Final Report

Impact of network thinning on the performance of the AHDB Potatoes aphid monitoring scheme

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1. SUMMARY

AHDB and its predecessor organisations have funded an aphid monitoring scheme to provide information on the presence of aphid vectors as part of an integrated approach to virus management in seed potato crops. The scheme is based on voluntary participation by growers, in nine regional blocks across GB, who maintain a series of water trap sites (~100) from which weekly samples are extracted and taxonomically identified by Fera staff. AHDB commissioned Fera to assess the impact of changing the number of traps (from 100 per annum) on the performance of the AHDB aphid monitoring scheme. Fera staff estimated the effect of thinning the trapping network on four measures of performance: the detection of *Myzus persicae* each week that it is present; the probability that a thinning causes a delay of at least one week in the reporting of *M. persicae*; the effect on the identification of high risk locations within regions; the effect on the regional average estimate of cumulative PVY vector pressure.

Three thinning regimes were examined: 80% of trap locations retained (low thinning); 50% retained (intermediate thinning), 20% retained (severe thinning).
Thinning was simulated by randomly removing trap locations from historic data.

It was estimated that:

- Approximately 92% {76%; intermediate thinning, 48%; severe thinning} recovery of the presence of *M. persicae* within a given week where the pest is known to be present in historic records.

- Following the above an approximately 8% (average across years) {23%; intermediate thinning, 40%; severe thinning} probability of a delay of at least one week being introduced in the reporting of *M. persicae* within a given region, relative to the full historic network.

- There is a 91% probability {72%; intermediate thinning, 43% severe thinning} that if a region previously contained a location with a high-risk value of the cumulative PVY vector pressure index (value greater than 10.0; red point on visualisation) it will continue to do so after thinning.

- There is a 95% chance that the random error introduced to the regional average estimate of cumulative PVY vector pressure index will lie between -6.4-5.9, {-14.1-16.0; intermediate thinning, -19.3-34.4; severe thinning} corresponding to an approximately 3% chance {7%; intermediate thinning, 11% severe thinning} that such introduced error would be sufficient (under worse case conditions) to allow a high-risk region (in a given week) to be misclassified as zero risk.

2. INTRODUCTION

Aphids are commercially significant pests and vectors associated with range of key UK crops. Of particular concern to AHDB Potatoes is the role played by aphids in the transmission of viral infections, particularly with respect to the seed potato crop, which can result in significant losses to growers. As a result, monitoring for the presence of aphid vectors at a regional level has been a long-term part of management strategies implemented by the AHDB in collaboration with Fera Science Limited. The scheme is based on voluntary participation by growers in nine regional blocks across the UK who maintain a series of water trap sites from which weekly samples are extracted and taxonomically identified by Fera staff. From these samples, via an online portal and weekly newsletter, intelligence relating to the presence of aphids of high concern (most notably peach-potato aphid; *Myzus persicae*), as well as constructing aggregated indices of total viral pressure based on a scaled count of collected individuals are disseminated to registered users. In this preliminary study the focus is on the transmission of Potato Virus Y (PVY), an important pest of potato crop and the primary concern of the current monitoring system.

The focus of this work was to explore, in the context of historic records, the potential impact of different schemes of network thinning (random reduction in the number of monitored sites) on the calculation of key reported statistics, and so inform AHDB as to the potential impacts of network reduction.

3. MATERIALS AND METHODS

Prior to outlining the approach taken in this preliminary examination it is important to emphasise that the analyses conducted address relative expectations of reduced performance under varying degrees of network thinning. We did not make estimates of the absolute performance of the network (existing or thinned) with respect to 'real' aphid populations in the UK. Instead the focus here is on assessing the internal consistency of regional signals, in particular the impact on regional statistics, such as the presence of *M. persicae* and the regional average estimate of aphid pressure of dropping random locations from the network.

For this study, thinning (defined here as the random reduction in the number of analysed localities) was applied at a complete network level (i.e. based on the total number of localities surveyed during a particular year). Within each replicate a (random) single location was selected for each region and additional locations added until the total number sums to a predefined fraction of the real data set. This ensures that estimates can be generated for each region for all years and reflects a realistic if very simple protocol by which the network could be thinned. For simplicity we estimated thinning at three different levels; so as to include 80% of sites in the real data set (henceforth 'low thinning'), 50% of sites (intermediate thinning) and 20% of sites (severe thinning). For each of the 14 included years for each level of thinning we calculated 1000 replicates and the results shown are averaged across all years except where otherwise stated.

