incorporating larger commercial flocks,
- Ensure unique individual animal identification, preferably with DNA tags,
- Establish parentage, ideally by tagging lambs at or near birth,
- Establish an understanding of the (genomic) relationships between flocks, and consider a range of options for genetic connectedness across flocks if required,
- Focus initially on comparing and ranking animals rather than breeds,
- Provide early returns to farmers' investments by generating useful results, and
- Demonstrate proof of concept to build confidence and wider future involvement.

Within the hill sector, there is a core need to generate both parentage information and commercial data on important traits, to evaluate the genetic merit of selection candidates. The proposed hill sheep data program (HSDP) is an initiative designed to address this need. The HSDP will also bring together a core set of breeders/ flocks that will fulfil a role in demonstrating the principles of data recording and genetic improvement. The initial focus should be to establish a within-breed genetic evaluation using HSDP data, rather than implementing a CPT structure for an across-breed evaluation and comparisons.

Genotyping will be used to understand genomic relationships and generate the reference population data to underpinning genomic evaluations. The proposed initial scale would result in 15% of a breeds' annual ram requirements, for the commercial ewe population, coming from the HSDP. Some 10,000 ewes across breeds are required to achieve this, with the sign-up of participating flocks expected to take 3 years. With the accumulation of genotypes, genomic evaluation results should be available in years 3-5 of the HSDP, depending on the breed. With knowledge exchange and demonstration, there is an opportunity to build buy-in and create value from year 1 of the program.

Supported by data from a survey conducted by Sheep Ireland, the HSDP and hill sheep genetic improvement program should focus on recording the core set of traits that target robustness in conditions in which hill sheep farmers are operating, including number of lambs born, ewe body condition score, ewe mouth score, mastitis incidence, lameness/ foot score, barrenness, and ewe mature weight (maintaining ewes in a challenging environment) and lamb survival, lamb vigour score, and weaning weight (selling lambs at weaning). Existing Sheep Ireland

infrastructure should be used wherever possible, including the genotyping pipeline, genetic evaluation system, and LambPlus service. Given the successful uptake of EuroSTARs as a mechanism to display estimate of genetic merit in the lowland breeds, EuroSTARs should also be used for hill sheep breeds.

Accounting for genotyping, data collection (i.e., labour provided by Sheep Ireland), and data management cost accumulated over 10 years, the net present value (NPV) of HSDP costs is €2,836,528 (discounted at 5%). The benefits (based on observed annual lowland genetic trends in the lowland adjusted for likely hill sector performance) accumulated over 15 years result in an NPV of €5,429,102. Based on these costs and benefits, a €1 investment into the HSDP is expected to return €1.91 to the hill sheep sector.

Across a range of sensitivity scenarios (e.g., annual rate of genetic gain, genotyping costs, weaning weight price, incentive to HSDP flock owners, and adoption) the HSDP and the hill sheep genetic improvement program is predicted to provide a net positive economic return, with benefit to cost ratios ranging from 1.48:1 to 2.31:1.

Recommendations

The recommendations are provided below.

1. Sheep Ireland should source 2,900, 2,400, 2,100, 1,200, 900, and 500 ewes for Mayo Connemara, Perth, Cheviot, Scotch Dingle, Lanark, and Swaledale, respectively, to join the HSDP, where these flock will generate data on important traits for genetic evaluation and constitute the reference population for the respective breeds.

2. Sheep Ireland should aim to recruit these flocks over a period of 3 years, as buy-in builds and to manage the workload for Sheep Ireland.

3. Sheep Ireland should not prioritise the development of a hill sheep sector CPT at this stage in the genetic improvement program and should instead focus on delivering within breed evaluations via the proposed HSDP structure.

4. HSDP flocks should be encouraged to tag and DNA sample all lambs (including tagging/ sampling dead lambs) at or near birth.

5. Sheep Ireland should focus on recording the core set of traits that target robustness in conditions in which hill sheep farmers are operating: number of lambs born, ewe body condition score, ewe mouth score, mastitis incidence, lameness/ foot score, barrenness, and ewe mature weight (maintaining ewes in a challenging environment) and lamb survival, lamb vigour score, and weaning weight (selling lambs at weaning).

6. Sheep Ireland should visit HSDP flocks at pregnancy scanning and weaning, to capture the required data.

7. Ultrasound muscle and fat scanning should be assessed, through a trial to collect 1,200 records, to determine the potential to select for muscle and fat depth in weaned lambs, and as a predictor of ewe BCS.

8. Sheep Ireland should assess the level of genomic relationships (connectedness) across the HSDP populations. In the absence of sufficient connectedness, Sheep Ireland should take an open approach to creating genetic connectedness and offer to HSDP members flocks the opportunity to share rams or swap ewes in the first instance, with AI used only if linkage can't be created in other ways.

9. Sheep Ireland should estimate variance components and build a genetic evaluation for ewe mouth score to support the trait needs of the hill sheep sector.

10. Sheep Ireland should estimate variance components for traits common to lowland and hill breeding objectives using hill sheep data only, as well as with lowland and hill sheep data combined, to guide potential areas of improvement in hill sheep recording practices and/ or genetic evaluation model development.

11. Existing Sheep Ireland genetic and genomic evaluation systems should be used for routine hill sheep evaluation, rather than a distinct hill sheep breed genetic evaluation.

12. Through genotyping ewes and lambs in the HSDP breeds, Sheep Ireland should establish a reference population and release estimate of genetic merit in years 3 (MC, PR, CH) and 5 (DS, LN, SD), but take the opportunity to release earlier if the evaluation outcomes permit.

13. Sheep Ireland should leverage existing infrastructure and initiatives in pursuit of a hill sheep genetic improvement program (e.g., genotyping pipeline, genetic evaluation system, and LambPlus service).

14. Sheep Ireland should use the lowland CPT as a resource to demonstrate the principles of data recording, genetic merit, and genetic improvement to hill ram breeders and farmers and, if capacity allows for it, use hill sheep breed rams in the lowland CPT.

15. Sheep Ireland should continue to engage hill ram group breeders, including as part of the HSDP, to sign up to Sheep Ireland and record parentage/ pedigree and performance data, with a goal of creating a 'flock book' structure for the respective breeds.

16. Sheep Ireland should create a hill sheep breeding objective and selection index, incorporating new traits and updating economic weights for existing traits to reflect economic drivers for hill sheep farmers, and implement EuroSTARs as a mechanism to display estimate of genetic merit.

Contents

EXECUTIVE SUMMARY 3

Recommendations 4

BACKGROUND 8

Purpose of this report 8

WORK PACKAGE 1: BASELINE ASSESSMENT AND CRITICAL FACTORS FOR SUCCESS 9

Baseline assessment 9

Critical factors for success 10

Engagement 11

WORK PACKAGE 2: STRATEGIC DEVELOPMENT PLAN 11

Development needs mapping 11

Breeding schemes 11

Hill sheep data program (HSDP) 11
Central Progeny Test 14

Trait recording 15

Genetic connectedness 17

Genetic evaluation 17

Genomic evaluation 18

Reference population 18
Establishment by breed 20

Alignment with existing Sheep Ireland initiatives 23

The role of hill ram groups 24

Breeding objective and selection index 24

WORK PACKAGE 3: POTENTIAL BENEFITS AND COSTS OF GENETIC IMPROVEMENT 25

Cost modelling 25

Benefit modelling 26

Trait genetic trends 26
Economic values 28

Commercial penetration and trait expression 29

Commercial sector trait and economic trends 32

Case for investment 33
Economic outcomes 33
Additional benefits 34

Sensitivity analysis 35

ROADMAP 37

Phase 1: Inception (Years 1-3) 38
Objectives 38
Actions 38

Phase 2: Routine (Years 4-7) 38
Objectives 38
Actions 38

Phase 3: Burn-in (Years 8-15) 39
Objectives 39
Actions 39

APPENDIX 1: HILL SHEEP FARMER SURVEY AND INDUSTRY CONSULTATION 40

Hill sheep farmer survey results 40

Industry consultation summary 43

APPENDIX 2: GENOTYPES BY BREED 45

APPENDIX 3: HILL SHEEP ULTRASOUND MUSCLE AND FAT DATA ANALYSIS 46

APPENDIX 4: HSDP COST CALCULATION PARAMETERS 47

APPENDIX 5: LOWLAND SHEEP GENETIC TRENDS 48

Background

Sheep Ireland, launched in 2008 following the delivery of the Breeding Profitable Sheep in Ireland strategic report and recommendations, has been successful in creating and providing the infrastructure to drive genetic improvement in the Irish sheep industry. Outcomes show the transformative nature of this long-term effort, with significant uptake of Sheep Ireland services by some 1,400 flocks and positive genetic trends in maternal and terminal selection indexes, delivering increased flock productivity and profitability (predicted to be worth €15.5M and €2.2M on the replacement and terminal indexes, respectively, over 20 years from 2018, with likely significantly higher benefits based on the genetic trends since 2018). However, genetic improvement has been largely confined to the lowland sheep sector, with the level of engagement by the hill sheep sector farmers much lower than their lowland counterparts.

The Hill sheep sector makes up a significant portion of the Irish sheep production industry (47.5% of ewes are Hill/ Hill Cross). To maximise the value that Sheep Ireland provides to the industry, there is a need to deliver value to the hill sheep sector through genetic improvement. The Sheep Improvement Scheme (SIS), offered by the Department for Agriculture Food and the Marine, has generated some momentum in the hill sheep sector in the form of genotyping. Sheep Ireland has started working with stakeholders to build a sustainable genetic improvement program for the Irish hill sheep sector. This includes recording trait data in several flocks and launching of the inaugural hill ram sale in October 2024. It is therefore an opportune time to build on this momentum, with farmer engagement and the delivery of a plan to support the hill sheep sector, through genetic improvement services.

Purpose of this report

This report provides an actionable strategic development plan to enable the Irish hill sheep sector to actively engage in, and benefit from, the services offered by Sheep Ireland. The analysis and planning herein provides a set of recommendations for sustainable future development of data recording and breeding schemes, so that Sheep Ireland can provide a genetic improvement service to hill sheep sector. The objectives of the project were to:

- Develop a baseline assessment of genetic improvement in the hill sheep sector, through analysis and consultation (work package 1),
- Create a strategic development plan (work package 2),
- Quantify the potential benefits and costs of genetic improvement to the hill sheep sector (work package 3), and
- Provide a roadmap/ plan with recommendations (work package 4)

The report is structured to align with the work packages.

Work package 1: Baseline assessment and critical factors for success

Baseline assessment

Genetic improvement is a well-established technology that provides cumulative and permanent improvements in animal performance, leading to increased farmer and supply chain productivity and profitability. This has been demonstrated by Sheep Ireland, with a genetic improvement program focused on lowland breeds over the last 17 years. The Irish hill sheep sector is very early in the journey of adopting genetic improvement but has the potential to contribute significant value to the Irish sheep industry through genetic improvement. There are some 830,000 pure mountain ewes and 457,000 mountain-cross ewes (national sheep and goat census, 2023), representing a significant proportion of the Irish sheep sector. With an estimated ewe to ram mating ratio of 1:40 (David Coen, pers. comm.), and a ram working life of 3.1 years (Appendix 1: Hill sheep farmer survey and industry consultation), approximately 6,700 new rams are required each year to service the pure mountain ewe flock. These rams are provided primarily by hill ram groups. There are 17 hill ram groups covering Mayo (2 groups), Cheviot (2), Perth (6), Dingle Scotch (2), Swaledale (2), and Lanark (3). Sheep Ireland has started to engage with these 17 groups. The extent to which rams are shared between flocks within ram group and between ram groups is unknown. There are some minor breeds, where ram breeding is more unstructured. In general, there is much less specialisation and differentiation between ram breeders and ram buyers in the hill sector when compared to the lowland sector.

While there are hill ram groups, there is no pedigree registration and flock book structure, as there is in the lowland breeds. This presents a challenge and several opportunities. The challenge is that a wider group of animals can’t be genetically evaluated, based on existing datasets, through pedigree information. The ability to provide estimates of genetic merit through pedigree information was one of the early wins in establishing the Sheep Ireland genetic improvement program for the lowland breeds. However, there is an opportunity to establish high quality datasets in a commercial hill sheep setting and to leverage genotypes and genomic prediction to establish genomic relationships and a reference population for the respective hill sheep breeds. This would represent a step change for the hill sector, to the use of advanced contemporary genetic improvement technology. Genomic selection also provides an immediate means of delivering scrapie genotypes, genomic inbreeding (as an indication of flock inbreeding levels), and major gene information, as early wins for hill ram breeders. There is a further opportunity, in that the development of a hill sheep genetic improvement program provides a system on which respective hill sheep breeds can create flock books and pedigree registration. The creation of such a system would require hill ram groups to interact collectively with Sheep Ireland, while also enabling them to leverage value from knowledge and information sharing (as estimates of genetic merit are generated by Sheep Ireland) and from breeding and selection initiatives (e.g. ram sharing and sales).

Generally, within the hill ram groups, there is limited individual animal identification and formal data recording. There are 34 hill flocks recording data, as part of Sheep Ireland (out of a total of ~1,500 flocks), to different degrees of quantity and quality. Of these flocks, 28 are from hill ram group flocks.

Sheep Ireland has put significant effort into genotyping rams for the hill sheep sector through the SIS and DNA collections days. This has yielded 6,754 genotypes (see Appendix 2: Genotypes by breed) and with sire verification on some 4,322 animals. This forms an excellent base from which to build services such as parentage verification & assignment, scrapie genotyping, genomic inbreeding coefficients, and ultimately a genomic evaluation for traits of economic importance.

