



# A Review of Large Scale Coordinated Mink Control in Scotland 2006 - 2015

---

Dr Matt Oliver

October 2015



This initiative was part funded by the Scottish Government and European Community Cairngorms, Highland, Moray, Rural Aberdeenshire, and Rural Tayside - Local Action Groups LEADER 2007 – 2013 Programme

## Contents

Acknowledgements.....	2
Executive Summary.....	2
History of Control.....	3
The Mink Raft Network.....	3
Annual Trends in the Mink Raft Network .....	4
Annual Trends in Mink Detections.....	8
Trends in American Mink Captures.....	11
Female American mink capture locations and raft coverage .....	13
Recommendations .....	15
The three stage approach: .....	15
Baseline Monitoring Data .....	19
References .....	25
Appendix I - Raft data .....	26
Number of active rafts.....	26
Number of raft checks .....	29
Appendix II - Mink detection rate data.....	34
Appendix III – Prioritising coverage of female capture locations .....	39

## Acknowledgements

The work described in this report was only possible due to contributions and funding from the following organisations and sources, to whom we give thanks: Rivers and Fisheries Trusts of Scotland (Invasive Species and Biosecurity Programme); Cairngorms National Park Authority; Scottish Natural Heritage (the Species Action Framework); University of Aberdeen; Scottish Wildlife Trust; People's Trust for Endangered Species; Tubney Charitable Trust; and the Scottish Government and European Community Cairngorms, Highland, Moray, Rural Aberdeenshire, and Rural Tayside - Local Action Groups LEADER 2007 – 2013 Programme.

## Executive Summary

Overall, the findings of this review highlighted that the work undertaken has been successful in negatively impacting American mink (hereafter referred to simply as 'mink') numbers and in sustaining a network of mink rafts, which are being actively monitored. Native species hitherto affected by mink predation now have the opportunity to recover. In addition, the investigation also illustrated a number of ways in which strategy could be improved to biologically and cost-effectively optimise mink control and monitoring.

Analysis of the raft network data, together with mink detection and capture records, indicate that across the SMI area current levels of mink activity are at less than a third of those recorded in the highest years in the history of coordinated mink control, whilst the numbers of active rafts and raft checks are strong and comparable to those years of high mink activity. Statistical analysis of long term data from three test catchments suggests that, at the catchment level, predicted mink detection rate (a proxy of abundance) decreases to 40 % of the initial level in the fourth year and to only 6 % in the 10<sup>th</sup> year.

An investigation of how mink detections, and in particular female captures, were distributed across different mink rafts, highlighted great variability in the importance of individual rafts and a high level of redundancy, i.e. some rafts that contribute relatively little to mink detection or captures. On the other hand, a relatively small number of rafts (268) were identified as important, constituting the nearest locations of all female mink captures.

An adaptive evidence-based strategy for large scale coordinated mink control, combining the information gained from the analysis of trends in mink abundance following control and the data on the relative importance of different rafts, is recommended. The strategy is defined by three stages, graduating from initial raft saturation, to coverage of a subset of female capture locations for low cost long term monitoring. The gradual decrease in mink raft coverage through this process should respectively be guided by data on mink detections, mink captures and female mink captures.

## History of Control

Large-scale coordinated American mink control has been underway in northern Scotland since 2006, when, under the pilot projects: the Cairngorm Water Vole Conservation Project (CWVCP) and the North East Scotland Water Vole Conservation Project (NESWVCP), in collaboration with fisheries trusts' biosecurity plans, networks of mink rafts and volunteers were initiated across the major river catchments of the rivers Dee, Deveron, Don, Spey, Tay and Ythan. These projects ceased in 2009 and a two year phase of reduced interim funding followed. At the same time, another pilot: the North West Highlands Mink Control Project (2009 – 2011) was initiated, establishing mink control on the rivers Beauly, Carron, Conon, Fleet, Kanaird, Kyle of Sutherland, Oykel, Runie and Ullapool.

The first phase of the Scottish Mink Initiative (SMI 1) was launched in 2011. The SMI 1 demonstrated that mink control could be coordinated on a very large scale using a project based approach, and consolidated mink raft and volunteer networks across the initial pilot project areas, as well as expanding to include the catchments of the rivers Brora, Findhorn, Gruinard, Lossie, Nairn, Naver and Ness, in addition to a number of tributaries, minor river systems, still water bodies and coastal areas. The SMI moved into its second phase (SMI 2) in 2013, which demonstrated that operations could also be successfully coordinated locally on the ground by fisheries trusts, rather than Project Officers. The initiative currently covers an area of c. 29,500 km<sup>2</sup> from northern Tayside across Aberdeenshire, Moray, and the Cairngorms National Park to the north and east Highlands. The southerly boundary runs from Lunan Bay to Forfar to Cupar Angus to Dunkeld to Aberfeldy and out to the west end of Loch Rannoch.

With coordinated American mink control activities now in their tenth year, the aim for the next phase of the process is to investigate and implement the mainstreaming of cost effective approaches developed in the previous phases within the framework of the Scottish Invasive Species Initiative (SISI). To this end this review evaluates key metrics of the SMI's activities and outcomes, in order to assess: 1) the current status of the SMI's coverage and activity; 2) impacts on American mink population levels; and 3) to analyse and harness the evidence accumulated over the last 10 years to inform and optimise large scale coordinated American mink control strategy.

## The Mink Raft Network

The main tool used to detect and trap mink is the mink raft. Originally conceived by the Game and Wildlife Conservation Trust (GWCT) (Reynolds et al. 2004), the mink raft is a floating platform with an attached tunnel, which covers a clay pad (Fig. 1). The raft is anchored to the bank of a waterway. Mink are predominantly active within 10 m of waterways (Yamaguchi et al. 2003) and being naturally curious and attracted to tunnels, investigate the raft, passing through the tunnel and leaving footprints on the clay pad. Rafts can be operated by volunteers or dedicated staff. When

footprints are detected during a raft check a live capture cage trap can be inserted in the tunnel to attempt to capture the mink. Since 2006, 2020 mink rafts have been deployed, however, the number active at any one time has varied annually as is described in the following section. In 2013, in collaboration with dot.rural (<http://www.dotrural.ac.uk/>) the MinkApp online platform (<http://smi.abdn.ac.uk/>) was launched as a tool for centralised data management and also to provide natural language generation feedback to users. The MinkApp now serves as the principle way in which data (e.g. records of: SMI contacts/volunteers; raft locations/status; raft checks; and mink sightings and captures) are stored and accessed.



Figure 1: Illustrating the GWCT mink raft used for mink monitoring and control. Left – rafts are anchored to the river bank and a smoothed clay detection pad is placed inside the tunnel. Centre – the clay pad is checked periodically for mink footprints. Right – if mink footprints are detected a trap is set on the raft to capture the mink.

## Annual Trends in the Mink Raft Network

Various metrics of the mink raft network activity reflect both the different phases of the work, as well as the overall geographical expansion of the SMI area through time (Fig. 2 & Fig. 3). The various funding phases are clearly apparent in the number of rafts deployed per year (Fig. 3 - left), which increases from 2006 to 2008 - the main time span of the CWVCP/NESWVCP - dropping slightly in 2009 as these projects came to an end, and then to a low in 2010 when there was an interim phase between funding tranches. This number increased dramatically with the commencement of SMI; over 350 new rafts were deployed in 2011 and over 450 deployed in 2012, dropping to around 200 for each of the years 2013 and 2014 as local coordination of the SMI passed from Project Officers to the local fisheries trusts, and, with mink monitoring and control already established in most areas, the requirement for new rafts to be deployed was reduced. In total, 2020 rafts were deployed between 2006 – 2015 and 994 of those recorded at least one raft check. Note that not all operators of mink rafts actively record the data, even though they may check the raft regularly. In some cases these active rafts may be confirmed by communication between a volunteer and a staff member, or by verification in the field.

The number of active rafts per year (those that were deployed in a given year; were deployed in a previous year, but confirmed active in a subsequent year; or where a raft check was recorded in that year) showed a general increase through the duration of the project, with the highest numbers qualified as active in 2012, 2013 and 2014 (Fig. 3, middle). Over 600 rafts were confirmed active in 2014, and 538 have been confirmed in the 12 months preceding July 2015. Decreases in the raft network during phases of reduced funding (2009 – 2010 & 2013 – 2015) were relatively small and demonstrate that efforts to sustain the raft network at these times have been successful.

The number of raft checks recorded each year have generally been high, at above 1200, although they dropped by around 1000 during the first interim phase (2010 – 2011). However, this has recovered strongly, with the highest record of over 2600 being reported in 2014 (Fig. 3, right). In the past 12 months (July 2014 – July 2015) 2776 raft checks were recorded from 300 rafts (note an additional 238 rafts were confirmed active, but did not record checks).

It is to be expected that the number of new rafts deployed will closely follow the funding of various phases of the work, as new hardware is required to fulfil raised goals, expanding into new areas and consolidating existing ones. During interim phases of reduced funding there is typically no expansion of the project boundaries and so the deployment rate of *new* rafts drops. However, the ethos of the initiative was to sustain the network of *existing* rafts, and the volunteers and practitioners that check them, in the long term. Therefore, it is important that the number of confirmed active rafts and raft checks do not unsystematically and rapidly decrease during periods between funding or interim funding phases, or following changes in how the work is coordinated. The graphs in Figure 3 clearly demonstrate that the project has been successful in building a sustained raft network. The number of active rafts has only dropped off gradually following the main funded phases, which is to be expected as coordinators will remove, or not replace, rafts from locations that are deemed unimportant for mink following a period *in situ*. Ideally, the raft network should be gradually phased down systematically to cover mainly essential locations as mink abundance decreases and the frontline of the project moves elsewhere. How and when this should be done is discussed in subsequent sections of this report.

The successful implementation and promotion of the MinkApp online recording system is also clear to see. In the first interim phase (2010 – 2011) there is a substantial drop in the number of raft check records submitted. This is unsurprising as at that time records were submitted from volunteers to Project Officers who would then record the data electronically. With broad scale usage of the MinkApp coming through from 2013 there has been a strong surge in the recording of raft check data, with the highest numbers yet recorded in 2014 and looking positive for 2015, where > 1500 checks have been submitted in the first seven months. This highlights the utility of the online data recording system as a way of maintaining a strong and accessible evidence base for assessing the SMI's activity and impact.

