Estimating the level of disease risk and biosecurity on commercial poultry farms in New Zealand

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Supplementary Information 2. Network graph construction and social network analysis.

In order to calculate a degree centrality score for each of the study farms, several network graphs were constructed from the reported on- and off-farm movement of goods and services. To begin with, bimodal networks were built with nodes representing either a study farm, a transporting company or a group of personnel. Transporting companies were identified from the survey responses with companies responsible for the on- and off-farm movement of either (i) feed, (ii) waste and litter, (iii) live birds and hatching eggs or (iv) any other poultry product. Before constructing the network graphs, the company names were cross-checked for variation and spelling errors to ensure that the same company was not listed multiple times. Where company descriptions were unclear, clarification was sought from PIANZ and/or MPI staff. If single companies had enterprises in multiple locations, each separate location was assigned a unique identification number by name and address so it would appear as a unique node in the network analysis. For the reported movement of personnel, neither individuals, or the companies they work for, could be identified from the survey responses, however, personnel had been categorised within one of five groups; (i) an employee, (ii) a contractor, (iii) an individual in contact with commercial poultry, (iv) an individual in contact with non- commercial poultry or (v) a veterinarian, advisor or industry representative. These categorises were used to create additional network nodes by subdividing personnel within each category by the district they originate from, as reported in the survey. For example, all veterinarians, advisors or industry representatives from the Manawatu region would form one group which could then be used as a node in the network in addition to transporting companies and study farms.

Network graphs could then be constructed by forming an undirected edge between each study farm and every transporting company or personnel group that they had reported in the survey. Each edge had information attached regarding the movement frequency; that is the number of days in between two consecutive movements, and the quantity of product moved. All the numeric variables describing the frequency and quantity of items transferred between the study farms were checked for conflicts in the unit of measure and standardised as needed. All together six bimodal networks were constructed such that each network graph showed just the movements relating to either (i) feed, (ii) waste and litter, (iii) live birds and hatching eggs, (iv) all other poultry products, (v) personnel or (vi) all the reported movements combined.

Using each of the bimodal networks, six additional unimodal network graphs were also constructed with nodes representing only the study farms. Unimodal network graphs were built by forming an undirected edge between each of the study farms in the network that shared a link to a common transporting company or personnel group (Supplementary Figure I). Both the bimodal and unimodal network graphs were plotted using a force-based algorithm proposed by Fruchterman and Reingold (1991) to help visualise the network structure (Supplementary Figure II). In each graph, any study farm that did not report a movement within one of the networks or reported internal movements (e.g. spreading litter on-site) can still be seen as isolated nodes without edges. Basic network statistics were calculated to describe each network graph in terms of their overall size, the frequency of movements and the quantity of products moved. In addition, the degree centrality and betweenness were also calculated for each of the study farms using the unimodal network graphs to identify individuals with the greatest number of on- and off-farm movements (degree) and individuals most frequently found on the shortest path between two other farms in the network (betweenness) (Supplementary Table I). The calculated degree measure from the combined unimodal network graph, showing all on- and off-farm movements, was used as the risk criterion in the main study analysis (Supplementary Table II). Lastly, degree distributions were plotted to distinguish any major network structures in comparison to other real-world networks (Supplementary Figure III).

Reference

Fruchterman TMJ, Reingold EM. Graph drawing by force-directed placement. S*oftware Pract. Exp.* 21, 1129-1164, 1991

Supplementary Table I. Network statistics for the six contact networks constructed from the on- and off-farm movements of (i) feed, (ii) litter and waste, (iii) live birds and hatching eggs, (iv) personnel, (v) additional poultry products and (vi) all goods and services combined across 120 producers in the New Zealand commercial poultry industry.

	Feed	Litter and waste	Live birds & hatching eggs	Personnel	Poultry products
Node structure					
Poultry premises[a]	115	112	117	92	45
Unique companies[b]	23	87	38	49	50
Total	138	199	155	141	95
Edge structure					
Onto-farm	5305	1246	3512	NA[7]	30
Off-farm	148	2337	3932		130
Total	5453	3583	7444	4462	160
Mean frequency[c] (range)	13 (1-270)	68 (1-450)	263 (1-18250)	20533 (1-799350)	9 (1-100)
Mean quantity[d] (range)	5101 tonnes (0.2-300000)	107 tonnes (0.01-4000)	54847 birds (210-413000)	1 person (NA)	1130 dozen (8-7000)
Mean degree[d] (range, median)	20.3 (0-42, 28)	11.7 (0-37,14)	20.6 (0-45, 26)	13.0 (0-43, 16)	1.1 (0-10, 0)
Mean betweenness[e] (range, median)	64.0 (0-2070, 0.0)	63.4 (0-1056, 1.3)	59 (0-551, 2.4)	46.6 (0-1186, 0.0)	0.1 (0-10, 0.0)