Critical factors for success

Taking learning from the development of a genetic improvement program in the lowland breeds and combining the unique features of the hill sheep sector, the critical factors for success are:

- It is essential, as it was for the lowland breed genetic improvement program, for hill sheep ram breeders (hill ram groups) and commercial farmers to have a say in the design of a hill sheep genetic improvement program. This will ensure industry buy-in in the long-term.
- Sheep Ireland have made great progress in genotyping rams and signing up hill sheep breeders. The flocks already engaged with Sheep Ireland and/ or those that have provided genotypes are obvious candidates from which data can be generated for genetic evaluation.
- The current average flock size in the hill sheep breeder sector is small, at 40-50 ewe. Including commercial, non-ram seller, flocks and removing the requirement to tag at birth could increase the average flock size and data volumes. If tagging is not taking place at birth, foetal aging will be required to establish estimated birth date.
- A prerequisite to any genetic improvement initiative is unique individual animal identification. Any animal joining Sheep Ireland as part of a hill sheep genetic improvement program will need to be tagged with a unique ID. Where the animal is to be genotyped, this will need to be a DNA tag.
- Establishing parentage is essential, and hill sheep production systems present a significant challenge in this context. Hill sheep breeders should be informed that the ideal approach to this is to tag lambs at or near birth (including with a DNA tag, if genotyping).
- Establishing an understanding of the (genomic) relationships between flocks will be critical, as this will inform whether estimates of genetic merit can be compared across flocks. Genomic relationship information will also determine how much effort should be put into creating connectedness through ram sharing, and/ or ewe swapping, and/ or artificial insemination.
- Importantly, the focus of the genetic improvement program and associated breeding scheme(s) needs to be, in the initial stages, on the comparison and ranking of animals and not breeds. In time, the data structure can be created to compare breeds, through crossbred flock ram sharing or a CPT (for example).
- Joining Sheep Ireland and a hill sheep breeding scheme will require an investment in time and changes to farm operations. It is important that farmers see a return on

their investment, as early as possible. With that in mind, it is important to establish enough scale (data), so to provide useful results to breeders in the short-term.
- To build confidence in the program, a proof of concept and demonstration is required to promote wider involvement in the future.

Engagement

A key contributor to the success of a hill sheep genetic improvement program is engagement with, and learning from, hill sheep farmers. A survey of hill sheep farmers was conducted between the 1st of October and the 14th of October 2024, where some 750 farmers were sent the survey. There were 94 responses. In addition to the survey, several industry groups were consulted, including: Teagasc, Meat Industry Ireland, Irish Farmers Association, Irish Natura & Hill Farmers Association, and the Irish Cattle and Sheep Farmers Association. Across all industry consultation, the Sheep Ireland hill breed genetic improvement program was seen as an important step forward and was very well supported. All groups consulted wished to remain informed as thing progress.

The full survey and a summary of consultation findings are presented in Appendix 1: Hill sheep farmer survey and industry consultation.

Work package 2: Strategic development plan

Development needs mapping

This section outlines key aspects of development required to deliver the data to Sheep Ireland for evaluation of hill sheep breeds, and to provide estimates of genetic merit to participants. The form and scale of breeding schemes are outlined, along with recommended traits to record, implications for genetic/ genomic evaluation, and the selection index needs for the hill sheep sector.

Breeding schemes

Hill sheep data program (HSDP)

Within the hill sector, there is a core need to generate both parentage information and commercial data on important traits, to evaluate the genetic merit of selection candidates. Sheep Ireland is experienced in running initiatives, such as the Central Progeny Test (CPT) and the, now terminated, Maternal Lamb Producer Groups (MALP), for the lowland breed. Along with data for genetic evaluation and a mechanism to identify elite individuals, these initiatives provide a platform on which to demonstrate the principles of genetic improvement and to exchange knowledge with farmers.

The hill sheep data program (HSDP) is an initiative designed to address the data and demonstration needs of the hill sheep breeds and the sector. It will be formed by bringing hill sheep flocks (ram breeder and commercial) into a formal program of data recording and engagement. Ideally, a significant proportion of the HSDP flocks will be from hill ram groups that will, in time, make up the core flock book (recording parentage/ pedigree and data) for the respective breeds. The HSDP will also bring together a core set of breeders/ flocks that will fulfil a role, much like the CPT has for the lowland breeds, in demonstrating the principles of data recording, genetic merit, and genetic improvement.

Given the challenges in generating pedigree by manual ewe-lamb matching, genotyping will be used to generate knowledge of the relationships among animals. In practice, these HSDP flocks will therefore generate the reference population data for the respective breed, underpinning a genomic evaluation.

The HSDP is proposed at an initial scale that would result in 15% of a breeds' annual ram requirements coming from the HSDP, for the major hill breeds, including Mayo Connemara, Cheviot (including North Country), Perth, Dingle Scotch, Lanark, and Swaledale. Minor breed (Herdwick, Rough Fell, and South County Cheviots) can be added if interest and demand grow.

Table 1 present the estimated proportion and number of ewes in each of the major hill sheep breeds, along with the target number of HSDP ewes required to deliver 15% of the annual ram requirements for the breed in the initial years of the breeding program. The parameters used to define the number of HSDP ewes, by breed, are a ewe to ram ratio (40:1), average working years for breeding rams (3.1; Appendix 1: Hill sheep farmer survey and industry consultation), the proportion of annual ram requirement coming from the scheme (15%), the proportion of rams sold for breeding (20%), and the number of lambs weaned per ewe lambing (1). Target ewe numbers within the program are therefore 2,900, 2,400, 2,100, 1,200, 900, and 500 for Mayo Connemara, Perth, Cheviot, Scotch Dingle, Lanark, and Swaledale, respectively.

Table 1: Estimated proportion and number of ewes in each of the major hill sheep breeds, along with parameters used to define the number of ewes in the HSDP, by breed, required to deliver 15% of the annual ram requirements for the breed.

Parameter	Total	Mayo Connemara (MC)	Perth (PR)	Cheviot (incl. North Country) (CH)	Dingle Scotch (DS)	Lanark (LN)	Swaledale (SD)
Proportion of commercial hill ewe flock	1	0.29	0.24	0.21	0.12	0.09	0.05
Number of mountain ewes	830,378	240,810	199,291	174,379	99,645	74,734	41,519
Total annual ram requirement	20,759	6,020	4,982	4,359	2,491	1,868	1,038
New annual ram requirement	6,697	1,942	1,607	1,406	804	603	335
Number of rams sold for breeding from the scheme	1,004	291	241	211	121	90	50
Number of rams weaned from the scheme	5,022	1,457	1,205	1,055	603	452	251
Number of lambs weaned from the scheme	10,045	2,913	2,411	2,109	1,205	904	502
Number of HSDP ewes	**10,045**	**2,913**	**2,411**	**2,109**	**1,205**	**904**	**502**

Selecting flocks

The required number of ewes is greater than those present in the hill ram group farmers (for example, according to Sheep Ireland data: Mayo Connemara – 17 Flocks with 1,400 breeding ewes and Donegal Cheviots – 11 flocks with 650 breeding ewes). This means that Sheep Ireland will need to engage additional flocks to be part of the scheme, to source the full complement of ewes for each breed. New flocks will need to be engaged to secure ewes for the HSDP in Perth, Scotch Dingle, Lanark, and Swaledale breeds. Sourcing larger flocks would make for easier program management and simpler logistics. The selection criteria for flocks to partake in HSDP are outlined below.

- Ideally, the flock would be a ram breeding flock included in hill ram groups, noting that there likely needs to be flocks sourced that do not currently sell rams but are bigger.
- All ewes to be tagged and DNA sampled for genotyping.
- All ewes must be pregnancy scanned for number of lambs and foetal age.
- All breeding rams used on the flock must be genotyped.
- Ideally, all lambs must be tagged and DNA sampled for genotyping (including tagging/ sampling dead lambs) at or near birth, noting that for some flocks tagging at weaning might be required.
- Male offspring left entire until data recording and genomic evaluation/ selection completed.
- The flock must be run in an environment that reflects commercial hill sheep farming conditions, as much as possible.

If possible, Sheep Ireland could include some flocks where both hill and lowland rams are used. To establish the HSDP as quickly as possible, and to deliver enough data for genomic evaluation, Sheep Ireland should aim to recruit the required number of flock/ ewes over a period of 3 years.

Recommendation 1: Sheep Ireland should source 2,900, 2,400, 2,100, 1,200, 900, and 500 ewes for Mayo Connemara, Perth, Cheviot, Scotch Dingle, Lanark, and Swaledale, respectively, to join the HSDP, where these flock will generate data on important traits for genetic evaluation and constitute the reference population for the respective breeds.

Recommendation 2: Sheep Ireland should aim to recruit these flocks over a period of 3 years, as buy-in builds and to manage the workload for Sheep Ireland.

Central Progeny Test

Central progeny test structures provide several benefits to a genetic improvement program, including 1) the creation of connectedness between flocks and breeds that would otherwise not have the data structure required to compare animals/ breeds, 2) as a resource to generate data on hard to measure or expensive to record traits, and 3) as a centrepiece for demonstration of the principles of data recording, genetic merit, and genetic improvement.

The most pressing need for the hill sheep sector, in the context of genetic improvement, is parentage data and core breeding objective trait data (weight, fertility, functionality). The recommended HSDP is designed to create this data. In the context of point 1 above, it is more important at this stage to create information that allows for comparison of genetic merit within breed and across flock than it is to create information for across breed comparison. Focusing on within breed also simplifies information and messaging in the early stages of adoption. For point 2, the early breeding objective for the hill sheep sector is not likely to include novel hard, or expensive, to measure traits such as feed intake or methane emissions, so a case can't yet be made for a CPT to deliver this outcome. The recommended HSDP can provide a demonstration resource for hill sheep farmers.

Practically, delivering a CPT for the hill sector would be difficult and expensive to do it under conditions that represent true hill conditions. The investment of resources is better placed in the HSDP at this early stage of development of the hill sheep genetic improvement program.

Recommendation 3: Sheep Ireland should not prioritise the development of a hill sheep sector CPT at this stage in the genetic improvement program and should instead focus on delivering within breed evaluations via the proposed HSDP structure.

Trait recording

Data from a survey conducted by Sheep Ireland (Appendix 1: Hill sheep farmer survey and industry consultation) suggests that the following 7 traits are important, listed in order of most selected as biggest issues/ challenges that are impacting flock performance and/ or profitability, to hill sheep farmers: lamb growth rate, lamb survival, ewe mouths, ewe longevity, barrenness, scanning rate (too low), and ewe mature weight. Sheep Ireland has the systems in place to record (and evaluate) most of these traits. Data from further industry consultation supports this trait listing (Appendix 1: Hill sheep farmer survey and industry consultation).

With the goal of recording data in an environment that reflects commercial hill sheep farming conditions, it is likely that for some HSDP flocks it will not be practical to tag/ DNA sample (live and dead) lambs at or near birth, to establish parentage. For these flocks, foetal aging should be recorded at pregnancy scanning to establish birth date estimates, with dead lamb records 'created' in the database based on absence at weaning and pregnancy scan data for birth and rearing rank data. Capturing birth date and birth/ rearing rank data is essential in estimating genetic merit for direct and maternal growth rate. This data will also inform estimates of direct and maternal lamb survival. For dead single-born lambs (not tagged), the data on direct lamb survival attributable to the sire will be lost (because there wil be no lamb to match to a sire). Through pregnancy scanning results, dead lambs will be attributable to dams, for maternal lamb survival estimates. Lamb vigour could also be an indicator of lamb survival. For flocks tagging at birth, a lamb vigour score should be recorded. Given most hill sheep farmers sell lambs into the store market at weaning, selection for growth should target the weaning weight trait. It is unlikely to be practical to bring in ewes from the hill pre-weaning to record 40-day weight. As such a maternal weaning weight trait is suitable for hill sheep genetic improvement.

Ewe longevity has been identified as an important trait by hill sheep farmers, and the main reasons for ewes being culled from the flock, listed in order of most selected, were mouths, age, mastitis, condition score, and prolapse (Appendix 1: Hill sheep farmer survey and industry consultation). Genetic evaluation for ewe longevity is difficult, because the phenotype is recorded late in the life of the ewe. There is also some potential for confounding between estimates of genetic merit for index traits and ewes leaving the flock (although this is unlikely to be an issue in the short- to medium-term). A way to increase ewe longevity is to record performance for the underlying commercial traits that contribute to ewes being culled from the flock early in life. Mouth score and mastitis should be recorded when the sheep are in for weaning. Ewe body condition score (BCS) and ewe mature weight should also be recorded at pregnancy scanning, along with barren ewes.

It is important to record ewe weight, as carrying heavier ewes has a cost and selection for early growth will impact ewe mature weight. Recording and evaluating ewe mature weight (and including it in the breeding objective and selection indexes) ensures that increases in ewe mature weight, linked to selection for growth to weaning, are managed and understood.

In lowland breed genetic improvement, ultrasound scanning is used to generate data and estimate genetic merit for muscle and fat depth, and carcase conformation and fat score in the breeding objective. With lambs sold at weaning, and payment at weaning largely linked to animal size/ weight, there is relatively little justification for ultrasound scanning animals for muscle at fat depth in the hill sheep sector. There are also challenges, based on a small research dataset, in capturing phenotypic variation in muscle and fat depth in hill sheep at the weaning, when commercial animals are sold (Appendix 3: Hill sheep ultrasound muscle and fat data analysis). However, it is important to understand the level of genetic variation for ultrasound fat and muscle traits and, therefore, the potential to select for these traits in the hill breed population. In particular, it is important to understand the genetic correlation between muscle and fat depth traits and BCS, so that ultrasound traits can ab used as early predictors of BCS and so that appropriate selection pressure can be applied to each of these traits in the breeding objective. In the future, with selection for muscle and fat depth, there is potential to create a market and price premiums for lambs with superior carcass conformation and carcass fat. Based on the reported heritability for ultrasound muscle and fat depth, approximately 1,200 ultrasound records would be required for accurate estimation of the genetic parameters of interest.

In the absence of a formal hill sheep breeding objective, and based on data collected from hill sheep farmers and industry consultation, the focus in the HSDP should be on recording the following traits:

- Pregnancy scanning litter size
- Foetal aging (potentially a subset of flocks)
- Number of lambs born (litter size)
- Lamb survival (dead lambs recorded directly or based on the difference between scanned litter size and lambs matched back to the ewe via genotypes)
- Lamb vigour score (for those tagging at birth)
- Weaning weight
- Ewe body condition score
- Ewe mouth score

- Mastitis incidence (as culling reason)
- Lameness/ foot score (as culling reason)
- Barrenness (as culling reason)
- Ewe mature weight
- Ultrasound muscle and fat depth (on a trial basis)

Recommendation 4: HSDP flocks should be encouraged to tag and DNA sample all lambs (including tagging/ sampling dead lambs) at or near birth.

