An Roinn Talmhaíochta,
Bia agus Mara
Department of Agriculture,
Food and the Marine

Food Institutional Research Measure (FIRM)

Final Report

'Gender, Age and Diet Effects on Lamb Meat Flavour and Sensory Quality'
RamLamb

DAFM Project Reference No: 11SF310

Start date: 01-09-2013

End Date: 31-08-2018

Principal Coordinator and Institution: Prof. Frank Monahan, University College Dublin
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Collaborating Research Institutions and Researchers: University College Dublin (Prof. Frank Monahan, Assoc. Prof. Alan Fahey, Assoc. Prof. Nigel Brunton; Teagasc (Prof. Michael Diskin, Dr Paul Allen, Prof. Aidan Moloney); Agri-Food Biosciences Institute (Dr Linda Farmer, Dr Aurelie Aubry).

Please place *one* "x" below in the appropriate area on the research continuum where you feel this project fits

Basic/Fundamental → Applied → Pre Commercial

1	2	3	4 x	5	6	7

Please specify priority area(s) of research this project relates to from the National Prioritisation Research Exercise* (NRPE) report;

Priority Area (s)	**H Food for Health** **I Sustainable Food Production and Processing**

Key words: Lamb, Flavour, Quality, Castration

1. Rationale for Undertaking the Research

There was concern in the Irish lamb meat industry about the marketability of lamb from uncastrated (ram) lambs, arising from a perception among suppliers, buyers and consumers that the sensory quality of such lamb is inferior to castrate lambs. The project set out to establish if there is any scientific evidence to support this perception. The project investigated the influence of different Irish lamb production systems on the sensory quality and acceptability of lamb meat, focussing specifically on the effect of castration of male lambs, their age at slaughter and diet, and interactions between these factors, on lamb meat quality, particularly flavour quality. Controlled lamb feeding trials were conducted in the Republic of Ireland and in Northern Ireland where lambs were assigned to treatments designed to determine the effect of gender, age at slaughter and pre-slaughter diet (and interactions between these factors) on lamb meat quality measured sensorially and instrumentally.

2. Research Approach

Four lamb feeding trials, involving a total of over 600 lambs were conducted, two in the Republic of Ireland (ROI) and two in Northern Ireland (NI). Trial one focused on gender (ram vs castrate), breed (Texel cross, Scottish Blackface) and age (range 7 to 12 months) effects on lamb meat quality in the ROI. Trial two focused on diet (cereal-based concentrate vs grass silage vs pasture) and duration of concentrate feeding on lamb quality in the ROI. Trials three and four were undertaken in NI and focused on gender (ram vs castrate), diet (concentrate, silage, grass, turnip, forage rape) and breed effects on lamb meat quality.

Lamb production data was collected and analysed. Detailed compositional analysis (proximate, fatty acids, flavour volatiles, collagen, texture) of lamb meat samples was undertaken. Sensory analysis of cooked lamb samples, using panels trained in lamb sensory analysis (one in the ROI and one in NI), took place, as did consumer sensory analysis. Large data sets were statistically analyzed.

The main challenge we faced was trying to get “problematic” samples of ram lamb from the industry.

3. Research Achievements/Results

- Results obtained using a trained sensory panel showed small differences due to castration, with rams having higher scores for Intensity of Lamb Aroma, Animal Smell/Farm Smell, Woolly Aroma, Rancid Aroma, Manure/Faecal Aroma, Sweaty Aroma and Off-flavours than castrates. The number of samples considered “extreme” in undesirable flavour attributes was higher among rams than castrates.
- A consumer study revealed that while meat from castrates was higher in Overall Liking, Flavour Liking and Tenderness Liking and lower in Unpleasant Taste/Off-Flavour Intensity than meat from rams, both meats were ‘liked’ by consumers.
- A trained sensory panel found few differences in sensory attributes (apart from small differences in Intensity of Lamb Aroma, Dry Aftertaste and Astringent Aftertaste) in lamb from rams fed different grass silage/concentrate ratios.
- A new rapid method was developed and validated for the determination of branched chain fatty acids (BCFA), known to be important contributors to lamb aroma and flavour.

4. Impact of the Research

The research has brought clarity to the question of the impact of castration on the quality (particularly flavour) of lamb.