Whilst examining total measures of the raft network provides a useful overview of work being undertaken, there is much variation across the catchments within the 29,500 km<sup>2</sup> of the target area, and this is further described and discussed in Appendix I. Broadly speaking, the available information on the raft network reflects the different stages that river catchments are at in terms of mink management, the resources that have been available for mink control in different areas, and the willingness of local coordinators and volunteers to submit information through the MinkApp. In all areas there are ways in which the richness of information and/or the distribution of rafts could be optimised, and this is covered in the Recommendations section of this report.

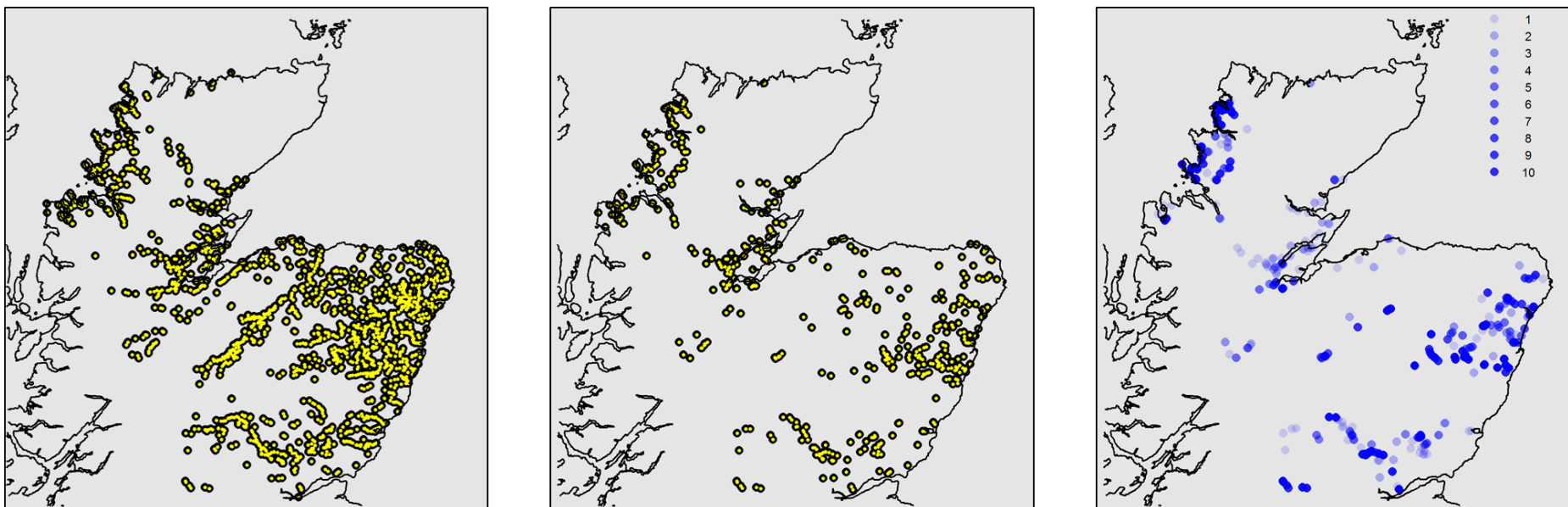


Figure 2: Maps illustrating mink raft coverage across the project area: Left - the locations of the 2020 rafts deployed between 2006 and 2015. Centre - the locations of the 538 rafts known to be active between July 2014 and July 2015 (deployed, confirmed active, or recorded a raft check since July 2014). Right - the distribution of the 2776 raft checks recorded between July 2014 & July 2015. The location of rafts where checks are recorded are indicated by blue dots, and the intensity of the blue reflects the number of checks as shown in the key in the top right.

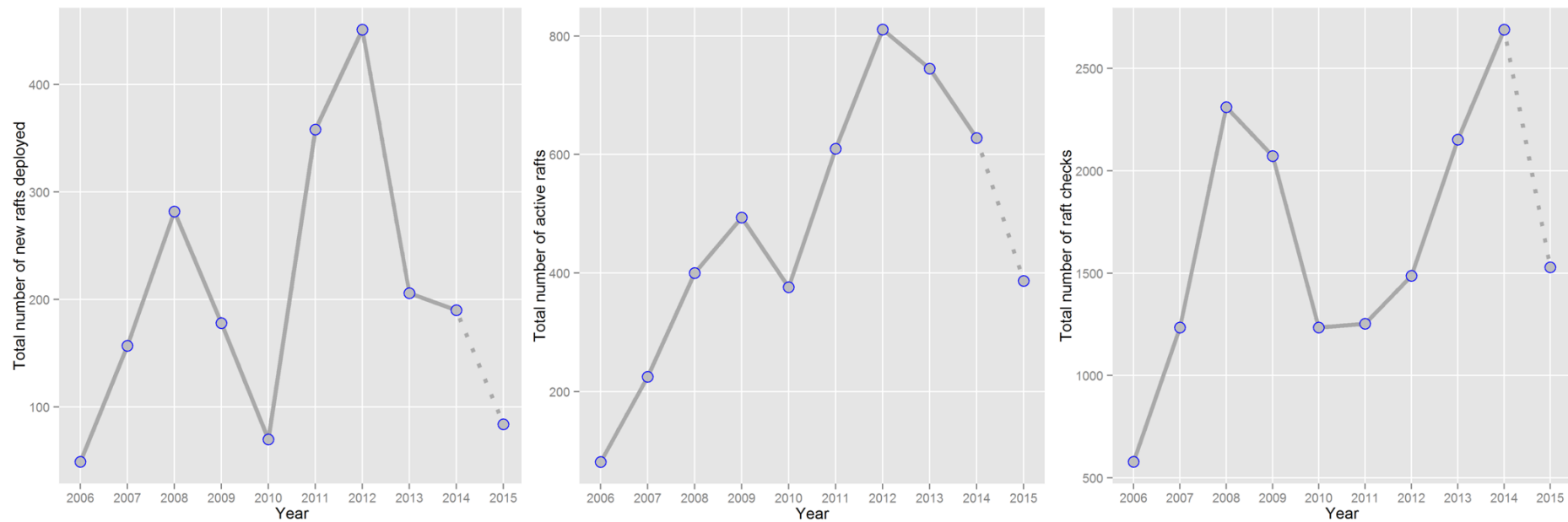


Figure 3: Graphs illustrating temporal trends in the mink raft network: Left, the number of rafts deployed per calendar year. Centre, the number of rafts confirmed active per calendar year. Right, the number of raft checks recorded per calendar year. The hatched lines between the data points for 2014 and 2015 indicate that the 2015 values are based on only 7 months data, up to July 2015.

## Annual Trends in Mink Detections

Of central interest to this review is the question – is large scale coordinated mink control having a substantial, biologically significant, impact on mink population levels? The best (least biased) data available to answer this are mink raft check records, which provide an incidence rate (number of checks where mink footprints are detected / total number of checks) and are therefore much less biased by relative effort than other metrics, such as number of captures, would be.

Of 16,544 raft checks recorded since 2006, 1,358 (8 %) have been positive for mink footprints. Generally, at the large scale, these have been distributed across the raft network (Fig. 4, left; and see Fig. 3 for reference to the raft network coverage). The exception to this is the area north of the Great Glen, where very few mink have been detected, despite there being relatively good raft (or the land based equivalent – the tracking tunnel) coverage and monitoring around a number of catchments, or areas. This is consistent with the view that the northern extent of the mink population in Scotland lies around Loch Broom and Ullapool on the west coast and the Dornoch Firth in the east (Fraser et al. 2013).

Across the entire SMI area, and considering all raft check records submitted in a calendar year, there has been a steady and substantial decline over the last few years, from a positive check rate of around 0.14 in 2011, to an all time low of around 0.02 in 2015 (with the caveat that the latter value does not include the autumn dispersal period). Whilst this trend reflects positively on the impact of mink control, taking such a broad overview does hide the influence of a number of factors. Breaking the trend down to individual catchments (see Appendix II), we can see that the decrease and very low current detection rates are largely driven by substantial reductions in catchments where mink control has been ongoing for many years (e.g. the rivers Dee, Ythan and Spey, Figs. 19 & 20, Appendix II), but also by an increase in mink surveillance in areas where initial mink densities appear to be very low, such as the far north west including Assynt, Gruinard and Kylesku (Fig. 21, Appendix II).

Of 2776 raft checks submitted between July 2014 and July 2015, mink footprints have been recorded in 86, and these have been primarily concentrated down the east coast, from the Tay catchment (as is expected from a frontier catchment receiving an influx of dispersing mink from outside of the control area) to far north east Aberdeenshire. A scattering of positive checks have also been recorded in more northern and western areas including the Oykel, Kylesku, Runie, Ness and Beaully. The apparent gaps in mink activity to the east of Inverness, and also around the North Esk and Bervie in Angus, should be interpreted with caution, as the amount of available evidence from this area, in terms of raft check records, is generally poor, as illustrated in Figure 2.

Changes in the overall detection rate can be hard to interpret due to mink control beginning in different catchments at different times, and also the level of effort within those catchments varying through time. Therefore, in order to simplify the process of evaluating how mink detection rate (as a proxy for abundance) is affected by mink control, an analysis was carried out on the data available for three 'test' rivers: the Dee, Spey and Ythan. These catchments represent the longest consistent available data; in each catchment mink control started in 2006 / 2007 and an active raft network has

been in place and monitored since. A statistical model analysing how mink detection rate changes with year of mink control, showed a clear and statistically significant ( $P < 0.0001$ ) negative effect on mink detection rate (Fig. 5; Table 1, Appendix II). Based on the fitted curves, the model predicts that mink abundance will be reduced to c. 40 % of the starting abundance in 4 years and further to around 6 % of initial levels after 9 years. A large amount of the uncertainty in the model's predictions (illustrated by the 95 % confidence intervals [shaded areas] in Fig. 5) is attributable to differences between the catchments, rather than the overall estimate of the effect of mink control (Table 1, Appendix II). In particular, the fitted curve poorly reflected the trend on the River Ythan, where the mink detection rate persisted at a high level for a number of years before dropping off abruptly, rather than following a smooth decrease (Fig. 20, Appendix II). This pattern corresponded with mink control extending to cover the lower catchment of the River Don, which is immediately adjacent to the Ythan, but had hitherto been largely unattended. Forty-four mink were removed from the Don in 2011 – 2012 and this will have contributed to stemming a flow of immigrants between the rivers. Due to the dispersal ability of American mink, the number of mink in a catchment depends on control both within that catchment and in neighbouring catchments. This highlights the importance of taking a coordinated multi-catchment approach to mink control.