Recommendation 5: Sheep Ireland should focus on recording the core set of traits that target robustness in conditions in which hill sheep farmers are operating: number of lambs born, ewe body condition score, ewe mouth score, mastitis incidence, lameness/ foot score, barrenness, and ewe mature weight (maintaining ewes in a challenging environment) and lamb survival, lamb vigour score, and weaning weight (selling lambs at weaning).

Recommendation 6: Sheep Ireland should visit HSDP flocks at pregnancy scanning and weaning, to capture the required data.

Recommendation 7: Ultrasound muscle and fat scanning should be assessed, through a trial to collect 1,200 records, to determine the potential to select for muscle and fat depth in weaned lambs, and as a predictor of ewe BCS.

Genetic connectedness

To ensure a data structure suitable for across flock genetic evaluations, animals with common genetic relationships need to be recorded across flocks. As a starting point, the initial genotypes collected from breeding ewes within the HSDP should be assessed to determine the level of genetic connectedness (genomic relationships) across flocks. In the absence of sufficient connectedness, ram sharing, ewe swapping, or artificial insemination initiatives could be implemented in the HSDP to achieve sufficient connectedness. There are some practical and financial challenges associated with these approaches. For example, sharing rams creates connectedness but there are challenges if flocks are small and few rams in total are used, meaning there isn't enough "space" for linkage rams. Swapping ewes at mating carries practical and, potentially, animal health challenges, while AI is expensive. Sheep Ireland should take an open approach to creating linkage and offer to HSDP flocks the opportunity to share rams or swap ewes in the first instance.

Recommendation 8: Sheep Ireland should assess the level of genomic relationships (connectedness) across the HSDP populations. In the absence of sufficient connectedness, Sheep Ireland should take an open approach to creating genetic connectedness and offer to HSDP members flocks the opportunity to share rams or swap ewes in the first instance, with AI used only if linkage can't be created in other ways.

Genetic evaluation

Based on the data provided by Sheep Ireland to populate Table 2, Sheep Ireland has genetic evaluations available for all hill sheep traits of interest, except for ewe mouth score. Variance component estimation, to calculate heritability and genetic and phenotype variances/ covariances, and a genetic evaluation should be developed for hill sheep breeds for this trait, when enough data becomes available.

A ewe mouth trait should be defined as the proportion of correct, broken, undershot, and overshot categories, if data permits, or proportion of the correct category and an aggregate of incorrect categories.

Variance component estimation, to calculate heritability and variances/ covariances, should be conducted for existing Sheep Ireland traits that will be common to hill and lowland breeding objectives using hill breed data only, as well as with lowland and hill sheep data combined, but treated as separate traits in bivariate analyses. While it is unlikely that hill sheep breeds would have a genetic evaluation distinct from the lowland evaluation, estimating variance components using hill breed data only would provide an understanding of how different the genetic parameters are. This would then guide potential areas of improvement in hill breed recording practices and/ or genetic evaluation model development. Even though there are not necessarily accuracy gains when data from multiple breeds are combined in a genomic evaluation, it generally is not harmful, and greatly simplifies the costs and logistics of undertaking the genetic evaluation.

Recommendation 9: Sheep Ireland should estimate variance components and build a genetic evaluation for ewe mouth score to support the trait needs of the hill sheep sector.

Recommendation 10: Sheep Ireland should estimate variance components for traits common to lowland and hill breeding objectives using hill sheep data only, as well as with lowland and hill sheep data combined, to guide potential areas of improvement in hill sheep recording practices and/ or genetic evaluation model development.

Recommendation 11: Existing Sheep Ireland genetic and genomic evaluation systems should be used for routine hill sheep evaluation, rather than a distinct hill sheep breed genetic evaluation.

Genomic evaluation

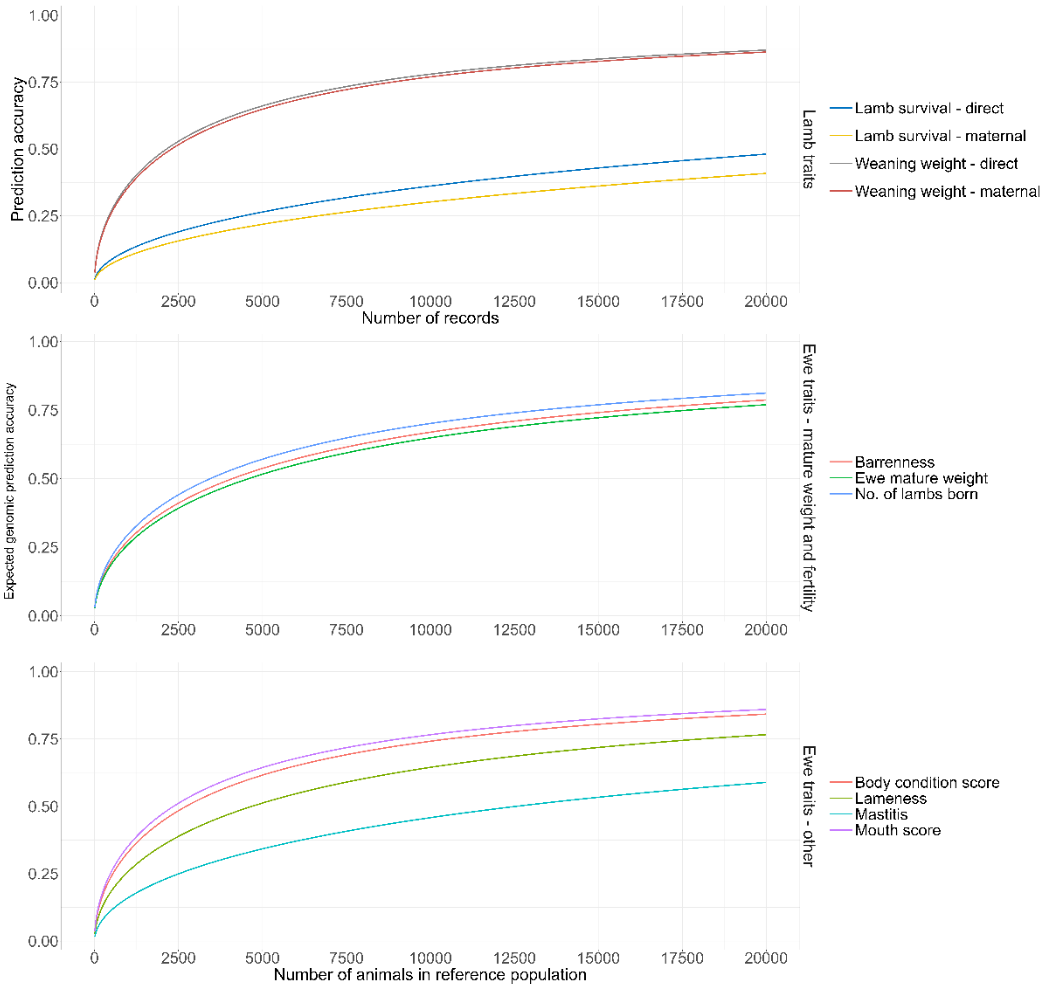
Reference population

Genomic evaluation will underpin the estimates of genetic merit for hill sheep breeds and, as such, a dataset corresponding to a reference population for each breed 'flock book' is required. The factor determining the genomic prediction accuracy is the heritability of the traits under selection. Heritability estimates for traits proposed in the in the Sheep Ireland hill sheep evaluation are presented in Table 2.

Table 2: Heritability estimates for traits proposed in the in the Sheep Ireland hill sheep evaluation (taken from Sheep Ireland or literature).

Trait	h2
Weaning weight	0.31
Maternal weaning weight	0.29
Lamb survival	0.03
Lamb survival maternal	0.02
Ewe mature weight	0.12
Body condition score	0.15
Mouth score[1]	0.13 – 0.39
Lameness score	0.11
Number of lambs born	0.11
Fertility (barrenness)	0.09
Mastitis incidence	0.04

Given the heritability estimates in Table 2, Figure 1 presents the expected genomic prediction accuracy for the suite of traits when different number of individual animals with performance records are included in the reference population.



[1] Mekkawy, W., Roehe, R., Lewis, R.M., Davies, M.H., Bünger, L., Simm, G. and Haresign, W., 2009. Genetic relationship between longevity and objectively or subjectively assessed performance traits in sheep using linear censored models. Journal of Animal Science, 87(11), pp.3482-3489.

Figure 1: Expected genomic prediction accuracy for a suite of traits with different number of individual animals with performance records included in the reference population.

Establishment by breed

A reference population of a size to deliver sufficient prediction accuracy across traits will differ by breed, because the ultimate size of the HSDP differs by breed (Table 1). Taking the number of ewes and lambs in the HSDP with associated performance records (Table 3) and the accuracy of prediction given the number of individual animals with performance records in the reference population (Figure 1), it is possible to estimate the prediction accuracy by trait, by breed, over time (as the number of animals in the HSDP increases). Table 4 presents the estimated genomic prediction accuracy, by breed, for weaning weight, mastitis, and number of lambs born, taken as traits representing the range of heritability/ prediction accuracy, in year 1, 3, and 5 of the HSDP.

Table 3: Number of accumulated records per trait in year 1,3 and 5 of the HSDP.

Trait	Mayo Connemara	Perth	Cheviot (incl. North Country)	Dingle Scotch	Lanark	Swaledale
Weaning weight						
Year 1	961	796	696	398	298	166
Year 3	2913	2411	2109	1205	904	502
Year 5	8739	7233	6327	3615	2712	1506
Lamb survival						
Year 1	1,250	1,034	905	517	388	215
Year 3	3,787	3,134	2,742	1,567	1,175	653
Year 5	11,361	9,403	8,225	4,700	3,526	1,958
Ewe mature weight[1]						
Year 1	769	637	557	318	239	133
Year 3	2330	1929	1687	964	723	402
Year 5	6991	5786	5062	2892	2170	1205
Body condition score, mouth score, lameness score, number of lambs born, barrenness, mastitis[1]						
Year 1	961	796	696	398	298	166
Year 3	2913	2411	2109	1205	904	502
Year 5	8739	7233	6327	3615	2712	1506

[1] The different number of records for ewe mature weight and other ewe traits reflects the assumption that body condition score, mouth score, lameness score, number of lambs born, barrenness, and mastitis can be recorded in hogget ewes, whereas ewe mature weight is recorded from 2 years old.

Table 4: Estimated genomic prediction accuracy, by breed, for weaning weight, mastitis and number of lambs born (NLB), in year 1, 3, and 5 of the HSDP,

Trait	Weaning weight			Mastitis			Number of lambs born		
Breed	Year 1	Year 3	Year 5	Year 1	Year 3	Year 5	Year 1	Year 3	Year 5
Mayo Connemara	0.36	0.56	0.76	0.16	0.27	0.43	0.29	0.47	0.68
Perth	0.33	0.52	0.73	0.14	0.25	0.40	0.27	0.43	0.64
Cheviot (incl. North Country)	0.31	0.50	0.70	0.13	0.23	0.38	0.25	0.41	0.62
Dingle Scotch	0.24	0.40	0.60	0.10	0.18	0.30	0.19	0.32	0.51
Lanark	0.21	0.35	0.54	0.09	0.15	0.26	0.17	0.28	0.46
Swaledale	0.16	0.27	0.44	0.07	0.11	0.20	0.13	0.22	0.36

Based on the data in Table 4, it is reasonable to expect that genomic predictions, with sufficient accuracy, will be available in year 3 for Mayo, Connemara, Perth, and Cheviot, and in year 5 for Scotch Dingle, Lanark, and Swaledale. At both these time points, there is some variation between breeds and across traits (e.g. Lanark breed has a lower prediction accuracy than Mayo Connemara for weaning weight), but this shouldn't hinder release of the genetic merit estimates to HSDP flocks.

Despite accuracies being lower in in earlier years, relative to the suggested release date for each breed, there is potential to release results to HSDP flocks earlier to build understanding and deliver value.

Recommendation 12: Through genotyping ewes and lambs in the HSDP breeds, Sheep Ireland should establish a reference population and release estimate of genetic merit in years 3 (MC, PR, CH) and 5 (DS, LN, SD), but take the opportunity to release earlier if the evaluation outcomes permit.

Alignment with existing Sheep Ireland initiatives

Existing Sheep Ireland infrastructure and initiatives should be used wherever possible, to deliver the hill sheep breed genetic improvement program. This includes the genotyping pipeline, genetic evaluation system, and LambPlus service. Specific messaging may be required for LambPlus, to build engagement by hill sheep breeders and commercial farmers.

Sheep Ireland have an existing CPT for lowland breeds that has delivered significant benefits to the Sheep Ireland genetic evaluation and the Irish sheep industry. The existing CPT can serve a purpose as a demonstration of the principles of data recording, genetic merit, and genetic improvement.

There is opportunity to also use hill rams in the CPT, to create interest among hill sheep breeders, to demonstrate the principles of comparison of rams across breed, and to begin the process of creating genetic connectedness within hill breeds, and between hill breed and lowland breeds. In doing this, it is important that AI is used such that the rams have progeny in the HSDP (ideally in multiple flocks), and in the CPT in the same season. This will be dependent on the capacity of the lowland CPT to use hill breed rams, and willingness of flock owners to retain daughters, in place of lowland breed rams and their progeny.

Recommendation 13: Sheep Ireland should leverage existing infrastructure and initiatives in pursuit of a hill sheep genetic improvement program (e.g., genotyping pipeline, genetic evaluation system, and LambPlus service).

Recommendation 14: Sheep Ireland should use the lowland CPT as a resource to demonstrate the principles of data recording, genetic merit, and genetic improvement to hill ram breeders and farmers and, if capacity allows for it, use hill sheep breed rams in the lowland CPT.