4(a) Summary of Research Outcomes

(i) Collaborative links developed during this research

Excellent collaborative links were formed in the course of the project. This was facilitated initially by the formation of a stakeholder advisory group at the start of the project. The stakeholder advisory group included representatives of the meat industry (Meat Industry Ireland), Bord Bia (the Irish Food Board), meat companies and farmers and representatives from ROI and from Northern Ireland. The functions of the advisory group were: (i) to offer their views on the research work of the project as it progressed; (ii) to offer advice on work proposed as the project progressed; (iii) to ensure that the project tasks met stakeholder needs and were not only of academic interest; (iv) to act as a conduit for dissemination of results as they emerged. Publications from the project were collaborative – across, ROI, Northern Ireland and New Zealand.

(ii) Outcomes where new products, technologies and processes were developed and/or adopted

The project did not set out to develop a new product *per se*. Had there been a major difference in the quality of lamb from rams compared to castrates them there would have been a need to investigate strategies/technologies (e.g. animal feeding approaches) to mitigate the problem.

(iii) Outcomes with economic potential

The main finding of economic relevance to the industry is that **ram lamb is not disliked by consumers, although it is liked slightly less than lamb from castrates**. We did not find evidence of a major problem with ram lamb. The output of the project is exploitable by the primary producers on the island of Ireland who deliver product to the Irish and Northern Irish economies, two thirds of which is exported. The Irish food sector needs to target high value markets through increased value-added output (Food Harvest, 2020); it is therefore essential that the quality of food products targeted for these markets be well characterised and underpinned by science. The project outcomes contribute to the scientific characterisation of Irish lamb meat quality.

(iv) Outcomes with national/ policy/social/environmental potential

The research supports the continued production of lamb (from rams or castrates) to meet Irish national and export needs. About 66% of the sheep flocks are in disadvantaged areas and play a significant part in supporting farm families where other farm enterprises are not an option; they are also of significance in maintaining delicate ecological systems in these areas.

4 (b) Summary of Research Outputs

(i) Peer-reviewed publications, International Journal/Book chapters.

Acceptable Format: ***Walsh, D.R., Murphy, O., Cosgrave, J. (2008). Echinococcosis - an international public health issue. Research in Veterinary Science 774, 891-902.***

1. Gravador RS, Brunton NP, Fahey AG, Gkarane V, Claffey NA, Moloney AP, Diskin MG, L. J. Farmer LJ, Allen P and Monahan FJ (2019). Effects of silage to concentrate ratio and duration of feeding on the fatty acid composition of ovine muscle and adipose tissue. Animal (in review).
2. Gkarane V, Allen P, Brunton NP, Gravador RS, Claffey NA, Harrison SM, Diskin MG, Fahey AG, Farmer LJ, Moloney AP and Monahan FJ (2019). Volatile and sensory analysis to discriminate lamb fed different concentrate-based diets. Animal Production Science (in review).