The overall trends are also very strongly influenced by a small number of rafts. Whilst a majority of rafts never detect any mink footprints, a few record many (Fig. 5 – right). The analysis accounted for this 'raft effect' which explains why the fitted curves on Figure 5 are lower in some cases than the detection rates apparent in the raw data as shown in Figures 19 & 20, Appendix II. This variation in the relative contribution of individual rafts to overall detection rates is important and relevant to improving the control strategy. Of the 994 rafts that recorded at least one raft check, 637 (64 %) never recorded mink footprints (Fig. 5 – right). Therefore, all of the information on mink presence came from a relatively small subset of the raft network (357 rafts, 36 %). In fact, a mere 59 rafts – only 6 % of all rafts to have recorded a raft check – were responsible for 637 (53 %) of the 1307 positive checks recorded. Although these figures are affected by the time that a raft is in place and monitored, prioritising the maintenance and monitoring of these rafts will nevertheless help to optimise the efficiency of mink control efforts. This is further discussed in the Recommendations section of this report.

Whilst the analysis shows that in different river catchments we should expect variability in the abundance of mink and the rate of decrease following control, it also provides a useful guideline to what we can predict in general, which – allowing for some variability – will help to estimate timelines for future targets, and also to inform long term strategy and costing. However, though this analysis can provide rough guidelines around trends, an additional source of information is available through the accumulation of capture data, which provides a richer knowledge on how large scale coordinated mink control can be effectively optimised. This is the focus of the following section.

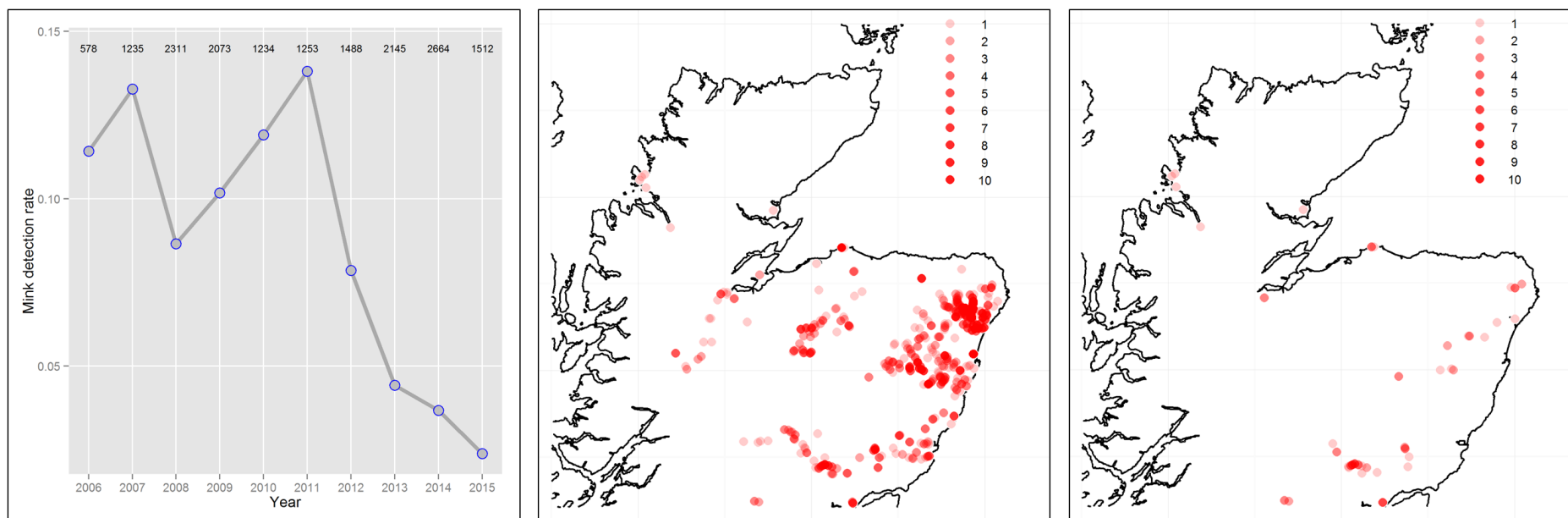


Figure 4: Left – Changes in the mink detection rate (number of positive raft checks / total number of raft checks) per year of coordinated mink control. Numbers above the points show the total number of checks that the rates are estimated from. Centre – Map of mink detections (positive raft checks) across the mink control area between 2006 and 2015. The colour intensity of the dot relates to the number of detections as shown by the key in the top right. Right – Map of mink detections recorded in the past 12 months (between July 2014 and July 2015).

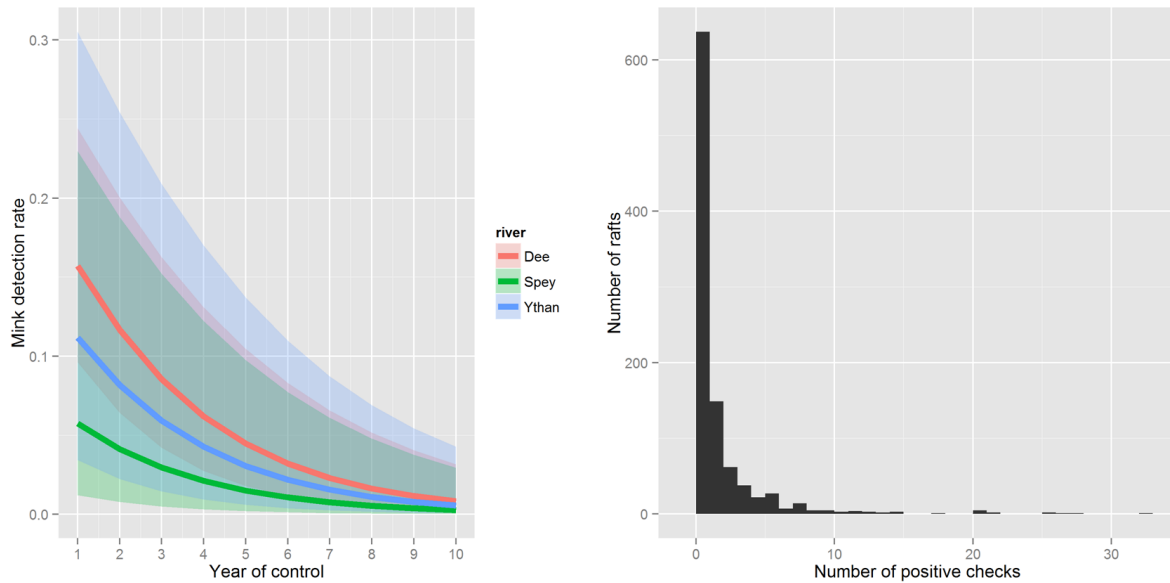


Figure 5: Left - Illustrating the effect of mink control on mink detection rates (abundance). The solid coloured lines are fitted curves for three different river catchments (see key). The coloured shaded areas are 95 % profile confidence intervals, which account for the uncertainty around all estimated parameters. The greatest amount of uncertainty is attributable to differences between the catchments, rather than the estimate of the effect of mink control. The statistical model is a generalised linear mixed effects model (GLMM) and accounted for differences between catchments, which was fitted as a fixed effect and as an interaction with time of mink control (i.e. the effect of mink control was allowed to vary by catchment). Non-independence between multiple records from the same raft(s) was accounted for by fitting raft as a random effect. Right - Histogram, showing the number of rafts that have reported each value of positive checks in the range 0 – 32 (the maximum). The data are based on the 994 rafts that recorded at least one raft check.

## Trends in American Mink Captures

Around 1600 mink have been trapped since the large scale coordinated mink control effort on mainland Scotland began in 2006. The trend in mink captures follows that of the detection rate of mink on mink rafts, with a substantial decrease from over 280 in 2012, to only 98 mink captured in the past 12 months, to July 2015 (Fig. 7 – left). Generally speaking, mink have been captured in most areas of the raft network (Fig. 7 – centre). The areas with the highest numbers of captures reflect both productive habitat for mink and, in some areas, a long history of control effort. In agreement with the mink raft detection data, nearly all of the captures in the last 12 months are from lowland or coastal areas, indicating an overall contraction of the mink population (Fig. 7 – right). It is also worth noting that historically a large number of mink have been captured in areas where few mink detections have been recorded on rafts (Fig. 7 – centre). This is indicative of active control being carried out in areas/catchments where mink raft operators and trappers do not necessarily report raft check data.

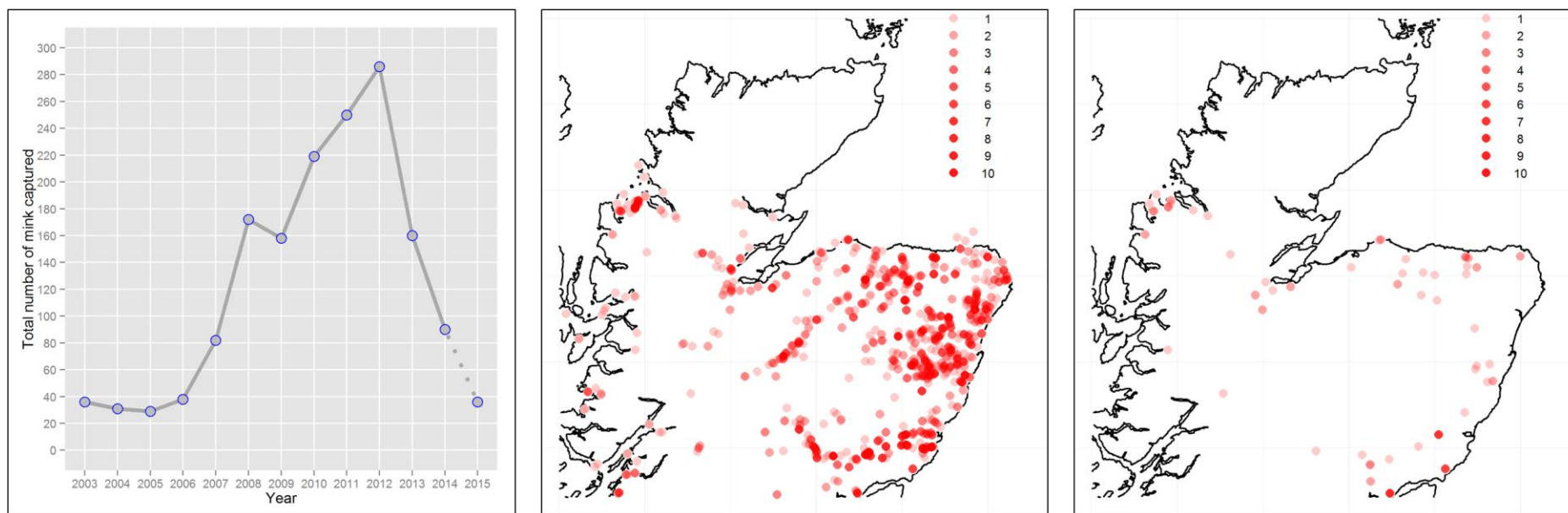


Figure 6: Illustrating the mink capture data. Left – the number of mink captured annually. The dotted line indicates that data for 2015 are only based on seven months, to July 2015. This graph also includes data from pilot projects pre-2006. Centre – map showing the locations of all mink captured. The intensity of the red indicates the number of mink captured at a given location (see key in the top right). Right – map showing the locations of mink captured in the last 12 months.