The role of hill ram groups

Within hill ram groups, there is currently no pedigree registration and flock book structure. There is also limited recording of performance data in an organised way, other than by those flocks that have engaged with Sheep Ireland to date. By leveraging the system that Sheep Ireland offers, there is an opportunity for respective hill ram groups to create flock books. In doing so they can interact collectively with Sheep Ireland, leverage value from knowledge and information sharing (as estimates of genetic merit are generated by Sheep Ireland), and organise breeding and selection initiatives (e.g. ram sharing and sales).

Hill ram groups will remain a key source of improved genetics for the hill sector. Given that, it is important that hill ram group breeders are encouraged to record parentage/ pedigree and performance data. It is essential that the HSDP is seen as a means of increasing the rate of genetic gain, rather than replacing the important role filled by hill ram groups. As much as possible, hill ram group breeders not involved in the HSDP should record the traits identified as important in the hill sector (identified in this report).

Recommendation 15: Sheep Ireland should continue to engage hill ram group breeders, including as part of the HSDP, to sign up to Sheep Ireland and record parentage/ pedigree and performance data, with a goal of creating a 'flock book' structure for the respective breeds.

Breeding objective and selection index

Ultimately, there should be a distinct breeding objective for the hill sheep sector. This breeding objective should include number of lambs born (litter size), weaning weight, ewe body condition score, ewe mouth score, mastitis incidence, lameness/ foot score, barrenness and ewe mature weight.

A distinct breeding objective for the hill sheep sector is driven by the need for traits specific to the hill sector that are not in the current Sheep Ireland replacement index and, likely, different economic weights for traits (common to both indexes) in a hill sheep index. Given the successful uptake of EuroSTARs as a mechanism to display estimate of genetic merit in the lowland breeds, EuroSTARs should also be used for hill sheep breeds.

Recommendation 16: Sheep Ireland should create a hill sheep breeding objective and selection index, incorporating new traits and updating economic weights for existing traits to reflect economic drivers for hill sheep farmers, and implement EuroSTARs as a mechanism to display estimate of genetic merit.

Work package 3: Potential benefits and costs of genetic improvement

Cost modelling

The base cost modelling assumes that the HSDP would be established and sustained for 10 years. During this period, participating flocks are assumed to be supported by Sheep Ireland to generate the required data. Such support covers the costs of genotyping, additional scanning costs associated with determining birth dates via foetal ageing, and data and program management. Costs also include Sheep Ireland labour provided to flocks at key data collection key timepoints (i.e., pregnancy scanning and weaning). A breakdown of the HSDP assumed cost parameters is provided in Appendix 4: HSDP cost calculation parameters.

To determine the accumulation of costs for the HSDP, a 3-year period for sign-up of the required number of ewes was modelled for all breeds (Table 1) (i.e., 33%, 66% and 100% of the ewe requirement signed-up in Year 1, 2 and 3, respectively).

The annual cost of the scheme was generally determined by multiplying the individual cost points by the total number of ewes/ lambs enrolled in the scheme (e.g. genotyping) or incurring the cost item (ultrasound muscle and fat scanning). For genotyping, the cost incurred upon flock sign-up is associated with genotyping all ewes and rams in a flock, as well as all lambs born (both stillborn and live births).

The base model assumes that sufficient genetic connectedness exists within breed or can be achieved through ram/ewe sharing (at no additional cost) and, therefore, there is no use if AI. In the base model, there is no ultrasound scanning for muscle and fat depth and no payment/ incentive paid to flock owners. Sensitivity analysis is used to determine the impact of AI, ultrasound scanning for muscle and fat depth, and incentivisation. The total costs and a breakdown of the nominal costs over a 10-year HSDP is outlined in Table 5, with the accrual of costs over time within the HSDP outlined in Figure 7.

Table 5: Hill Sheep Data Scheme 10-year costs (nominal value).

Parameter	Cost (€)
Genotyping	3,187,622
Labour	405,940
Admin/data management	90,354
Foetal aging scanning	27,610
Total	3,717,525

Benefit modelling

Trait genetic trends

Benefits were calculated based on the estimated genetic trends derived from the HSDP and underlying genomic evaluation. The traits identified as important to hill sheep farmers were lamb growth rate, lamb survival, and ewe longevity, ewe mouths, barrenness, and scanning rate (too low), and ewe mature weight (Appendix 1: Hill sheep farmer survey and industry consultation). Given this suite of traits, benefit modelling was built on improving direct lamb growth to weaning, lamb survival, maternal lamb growth to weaning, a combination of increased reproductive rate and reduced barrenness, ewe longevity, and ewe mature weight. Annual genetic trends in lowland breeds for these traits (from 2015-2024), except for longevity, were used to benchmark the genetic trends in the hill sheep sector. More recent lowland breed genetic trends were used rather than those spanning the period from the beginning of Sheep Ireland. The hill sheep genetic improvement program, and genetic trends, will likely benefit from both the advanced infrastructure that Sheep Ireland has developed and from genomic selection. Two features that were not in place or available to the lowland breeds in the early stages of Sheep Ireland.

The estimated hill breed genetic trends for lamb survival and reproductive rate were reduced relative to the lowland breed trends, by a factor of 0.7 and 0.3, respectively. For lamb survival, this reflects the expected difficulty in generating quality phenotypic datasets in the hill sheep setting, while for reproductive rate, this reflects the likely lower economic value of increased number of lambs born in the hill sheep breeding objective. The expected result for both traits is reduced genetic trends, relative to lowland breeds. A conservative approach has been taken to modelling hill breed genetic trends, with reduced trends also in weaning weight, maternal weaning weight, and ewe mature weight in hill breeds, relative to lowland breeds (Table 6).

Estimated annual trend in PTA for weaning weight, lamb survival, maternal weaning weight, (combined) reproductive rate and barrenness, and ewe mature weight in the hill sheep sector and the observed lowland breed annual PTA trends in the same traits from 2015-2024, are presented in Table 6 (Appendix 5: Lowland sheep genetic trends).

An annual genetic trend in longevity was assumed to be achieved through improvements in ewe robustness (improvements in mouths and body condition score, and reduced barrenness and mastitis). While no genetic trends are available for ewe longevity in the lowland sheep breeds, benchmarking based on published genetic parameters for ewe longevity[2] and trends for other lowland breeding objective traits was used to inform the modelling here. Ewe longevity is reported as a lowly heritable trait (h_2 = 0.06), with genetic trends for lowly heritability traits included in the Irish lowland breeding objective equating to an average annual change of 0.26 genetic standard deviations. Based on the published genetic standard deviation for ewe longevity[2], an assumed annual trend in ewe longevity of 0.03 equates to 0.20 genetic standard deviations per year.

[2] Borg RC, Notter DR, Kott RW. Genetic analysis of ewe stayability and its association with lamb growth and adult production. J Anim Sci. 2009

Table 6: Estimated annual hill breed PTA trend for weaning weight, lamb survival, maternal weaning weight, (combined) reproductive rate and barrenness, and ewe mature weight, the observed annual lowland breed PTA trends in the same traits from 2015-2024, estimated contribution of annual trend in PTA to weight of lamb weaned gain (%), and annual contribution to weight of lamb weaned gain (kg) in the hill sheep sector.

Trait	Estimated annual hill breed PTA trend[1]	Observed annual lowland breed PTA trend (2015-2024)	Contribution to weight of lamb weaned gain (%)	Annual contribution to weight of lamb weaned gain (kg)
Weaning weight	0.179	0.183	49%	0.179
Lamb survival[2]	0.00023	0.00032	1%	0.004
Maternal weaning weight	0.066	0.070	18%	0.066
Reproductive rate, barrenness (combined)[3]	0.0048	0.0183	32%	0.117
Ewe mature weight[4]	0.0206	0.0211	n/a	n/a
Total	-	-	100%	0.366

[1] Estimated annual hill breed PTA trends have been generated based on lowland breed trends, with some adjustments, in the absence of a hill sheep breeding objective. While the genetic trends modelled are achievable, based on lowland breed data, the realised genetic trends in the hill breeds may differ when analyses are based on data available from the HSDP and when selection in based on a hill sheep breeding objective.

2 When converted to weight of lamb weaned, 0.0023 additional lambs surviving per year amounts to 0.005kg of lamb weaning weight (0.00023 * 24kg).

3 When converted to weight of lamb weaned, 0.0048 additional lambs (as a combination of the reproductive rate and barrenness), amounts to 0.115kg (0.0048 * 24).

[4] The impact of ewe mature weight is accounted for though an economic value on ewe mature weight (not through contribution to weaning weight).

In the benefit model, counterfactual annual genetic trends are assumed to be zero for direct growth to weaning, -0.00023 lambs for lamb survival, -0.066kg for maternal weaning weight, -0.0048 lambs for (combined) reproductive rate and barrenness, and -0.03 years for longevity. Current selection practices employed by hill sheep ram breeders are likely to be reasonably accurate for direct growth (high heritability, selection on animal size). However, there is a positive, antagonist genetic correlation between early growth and ewe mature weight (r_g = 0.40). Without recording and managing associated increases in ewe mature weight, any current economic gains resulting from improvement in early growth are likely to be offset by increased costs associated with growing and maintaining heavier ewes. For this reason, the annual genetic trend for direct growth to weaning is assumed to be zero. The economic impact of increasing ewe mature weight is accounted for within the weaning weight counterfactual genetic trend, so a counterfactual for ewe mature weight is not modelled separately. Phenotypic selection for growth, favouring single rather than twin-born animals, is likely to result in deterioration in maternal performance, due to a negative, antagonistic genetic correlation between growth rate and fertility/ reproductive rate (r_g = -0.37). This was observed in Sheep Ireland lowland breeds in the early stages of the genetic improvement program[3]. The counterfactual for maternal traits therefore assumes performance is declining by an equivalent magnitude to the potential trends from genetic improvement under the Sheep Ireland breeding program. It could be argued that natural selection might support improvements in lamb survival and ewe longevity. However, poor inbreeding management is likely to negatively impact fitness and survival of both lambs and ewes, more so than natural selection might improve them.

[3] https://www.dev-icbf.com/wp-content/uploads/2018/12/Amer_20-years-of-ICBF.pdf (slide 21)

Economic values

There is not yet an official breeding objective for the hill sheep sector. As such, the profit realised from genetic improvement was modelled using the contribution of annual trait genetic trends to improvements in weight of lamb weaned and reduced replacement costs, offset by costs associated with genetic trends in ewe mature weight.

Average weight of lamb weaned is 24kg based on average lamb weight of 24kg[4] and weaning rate of 1 lamb per ewe (Sheep Ireland, personal communication). The estimated annual hill breed PTA trends for weaning weight, lamb survival, maternal weaning weight, and (combined) reproductive rate and barrenness would deliver an additional 0.366kg of lamb weaning weight (Table 6) or a 15.25% increase.

The value of increased weight of lamb weaned is based on the average price of a weaned hill lamb and an estimate of the increased marginal cost associated with increased weaning weight. With an assumed future price per kg of weaning weight of €2.80 (Sheep Ireland, personal communication) and cost accounting for 33%[5] of the additional revenue, the value of 1kg of weaning weight is €1.88.

The cost of increased ewe mature weight in the hill sheep sector was calculated using the value of weaning weight calculated above (€1.88), and the ratio of the economic value for ewe mature weight to the economic value for days to slaughter in the lowland breeding objective[6]. The days to slaughter economic value (-€0.39/ day) was first converted to per 1 kg of slaughter live weight (€1.76), assuming a growth rate of 0.221kg/ day. This assumes that 1 kg of weaning weight manifests in 1 kg of live weight at slaughter. Secondly, the economic values for the cull (€0.16), maintenance (-€0.59), and replacement (-€0.09) components of ewe mature weight were weighted to account for the expression of each component on a per flock ewe basis, at 0.15, 1, and 0.2 for cull, maintenance, and replacement, respectively, to give an economic value for ewe mature weight (-€0.58). The hill breeding objective economic value for ewe mature weight was calculated as follows:

Hill sheep ewe mature weight economic value = 1.88 * Y,

where Y is the ratio of the economic value for ewe mature weight to the economic value for days to slaughter in the lowland breeding objective after the adjustments outlined above (-0.33). The value of 1 kg of ewe mature weight was calculated at -€0.62.

For longevity, the profit is modelled as the change in replacement rate and cost of replacement (opportunity cost arising from the sale of a weaned lamb plus feed costs to replacement age) after accounting for the revenue from the cull ewe, associated with a change in longevity. The base replacement rate is calculated at 19.12% (1/ average longevity of 5.23). A change in longevity of +n years changes the replacement rate by 1/ 5.23+n and this

[4] Nolan, T., Hanrahan, J.P. and O'Malley, L., 2003. Integrated hill sheep production systems. Teagasc
[5] https://ahdb.org.uk/lamb-cost-of-production-benchmarks
[6] Relevant lowland breeding objective economic values provided by Dr Nóirín McHugh (by email, dated 18/12/2024)

reduces the number of replacements required. For example, an increase in longevity of 0.06 years would result in a replacement rate of 18.90%, calculated from 1/ 5.23+0.06.

The cost of replacement is calculated at €78.49, based on Teagasc values[7] adjusted for inflation using the Agricultural Price index (conversion of 2009 prices to 2024 prices).

Estimated annual PTA genetic trends (Table 6) were modelled to accrue linearly over a 10-year period in the commercial sector, with the total accrued gain assumed to be expressed as burn in from year 11 (for the given trait/ trait grouping) onwards (Figure 3). The total benefit modelling period was 15 years.

Commercial penetration and trait expression

The economic benefits of genetic trends in the commercial hill sheep sector were assumed to be derived from the mating of four distinct ram cohorts to commercial ewes:

1. Genotyped rams delivered directly from HSDP flocks (HSDP rams),
2. Genotyped rams delivered from non-HSDP flocks (non-HSDP rams),
3. Non-genotyped sons of HSDP rams (HSDP sons), and
4. Non-genotyped sons of non-HSDP rams (non-HSDP sons).

On the basis that HSDP rams (1) are bred from flocks directly involved in providing data to establish genomic evaluations, the commercial progeny of these rams express the full PTA trend benefits (Table 6).