3. Claffey NA, Fahey AG, Gkarane V, Moloney AP and Monahan FJ and Diskin MG. (2018). Effect of breed and castration on production and carcass traits of male lambs following an intensive finishing period. Transl. Anim. Sci. doi: 10.1093/tas/txy070
4. Claffey NA, Fahey AG, Gkarane V, Moloney AP, Monahan FJ, and Diskin MG. (2018). Effect of forage to concentrate ratio and duration of feeding on growth and feed conversion efficiency of male lambs. Transl. Anim. Sci. doi: 10.1093/tas/txy071
5. Gkarane, V., Allen, P., Gravador, R. S., Diskin, M. G., Claffey, N. A., Fahey, A. G., Brunton, N. P., Farmer, L. J., Moloney, A. P., & Monahan, F. J. (2017). Effect of castration and age at slaughter on sensory perception of lamb meat. Small Ruminant Research, 157, 65-74. doi:https://doi.org/10.1016/j.smallrumres.2017.10.011
6. Gkarane, V., Brunton, N. P., Allen, P., Gravador, R. S., Claffey, N. A., Diskin, M. G., Fahey, A. G., Farmer, L. J., Moloney, A. P., & Alcalde, M. J. (2018). Effect of finishing diet and duration on the sensory quality and volatile profile of lamb meat. Food Research International, 115, 54-64. doi:https://doi.org/10.1016/j.foodres.2018.07.063
7. Gkarane, V., Brunton, N. P., Harrison, S. M., Gravador, R. S., Allen, P., Claffey, N. A., Diskin, M. G., Fahey, A. G., Farmer, L. J., Moloney, A. P., & Monahan, F. J. (2018). Effect of castration and age at slaughter on the volatile profile of grilled lamb in two breeds. Journal of Food Science, 83(10), 2466-2477. doi:https://doi.org/10.1111/1750-3841.14337.
8. Gravador R. S., Pace E., Mooney B.R., Jaeger S., Gkarane V., Fahey A.G., Brunton N.P., Claffey N.A., Allen P., Diskin M.G., Moloney A.P., Farmer L.J., Monahan F.J. (2018). A consumer of the effect of castration and slaughter age of lambs on the sensory quality of meat. (2018). Small Ruminant Research. doi.org/10.1016/j.smallrumres.2018.09.011
9. Gravador, R.S., Moloney, A.P., Brunton, N.P., Gkarane, V., Allen, P. Fahey, A.G., Claffey, N. A., Diskin, M.G., Farmer, L.J. Monahan, F.J. (2018). Effects of castration and slaughter age on the fatty acid composition of ovine muscle adipose tissue from two breeds. Small Ruminant Research. 168, 94-100. doi.org/10.1016/j.smallrumres.2018.09.018
10. Gravador, R.S., Harrison, S.M., Monahan, F.J., Gkarane, V., Farmer, L.J. & Brunton, N.P. (2018). Validation of a rapid microwave-assisted extraction method and GC-FID quantification of total branched chain fatty acids in lamb subcutaneous adipose tissue. Journal of Food Science, 84, 80-85. https://onlinelibrary.wiley.com/doi/epdf/10.1111/1750-3841.14410

(ii) Popular non-scientific publications and abstracts including those presented at conferences

1. Diskin, MG., Claffey, N, Hynes, F & Kelly, I (2014). Options for finishing hill lambs. Irish Farmers Journal September 27 2014
2. Diskin, MG., Claffey, N, Hynes, F & Kelly, I (2014). Options for finishing hill lambs. Todays Farm, Volume 25, No 6. Nov-Dec 2014. Pages 24-27
3. Diskin, MG, Claffey, N. & Hynes, F (2015) Options for finishing hill Lambs. Proceedings Teagasc Hill Sheep Conference, Westport, 28th January 2015. Pages 4-10.
4. Diskin, MG, Claffey, N., Hynes, F. Gottstein, M. (2015) Finishing hill lambs. Published by Teagasc. June 2015. 8 pages
5. Gkarane V., Gravador R.S., Claffey N.A., Allen P., Brunton N.P, Fahey A.G, Moloney A.P., Farmer L.J, Disking M.D, Monahan F.J. (2017). Effect of diet on the sensory quality and volatile profile of lamb. In 5th Nursten Flavour Symposium, Belfast, Northern Ireland, June 29-30, 2017.
6. Gravador, R.S., Gkarane, V., Pace, E., Allen, P., Brunton, N.P., Claffey, N.A., Fahey, A.G., Moloney, A.P., Diskin, M.G. & Monahan, F.J. (2017). Castration and age effects on lamb sensory quality: A consumer study. 5th Nursten Symposium. Belfast, Ireland. June 29-30, 2017.
7. McKinnie-Hill, J. S, Monahan, F, Aubrey, A, Hagan, T, Farmer, L, Diskin, MG. Studies on Aromas & Off-flavours in Lamb. 5th Nursten Flavour Symposium, Belfast, 30th June 2017.