The data underlying the analyses is derived from annual data extractions made of the 8th of January 2018 for years between 2004 and 2017. Each extraction includes weekly (or approximately weekly; see below), by species, counts of individuals collected at included localities with regional identification. Nine regions were considered "Angus & Perthshire", "Borders", "East Anglia", "Grampian", "Midlands", "North Scotland", "Northern England", "South-West" and "Yorkshire" {the last is valid only for 2004 and since combined into Northern England}, corresponding to pre-existing definitions in the underlying database.

The parameters examined derived from existing reporting and reflect a) the occurrence of the focal pest *M. persicae* (henceforth M.p.) in a region within a particular week and b) the aggregated estimate of the cumulative value of the PVY vector pressure index {cPVYvpi} for a given region. The cPVYvpi is a composite index derived from the count of individuals at a

location belong to a particular species and scaled to a factor reflecting their relative capacity to transmit PVY (see http://aphmon.fera.defra.gov.uk/pvy_vector_info.cfm). The index is cumulative in that each value reflects the sum of the previous two weeks of collections from the named date (calculation done during processing). Based on these concepts the following four measured variables were calculated for each replication relative to the historic baseline data for a that year.

1. Recovery of regional occurrence of M.p. if present in baseline. This statistic is simply the proportion of instances where a known occurrence of M.p. a particular region is also recovered in the replicated thinned data set. NA values (reflecting where all localities reporting in a given week are loss to thinning) are treated as false for the purposes of this statistic.

2. Change in the distance to the next occurrence of M.p. in region. This statistic attempts to quantity any delay that might be imposed on reporting the presence of M.p. in a region due to the effect of network thinning. Here we focus on calculating the proportion of weekly periods where the estimated difference in the distance to the next occurrence of M.p. within a year between the historic baseline and the thinned replicate sample is greater than 1 week. This includes all cases where within the thinned sample occurrences of M.p. within regions are lost (represented as infinite distances to next occurrence) but excludes weeks where complete records show no further occurrence of M.p. during that year. This value can be visualised as the probability for a given week within a given region that there will be at least a one-week delay in reporting the occurrence of M.p. relative to reporting from the complete network.

3. Recovery of regional occurrences of site(s) where the location estimate of cPVYvpi exceeds predefined threshold values. A simple proxy for hazard within a region is the occurrence of locations with high local cPVYvpi values. The online portal denotes locations in the following categories; low risk cPVYvpi 0-2.0, medium risk cPVYvpi 2.01-10 and high risk cPVYvpi >10. This statistic is therefore the proportion of weeks for a given region where at least one site exceeded these threshold values in the historic baseline which were also recovered in the replicated thinned sample.

4. Regional average value of cPVYvpi. This is the mean average cPVYvpi value taken across locations within a particular region in a particular week. For comparison with thinned data sets we focus on the distribution of differences between the thinned sample and the historic baseline. Presented tables are the 95% quantiles on the values of these differences as well as the portion of recovered differences which would be sufficiently large so as to allow for misclassification of regions based on the risk scheme presented above (i.e. of an absolute magnitude of greater than 2.0 or 10.0 units).

A note on weekly binning:

In principal the raw data consists of weekly reports from each participating locality from which the parameters of interest can be estimated. However, in many cases, due to for example participants failing to empty the trap every week, a single record in the database represents multiple weeks of trapping at a location This results in a need to insert dummy records for localities where data is missing. In resolving this we have taken the conservative view that the weekly estimate of PVY vector pressure index (prior to calculating the cumulative element) can be divided equally among each of the weeks represented by the resulting sample (which will then contribute as otherwise to the aggregated estimate of cPVYvpi). We have also assumed that for these inserted weeks M.p. should be considered as absent (even if present in the underlying sample) as there would be no way for information regarding its present to be

distributed to other users during the inserted week. This standardisation is applied to all data sets (real and simulated) prior to inclusion in the reported values.