The genotyped non-HSDP rams have breeding values generated from genomic evaluation (in flocks that have genotyped ram candidates) and have been selected to sell for breeding. The progeny of these non-HSDP rams receive 33% of the PTA trend observed in HSDP ram progeny.

Sons of HSDP rams and sons of non-HSDP rams come from breeder flocks using genotyped HSDP and non-HSDP rams (1 and 2, respectively) that sell their sons to commercial farmer. In these breeder flocks, 20% of rams are sold to commercial farmers and the progeny from sons of HSDP rams and sons of non-HSDP rams (3 and 4, respectively) express 50% the trend of the genotyped HSDP and non-HSDP rams (1 and 2, respectively).

Within breed, there are differences in the time at which benefits begin to accumulate, with benefits assumed to begin to accumulate when the genomic evaluation delivers sufficient accuracy (see Table 3 for accuracies by year, by breed). The accumulation of benefits begins in year 3 of the scheme for Mayo Connemara, Perth, and Cheviot (incl. North Country) (large breeds) and year 5 for Dingle Scotch, Lanark, and Swaledale (small breeds), as ram cohorts enter the commercial flock (Figure 2). Annual increases in adoption from inception (% of commercial flock ewes mated to ram cohorts) are assumed to be:

1. 3% for genotyped rams delivered directly from HSDP flocks (HSDP rams), and
2. 4% for genotyped rams delivered from non-HSDP flocks (non-HSDP rams),

[7] https://www.teagasc.ie/media/website/publications/2010/ReplacementPolicyManagement.pdf

Adoption of HSDP sons and non-HSDP sons follow the adoption profiles of HSDP rams and non-HSDP rams, respectively, but with relevant delays and a factor of 0.2 (to account for the proportion of rams are sold to commercial farmers).

At maximum adoption (in year 15), 37.5% of commercial ewes are mated to HSDP rams (sum of the blue segments in year 15 in the large and small breed graphs in Figure 2). To achieve this level of adoption with a fixed number of ewes in the scheme, participating HSDP flocks would need to sell 50% of rams to commercial farmers. The assumption is that the genetic merit of animals in these flocks will be superior to animals in the rest of the industry and, as such, HSDP flocks should be able to sell a higher proportion of their rams (50% versus 20% for non-HSDP ram breeders). At maximum adoption (in year 15), 35% of commercial ewes are mated to genotyped non-HSDP rams (sum of the green segments in year 15 in the large and small breed graphs in Figure 2).

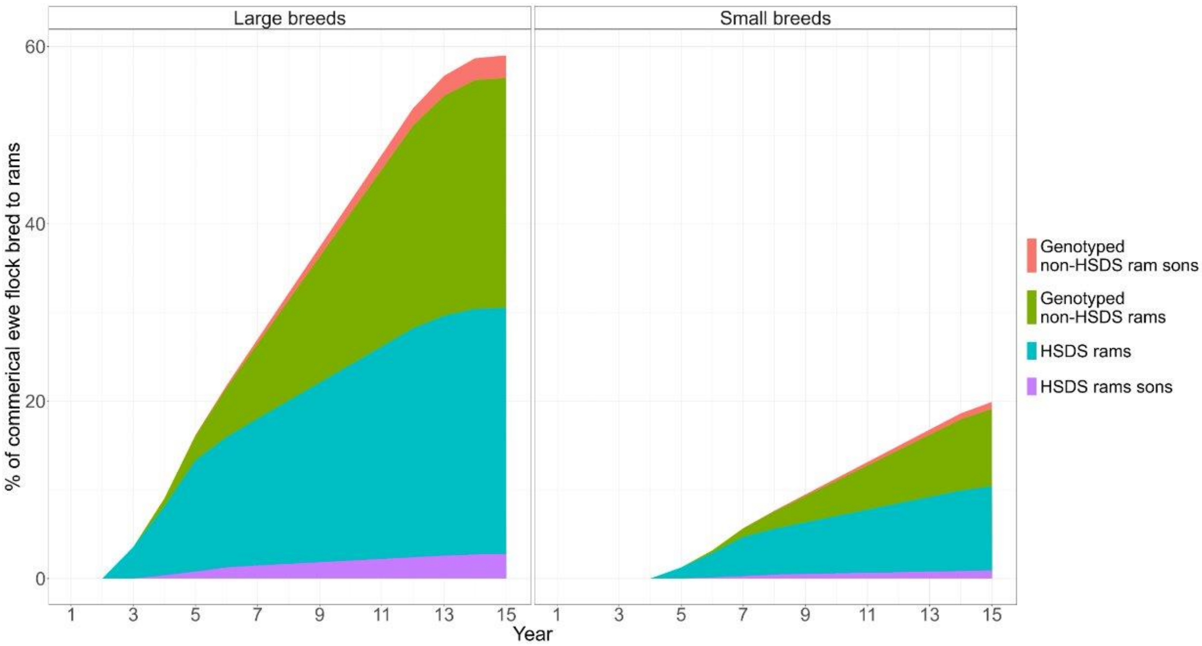


Figure 2: Adoption profiles (% of commercial flock ewes mated to ram cohorts) for large and small breeds over 15 years.

In the genetic trends underpinning the benefits, there are traits expressed by sale lambs (weaning weight, lamb survival) and expressed by replacements females across their productive life (maternal weaning weight, reproductive rate, barrenness, ewe mature weight) and at the end of their productive life (longevity). Benefits therefore accrue in different animals and at different times. Figure 3 presents the framework and timeline for the establishment of the HSDP (sign up and run time) and genomic evaluation release, benefit calculation period, commercial penetration (by ram cohort) and trait expression (by trait grouping), by breed grouping (large and small).

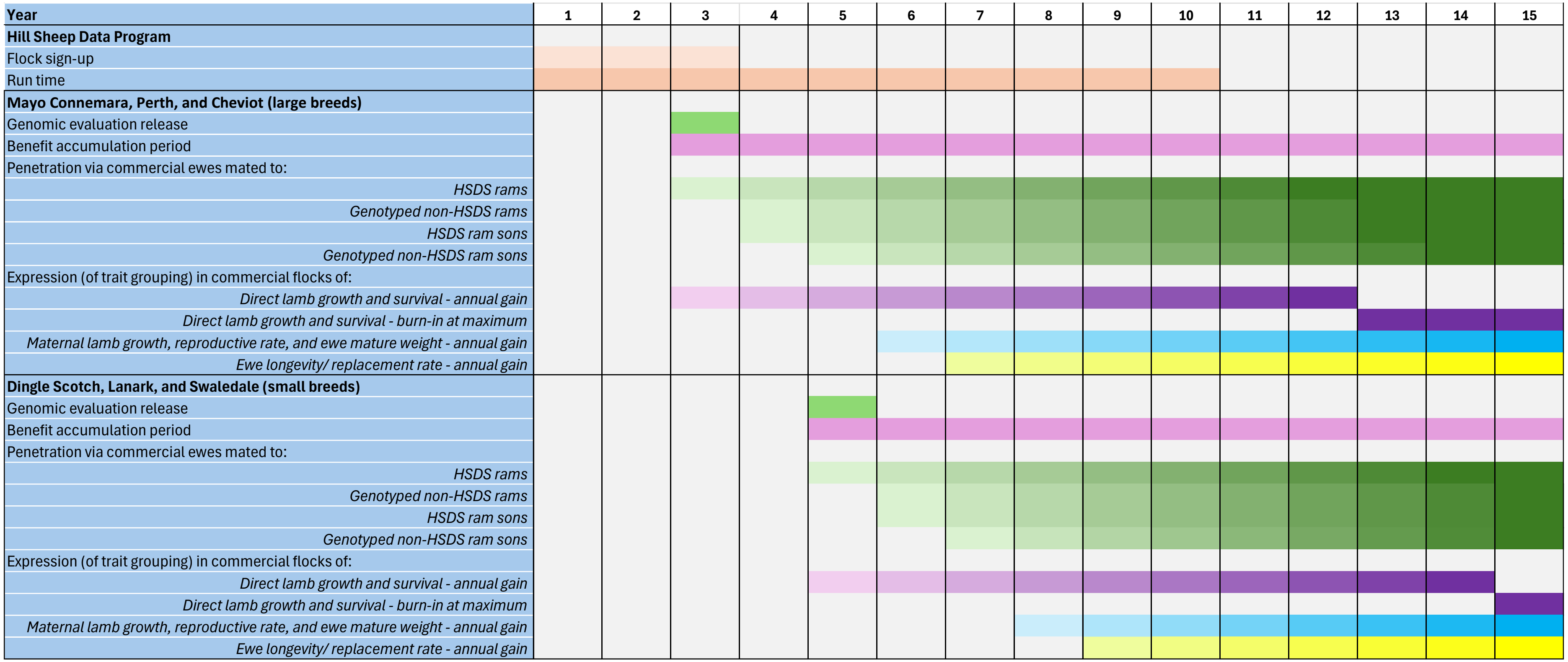


Figure 3: Framework and timeline for the establishment of the HSDP (sign up and run time) and genomic evaluation release, benefit calculation period, commercial penetration (by ram cohort) and trait expression (by trait grouping), by breed grouping (large and small). NB: Within expression in the commercial flock (by trait grouping), each trait trend is assumed to accrue for 10 years from first expression in the commercial sector (e.g., direct lamb growth and survival - annual gain - for large breeds is expressed from year 3 to year 12, inclusive). Beyond year 10, the total accrued gain is assumed expressed as burn in (e.g., for direct lamb growth and survival – burn in - for large breeds is expressed year 13 to year 15). Expression in the commercial sector for some trait groupings (e.g. ewe longevity/ replacement rate - annual gain – for small breeds) extends beyond the 15-year modelling period.

Commercial sector trait and economic trends

Genetic improvement (in kg of weight of lamb weaned), along with economic benefit (€) per ewe joined by ram cohort, in the commercial flock for large and small breeds over 15 years is presented in Figure 4.

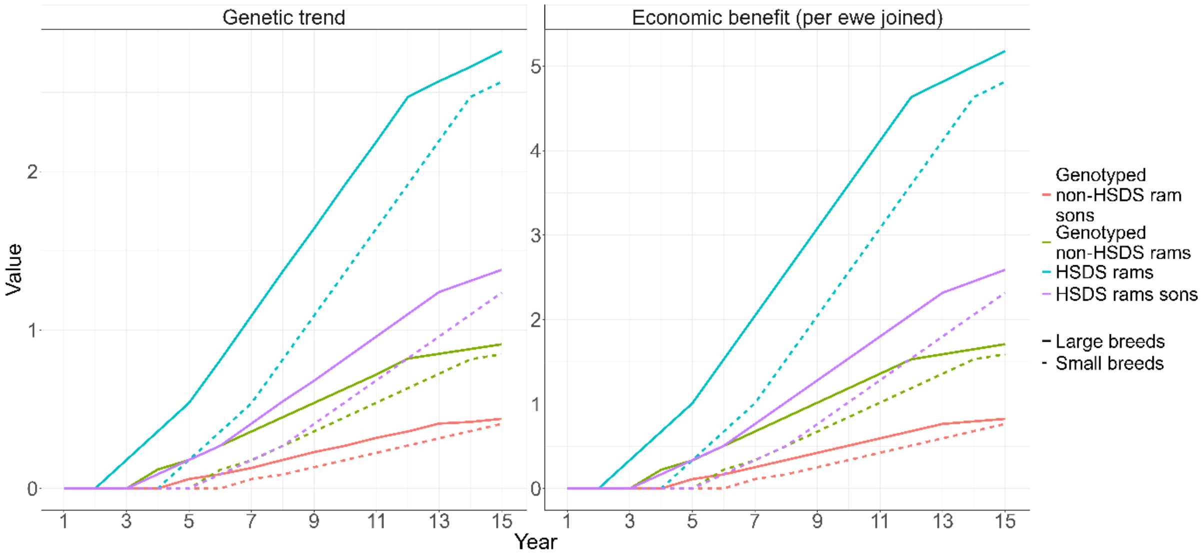


Figure 4 Genetic improvement (in kg of weight of lamb weaned), along with economic benefit (€) per ewe joined by ram cohort, in the commercial flock for large and small breeds over 15 years.

Genetic improvement (in kg of ewe mature weight), along with economic benefit (€) per ewe joined by ram cohort, in the commercial flock for large and small breeds over 15 years is presented in Figure 5.

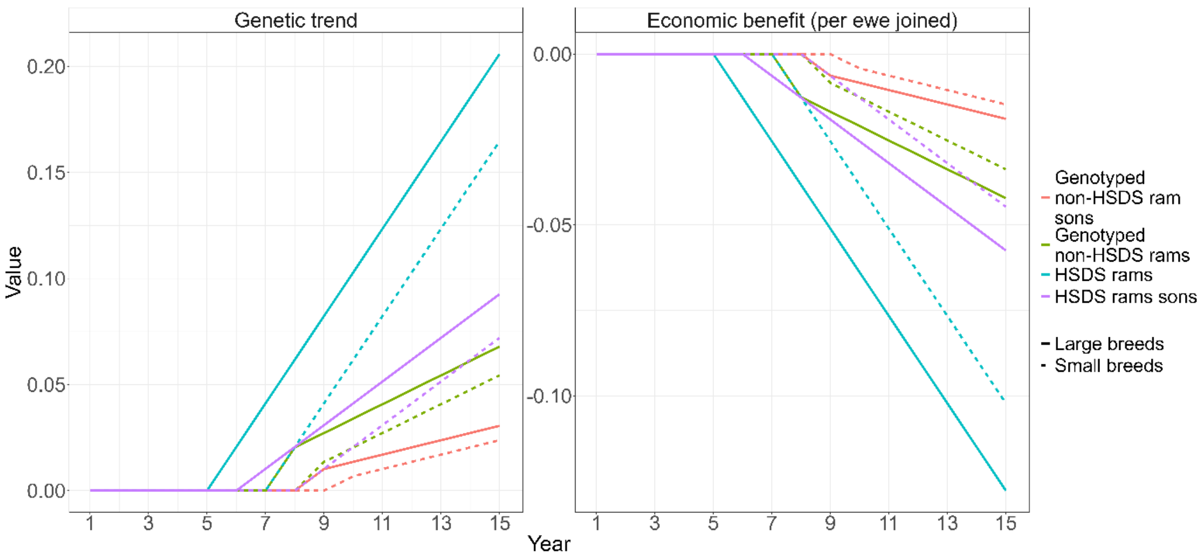


Figure 5: Genetic improvement (in kg of ewe mature weight), along with economic benefit (€) per ewe joined by ram cohort, in the commercial flock for large and small breeds over 15 years.