### Female American mink capture locations and raft coverage

The previous sections provide an encouraging overview of the status of the mink control effort on mainland Scotland, with the mink raft network being sustained at a good level of coverage, large numbers of raft checks being submitted by volunteers and staff, and a general decline in both mink detection rate and mink captures. Additionally, the previous sections also highlighted that within the mink raft network *all rafts are not equal*, with a relatively small proportion of rafts being responsible for the majority of mink records. Therefore, there is a level of redundancy that could be altered to improve the effectiveness of mink removal and overall cost-efficiency as the relevant information on mink presence becomes available. However, the optimisation of the raft network requires that hand-in-hand with reducing redundancy, comes ensuring that the positioning of rafts targets priority areas for mink control, and that areas of high mink productivity are adequately covered and not overlooked.

From a population biology perspective, removing breeding female mink will have the largest relative impact on population growth rates and *vis a vis* the success of control. Therefore, to reduce mink numbers to near zero requires that all female mink are located and culled before being able to breed. In Figure 8 we see the locations of 489 female mink captures (which have spatial location data available) overlaid on top of the network of rafts that have been confirmed active between July 2014 and July 2015. Even at this very broad scale it is clear that there are a number of areas where female mink have been captured (red-scale dots on the map), which are not covered by a raft that is known to be active (yellow dots). Looking at this in finer detail, the histogram in Figure 8 shows that, whilst 172 (35 %) and 246 (50 %) female mink capture locations are within 1 km and 2 km of a currently active raft respectively, 108 (24 %) have no presently active raft within 5 km. Ensuring that female mink capture/breeding locations are covered should be a priority, addressed on a catchment by catchment basis. The data required for this are provided in Appendix III, and an example of optimisation of a raft network, reducing rafts, but increasing coverage of female capture locations at the catchment level is provided in the Recommendations section of this report.

Individual mink rafts also varied in importance, both in terms of their locations with respect to female mink capture sites, and also how many females had been captured at each raft. A set of 268 rafts could account for being the (historic) closest raft deployment location for all of the 489 female mink captured. Moreover, 111 of these raft locations were the closest to 2 or more female captures (Fig. 8 – right). In fact, these 111 raft locations were the closest for 332 (68 %) of female capture locations. This is a relatively small number of rafts, equivalent to about 20 % of the current raft network and 5 % of all rafts ever deployed. The locations of these rafts is shown in the map in Figure 8, and a list of the raft ids, coordinates and other relevant information is now available for strategic optimisation in the next phase of the mink control process. The maintenance, retention (or reinstatement) and monitoring of these rafts should be a top priority for the mink control strategy.

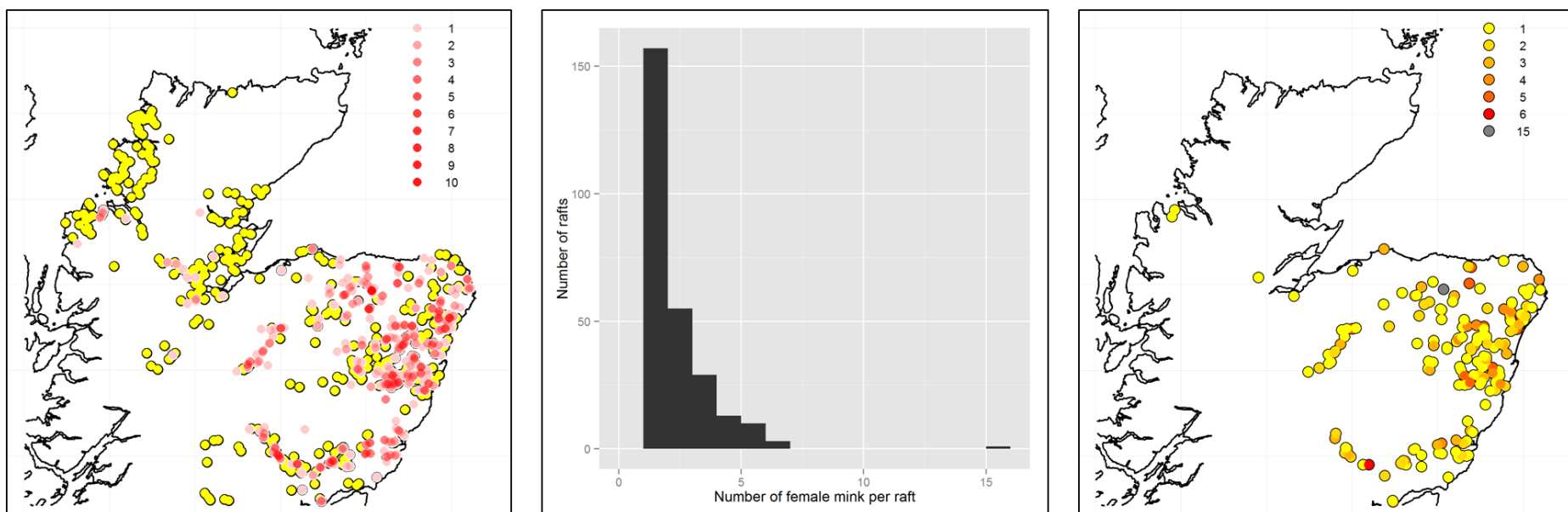


Figure 7: Left, Map showing 489 female mink capture locations (red-scale dots) overlaid across the network of mink rafts that have been confirmed as active in the past 12 months (since July, 2014). The intensity of the red dots relates to the number of female mink captured at a particular location following the key in the top right. Centre, Histogram showing the frequency of female mink captures per raft (i.e. where the raft is the nearest to the capture location) for the 268 rafts that were closest to the capture locations of 489 female mink. Right, Map showing the distribution of these 268 *priority* rafts (i.e. those that are the nearest to female capture locations). The key indicates the number of female mink captures associated with each raft location and is an indicator of priority.

## Recommendations

The data reviewed not only provide valuable information about both the success and status of the project, but also how strategy can be optimised to maximise the rate at which mink are removed, whilst minimising costs and effort. The analysis of the trends in long term mink abundance following control indicated that abundance will be more than halved following four years of control and reduced to < 10 % by ten. The distribution of deployed rafts should be reduced over this timescale to reflect the predicted decrease in an adaptive manner, informed by the capture data collected. The goal is to start with a saturated raft network that monitors as much as possible of the suitable mink habitat based on some simple proxies, such as altitude and land use, and end with a fraction of the number of rafts and greatly reduced coordination requirements, monitoring only the key areas for mink breeding in the catchment. This approach makes two key assumptions: firstly, that mink are using most of the available habitat in the initial stages of control; therefore, providing the requisite information on female breeding locations following control. Secondly, that mink, as a highly mobile and generalist predator, effectively acquire information from the environment and subsequently make dispersal and settlement decisions based on habitat quality. Thus, as the population is reduced through control, it would be predicted that the best habitat will be preferentially reoccupied, and this information is available to the project as locations where breeding female mink were previously captured. Researchers at the University of Aberdeen are currently investigating the preferential use of habitat by mink in different population density scenarios and how this could help to optimise mink control. These analyses should help to further inform the mink control strategy in the future.

Ideally, the process of moving from establishing a saturated raft network in a new catchment to long term monitoring of key sites should be a graduated process through three main stages (Figs. 9 & 10). Strategic reviews of raft and capture data should be carried out annually between local and central coordinators to assess targets concerning priority areas, and to adapt the raft network based on the relevant information as it becomes available. The data required to move toward Stage 2 (see below) for the catchments currently under mink control are provided in Appendix III. Fundamentally, the two data requirements are accurate information on the locations and monitoring status of most active rafts, and the locations and sex of captured mink. The previous sections of this report highlighted that in some catchments the available data on raft coverage and monitoring are poor, and don't necessarily reflect reality. These areas of poor data reporting would require to be addressed in order for the evidence based strategy to work effectively.