4. RESULTS

4.1. Recovery of presence of *Myzus persicae* within regions in weeks where it is present in the full network

A simple index of whether the (known) presence of M.p. is found in a region for a given week under varying levels of thinning is shown in **Error! Reference source not found.**. These reveal that under low thinning 92% of known instances of M.p. in a region in a given week are recovered in across the conducted replications. This probability of recovery is reduced to 76% under intermediate thinning and 48% under the most sever thinning regime considered. The difference between these values reflects a near halving of the power of the network under the most severe thinning regime. However, under limited thinning (80 of sites remaining) there is less than a 7% chance that a known occurrence of M.p. should fail to be reported simply as result of the thinning process (although as noted we cannot comment on the relationship between detection and the true prevalence of M.p. in the UK based on this data).

Table 1 Regional estimates of the % of weeks where M. p. is known to be present in the historic baseline which are also recovered in the thinned samples. Values given are averaged over all years.

Region	Thinning to 80% of sites	Thinning to 50% of sites	Thinning to 20% of sites
	% recovery of weeks where M.p. is known to be present in thinned samples	% recovery of weeks where M.p. is known to be present in thinned samples	% recovery of weeks where M.p. is known to be present in thinned samples
Angus & Perthshire	91.2	70.4	35.3
Borders	87.6	64.3	35.0
East Anglia	94.7	82.1	55.1
Grampian	90.8	70.4	36.5
Midlands	93.9	81.2	58.5
North Scotland	88.2	67.5	37.8
Northern England	95.7	86.8	64.2
South-West	93.2	78.6	51.7
Yorkshire {combined in Northern England since 2004}	92.1	78.5	51.2
Overall	92.5	76.6	48.5

4.2. Estimated delay until next recording of *Myzus persicae* within region

One of the most informative measures available for estimating network performance is the implied delay that thinning would cause in the reporting of the M.p. The estimates used here are based on the real reporting structure of the historic baseline (i.e. inserted rows are treated as false for occurrence).

Table 3 shows the estimated proportion of weeks for a given region where the estimated delay (or change in distance to next occurrence of M.p.) is greater than one week. The values given are for the average across years, with a worst observed case given in braces. This value can be visualised as the probability in a given week for a region of there being at least a one-week delay on reporting a real occurrence of M.p. At low thinning levels there is overall approximately an 8% chance of delay being introduced due to network thinning. This estimate is subject to significant regional variation, particularly in the regions of East Anglia and Northern England, which may reflect either greater prevalence of M.p. (hence greater chance of multiple localities

reporting at the same time) or difference in the spatial dynamics of localities and populations (e.g. if locations are on average closer together). At more extreme levels of thinning the chance of delay increases rapidly leading to a 24% probability of delay if only 50% of sites are retained and a 40% probability if only 20% are retained. The importance of this increased delay will depend of the value of timeliness in managing response to M.p. but it does suggest a likely systemic failure where a network has been over-thinned.

Table 2 Regional estimates of the % of weeks (where the issue can be meaningfully addressed) where there is a delay of at least 1 week on the next occurrence of *Myzus persicae* within a region, across the different levels of thinning considered. Values given are averaged over all years and the value for the worse single year in the database

Region	Thinning to 80% of sites	Thinning to 50% of sites	Thinning to 20% of sites
	% weeks with at least one weeks delay in recovery of *Myzus persicae due to thinning {% for the worse single year}*	% weeks with at least one weeks delay in recovery of *Myzus persicae due to thinning {% for the worse single year}*	% weeks with at least one weeks delay in recovery of *Myzus persicae due to thinning {% for the worse single year}*
Angus & Perthshire	8.84 {16.8}	26.5{44.9}	44.6 {70.3}
Borders	13.2 {17.9}	33.6 {41.4}	50.0 {58.0}
East Anglia	5.24 {9.99}	16.0 {24.2}	29.6 {40.9}
Grampian	9.38 {17.7}	28.8 {45.4}	53.4 {69.1}
Midlands	7.06 {13.2}	19.3 {32.3}	33.0 {57.5}
North Scotland	14.3 {21.9}	35.7 {48.4}	55.3 {71.4}
Northern England	4.37 {8.78}	12.7 {25.9}	26.6 {46.0}
South-West	7.49 {15.2}	19.0 {35.3}	31.6 {52.0}
Yorkshire {combined in Northern England since 2004}	3.73	9.76	24.5
Overall	8.54 {24.4}	23.6 {57.8}	40.1 {96.8}

Table 3 Regional estimates of the average difference between historic baseline and thinned samples in distance to next period where M. p. recovered in region or end of season (defined as one week after the last data point for that region in the year). Distances given in weeks.

