A network analysis of live fish movements:

Implications for pathogen spread

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Background and Aims

Large numbers of ornamental fish are imported from overseas and if these are released, infections can be seeded in fisheries. In 2003, koi herpesvirus (KHV), a serious pathogen of carp (*Cyprinus carpio*) emerged in sport fisheries in the UK. The virus has since spread through the sector via live fish movements.

Previous studies attempting to model the spread of pathogens by live fish movements were limited by a lack of knowledge of the contacts that exist between sites due to live fish movements (Taylor et al. 2011).

This study aimed to create a **real life network of live cyprinid movements** between farms and fisheries, and assess the potential for pathogen spread through the network, thus informing surveillance and control strategies.

Methods

Data and data extraction: Data on live fish movements of species susceptible to KHV were extracted from the Fish Health Database (Defra / Cefas / Environment Agency) for one year (2009). The data consisted of (i) 'Section 30' consents for live fish movements to open waters (i.e. fisheries), and (ii) registered farm to farm movements.

Network Analysis: The R package 'igraph' was used to create a network from the spreadsheet and investigate its structure. The network consists of a number of **'nodes'** (farm or fishery sites) and **'edges'** (movement of one or more live fish consignments between two sites during the year) (Figure 1). The distributions of three measures of node **'centrality'** (influence) were analysed: **degree** (number of connections per node), **closeness** (the mean number of steps required to reach each other node in the network), and **betweenness** (a measure of how important a node is in allowing flows through the network). The network attributes network **density** (number of edges as a proportion of number of possible edges) and **assortativity** (to what extent nodes of similar degree preferentially connect to each other) were calculated. The size of the largest **'strongly connected component'** (SCC - a component of the network where all nodes are connected to each other in both directions) and **'weakly connected component'** (WCC - a component where all nodes are connected to each other, by any number of steps, in any direction) were determined.

Seasonality: The numbers of live cyprinid movements made in each month of 2009 were calculated to assess seasonality.