### The three stage approach:

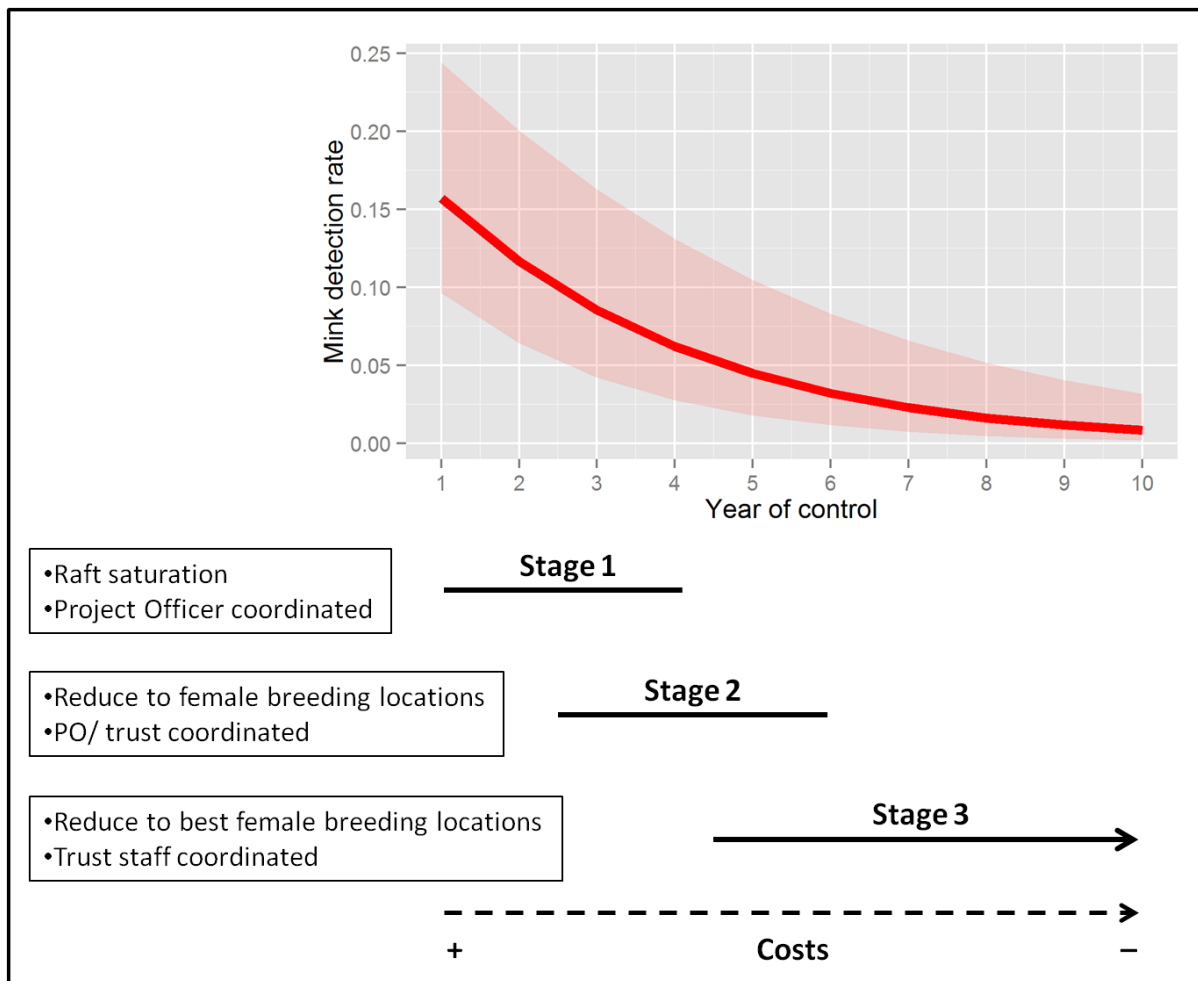
**Stage 1: Saturation.** Rafts should initially be deployed at c. 2 km intervals across suitable habitat using altitude and/or the grassland/moorland ecotone as a guideline. This can be identified relatively easily with GIS or a combination of OS maps, Google Earth and field surveying. Initially the most likely areas should be prioritised: lower river intersections; coastal areas; areas of high productivity inferred from where mink are captured in other areas (typically where there is a good prey base). At this stage the aim is to establish a comprehensive raft network that can detect all areas where mink are present and guide trapping to rapidly reduce the population. It is essential to achieve access permissions and engage volunteers wherever possible, but the latter should not be to the detriment

of establishing the raft network at this stage. This phase will put a relatively high deployment, maintenance and trapping burden on the local coordinator.

**Stage 2: Evidence based reduction.** Based on the data obtained during Stage 1, map out the capture locations of female mink (consider whether to include female mink in the dispersal phase [ $< 1$  year old, Sept – Nov]) and ensure that all are covered by the raft network. Each location should preferably have a raft within 1 km, and certainly within 2 km. Assuming that most suitable mink habitat is being used in the initial stage of mink control, these sites of previous female breeding should be settled/recolonised first when made vacant by trapping. This should represent a substantial contraction of the catchment's raft network, and ideally priority rafts should be matched with a dedicated and reliable volunteer whenever possible. Those rafts that have never recorded any mink footprints (outwith the male rutting season, when non-breeding habitat may be temporarily occupied) should be removed first.

**Stage 3: Reduced long term monitoring with responsive redeployment.** Informed by captures in Stage 1 and 2, and following evidence of a much depleted local mink population, the raft network should be further reduced, prioritising coverage of the most productive of female mink capture locations and maintaining an even spread across the catchment, whilst maximising the efficiency of raft locations to cover multiple female capture locations where possible. Raft deployment can be scaled up in any areas where 'flare-ups' are detected in the local area. Note that it may not be possible to transition from Stage 2 to Stage 3 in areas where control is not ongoing in adjacent catchments due to the constant impact of recolonisation through dispersal. If the majority of rafts within a catchment at Stage 2 are monitored by volunteers it may not be necessary to downscale to Stage 3 if the costs of maintenance and coordination are sufficiently low to be sustainable in the longer term.

The coverage of female capture locations by currently active rafts on 18 of the major river catchments under mink control is illustrated in Figures 22 – 26 in Appendix III. These maps show a traffic light priority system: female capture locations that are well covered (i.e.  $\leq 1$  km to the nearest raft) are green; those that have some coverage ( $\leq 2$  km to the nearest raft) are amber; and those with poor coverage and in need of urgent attention (no raft within 2 km) are red. A high level of variability can be observed in both the current raft coverage in general, as well as how well raft coverage corresponds to female capture locations. To establish at which of the three stages each catchment is placed, requires mapping out all historic raft locations (to ensure Stage 1 saturation, and the potential to map female breeding locations, has been achieved ) and then using the green-amber-red system to adjust raft coverage to reflect Stage 2 and subsequently Stage 3 objectives.



**Figure 8: Schematic of a graduated three phase strategy for mink control.** In Stage 1 (years 1 – 4) mink abundance is at its initial maximum. A saturated raft network is deployed, which rapidly reduces abundance and provides the requisite data on breeding female mink locations to inform the transition to Stage 2. Rafts can begin to be removed on the basis of mink absence following annual data reviews. With greatly reduced mink abundance the target for Stage 2 is to cover and monitor all known female mink breeding locations. Once these sites have been established as free of breeding mink the raft network can be further reduced during Stage 3, focussing on the most prolific sites and optimising raft locations to maintain an even spread across breeding habitat. Reactive redeployment may be required in response to localised increases in mink activity. The data presented are based on the River Dee. The aim of the strategy is to actively adapt the raft network in a cost effective way, based on the best available evidence and scientific understanding.

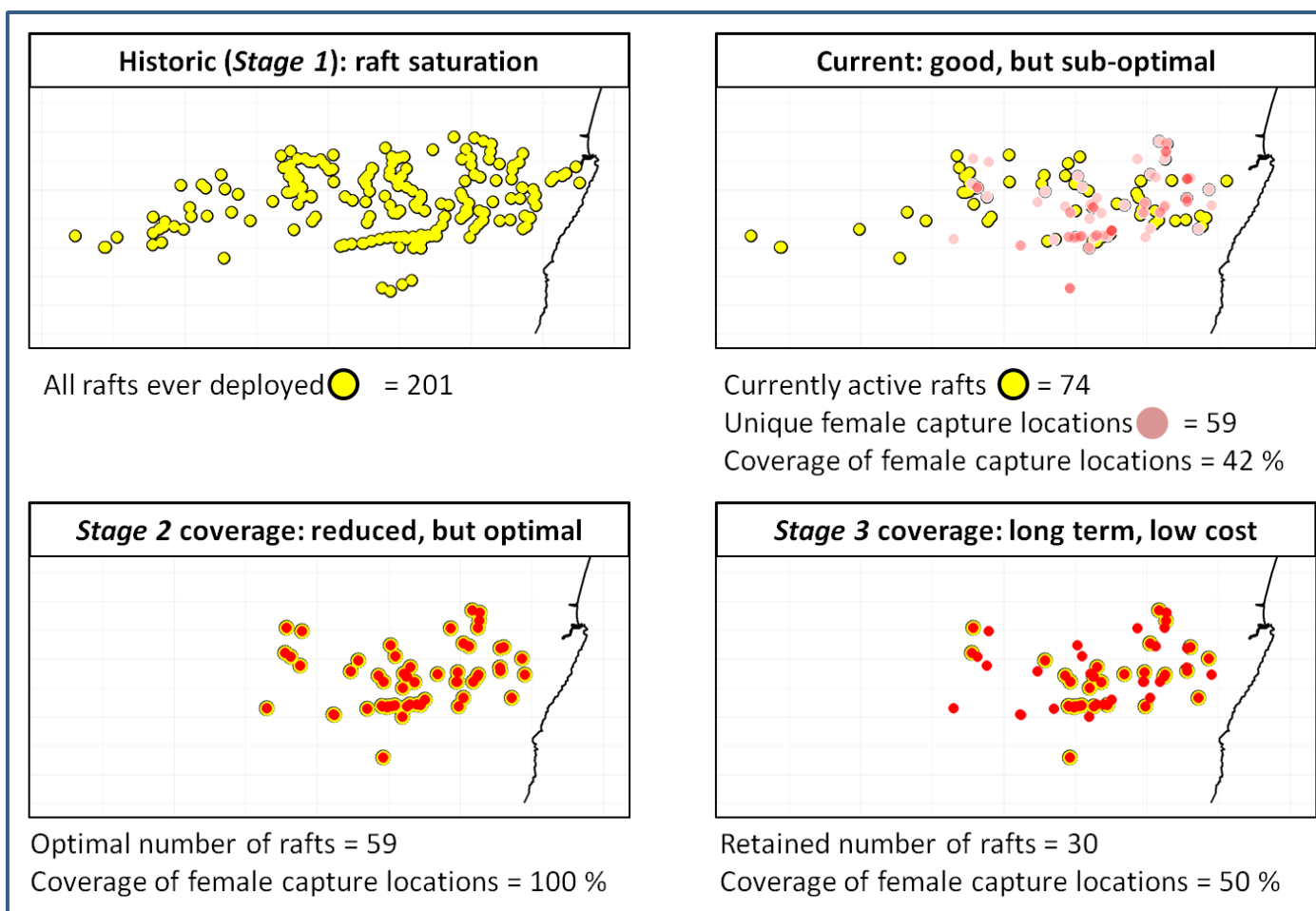


Figure 9: Illustrating how the distribution of female mink captures could be used to adaptively reduce the mink raft network through a three stage strategy, using the River Dee as an example. From top left to bottom right the maps show: top left – the locations of the 201 rafts ever deployed, consistent with *Stage 1* saturation; top right – the current scenario with a good number of rafts in action, but 42 % of female capture locations not covered (i.e. no raft < 1 km); bottom left - based on the capture data collected an ‘optimal’ *Stage 2* distribution of rafts, requiring 20 % less than the current network, but covering 100 % of female capture locations; bottom right – a random selection of 50 % of female capture locations covered for *Stage 3* low cost, long term monitoring. In reality the rafts retained would be selected based upon their productivity and maintaining an even spread across the catchment.

## Baseline Monitoring Data

Although a wealth of data has been collected between 2006 and 2015 through raft check and mink capture records, it was apparent that there was considerable variation in the amount of data available for different catchments across the SMI area. As a general recommendation this situation should be improved, as the provision of monitoring and capture data will be fundamental to implementing, and demonstrating the success of, an adaptive mink control strategy. It is important to note that a proportion of the SMI's activities (monitoring of some mink rafts or e.g. regular patrolling of fishing beat by fishing ghillies) may provide limited data, as some individuals are happy to be practically involved with the project, but have little or no interest in recording data. Therefore, it is also useful to establish a guideline for the minimal amount of data that is required to provide robust estimations of mink population levels in order to measure the success of control efforts. To this end, an investigation was carried out performing simulations based on the long term data collected from the Dee and Ythan catchments.