Region	Thinning to 80% of sites	Thinning to 50% of sites	Thinning to 20% of sites
	Average (mean) difference in time to next recovery of *Myzus persicae (or to end of season) due to thinning (weeks)*	Average (mean) difference in time to next recovery of *Myzus persicae (or to end of season) due to thinning (weeks)*	Average (mean) difference in time to next recovery of *Myzus persicae (or to end of season) due to thinning (weeks)*
Angus & Perthshire	0.65	2.01	4.82
Borders	0.40	1.36	2.93
East Anglia	0.32	1.11	2.93
Grampian	0.32	1.15	3.04
Midlands	0.21	0.705	1.87
North Scotland	0.63	1.82	3.46
Northern England	0.25	0.768	2.01
South-West	0.39	1.26	2.86
Yorkshire {combined in Northern England since 2004}	0.46	1.29	2.83
Overall	0.411	1.31	3.07

Table 3 shows the results of a subtle variation in the calculation of delay in an attempt to estimate the average length of the differences generated. In this case the estimated distance is either to the next occurrence of M.p. in a given region or to the end of the reporting season (here defined as one week after the last reported for a given region in a given year). This resolves the issue of where occurrence of M.p. are lost entirely which can otherwise lead of infinite distances to the next occurrence. This adjustment shows that the average delay under low thinning is less than a week, while under the most severe regime it can be more than three weeks relative to the historic baseline. Note that these are averages and then the observed delay for a given week in a region may in fact be much longer under severe thinning depending on the observed conditions.

4.3. Presence of sites with above threshold values of cPVYvpi within region

The presence or absence of sites with cPVYvpi values above the threshold limits of 2.0 and 10.0 shows patterns very similar to the occurrence of M.p. (unsurprising as this taxon is a major contributor to the aggregated cPVYvpi calculation). Considering initially the higher threshold of 10.0 (a red point on the current interface) the across-year averages suggest an approximately 9% chance that if any such a locality is present in the historic baseline it will fail to be recovered after low thinning; Table 4. Where thinning levels are increased this value rises to 27% and further increases to 57% under the most severe thinning levels considered. There is a strong regional signal in property, in that regions in Scotland, which have low net aphid pressure show reduced recovery of known signals (presumably because the probabilities of multiple sites within a region with above threshold values are much lower than in southerly regions). This increased heterogeneity means that the Scottish sites are subject to a disproportionate impact of thinning (although this is to a degree mitigated as the predictive power of an above-threshold site being present is presumably lower in the Scottish samples). Comparable patterns are observed in the recovery of periods with moderate/high sites (values over 2.0); **Error! Reference source not found.**

Table 4 Regional estimates of the % of weeks where a site with a cPVYvp value greater than 10.0 is known to be present in the historic baseline in which such a site is recovered in the thinned sample. Values given are averaged over all years.

Region	Thinning to 80% of sites	Thinning to 50% of sites	Thinning to 20% of sites
	% recovery of weeks where a site of high risk (cPVYvp >10.0)	% recovery of weeks where a site of high risk (cPVYvp >10.0)	% recovery of weeks where a site of high risk (cPVYvp >10.0)
Angus & Perthshire	87.9	63.7	29.0
Borders	85.3	61.6	31.7
East Anglia	92.0	73.7	42.0
Grampian	82.9	55.4	23.0
Midlands	92.0	76.0	51.4
North Scotland	88.5	64.6	30.5
Northern England	93.2	79.3	52.0
South-West	90.1	70.6	40.2
Yorkshire	92.8	75.1	37.8
Overall	91.0	72.7	43.0

Table 5 Regional estimates of the % of weeks where a site with a cPVYvp value greater than 2.0 is known to be present in the historic baseline in which such a site is recovered in the thinned sample. Values given are averaged over all years.

