Characterization of the live fish movement network in the Irish salmon farming industry

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ABSTRACT

The network of live Atlantic salmon movements within Ireland was analyzed using Social Network Analysis (SNA) methodologies. During the January 2011 – December 2013 period there were a total 239 movements from 52 farms, representing 43 million fish. The months where most of the fish were moved were January-March and July-September, with a mean distance of each movement of 162 Km. The network had a density and transitivity of 0.10 and 0.25, respectively, and was disconnected into 2 sub-networks: a major and a small one of 45 nodes and 3 nodes, respectively. The former had a diameter of 10 nodes. Node standardized centrality measures tended to be located in North Western and Western parts of Ireland. This study can provide insight for the development and evaluation of risk based disease surveillance and control programs.

INTRODUCTION

The movement of animals is one of the most important ways for disease spread. Live fish transport has been implicated in facilitating the spread of infectious salmon anemia in Scotland (Murray *et al*., 2002), Chile (Mardones *et al*. 2014), and in the spread of bacterial kidney disease in UK in 2005 (green *et al*. 2009). The aim of this study was to characterize the network of live fish movements within the Irish salmon farming industry, in order to understand its potential vulnerability for disease spread.

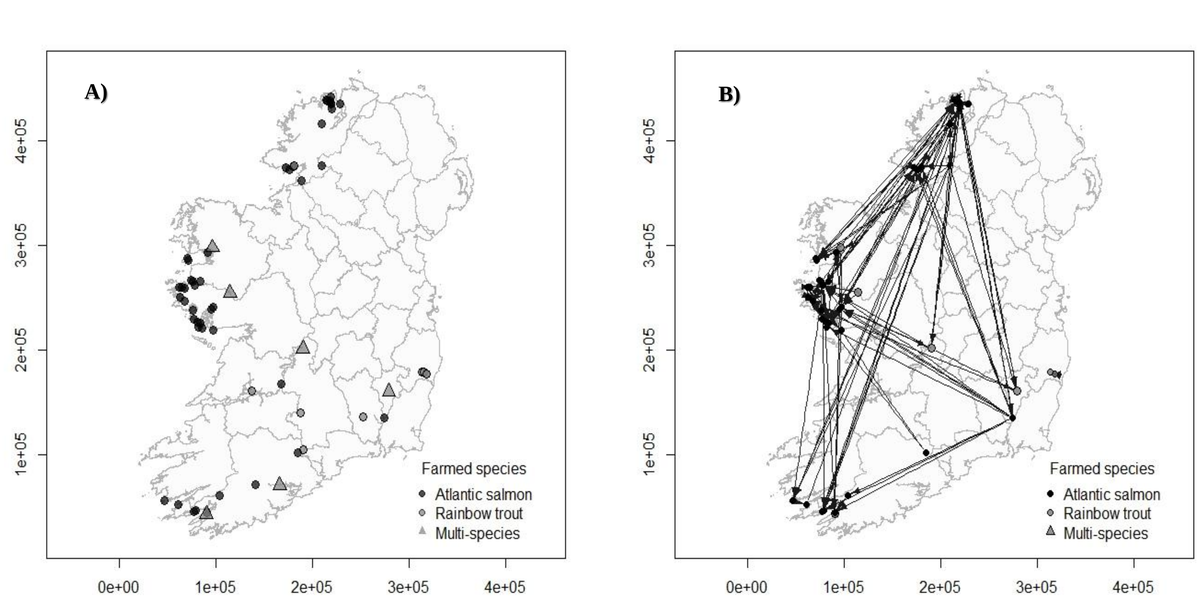

Figure 1. Salmonid farms moving fish in Ireland during the 2011-2013 period. A) locations of farms, B) 2011-2013 network

MATERIALS AND METHOD

Data source: A codified database with information regarding movement live fish of all developmental stages was provided by the Irish Marine Institute (MI). **Population and study period:** Farms with ≥1 movement of Atlantic salmon from January 2011 through December 2013 (Figure 1).

Data analysis: Descriptive statistics and temporal-spatial patterns of the network were analyzed, namely the number of fish moved per month, Euclidean distances of shipments, shipment size, network diameter, density, and transitivity. Also, standardized centrality measures of farms, such as degree, closeness, betweenness, and eigenvector centrality were estimated, the former two for both incoming and outgoing movements, considering the directed nature of the network.