[a] Poultry premises with degree>0

[b] Companies are those providing goods and services to poultry premises in the network. If single companies had enterprises in multiple locations, each separate location was assigned a unique identification number by name and address so it would appear as a unique company in the network analysis

[c] Frequency; the number of days between two consecutive contacts on the same farm

[d] Quantity; the amount of goods transferred in each movement. Units vary across contact networks

[e] Degree; the total number of movements onto and off a farm

[f] Betweenness; the frequency a farm is in the shortest path between two other farms in the network

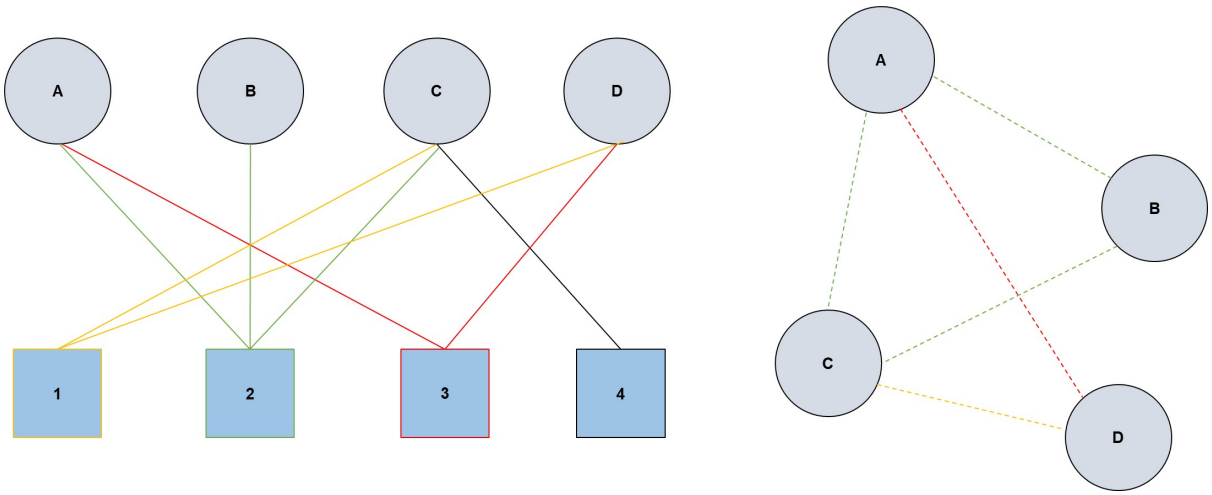
[g] Movement of personnel considered undirected

Supplementary Table II. Basic network statistics for the contact network constructed from the on- and off-farm movements of all goods and services across 120 producers in the New Zealand commercial poultry industry including 33 layer enterprises, 57 broiler enterprises, 24 breeder enterprises and 6 enterprises representing either duck, turkey or pullet operations. Definitions of each measure are provided in the table footnote.