8. Claffey, NA., Fahey, AG., Monahan, FJ and MG Diskin MG. (2017). Effect of breed and sex on production and carcass traits of male lamb following an intensive finishing period. Proc BSAS annual conference, Chester 25th April 2017.
9. Gkarane V., Allen P., Gravador R.S., Brunton N.P., Claffey N.A, Fahey A.G., Moloney A.P., Farmer L.J., Alcalde M.J., Diskin M.G., Monahan F.J. (2017). Effect of feeding duration on sensory quality of lamb meat. In Proceedings of the 63rd International Congress of Meat Science and Technology. (Cork, Ireland, 13-18 August 2017).
10. Gravador, R.S., Gkarane, V., Mulligan, J.E., Allen, P., Brunton, N. P., Claffey, N.A., Fahey, A.G., Moloney, A.P., Diskin, M.G. & Monahan, F.J. (2017). Oxidative stability of meat from lambs finished on different concentrate diets. In Proceedings of the 63rd International Congress of Meat Science and Technology. (Cork, Ireland, 13-18 August 2017).
11. McKinnie-Hill, J. S, Aubrey, A., White, A., Hagan, T. D, McRoberts, C., Monahan, F., Farmer, L. J. Studies on off-flavours in lamb. In: Proceedings of 15th Weurman Flavour Research Symposium, Austria, 18th-22nd September 2017.
12. MG Diskin, N Claffey, M Gottstein, F Hynes, C. Lynch, P Creighton, B. Good, I. Kelly, D Costello & B. Garry, F Campion (2016) Finishing Store Lambs on Autumn Pastures and on All-Concentrate Diets. Teagasc Store Lamb Open Day, 15 November 2016. 12 pages. https://www.teagasc.ie/media/website/publications/2016/Store-Lamb-Open-Day-Booklet-Final-14-11-2016.pdf
13. MG Diskin. (2016) Finish store hill lambs. Irish Farmers Journal You tube https://www.youtube.com/watch?v=W8p_8zZZtnw . 8 minutes.
14. Gkarane V., Claffey N., Diskin M.G., Allen P., Fahey A., Gravador R., Moloney A., Brunton N., Monahan F.J. (2017). Is there a difference in the eating quality of lamb from rams compared to castrates? Teagasc Sheep Open Day, Section on Meat Quality and Rumen Function, Athenry, Animal & Grassland Research and Innovation Centre, 21 June, 2017. Proceedings of Teagasc Open Day, pp 114-116.
15. Claffey N., Diskin M.G. Effects of breed and gender on carcass traits and meat quality attributes of male lambs. Teagasc Sheep Open Day, Section on Meat Quality and Rumen Function, Athenry, Animal & Grassland Research and Innovation Centre, 21 June, 2017. Proceedings of Teagasc Open Day, pp 100-106.
16. Gkarane ,V., Brunton, N., Allen, P., Harrison, S.M., Gravador, R.S., Claffey, N.A., Fahey, A.G., Diskin, M.G., Moloney, A.P., Farmer, L.J., Murphy, P., Monahan, F.J. Discrimination of lamb meat from rams fed different concentrate-based rations, In Proceedings of the 64th International Congress of Meat Science and Technology (in press) (Melbourne, Australia, 12-17 August 2018).
17. Gravador, R.S., Casey, C., Gkarane, V., Brunton, N. P., Fahey, A.G., Moloney, A.P., Allen, P., Claffey, N.A., Diskin, M.G., Farmer, L.J., Allen, P. & Monahan, F.J. Consumer acceptability of meat from lambs fed different pre-slaughter diets. (2018). In Proceedings of the 64th International Congress of Meat Science and Technology. (Melbourne, Australia, 12-17 August 2018).
18. Gravador, R.S., Moloney, A.P., Fahey, A.G., Brunton, N. P., Gkarane, V., Allen, P., Claffey, N.A., Diskin, M.G. & Monahan, F.J. (2018). Effect of duration of concentrate feeding on the n-3 PUFA content of lamb. In Proceedings of the British Society of Animal Science. (Dublin, Ireland, 9-13 April 2018).
19. Speers, J., Aubry, A., Hagan, T.D.J., Monahan, F., McRoberts, W.C., White, A. and Farmer, L.J. Studies on Off-Flavours in Lamb. In: Proceedings of the XV Weurman Flavour Research Symposium (Siegmund, B., Leitner, E. Eds.), Graz, September 2017, p347-350.
20. Claffey, N.A., Diskin, M.G., Gkarane, V., Monahan, F.J., Moloney, A.P., & Fahey, A.G. 2018. Effect of breed and sex on selected meat quality traits of Irish lambs. In Proceedings of the British Society of Animal Science. (Dublin, Ireland, 9-13 April 2018).
21. Claffey, N.A., Diskin, M.G., Gkarane, V., Monahan, F.J., Moloney, A.P., & Fahey, A.G. 2018. Meat Quality attributes of Irish Male Lambs. Teagasc TResearch Autumn Publication, Vol.3 24-25.