Network analysis and mapping was conducted with R statistical software, using the igraph package for the former and packages maps, maptools, mapproj, rgdal, sp, and spdep for the latter.

RESULTS

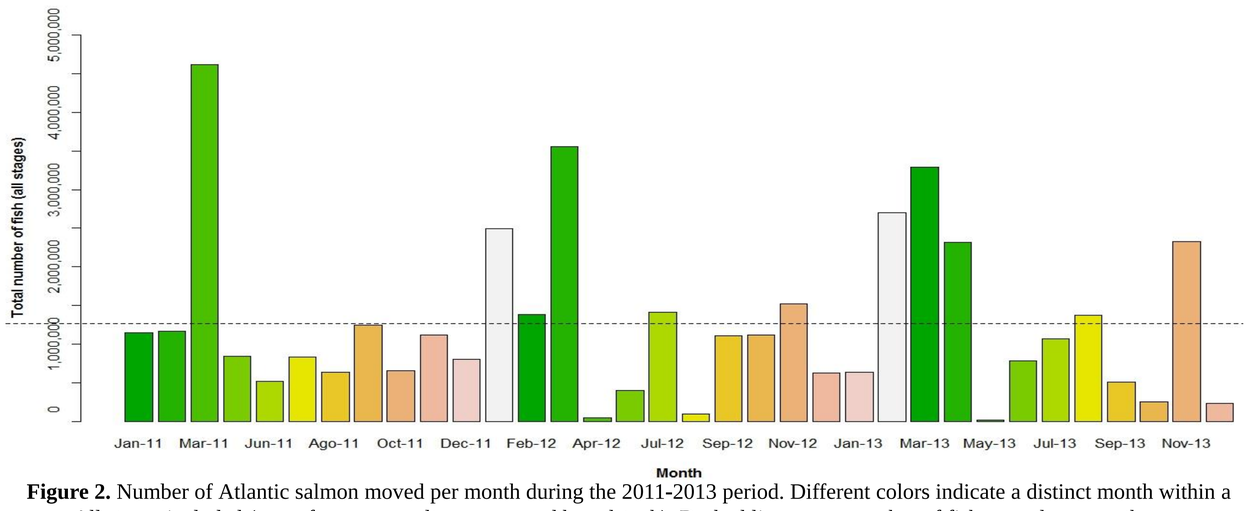

Figure 2. Number of Atlantic salmon moved per month during the 2011-2013 period. Different colors indicate a distinct month within a year. All stages included (eggs, fry, parr, smolt, growers and broodstock). Dashed line: mean number of fish moved per month

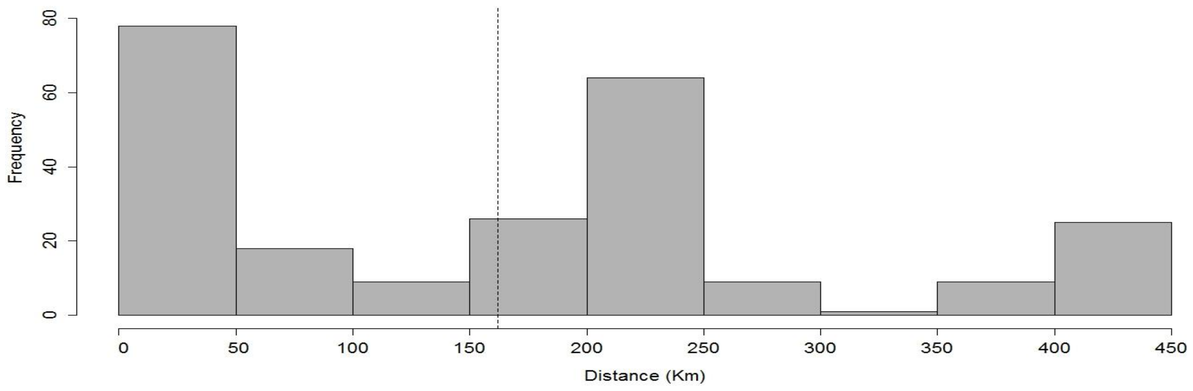

Figure 3. Histogram of distance (Km) of live A. salmon shipments in the Irish salmon farming industry during the 2011 – 2013 period. Dashed line: mean distance of shipments

A total of 239 Atlantic salmon movements (all life stages) were registered during the 36 month study period, originating from 52 locations (46 A. salmon and 6 multi-species farms). This represents a total of about 43 million fish moved: 8.5 million eggs, 7 million juveniles, 17 million smolts, 10.5 million growers and about 12 thousand broodstock.