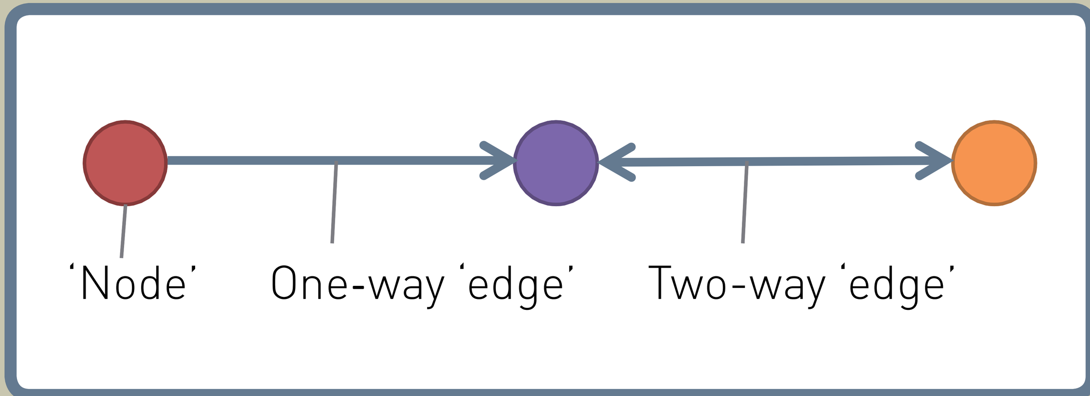

Figure 1. An illustrative diagram of a network

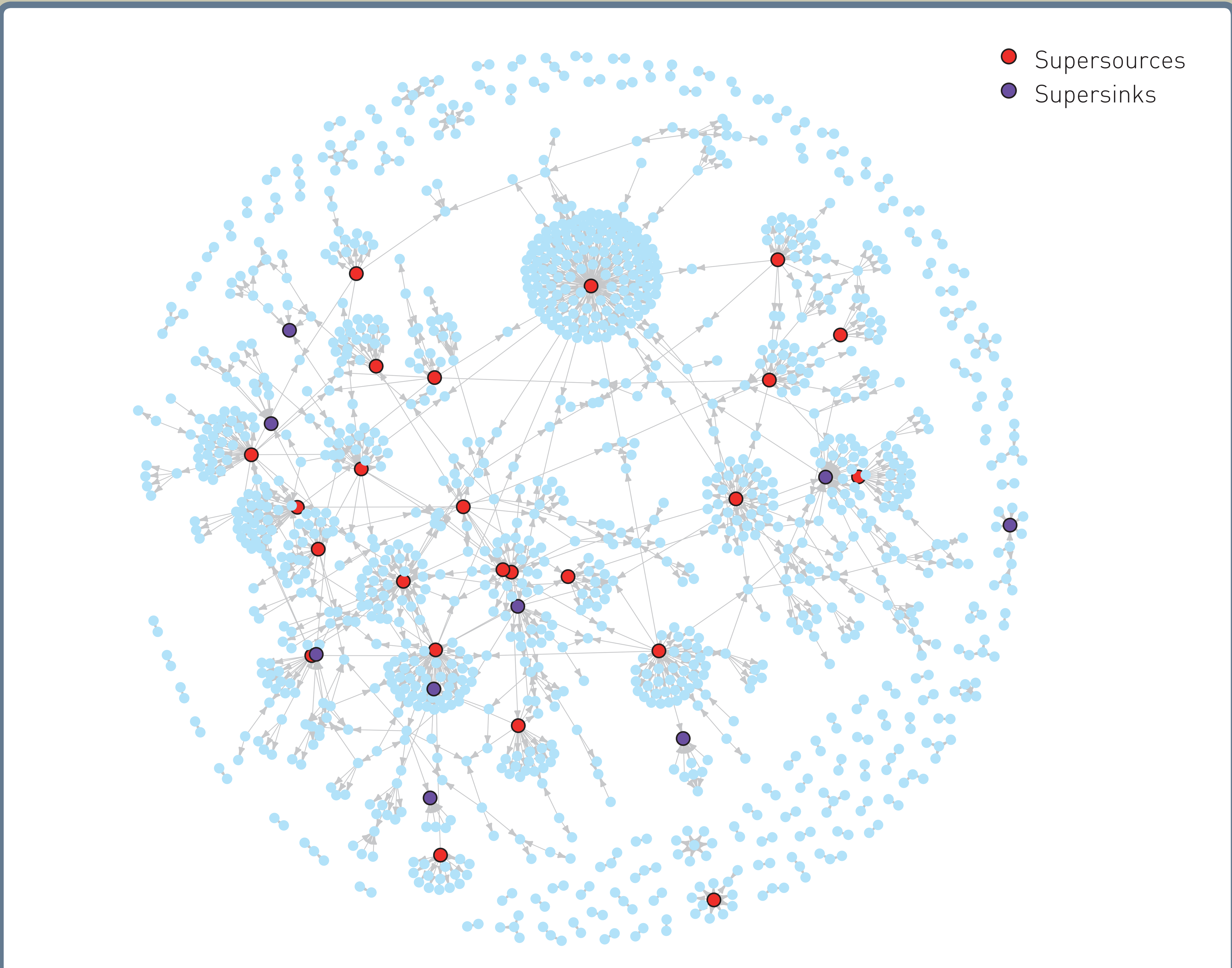

Figure 2. A diagram of the network. Each dot represents a node, and each grey line an edge. The supersources (red nodes) are those that supply fish to at least 10 other sites, while the supersinks (green nodes) receive fish from at least five

Results

- The network consists of 1329 nodes connected by 1354 edges.
- It is **highly directional**, i.e. nodes tend to either be sources or receivers. The direction of movement is predominantly farms -> fisheries, and farms -> farms
- A few **central (influential) nodes** with high values for degree and closeness dominate the network. These are 'supersources', farms supplying fish to many other sites (>10), and 'supersinks', sites receiveing fish from many sites (>5) (Figure 2). The majority of nodes have low values for degree and closeness; both measures are highly skewed.
- The network is **disassortative** (assortativity value of -0.2), i.e. the supersources tend to connect to nodes of low degree rather than other supersources: the network is heterogeneous
- The largest WCC has 1008 nodes (76% of the network), the largest SCC is very small (3 nodes)
- Live fish movements are **seasonal**; the most movements in spring and autumn (Figure 3).