(iii) National Report

n/a

(iv) Workshops/seminars at which results were presented

1. Monahan, FJ, Diskin, MG et al. RamLamb stakeholder meeting. Teagasc Ashtown, 9 Dec 2013
2. Diskin, MG (2014). Teagasc Mart Event Donegal Town, Presentation on "Finishing Hill Lambs", 21/08/14
3. Diskin, MG (2014). In-Service Training Teagasc, Sheep Advisors, Kildalton. Presentation on "Options for finishing hill lambs". 4th September 2014.
4. 2Diskin, MG (2014). Teagasc Open Day Better Farm, Aclare, Co. Sligo. Presentation on "Finishing Hill Lambs". 9th September 2014.
5. Diskin, MG (2014). Finishing Hill lambs. Teagasc Open Day Better Farm, Westport, Co. Mayo, 11th September 2014
6. Diskin, MG. Claffey, N, Hynes, F & Kelly, I (2014). Options for finishing hill lambs. Open Day for Discussion Groups, Teagasc, 16th September 2014
7. Diskin, M.G. (2014). On-going studies relating to the effects of gender, breed and age on lamb meat quality attributes. IFA and Meat Industry Ireland Representatives, Teagasc Athenry, 23rd October 2014
8. Diskin, M.G. (2014). On-going studies relating to the effects of gender, breed and age on lamb meat quality attributes, Teagasc Sheep Stakeholders Committee, Athenry, 31st October 2014.
9. Diskin, M.G. (2015). Studies relating to the effects of gender, breed and age on lamb meat quality attributes. Presentation to Meat Industry Ireland and Sheep Ireland. Tullamore, Co. Offaly. 21st April 2015.
10. Claffey, N. (2015) Options for finishing store lambs. Sheep 2015. Athenry. 20th June 2015.
11. Diskin, M.G. (2015). Finishing Hill Lambs on Autumn Pastures and on an All Concentrate Diets. Irish Farmers Journal 24th September 2015.
12. Diskin, M.G. (2014). On-going studies relating to the effects of gender, breed and age on lamb meat quality attributes, Teagasc Sheep Stakeholders Committee, Athenry, 22nd April 2016.
13. Diskin MG (2017) Options for hill lambs. Hill Sheep farmers Meeting, Roundstone, Co. Galway. 23rd May 2017.
14. Diskin MG (2017) Up-date on effects of gender on meat quality attributes. IFA Hill Sheep farmer's conference, Maam Cross 23rd May 2017.
15. Diskin MG (2017) Up-date on effects of gender on meat quality attributes. Teagasc Stakeholder Committee, 21st November 2016
16. Diskin MG (2017) Effects of leaving lambs entire on meat quality attributes. Meeting with Meat industry Ireland, Dublin. 13th April 2017
17. Diskin MG (2017) Up-date on effects of gender on meat quality attributes. Teagasc Stakeholder Committee, 8th Dec 2017.
18. Aubry A. (2016) AFBI sheep on farm research update to 12 co research farmers, levy board and CAFRE stakeholders, AFBI Hillsborough. Update on RamLamb production trial. 14 Dec 2016
19. Aubry A (2017) Production performance of ram and castrated hill lambs offered a range of diets. Invited talk at the Sheep Conference organised by Trouw Nutrition, 19 Jan 2017, Ireland(100 attendees)
20. Aubry A (2017) AFBI sheep research programme, including overview of RamLamb project to 12 AFBI board members, AFBI Hillsborough, 1 Feb 2017.
21. Aubry A. (2017) Talk entitled Feed Into Lamb: how to increase feed efficiency in sheep production systems, including RamLamb project, CIEL stakeholder event at AFBI Hillsborough, 28 Feb 2017, 35 attendees.