The months where the greatest number of A. salmon was moved were noticeably the January-March period (due to movement of eggs and smolts for hatcheries and sea sites stocking, respectively). Also there was a greater movement of fish during July-September (due to juvenile and growers movements) (Fig. 2). The average shipment size was 162.300 individuals (95% between 995 and 762,000 fish). The average shipment distance was 162 Km (95% between 2 and 415 Km, Fig. 3).

For estimating network metrics, only farms with valid geographic coordinates were used (48 farms). The network had a density (proportion of possible arcs present) of 0.10, and a transitivity (proportion of possible triads present) of 0.25. Overall, the network was disconnected, with a major sub-network comprising 45 farms and a small one with only 3 farms. The major sub-network had a diameter of 10 nodes. The mean (95% percentile range) for estimated standardized centrality measures were 0.10 (0.00, 0.32) for indegree, 0.10 (0.00, 0.45) for outdegree, 0.04 (0.02, 0.04) for incloseness, 0.05 (0.02, 0.08) for outcloseness, 0.03 (0.00, 0.27) for betweenness, and 0.11 (0.00,0.45) for Eigenvector centrality. Farms with higher standardized centrality measures tended to be located in North Western and Western Ireland. Figure 4 shows the locations of farms with high (above 90th percentile) indegree, betweenness and Eigenvector centrality (Fig. 4)

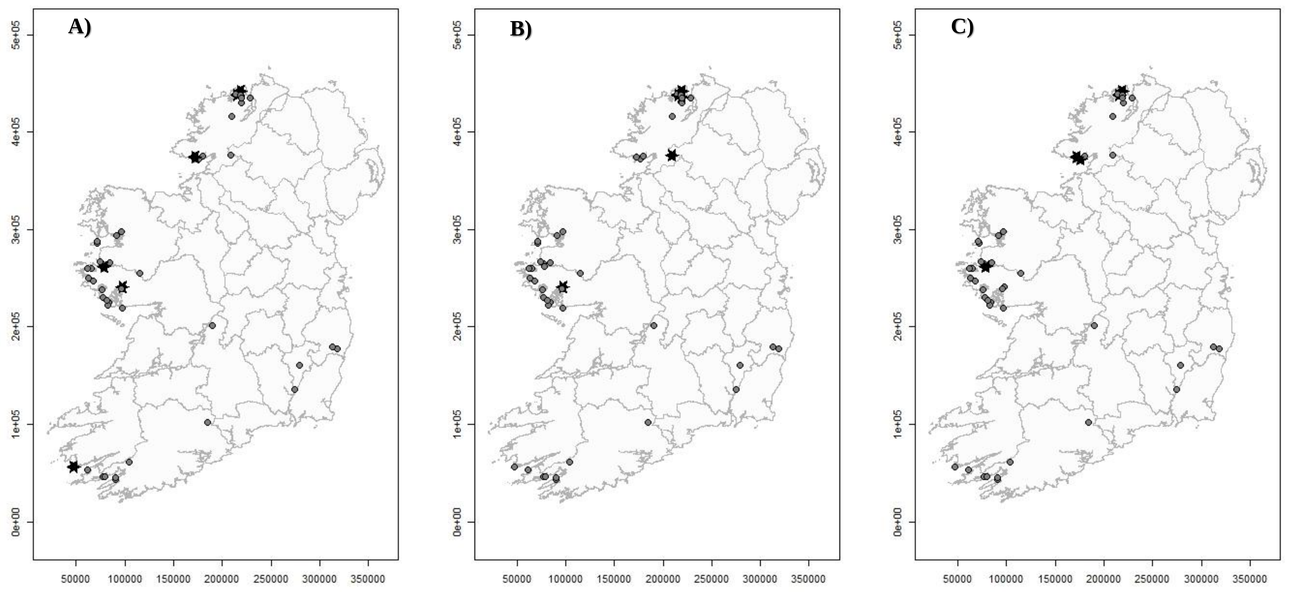

Figure 4. Farms reporting A. salmon movements in Ireland during the 2011-2013 period, according to node centrality measures. A) normalized indegree, B) normalized betweenness, C) Eigenvector centrality. ✸ : node centrality above the 90th percentile (0.19, 0.07, and 0.22 for the three measures formerly mentioned, respectively)