Genetic improvement (in percentage change in replacement rate), along with economic benefit (€) per ewe joined by ram cohort, in the commercial flock for large and small breeds is presented in Figure 6.

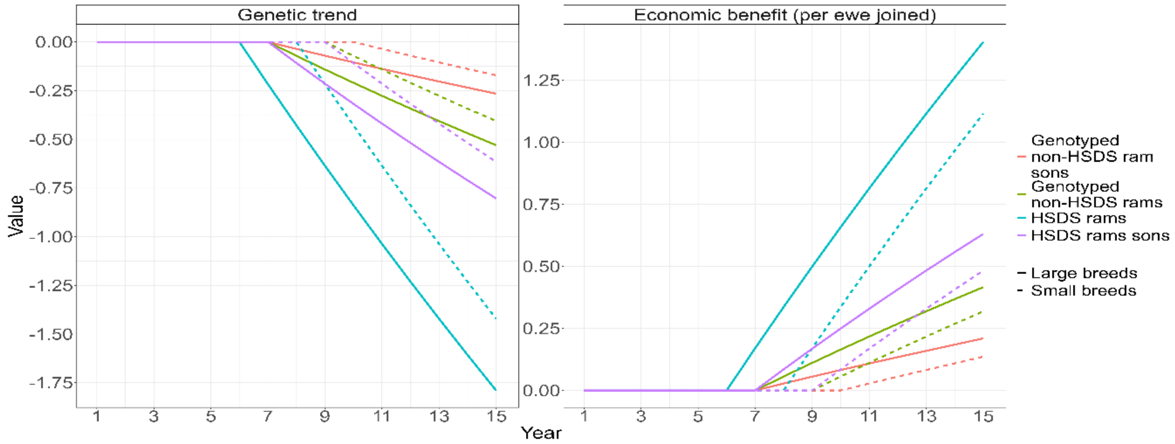


Figure 6: Genetic improvement (in percentage change in replacement rate), along with economic benefit (€ in cost savings for replacements) per ewe joined by ram cohort, in the commercial flock for large and small breeds over 15 years.

Case for investment

Economic outcomes

Based on the outlined assumptions and calculation framework, the HSDP is expected to incur nominal costs of €3,717,525 over 10 years. The annual accrual of (nominal) costs for different components of the HSDP over 10 years is presented in Figure 7.

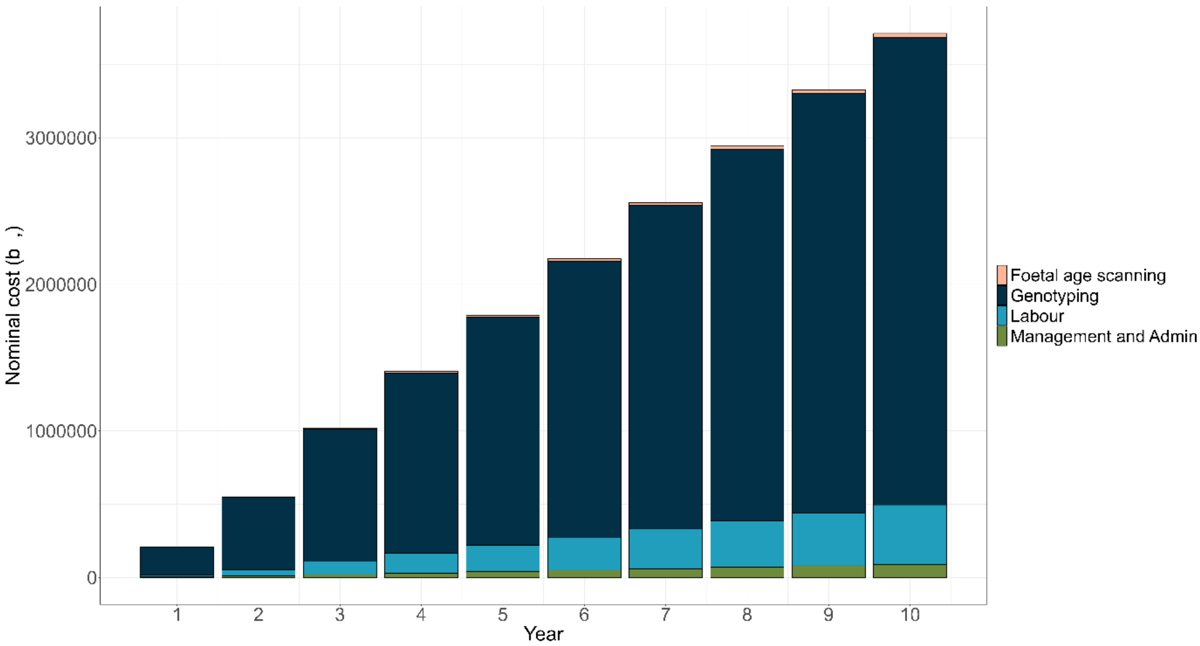


Figure 7: The annual accrual of (nominal) costs for different components of the HSDP over 10 years.

At a discount rate of 5%, the net present value of costs for the HSDP is €2,836,528.

Based on the outlined assumptions and calculation framework, the HSDP is expected to deliver nominal economic benefits of €9,687,962 over 15 years. The annual accrual of (nominal) benefits from weight of lamb weaned and reduced replacement costs, offset by costs associated with genetic trends in ewe mature weight over 15 years is presented in Figure 8.

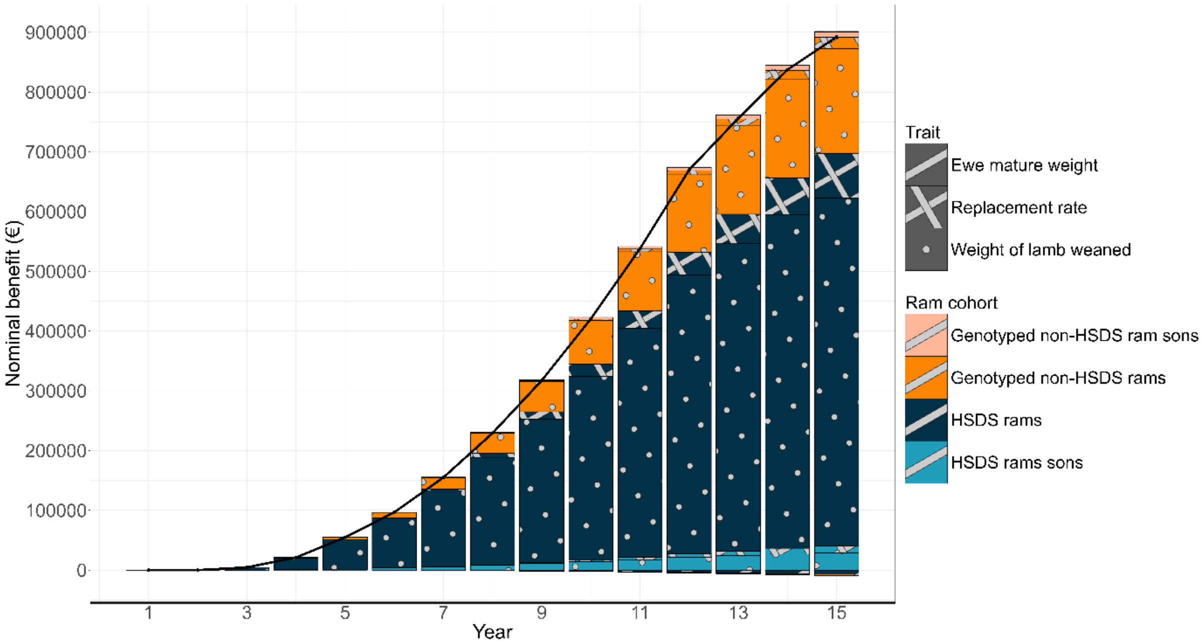


Figure 8: The annual accrual of (nominal) benefits/costs from weight of lamb weaned replacement rate, and ewe mature weight from different ram cohorts (represented by bars), as well as the total annual benefit accrued (represented by the line) over 15 years.

At a discount rate of 5%, the net present value of benefits from the HSDP is €5,429,102.

Taking the discounted costs and benefits, every €1 investment into the HSDP is expected to provide an economic return of €1.91 to the hill sheep sector; a benefit to cost ratio of 1.91:1.

Additional benefits

There is potential for greater economic benefits in the later stages of the modelled genetic improvement program and beyond. Comparing the lowland breed genetic trends for the modelled traits for the periods 2008-2014 and 2015-2024 (Appendix 5: Lowland sheep genetic trends), demonstrates increases in the rate of genetic gain over time. It is realistic to expect the rate of genetic gain will increase further in the future, as Sheep Ireland includes more traits in the hill sheep breed genetic evaluation and leverages advances in technology.

The realisation of genetic improvement in the Irish Hill Sheep sector will provide benefits to the industry beyond just economic benefits. Genetic improvement in key economic traits is expected to improve the economic viability of the hill sheep sector. In turn, increased economic viability will help to ensure the sector remains attractive to future generations and, in doing so, contributes to the maintenance of the fabric of rural society.

Furthermore, ensuring hill flocks are maintained and that the hills continue to be grazed means that associated biodiversity is also protected and maintained. Other benefits provided by the genetic improvement program not captured in the benefit calculation herein include the establishment of flock books, deeper engagement with the hill sector, and the provision of flock-specific performance reports to benchmark and improve overall flock performance.

In all, investment into the HSDP and a hill sheep breed genetic improvement program presents a net-positive economic return over the first 15 years of the program, with potential for greater economic and societal benefits outside those calculated here.

Sensitivity analysis

The costs of, and benefits from, the HSDP are underpinned by various estimated parameters. While these assumptions are informed by industry stakeholder consultation and feedback, as well as available industry data and scientific information, these estimates are subject to change in the future. An analysis was conducted on the sensitivity of the benefit to cost ratio to changes in key input parameters. The sensitivity scenarios were:

1. Annual rate of genetic gain for modelled traits
    a. -10%
    b. +10%
2. Genotyping costs (base cost: €25)
    a. 20% higher cost
    b. 20% lower cost
3. Percentage of ewes bred to AI
    a. 5%
    b. 10%
    c. 15%
4. Weaning weight price (base price: €2.80)
    a. 20% higher price
    b. 20% lower price
5. Ewe replacement cost (base cost: €78.49)
    a. 20% higher cost
    b. 20% lower cost
6. Ultrasound scanning for muscle and fat depth
    a. Collection of 1,200 records to estimate variance components
    b. Routine collection of ultrasound records (e.g., ultrasound scan all lambs weaned from HSDP)
7. Ewe mature weight cost (per kg mature weight) (base cost: -€0.62)
    a. 20% higher cost
    b. 20% lower cost
8. Release year of genomic evaluations (base year of evaluations: year 3 for large breeds and year 5 for small breeds)
    a. -1 year
    b. +1 year

9. Incentive to HSDP flock owners (base incentive €0/ewe) without/ with earlier deployment
    a. €5/ewe with base deployment of genomic evaluations (i.e., year 3 and 5, for large and small breeds, respectively)
    b. €5/ewe with -1 year deployment of genomic evaluations (i.e., year 2 and 4)
    c. €10/ewe with base deployment of genomic evaluations
    d. €10/ewe with -1 year deployment of genomic evaluations
10. Incentive to non-HSDP ram breeding flocks to genotype ram breeding candidates of €9.60/ram breeding candidate (aligns with current incentive provided for ram genotyping), with a requirement to genotype two ram lambs for every ram sold for breeding
    a. Incentive to achieve base assumed adoption of non-HSDP rams (i.e., increasing adoption by 3%/year)
    b. Incentive to achieve increased adoption of non-HSDP rams (i.e., increasing adoption by 4%/year)
11. End adoption of HSDP rams
    a. -10%
    b. +10%
12. End adoption of genotyped non-HSDP rams
    a. -10%
    b. +10%
13. End adoption of HSDP and genotyped non-HSDP rams
    a. -10%
    b. +10%

The benefit to cost ratio for each sensitivity scenario is presented in Table 7.

Across sensitivity scenario, the HSDP and the hill sheep genetic improvement program is predicted to provide a net positive economic return over a 15-year period, with benefit to cost ratios ranging from 1.48:1 to 2.31:1. The lowest benefit to cost ratio of 1.48 was associated with a delay in the deployment of genomic evaluation, with the highest benefit to cost ratio of 2.31 associated with reduced genotyping costs. Providing an incentive of €10/ ewe for HSDP breeders and deploying the genomic evaluation one year earlier in both large and small breeds delivers a ratio of 1.84:1. Where there is a requirement to incentivise (non-HSDP) ram breeders to genotype breeding candidates, to facilitate the assumed adoption in genotyped non-HSDP rams, and if the incentive is paid for the 10-year period of the HSDP, the benefit to cost ratio is 1.77:1. This scenario assumes that ram breeders would not be willing to cover the full cost of genotyping ram candidates to generate genomic breeding values. At marginally higher rates of genetic gain for the traits of interest, the benefit to cost ratio increases to 2.10:1. Should the assumed rate of gain not be achieved (e.g., a 10% reduction in rate of genetic gain), a net positive benefit to cost ratio is still achieved (i.e., 1.72:1).

Table 7: Benefit to cost ratio for the different sensitivity scenarios.