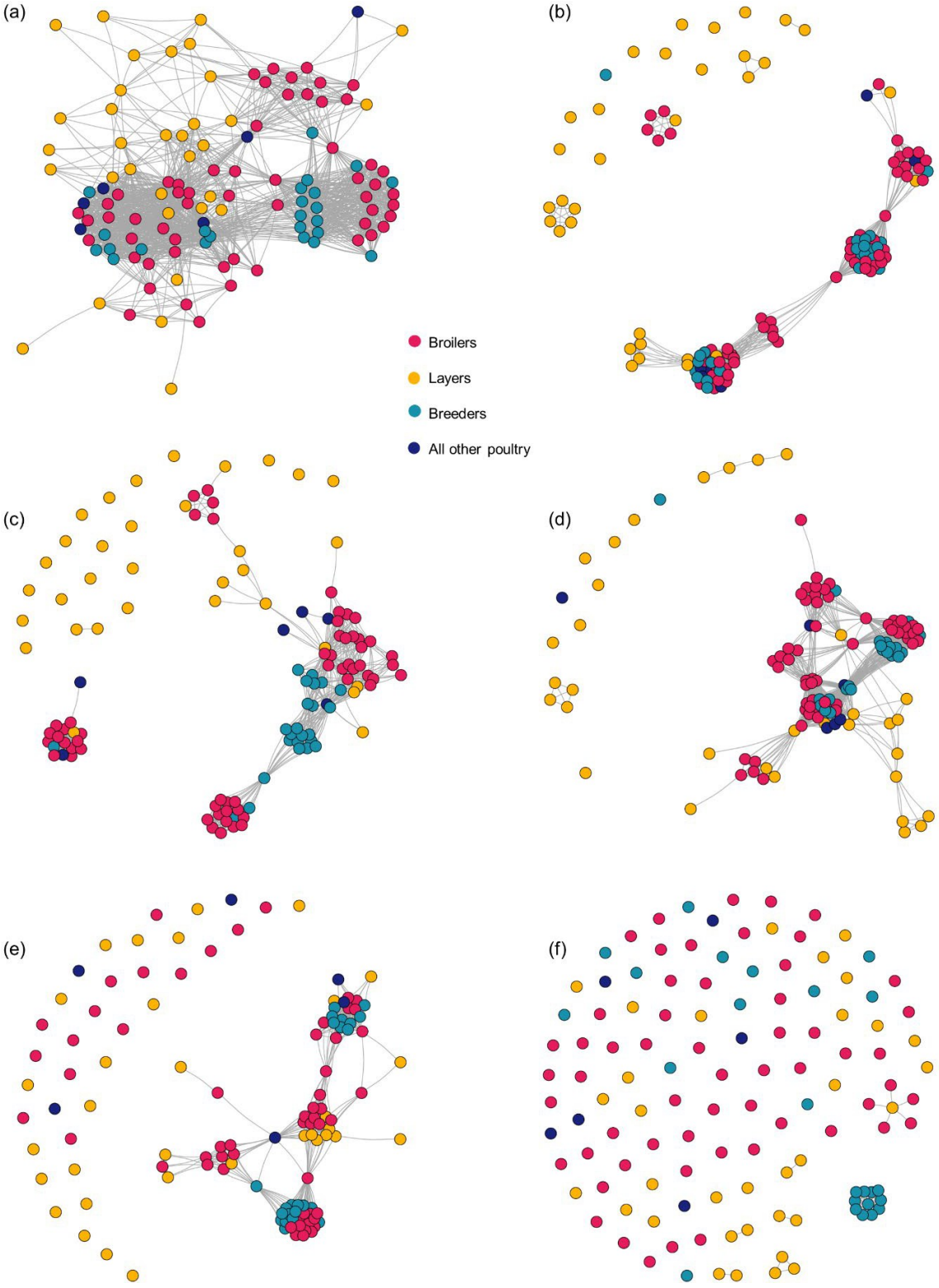
Network statistic	Network nodes	
Mean degree[d] (range, median)	Layers (n = 33)	13.0 (0-41, 9.0)
	Broilers (n = 57)	29.6 (8-57, 29.0)
	Breeders (n =24)	35.5 (22-50, 34.0)
	Other poultry (n = 6)	29.7 (4-37, 34.0)
	All nodes (n = 120)	26.2 (0-57, 29.0)
Mean betweenness[e] (range, median)	Layers (n = 33)	92.0 (0-640, 33.8)
	Broilers (n = 57)	59.7 (0-650, 4.8)
	Breeders (n =24)	52.7 (0-223, 42.7)
	Other poultry (n = 6)	132.9 (0-545, 0.9)
	All nodes (n = 120)	70.9 (0-650, 20.6)
Network density[c]	All nodes (n = 120)	0.220
Average path length[d]	All nodes (n = 120)	2.211
Clustering coefficient[e]	All nodes (n = 120)	0.777
Network diameter[f]	All nodes (n = 120)	6
Fragmentation[g]	All nodes (n = 120)	0.017

[a] Degree; the total number of movements onto and off a farm
[b] Betweenness; the frequency a farm is in the shortest path between two other farms in the network
[c] Network density; the proportion of all possible links between farms in the network that are actually present
[d] Average path length; the average shortest path between any pair of farms in the network averaged over all pairs of farms
[e] Clustering coefficient; for any farm in the network the clustering coefficient is the proportion of neighbouring farms in direct contact with the farms that are also connected to each other.
[f] Network diameter; the longest path between any two pair of farms in the network
[g] Fragmentation; the proportion of farm pairs for which a path does not exist between them.

Supplementary Figure I. Bimodal networks (BMN) have vertices (V) belonging to different groups or modes. (1a) a schematic of the study BMN; V1 (A, B, C, and D) are poultry enterprises and V2 (1, 2, 3 and 4) are those companies providing goods and services to each operation. (1b) the unimodal network (UMN) constructed from the BMN (1a) by forming an edge between vertices belonging to V1 if they share common vertices belonging to V2 i.e. A is connected to D via their shared connection to 3. Edge colour in both (1a) and (1b) corresponds to the movement of different goods and services in the networks.



Supplementary Figure II. Six contact networks constructed from the on- and off-farm movements of (a) all goods and services, (b) feed, (c) waste and litter, (d) live birds and hatching eggs, (e) personnel and, (f) table eggs and poultry products reported by 120 producers within the New Zealand commercial poultry industry.



Supplementary Figure III. Degree distribution for the six contact networks constructed from the on- and off- farm movements of (a) all good and services, (b) feed, (c) waste and litter, (d) live birds and hatching eggs, (e) table eggs and poultry products and, (f) personnel report by 120 producers within the New Zealand commercial poultry industry. Graphs include the mean degree (μ) and median degree (x̃) for each network