22. Aubry A (2017) AFBI sheep research programme, including overview of RamLamb project to 4 advisors from Trouw Nutrition at AFBI Hillsborough, 14 March 2017.
23. Aubry A (2017) Poster summarising the Ramlamb project to 300 farmers and advisors attending the National Sheep Association event at Ballymena, 3 July 2017
24. Aubry A (2017) AFBI sheep research programme, including overview of RamLamb project to 5 scientists from SRUC, AFBI Hillsborough, 29 July 2017.
25. Monahan, F; Aubry, A., Farmer, L., Moloney, A., Claffey, N., Diskin, M., Fahey, A., Allen, P., Brunton, N., Gkarane, V., Hagen, T., McKinnie-Hill, J., Gravador, R. (2017) Project Stakeholder meeting. Update on RamLamb project findings, Teagasc, Ashtown, 28 February 2017 (see appendix 1).
26. Speers, J. Causes of off-flavour in lamb, AFBI Food Research Branch "Key Customer Day" – 20 April 2018
27. Monahan, F.J. & Diskin, M.G. A consumer study of the effect of castration and slaughter age on the sensory quality of lamb meat – Teagasc Sheep Open Day, Athenry 7 July 2018.
28. Monahan, F.J. & Diskin, M.G. Consumer acceptability of meat from lambs fed different pre-slaughter diets – Teagasc Sheep Open Day, Athenry 7 July 2018.
29. Monahan, F.J. & Diskin, M.G. Discrimination of lamb meat from rams fed different concentrate-based rations – Teagasc Sheep Open Day, Athenry 7 July 2018.
30. Monahan, FJ. Lamb meat quality – is there a ram effect? All Ireland Meat Science Network Meeting, 28 Feb - 1 March, 2019.
31. Farmer, LJ. Factors affecting lamb meat flavour. All Ireland Meat Science Network Meeting, 28 Feb - 1 March, 2019.

(v) Intellectual Property applications/licences/patents

No IP has arisen from the project.

(vi) Other

Diskin, MG, Claffey, N. Bohan, A (2015) Store lamb finishing calculator.
http://tnet.teagasc.net/sheep/docs/Final_Store_lamb_finishing_calculator_20-07-2015.xlsx

5. Scientists trained by Project

Total Number of PhD theses: **2**

Claffey, N.A. (2018). Gender, Age and Diet Effects on Lamb Meat Quality (submitted May 2018). University College Dublin.
Gkarane, V. (2018). Gender, Age and Diet Effects on Lamb Meat Flavour and Sensory Quality (submitted January 2018). University College Dublin.

Total Number of Masters theses: **0**

6. Permanent Researchers

Institution Name	Number of Permanent staff contributing to project	Total Time contribution (person years)
UCD	3	1.75
Teagasc	5	2.09
AFBI	10	1.12
Total	**18**	**4.96**

7. Researchers Funded by DAFM

Type of Researcher	Number	Total Time contribution (person years)
Post Doctorates/Contract Researchers	4	8.15
PhD students	1	4
Masters students		
Temporary researchers	3	3.7
Other		
Total	**8**	**15.9**

8. Involvement in Agri Food Graduate Development Programme

Name of Postgraduate / contract researcher	Names and Dates of modules attended
n/a	

9. Project Expenditure

Total expenditure of the project:	€816,755
Total Award by DAFM:	€833,482.04
Other sources of funding including benefit in kind and/or cash contribution(specify):	
Teagasc Walsh Fellowship (award 2013058)	€90,666

Breakdown of Total Expenditure

Category	Name Institution 1 UCD	Name Institution 2 Teagasc	Name Institution 3 AFBI	Name Institution 4	Total
Contract staff	25405.47		26959.53		52365.00
Temporary staff			25213.31		25213.31
Post doctorates	168774.46		115008.49		283782.95
Post graduates		87189.84			87189.84
Consumables	24,533.53	74501.02	46,645.52		145680.07
Travel and subsistence	12,864.94	12488.91	8271.33		33625.18
Sub total	231,578.40	174179.77	222098.19		627856.36
Durable equipment	985.48				985.48
Other					
Overheads	69,549.28	50,866.80	67,497.37		187913.45
Total	302,113	225,047	289,596		816,755

10. Leveraging

A Teagasc Walsh Fellowship was awarded to fund the PhD work of Noel Claffey (Award number 2013058).

11. Future Strategies

Outline development plans for the results of the research.

The results of the research have been extensively publicised through stakeholder engagement, publications in the popular press, conference presentations and peer reviewed publications as outlined in section 4b. Further work is required to identify definitively what compounds in lamb are responsible for the differences in flavour quality detected between lamb from rams and castrates.

12. Consent to Publish Final Report on the DAFM Website and/or Through Other Dissemination channels

I consent to this report being made available to the public, through the Department's website and other dissemination channels.

Yes x No ☐

13. Declaration

I declare that the information contained in this final report is complete and true to the best of my knowledge and belief.

Signed: Frank J. Monahan Project Coordinator

Date: 30 July 2019