Scenario	Benefit to cost ratio
Base scenario	1.91
Rates of genetic gain	
+10	2.10
-10%	1.72
Genotyping costs	
+20%	1.63
-20%	2.31
Percentage of ewe bred to AI	
5%[1]	1.83
10%	1.76
15%	1.69
Weaning weight price	
+20%	2.28
-20%	1.55
Ewe replacement cost	
+20%	1.93
-20%	1.90
Ultrasound scanning for muscle and fat depth	
For variance components	1.91
Routine collection	1.85
Ewe maintenance cost (per kg mature weight)	
+20%	1.91
-20%	1.92
Deployment of genomic evaluations	
-1 year	2.27
+1 year	1.48
Incentive to HSDP flock owners (€/ewe) without/ with earlier deployment	
€5/ewe with base evaluation deployment	1.71
€5/ewe with -1 year earlier evaluation deployment	2.03
€10/ewe with base evaluation deployment	1.54
€10/ewe with -1 year evaluation deployment	1.84
Incentive (€9.60) for genotyping non-HSDP ram breeding candidates to achieve:	
Base adoption of non-HSDP rams of 3%/year	1.77
Increased adoption of non-HSDP rams of 4%/year	2.15
End adoption of HSDP rams	
-10%	1.79
+10%	2.04
End adoption of genotyped non-HSDP rams	
-10%	1.88
+10%	1.95
End adoption of HSDP and genotyped non-HSDP rams	
-10%	1.75
+10%	2.08

[1] Represents the base scenario assumptions

Roadmap

The HSDP aims to enable a structured and scientific approach to genetic improvement and, in turn, increase the overall productivity and profitability of hill sheep. This roadmap outlines phased implementation, continuous monitoring, and industry collaboration, to ensure the te hill sheep breed genetic improvement program is successful.

Phase 1: Inception (Years 1-3)

Objectives

- Raise awareness and promote the benefits of genetic improvements among flock owners.
- Establish HSDP with flock sign-up, and data collection and genotyping programs.

Actions

- Interact with hill sheep farmers to highlight:
    - The strategy and potential benefits of establishing a breeding program in the hill sheep sector, and
    - Requirements for participating flock owners to routinely record data and genotype animals in their flock.
- Sign-up interested farmers for each breed over three years.
- Support new flocks to the HSDP in establishing a data collection protocol using Sheep Ireland/ LambPlus tools.
- Within a subset of HSDP flocks, conduct a trial collecting ultrasound fat and muscle depth records from weaned lambs, and calculate variance components from the resultant data.
- Utilise genomic records collected early in the HSDP to determine the level genomic connectedness across flocks, and to inform the need for ram/ewe sharing and AI.
- Estimate variance components and build a genetic evaluation for ewe mouth score
- Conduct additional analyses to enable genomic evaluations.
- Publish genomic evaluations for larger hill sheep breeds by year 3 (or earlier if possible).

Phase 2: Routine (Years 4-7)

Objectives

- Robust datasets (performance and genotypes) available for all target hill sheep breeds.
- Upskill ram breeders not in the HSDP on the use of genomic evaluations to select rams for sale.
- Promote the adoption of HSDP and genotyped non-HSDP rams across the hill sheep farmer population.

Actions

- Provide continued support to flock owners in the HSDP (through scheduled visits and LambPlus).
- Publish genetic evaluations for smaller breeds in year 5 (or earlier if possible).

- Calculate genetic trends and validate breeding program benefits (i.e., productive and economic).
- Engage with ram breeders not in the HSDP to utilise genomic evaluations to select rams to sale (e.g., through incentivisation of genotyping).
- Promote the adoption of genetically elite rams to the wider cohort of hill sheep flock owners based on observed data and validation from the HSDP (demonstration).

Phase 3: Burn-in (Years 8-15)

Objectives

- High levels of adoption across the sector.
- High rates of genetic gain.
- A secure future/ viability of the breeding program.

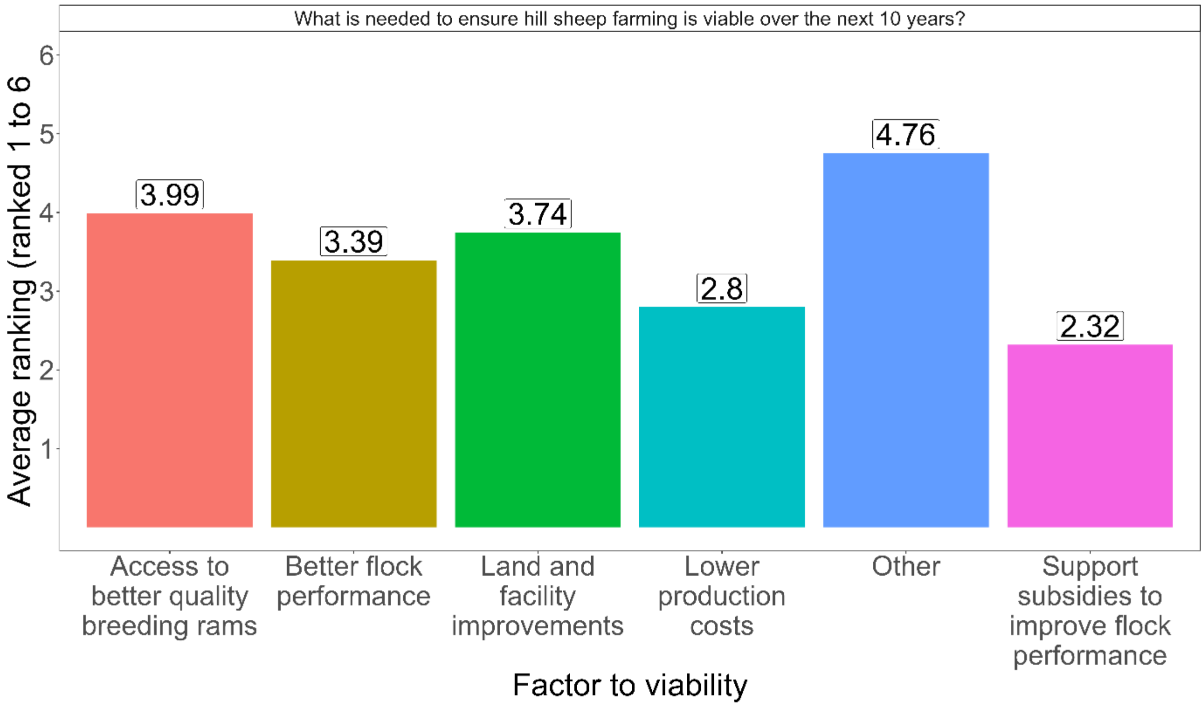
Actions

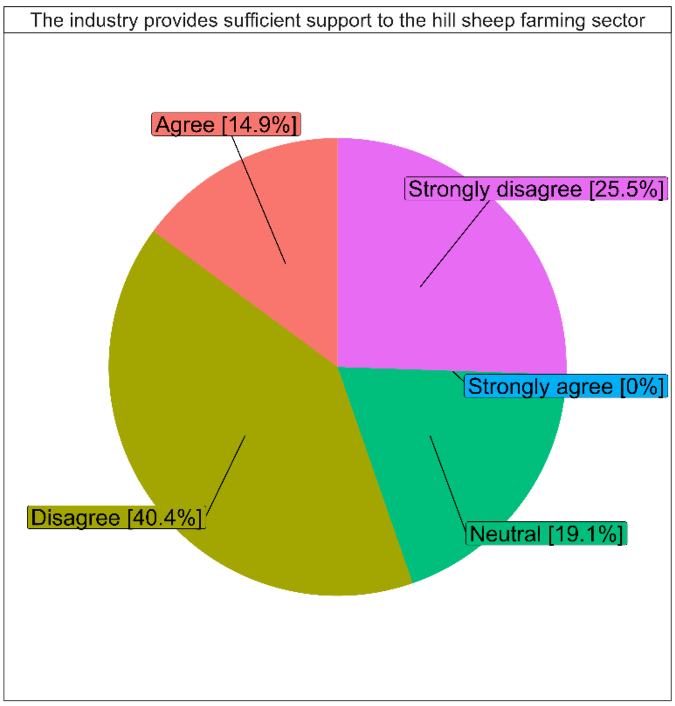
- Continue to track genetic trends and validate breeding program benefits.
- Ensure data collection and genotyping can continue in the absence of the HSDP.
    - Communicate the observed benefits associated with the breeding program and the requirement for data collection to realise the benefits.

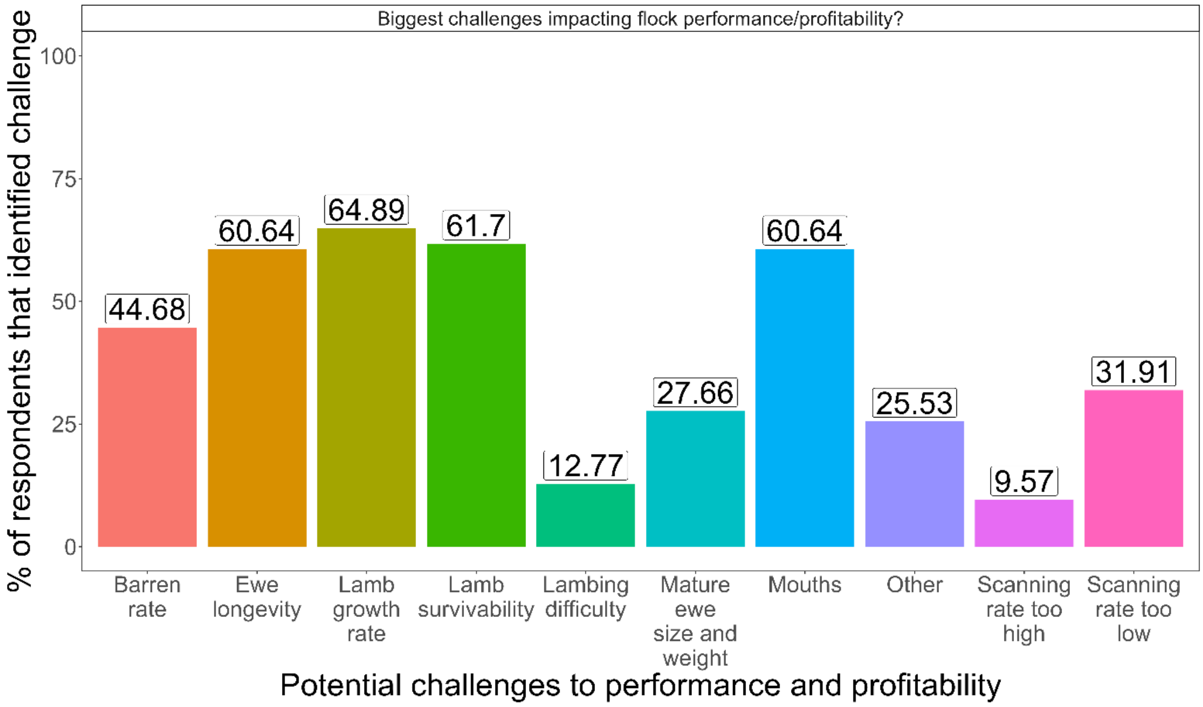
Appendix 1: Hill sheep farmer survey and industry consultation