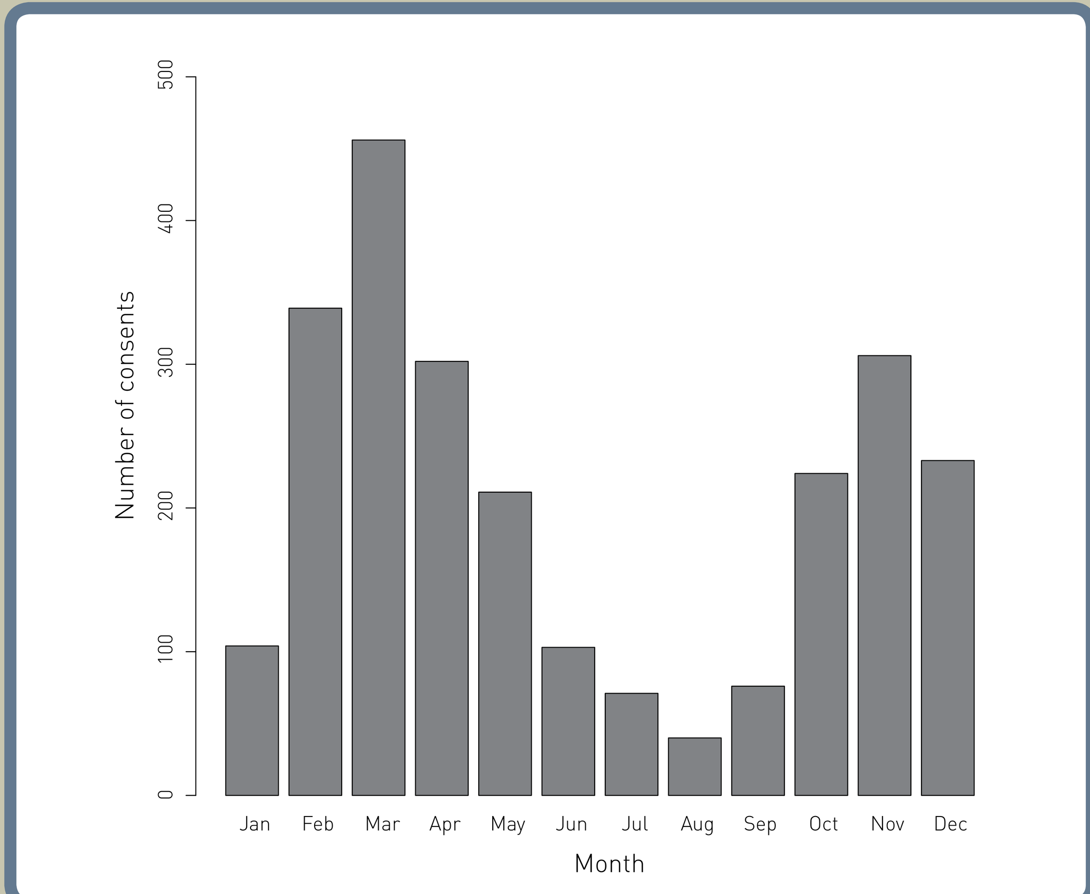

Figure 3. A plot of the number of live fish movements into fisheries in 2009 by month.

Conclusions

- Pathogen spread through the network would be limited by its **highly directional nature** (a property of live fish movement networks in general (Green et al. 2009)), demonstrated by the small size of the largest SCC.
- The largest WCC is substantial, but due to the network's directionality, the level of pathogen spread depends on where an infection is seeded: seeding a 'supersource' (farm) may allow a pathogen to spread to a moderate number of sites, while infection of a low degree node (even within the large WCC), would result in either no spread, or spread to just few other sites. **Surveillance of supersources should therefore be prioritised**.
- While supersources do not generally connect directly to each other, **farm to farm movements** connect some supersources together, and should be a priority for surveillance.
- Most movements are made in spring and autumn, when water temperatures are **outside the permissive range** for KHV clinical disease (>15°C). The movement of sub-clinically infected fish during these periods may explain the high proportion of sampled fisheries which tested positive for KHV antibodies (Taylor et al. 2008).

Acknowledgements

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References

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