Region	Thinning to 80% of sites	Thinning to 50% of sites	Thinning to 20% of sites
	% recovery of weeks where a site of moderate or high risk (cPVYvp >2.0)	% recovery of weeks where a site of moderate or high risk (cPVYvp >2.0)	% recovery of weeks where a site of moderate or high risk (cPVYvp >2.0)
Angus & Perthshire	90.0	68.9	34.8
Borders	87.5	64.2	34.7
East Anglia	94.4	81.7	54.8
Grampian	87.3	63.6	29.1
Midlands	94.7	82.1	58.7
North Scotland	91.1	73.0	42.6
Northern England	94.3	83.4	60.1
South-West	92.2	75.6	48.3
Yorkshire	92.6	75.8	43.2
Overall	92.3	76.3	48.4

4.4. Regional average values of cPVYvpi

Random thinning as implemented in this study has an equal chance of removing from a given sample localities with high or low values of cPVYvpi. This results in bi-directional changes to the observed regional average which can increase or decrease depending on which subset of underlying localities are retained in a given sample. This practice, as in most regions and weeks there are greater numbers of locations with low values of cPVYvpi there is a tendency towards a slight negative skew in the estimation of change relative to the historic baseline (as on average there will be more samples which include a higher proportion of low value site). Under low or intermediate levels of thinning this effect tend to be modest resulting in an approximately symmetrical distribution of values of change around 0, however under the most severe thinning conditions this negative skew becomes apparent when considering all regional estimates of change (although for the overall estimate this is masked by the magnitude of differences between regions); Table 6.

In terms of the expected magnitude of change on average cPVYvpi under thinning, there is strong regional variation which, to an extent, is masked when considering aggregated estimates. **In general, the amount of variation introduced by thinning is based on a combination of both the extent of thinning and the amount of intrinsic variation observed between locations within a region.** In effect, for regions in the north of Scotland, where few records of localities report high values of cPVYvpi (because the ambient aphid pressure is low) the relative change introduced by thinning will be constrained by this lack of variation. Hence, under the same thinning regime (value given for low thinning) the estimated uncertainty of the regional average of cPVYvpi can range from approximately 2 units for the North Scotland region verses approximately 27 units for Northern England and the South West; Table 6.

Accepting that regional variation is an intrinsic property of the implemented sampling process we can nevertheless observe trends in responses of estimated uncertainty to thinning to different thinning regimes which appear to be consistent across the dataset. Overall, across the regions the implied uncertainty in weekly regional estimates (in effect the interval within which the true historic value may be approximated from the thinned records) more than doubles in the change from a low thinning regime (CI -6.4-5.9, 12.4 units) when compared to the considered intermediate regime (30.1 units). Under the most severe thinning regime considered uncertainty increases further to around 50.6 units, and similar patterns are observable across the regional groups (where the values are more comparable then for the aggregated set); Table 6.

Given the challenges of interpreting the absolute magnitude of changes imposed by thinning an informative alternative is to consider the extent to which changing values impact on the risk category reported for a given region. In the weekly alerts currently provided to stakeholders the weekly regional averages of cPVYvpi are assigned to risk categories based on the same thresholds previously discussed for single localities (2.0 and 10.0; see discussion above). It is therefore informative to consider the proportion of the implied changes for a given thinning regime which would (under the worst-case scenario) be sufficient to cause the risk category of a region to be mis-assigned (e.g. if the change is greater than 10.0 units then a potentially high-risk region could be reported as low risk and vice versa). Considered in this framework, the probability of random thinning introducing changes in value of at least 10.0 units increased from 3.3% under the low thinning regime, to 7.4 (moderate thinning) and up to 11.1% under the most severe thinking regime considered; **Error! Reference source not found.**. This is a worse case estimate (as not every occurrence of a change in 10 units) will result in a misclassification of regional risk but it serves to highlight how likely the potential for such misclassification is increases under different thinning regimes. As with the absolute estimates discussed above these overall values mask significant regional variation as the probability of average change exceeding 10 or 2.0 units is elevated in regions where locations with such high values are comparatively commonplace.