DISCUSSION

(1) The network of live fish movements in Ireland is small and seasonal, with periods of high fish movement mostly related with productive phases of A. salmon cycle, which are periods of higher connectivity, such as Jan- March and July-September. (2) The life stage that represented most of the movements were smolts moving from mostly inland sites to marine sites, nevertheless, there was a high volume of fish moved between sea sites. (3) High farm level centrality measures were mostly located in the North Western and Western areas of the country, indicating that highly connected farms are located in these areas. Interestingly, eigenvector centrality (which relates not only to the connectivity of the node, but also to the connectivity of the nodes which are connected to this one), showed high values for farms that also exhibited high indegree and betweenness (Pearson correlation of 0.90 and 0.58, respectively, Fig. 4).

All the above network characteristics can be used to identify at which periods specific farms and areas of Ireland are at higher risk of disease introduction and spread, which in turn can provide insight into the development and evaluation of risk based disease surveillance and control programs.

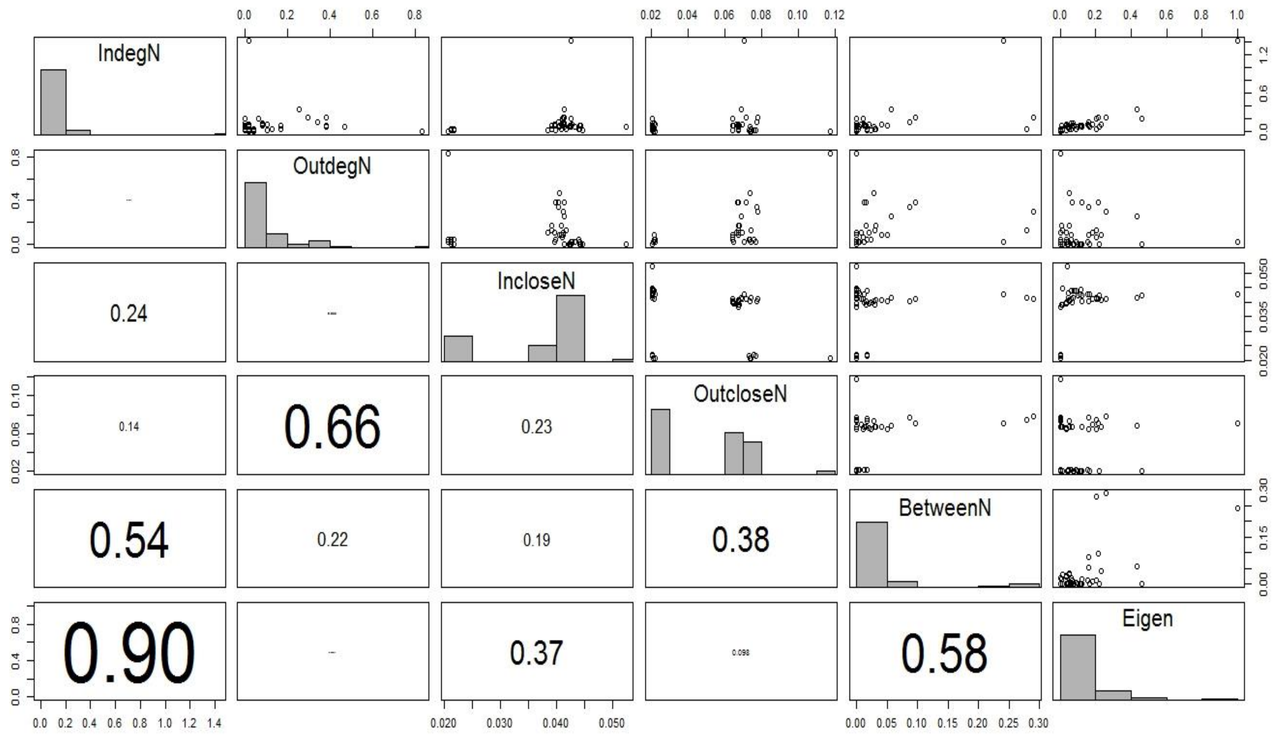

Figure 5. Pairs plot of standardized centrality measures estimated at the farm level. Upper pane: scatter plot; main diagonal: histogram; lower pane: Pearson correlation values

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