The aim of the exercise was to estimate the precision and uncertainty of estimates of mink presence obtained from different raft coverage scenarios for different levels of mink occupancy (number, or proportion, of all potential territories where a mink was present) within a catchment. As can be observed in Figure 24, Appendix III, the number of unique female capture locations (a proxy for number of breeding territories) for the Dee and Ythan, were around 60 and 20 respectively. Computer simulations were run with mink being randomly assigned to territories for scenarios of 80 %, 60 %, 40 %, 20 %, 10 %, and 5 % occupancy (a territory to which a mink was randomly assigned was considered occupied). This is equivalent to 48, 36, 24, 12, 6 and 3 of 60 potential mink territories being occupied in the Dee scenario, and 16, 12, 8, 4, 2 and 1 of 20 territories being occupied in the Ythan scenario. Different raft coverage scenarios were then applied to each occupancy scenario, using the same approach and randomly assigning rafts to 80 %, 60 %, 40 %, 20 %, 10 %, and 5 % of potential mink territories. This resulted in 36 and 30 different occupancy vs raft coverage combinations for the Dee and Ythan scenarios, respectively. Since the simulated level of occupancy was 'known' this could be compared to that which was 'observed' or detected by the raft network. The random simulation process was repeated 1000 times for each occupancy – raft coverage combination to obtain a probability distribution of outcomes to understand how well a given coverage of rafts should detect a given occupancy of territories by mink. Thus, each of 1000 permutations of the simulation process generated a different allocation of rafts and mink to potential territories where the detected occupancy could be compared to the known occupancy. An example to illustrate this is presented in Figure 10.

One of the implicit underlying assumptions of the exercise is of 100 % detectability i.e. a raft will always detect a mink assigned to the same territory. We do not currently have estimates of detectability for mink on mink rafts, though research being carried out by the University of Aberdeen may help to inform this in the future. Notwithstanding, the mink raft method has been extremely effective at decimating mink population levels over relatively short periods of time, which suggests that detectability is high, particularly if considered over longer periods of time that will include multiple raft checks, rather than the probability of detecting a mink that is present with a single raft

check. As a rule of thumb the lower the detection probability the higher the required number of rafts to maintain the same accuracy. On average the number of rafts required to maintain the same level of accuracy will generally be the reciprocal of the detection probability multiplied by the estimated required number of rafts (e.g. if the estimated required number of rafts is 20 and the detection probability is 0.9 the new required number of rafts would be c. 22; if the detection probability is 0.5, the required number of rafts would be 40, etc).

The simulations are also based on female territories, rather than territories *per se*, since this is more relevant to Stages 2 and 3 of the proposed mink control strategy which will aim to target female territories. The inferences to be taken from the simulations may therefore be less applicable to the initial stage of mink control, before female capture locations have been identified. However, assuming an approximately even sex ratio, the same number of rafts placed in good mink habitat (according to expert knowledge) should on average detect the same level of occupancy (of females and/or males), though the margins of error would increase.

A secondary, and related, issue is that adjustments in the positioning of rafts based upon acquired capture data will likely bias estimates of mink presence, since 'blind' positioned rafts early in the control process are less likely to be encountered by mink than those that are subsequently targeted to known capture locations. One way around this is to keep the core of baseline monitoring rafts at fixed locations. However, this is likely to be inconvenient and non cost-effective for control operations. As such, if baseline monitoring rafts are relocated to target known capture locations it should be understood and acknowledged that this is likely to upwardly bias estimates of mink presence relative to earlier years.

The results of the simulation exercise are presented in Boxes 1 & 2. For the Dee scenario (60 potential territories, Box 1) a raft network covering 40 % of potential female territories (24 rafts) accurately estimates mink presence across the range of 80 % to 10 % of territories being occupied. However, at 5 % occupancy (3 of 60 territories occupied) the lower 95 % confidence interval of mink presence for 40 % raft coverage is at zero. Notwithstanding, a mink presence of > 0 was recorded in 80 % of simulations with 40 % raft coverage and 5 % occupancy. Therefore, in practical terms 0 mink recorded with 40 % raft coverage could confidently be interpreted as representing between 0 and 5 % occupancy. In this scenario, c. 40 % coverage and c. 24 well placed rafts would be the *minimum* core data requirement for monitoring changes in mink population levels.

For the Ythan scenario (20 potential territories, Box 2) a greater percentage level of raft coverage was required to obtain accurate estimates with a reasonable level of certainty across the range of percentage mink occupancy. In fact, 80 % (16 of 20) coverage of potential territories was required to obtain lower 95 % confidence intervals above zero at 10 % occupancy, but even this was not entirely sufficient with 5 % occupancy, where a 20 % false negative error rate was observed. Nevertheless with 80 % coverage, zero mink detections could be interpreted with confidence as mink being present at 0 to 5 % (equivalent to only 1 occupied territory) in catchments of that size.

These simulations provide a guideline to the number of rafts that would need to be maintained and monitored to provide robust estimates of mink population levels with constant effort surveying. The number would have to be adjusted for different catchments, but extrapolating from the scenarios here, based on the Dee and Ythan, should be relatively straightforward. From both a biological and management perspective the principal period of interest is the breeding season, when most animals

are settled, rather than being in flux during dispersal or the rut. Annual surveys should suffice for a core of high quality monitoring data and these should consist of a first visit to make sure the raft is in good order with fresh clay, etc, followed by at least one subsequent visit  $\geq$  two weeks later to check for mink footprints. Further follow up visits would be desirable and three checks (a total of 4 visits) should allow an 'estimation' of detectability, which would increase the robustness of population estimates. The recommendation is to carry out 'Annual Mink Survey' events across the Initiative area, involving as many volunteers and practitioners as possible to perform and record raft checks according to a standardised protocol. This approach has been successfully implemented by Saving Scotland's Red Squirrels for obtaining annual data on the distribution and population levels of red and grey squirrels across NE Scotland. Such surveys are effective in concentrating and engaging stakeholders as well as gathering a large amount of high quality data, the results of which are fed back to participants in an annual report.