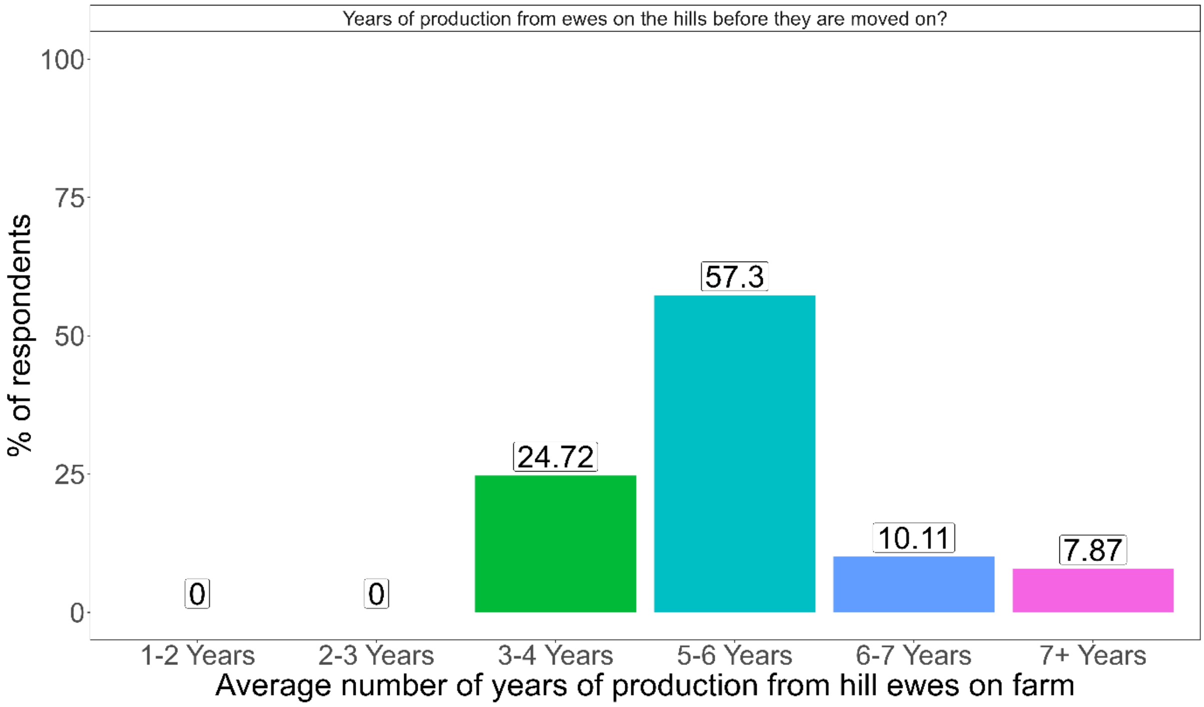
Hill sheep farmer survey results

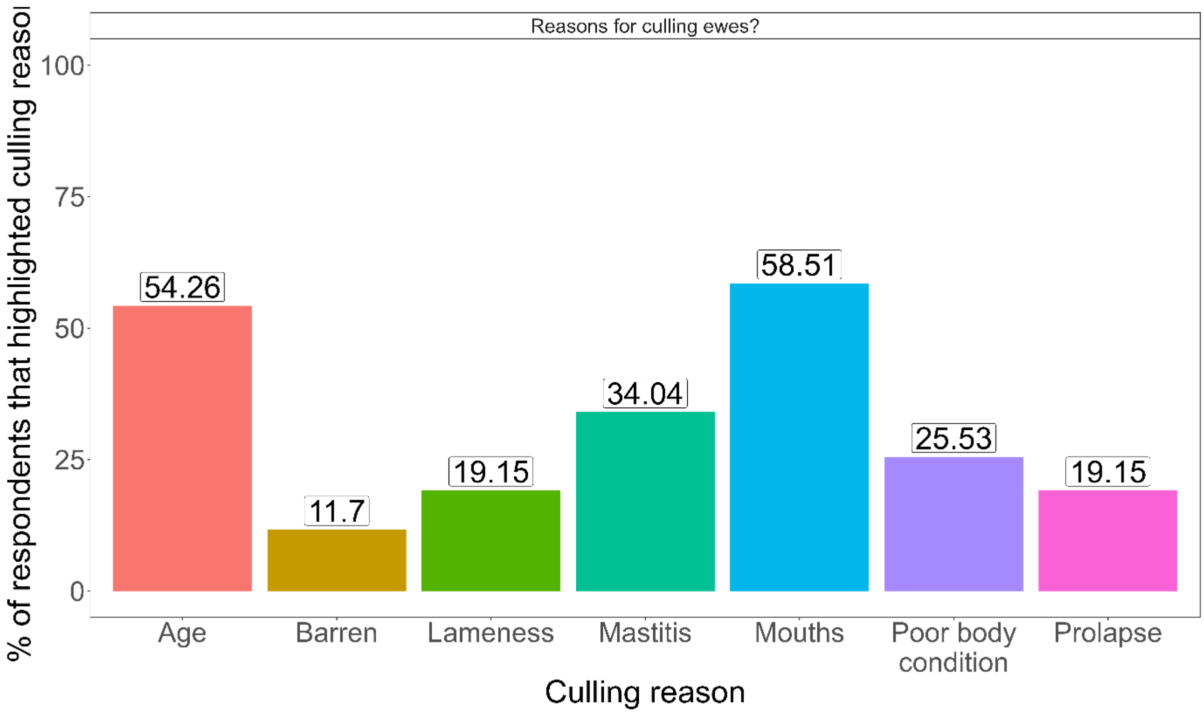
The survey was sent to some 750 farmers, and there were 94 responses. An analysis of those 94 responses is presented below.

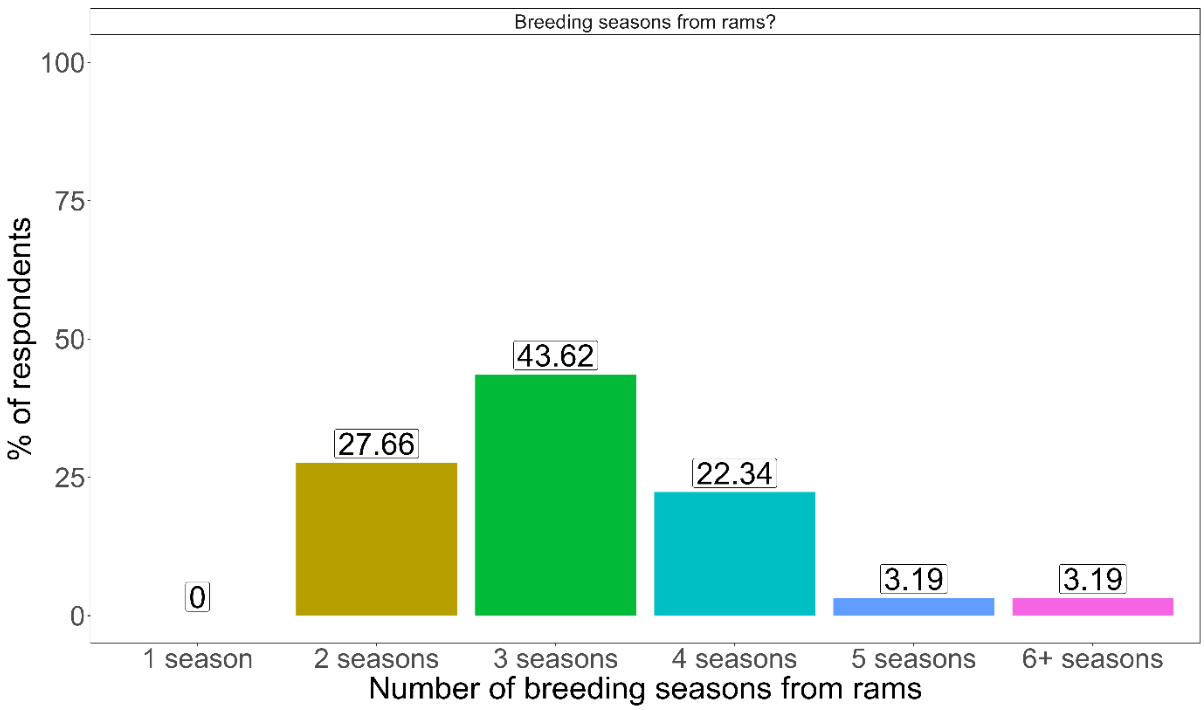


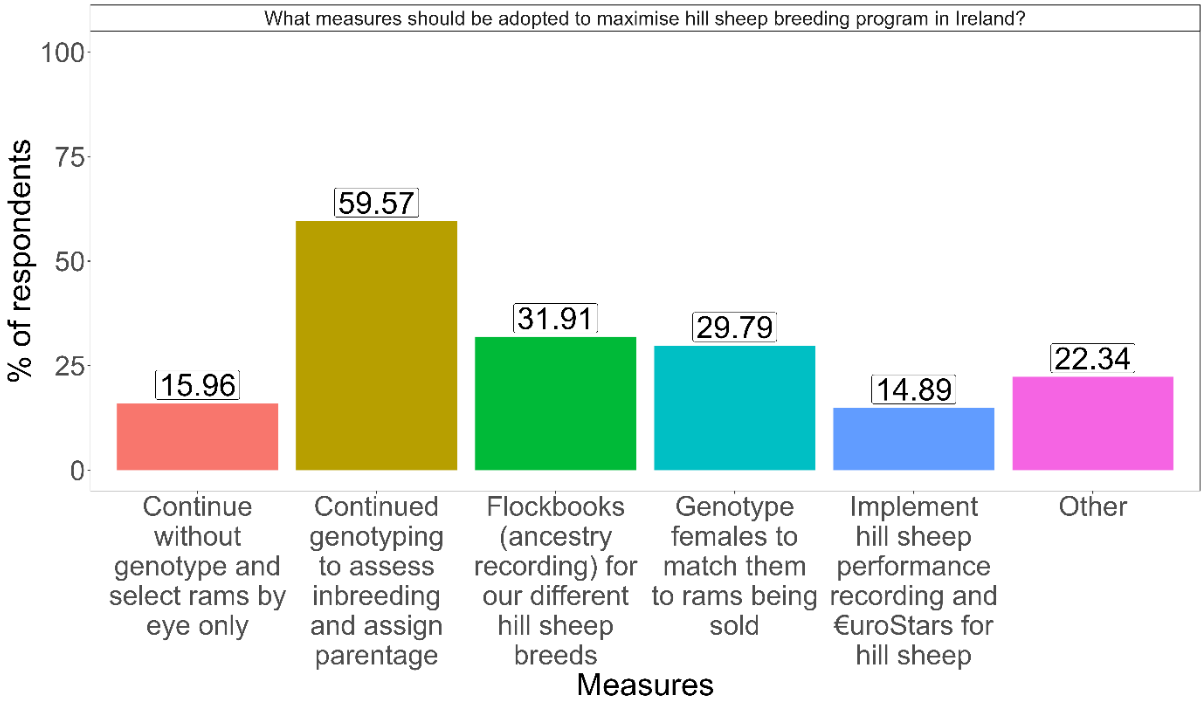


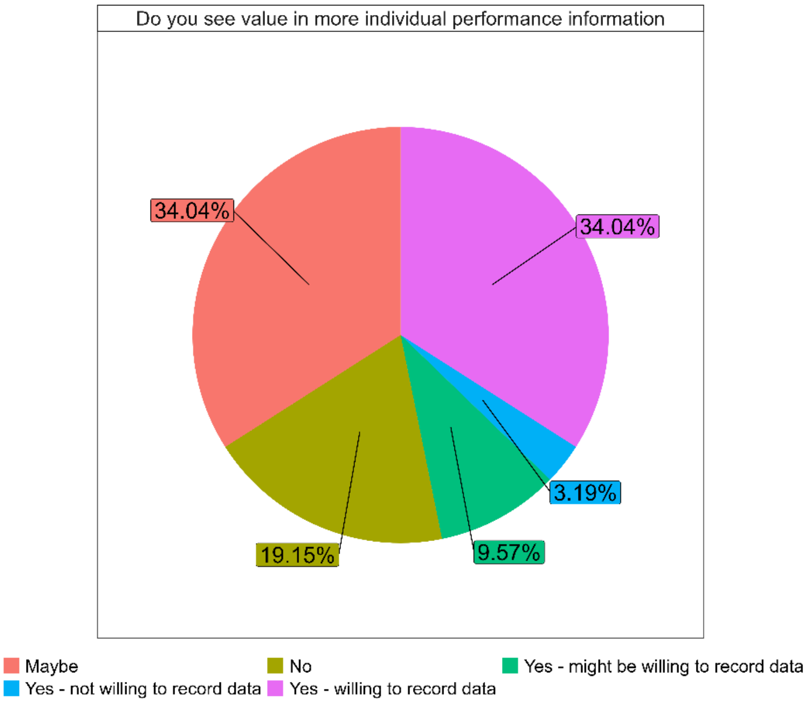

Biggest challenges impacting flock performance/profitability?
% of respondents that identified challenge
100
75
50
25
0
44.68
60.64
64.89
61.7
12.77
27.66
60.64
25.53
9.57
31.91
Barren rate
Ewe longevity
Lamb growth rate
Lamb survivability
Lambing difficulty
Mature ewe size and weight
Mouths
Other
Scanning rate too high
Scanning rate too low
Potential challenges to performance and profitability


Years of production from ewes on the hills before they are moved on?
% of respondents
100
75
50
25
0
0
0
24.72
57.3
10.11
7.87
1-2 Years
2-3 Years
3-4 Years
5-6 Years
6-7 Years
7+ Years
Average number of years of production from hill ewes on farm


Reasons for culling ewes?
% of respondents that highlighted culling reaso
100
75
50
25
0
54.26
11.7
19.15
34.04
58.51
25.53
19.15
Age
Barren
Lameness
Mastitis
Mouths
Poor body condition
Prolapse
Culling reason


Breeding seasons from rams?
% of respondents
100
75
50
25
0
0
27.66
43.62
22.34
3.19
3.19
1 season
2 seasons
3 seasons
4 seasons
5 seasons
6+ seasons
Number of breeding seasons from rams





Industry consultation summary

Across all industry consultation, the Sheep Ireland hill breed genetic improvement program was seen as an important step forward and was very well supported. All groups consulted wished to remain informed as thing progress. The key points taken from industry consultation are detailed below.

- Traits identified as important in for a hill index include ewe longevity, mouths, barren rate, milking ability, health traits, and lameness.

- Grazing adaptability over lamb growth rate was mentioned, highlighting different management styles due to regional variations in hill vegetation.
- Importance was placed on allowing ewes to mature before mating to ensure their development and longevity.
- Lamb growth rate was identified as important but must be balanced with the increased demand on the ewe so that it does not decrease in ewe longevity and/ or increase ewe size too much.
- Suggestions for increasing breeder engagement included star-rated rams, female genotyping, and focus flocks within breeding groups.
- There is a need for support in performance recording and access to bloodlines outside of regions.
- There are challenges unique to the hill sector and profit margins are small for hill lamb. The main issue is small, underweight, lambs often only 15-17kgs, which are less profitable. Increasing lamb weights to 18-20kgs opens larger markets and better margins.
- Closing the gap between live weight at weaning sales and slaughter weight could benefit everyone.
- Teagasc's trials on finishing lambs need wider adoption.
- Lamb weight is more important than quality, in the first instance, in terms of price received.
- There was acknowledgement of the success of the SIS in ram purchases, noting the benefits of having breeding information and scrapie status available to buyers.
- Some concern expressed about the potential mandatory link between EBVs in hill sheep and DAFM schemes, fearing it could force hill farmers to buy unsuitable rams
- In some cases, hill rams are being produced off lowland systems, which affects their adaptability and performance on hill terrains. Regional differences in hill lands mean that rams suitable for one area may not thrive in another.
- Concern expressed over the lack of succession in the hill sector
- The impact of organic payments on hill sheep farming was also noted, with a shift away from lamb production.

Appendix 2: Genotypes by breed

Breed	Genotypes in the Sheep Ireland database
Mayo Connemara	2,568
Cheviot	1,274
Perth	1,231
Dingle Scotch	674
Swaledale	460
Lanark	423
North County Cheviot	114
Herdwick	3
Rough Fell	3
South County Cheviot	4
Total	6,754

Appendix 3: Hill sheep ultrasound muscle and fat data analysis

Parameter	Value
Standard deviation	
Muscle	1.567 mm
Fat depth 1	0.78 mm
Fat depth 2	0.83 mm
Variation explained by scanning weight and age	
Muscle	24.7%
Fat depth 1	6.1%
Fat depth 2	8.5%

Appendix 4: HSDP cost calculation parameters

Parameter (per head)	Value
Genotyping (including tag and postage)	€25
Standard pregnancy scanning cost (including call out fee)	€1.13
Premium for foetal age scanning	25%
Muscle and backfat ultrasound scanning[1]	€1.50
CPT labour costs/ewe/visit	€4.49
HSDP annual number of visits	2
Labour intensity per visit in HSDP flocks relative to CPT flocks	50%
AI cost per ewe	€37
Proportion of ewes in HSDDS bred to AI	0.05
Discount rate	5%

[1] Sheep Ireland, personal communication. this low cost reflects the fact that a call-out fee for muscle and backfat scanning would not be required, with Sheep Ireland already present on-farm at weaning to support the collection of data of ewes and lambs.

Appendix 5: Lowland sheep genetic trends