Table 6 Regional estimates of the quantiles and median of the difference in cPVYvpi between the historic baseline and thinned sample across all weeks and years across the three degrees of thinning considered in study

Region	Thinning to 80% of sites			Thinning to 50% of sites			Thinning to 20% of sites		
	2.5% Quantile (change in cPVYvpi)	Median (change in cPVYvpi)	97.5% Quantile (change in cPVYvpi)	2.5% Quantile (change in cPVYvpi)	Median (change in cPVYvpi)	97.5% Quantile (change in cPVYvpi)	2.5% Quantile (change in cPVYvpi)	Median (change in cPVYvpi)	97.5% Quantile (change in cPVYvpi)
Angus & Perthshire	-1.24	0.0	1.25	-2.46	0.0	3.01	-3.92	-0.09	6.20
Borders	-1.68	0.0	1.92	-4.10	0.0	6.60	-4.41	-0.156	11.8
East Anglia	-11.8	0.0	12.5	-25.4	0.0	26.6	-42.0	-0.357	50.7
Grampian	-1.19	0.0	1.27	-3.11	0.0	4.18	-3.26	-0.146	5.68
Midlands	-13.04	0.0	11.7	-29.1	0.0	28.0	-41.5	-0.475	74.2
North Scotland	-0.971	0.0	0.885	-1.88	0.0	2.51	-2.03	-0.109	7.15
Northern England	-15.5	0.0	11.3	-29.0	0.0	38.6	-41.0	-0.49	86.6
South-West	-13.2	0.0	13.9	-32.7	0.0	39.1	-47.6	-0.55	56.0
Yorkshire {combined in Northern England since 2004}	-4.59	0.0	7.56	-11.3	0.0	11.3	-25.8	-0.361	17.4
Overall	-6.48	0.0	5.89	-14.1	0.0	16.0	-19.3	0.112	31.4

Table 7 Regional estimates of the percentage of thinned samples, across all weeks and years where the absolute difference in the cPVYvpi between the historic baseline and thinned sample is greater then a) 2.0 or b) 10.0 across the three degrees of thinning considered in study

Region	Thinning to 80% of sites		Thinning to 50% of sites		Thinning to 20% of sites	
	% of value of absolute change greater than 2.0 between historic and sample	% of value of absolute change greater than 10.0 between historic and sample	% of value of absolute change greater than 2.0 between historic and sample	% of value of absolute change greater than 10.0 between historic and sample	% of value of absolute change greater than 2.0 between historic and sample	% of value of absolute change greater than 10.0 between historic and sample
Angus & Perthshire	2.66	0.02	7.22	1.01	13.4	9.18
Borders	4.36	1.06	10.6	2.79	16.1	4.15
East Anglia	20.1	5.94	33.6	13.2	42.5	19.3
Grampian	2.80	0.006	8.33	0.31	12.0	1.46
Midlands	17.2	5.74	32.1	12.6	42.01	18.2
North Scotland	2.83	0.446	5.40	1.86	8.30	3.00
Northern England	19.1	6.18	31.1	12.1	40.9	19.1
South-West	19.4	6.96	33.9	14.7	43.5	20.3
Yorkshire {combined in Northern England since 2004}	21.2	1.00	39.9	6.89	53.5	16.5
Overall	11.2	3.33	20.5	7.38	27.8	11.1

5. DISCUSSION

The goal of this analysis was quantification of the magnitude of change in key reporting parameters for the aphid monitoring scheme under varying degrees of random thinning. We conclude that (with significant regional variation) low levels of thinning resulting in the loss of 20% of currently analyses sites is likely (based on historic records) to result in the following:

- An approximately 8% reduction in the recovery of *M. persicae* within a given week where M.p. is recovered in the full network.

- Following the above an approximately 8% (average across years) of a delay of at least one week being introduced in the reporting of M.p. within a given region, where it was recovered in the full network.

- There is a 91% chance that if a region previously contained a location with a high-risk value (red point on visualisation) it will continue to do so after thinning.

- A there is a 95% chance that the random error introduced to the regional average estimate of cPVYvpi will lie between -6.4-5.9, corresponding to an approximately 3% chance that such introduced error would be sufficient (under worse case conditions) to allow a high risk region (in a given week) to be misclassified as zero risk.

The aim of this quantification is to permit AHDB to visualise the potential risks associated with network reduction. To that end, and because the situation considered here is deliberately simplified for tractability, we refrain from making explicit recommendations on the course of action to be undertaken.

Note that the simplified comparison conducted here could provide the basis for a more in-depth model approach which considers either a more sophisticated regime of network thinning (which may result in improved parameter estimates) or alternatively if, allied with explicit spatial

modelling of aphid populations, may allow for better commentary on the absolute effectiveness of the current and any proposed networks as opposed than the relative approach adopted here.