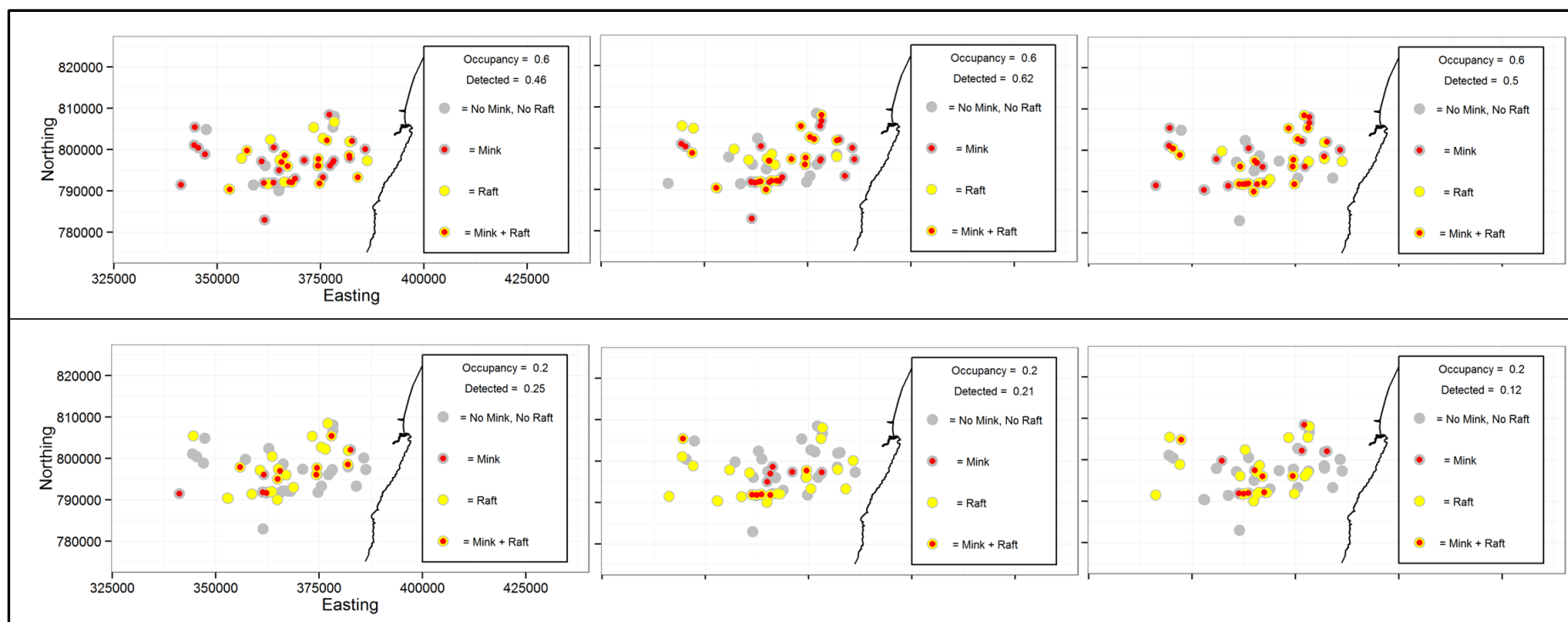
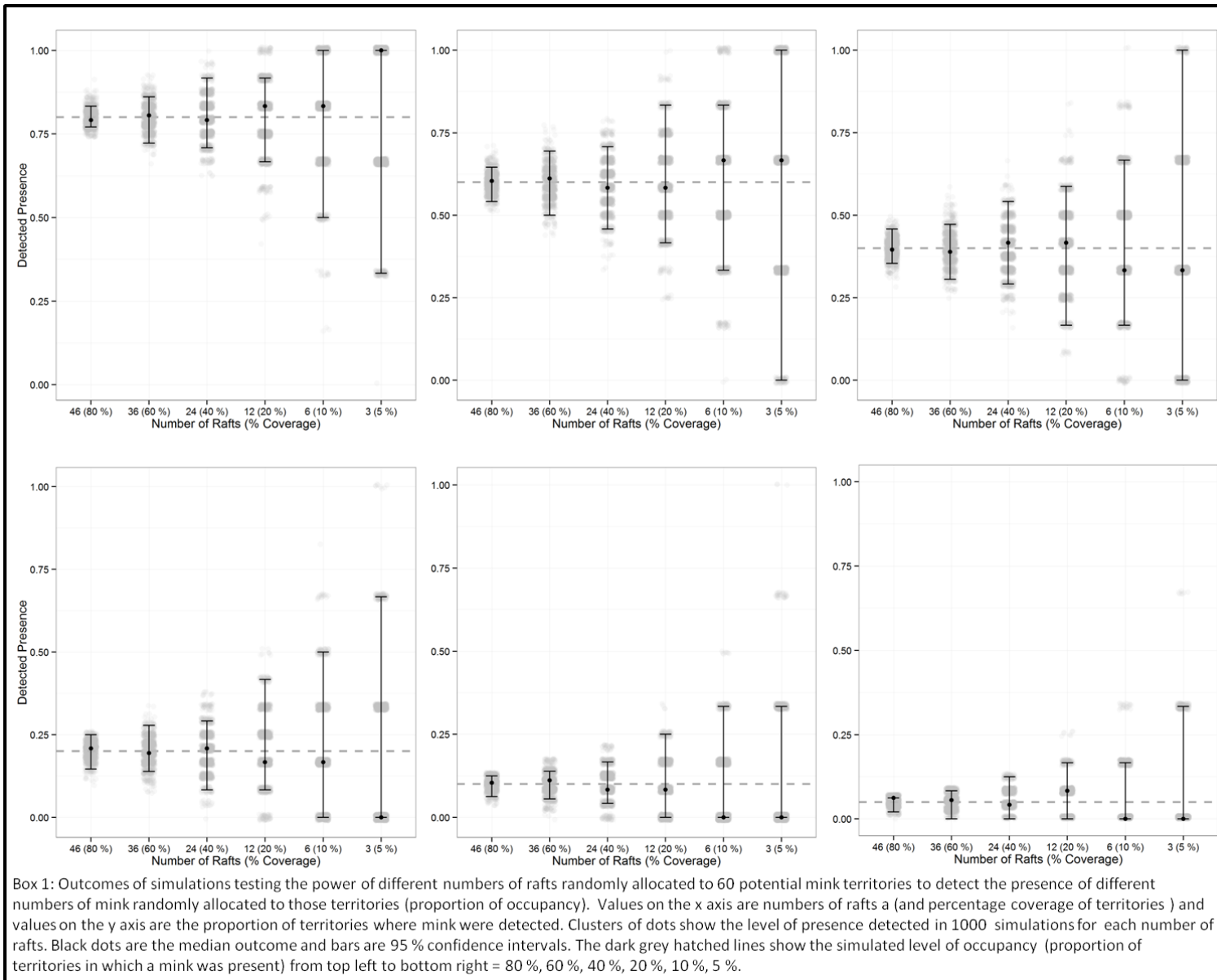
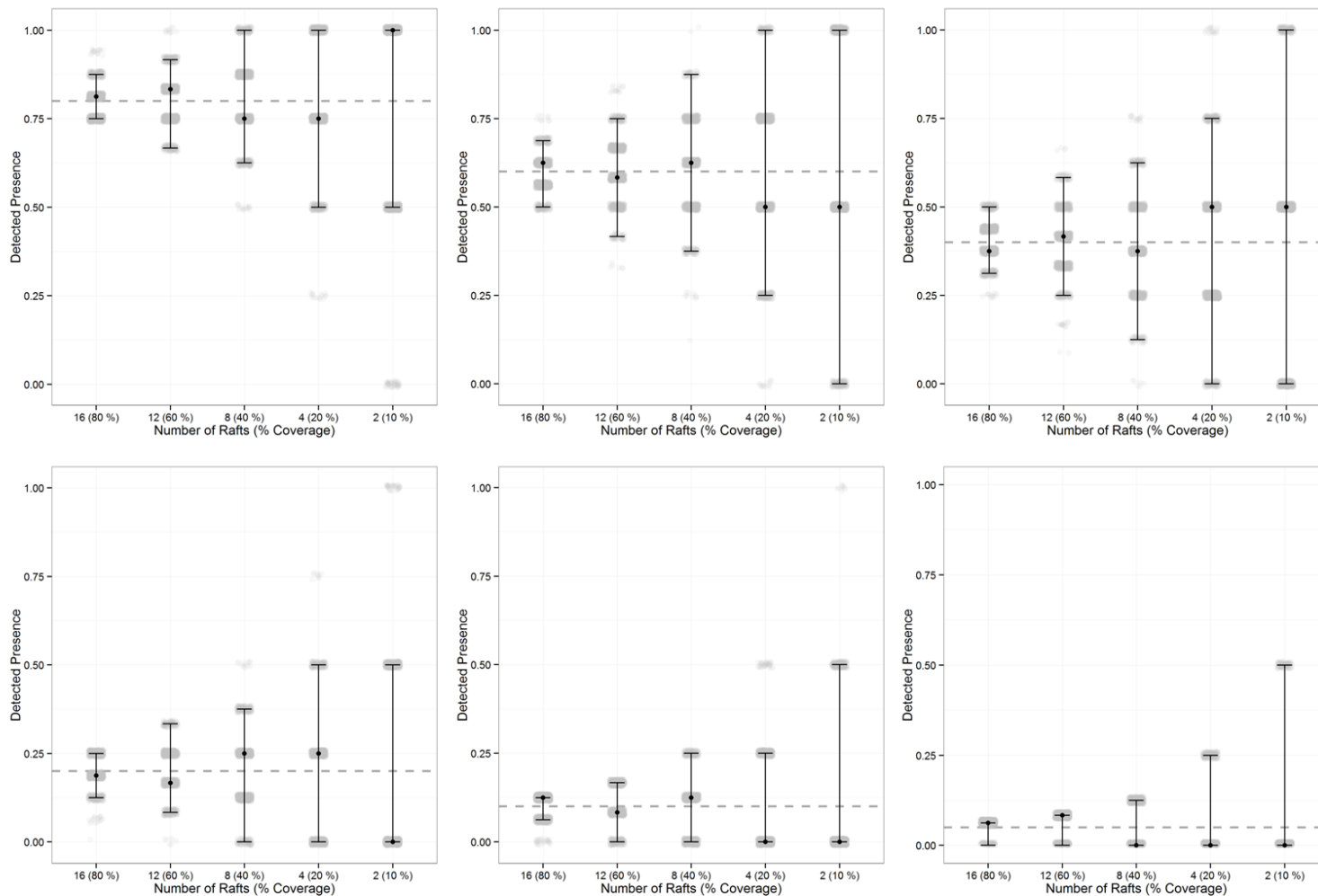


Figure 10: Illustration of the simulation process using the River Dee example with 59 unique potential female mink breeding locations (all dots). The figures on the top row show the outcomes of different independent randomised permutations when the occupancy (proportion of breeding sites that are occupied by mink) is 0.6 (i.e. 60 %; 35 mink are randomly allocated to any of the 59 breeding locations) and raft coverage is 0.4 (i.e. 40 %; 24 rafts are randomly allocated across the 59 breeding locations). The figures on the bottom row show outcomes of different permutations when the occupancy is 0.2 (i.e. 20 %; 12 mink are randomly allocated to any of the 59 breeding locations for the same raft coverage of 0.4). Grey dots = potential breeding locations that are not allocated a female or a raft. Grey dots with a red interior = potential breeding sites that are occupied by a mink. Grey edged yellow dots = potential breeding sites that are allocated a raft. Grey edged yellow and red dots = potential breeding sites that are allocated a mink and a raft. When a mink and raft are allocated to the same location the location is recorded as occupied. The parameter of interest is the detection rate ('Detected' in the key) and how well that corresponds to the actual occupancy ('Occupancy' in the key). The figure shows that each permutation of the simulation process can produce very different arrangements of rafts and mink across the 59 potential breeding locations. How well 'Detected' = 'Occupied' informs us of the probability that a given raft coverage will precisely estimate a given level of occupancy. Whilst these show the outcomes of only three different permutations for each of two levels of occupancy, the simulations repeated this process 1000 times to generate the distributions of detected presence illustrated in Box 1 & 2. The 40 % raft coverage used here was chosen as this is the minimum level of coverage recommended for core data required to accurately measure a range of mink occupancy levels for a catchment of this size.





Box 2: Outcomes of simulations testing the power of different numbers of rafts randomly allocated to 20 potential mink territories to detect the presence of different numbers of mink randomly allocated to those territories (proportion of occupancy). Values on the x axis are numbers of rafts a (and percentage coverage of territories ) and values on the y axis are the proportion of territories where mink were detected. Clusters of dots show the level of presence detected in 1000 simulations for each number of rafts. Black dots are the median outcome and bars are 95 % confidence intervals. The dark grey hatched lines show the simulated level of occupancy (proportion of territories in which a mink was present) from top left to bottom right = 80 %, 60 %, 40 %, 20 %, 10 %, 5 %.

## References

Bryce R., Oliver M.K., Davies L. & Gray H. (2011) Turning back the tide of American mink invasion at an unprecedented scale through community participation and adaptive management. *Biological Conservation*, 144, 575-583

Fraser, EJ; Macdonald, DW; Oliver, MK; Pieltney, SB Xavier Lambin Using population genetic structure of an invasive mammal to target control efforts – an example of the American mink in Scotland. *Biological conservation*, 167:35-42.

Reynolds, J.C., Short, M.J., Leigh, R.J., 2004. Development of population control strategies for mink *Mustela vison*, using floating rafts as monitors and trap sites. *Biological Conservation* 120, 533–543.

Yamaguchi, N., Rushton, S. P. & Macdonald, D. W. (2003). Habitat preferences of feral American mink in the Upper Thames. *Journal of Mammalogy* 84:1356–1373.

## Appendix I - Raft data

### Number of active rafts

The following graphs illustrate annual trends in the number of rafts recorded as active within specific river catchments. For convenience, catchments are assigned to being in southern, eastern, central or north western parts of the mink control area.

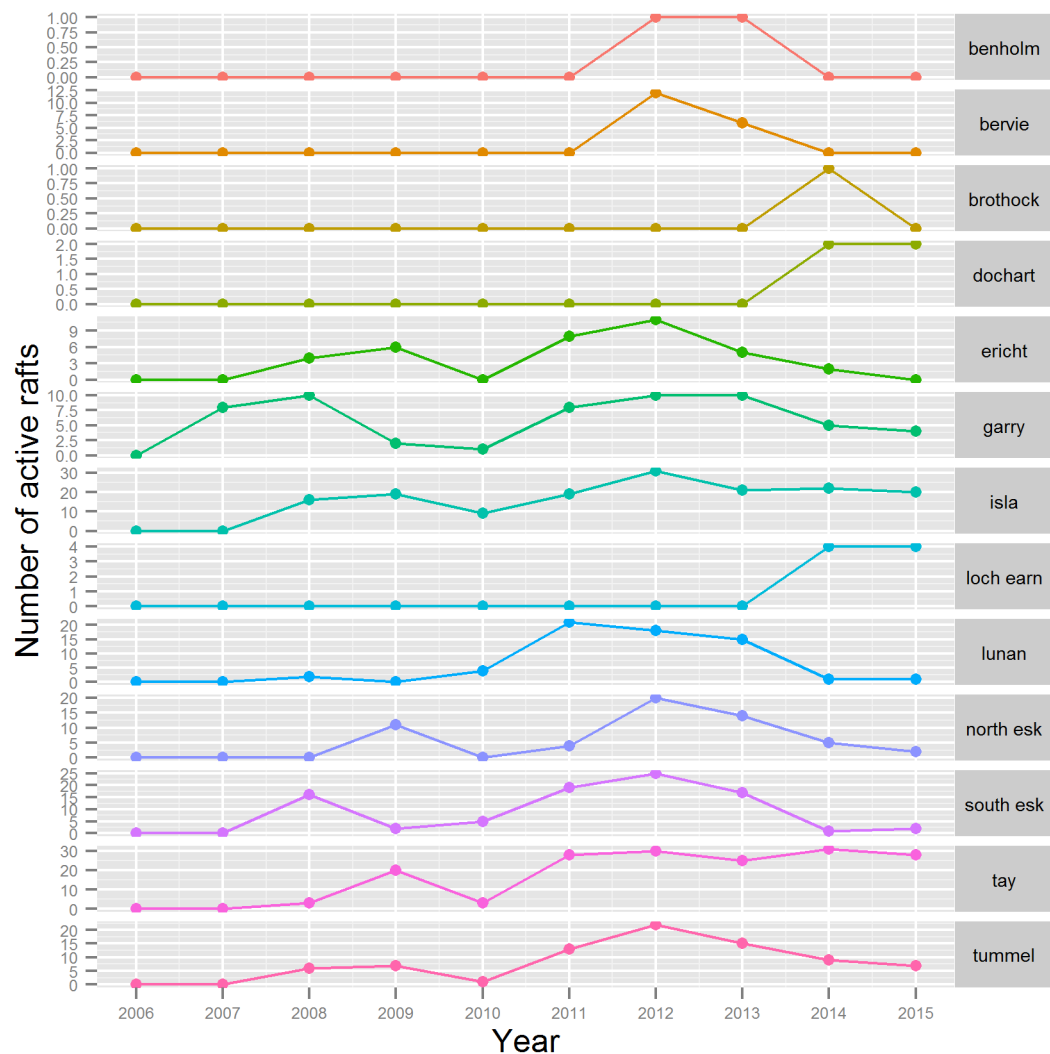


Figure 11: Active rafts (confirmed active before and after, or during that year; deployed in that year; or submitting a raft check in that year) for catchments in the southern part of the mink control area. Note the scale of the vertical axis changes between catchments.

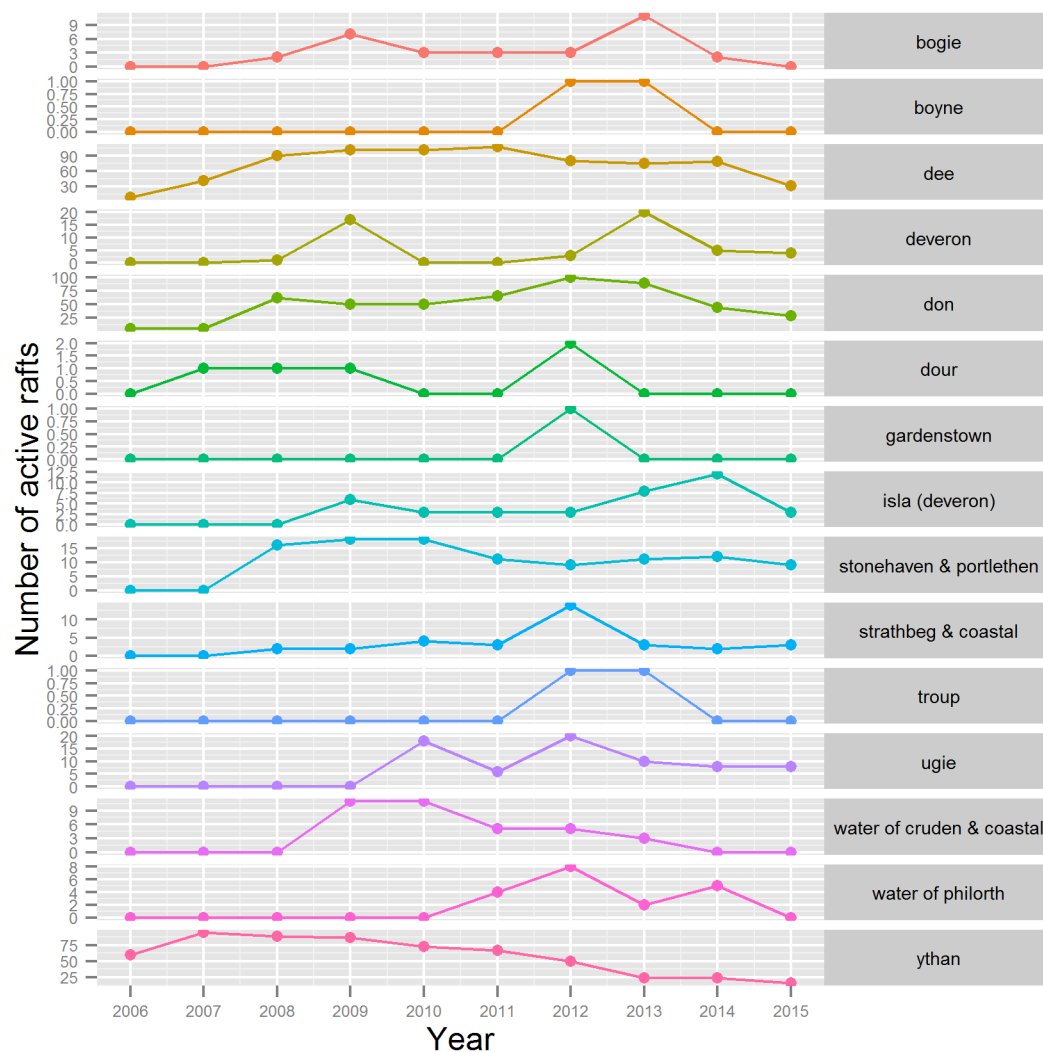


Figure 12: Active rafts (confirmed active before and after, or during that year; deployed in that year; or submitting a raft check in that year) for catchments in the eastern part of the mink control area. Note the scale of the vertical axis changes between catchments.

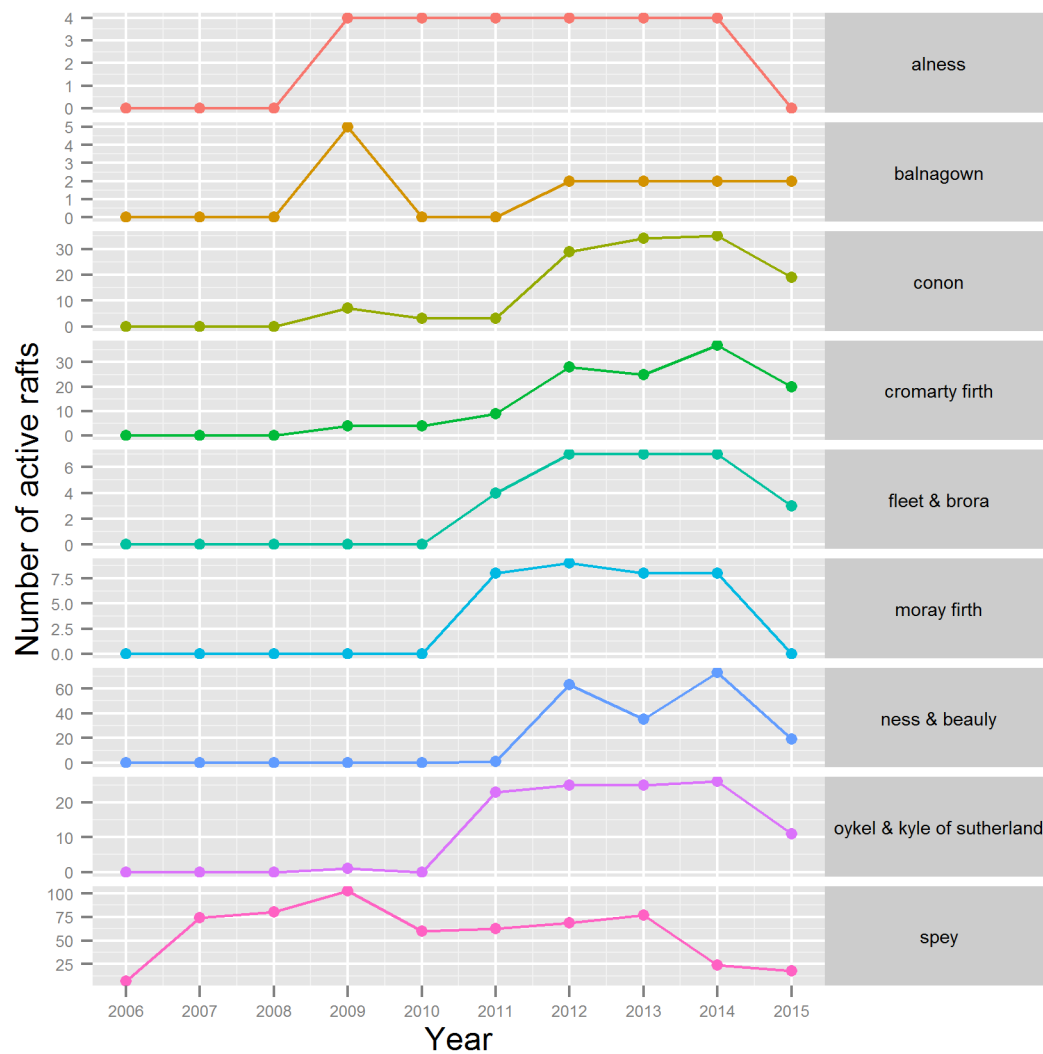


Figure 13: Active rafts (confirmed active before and after, or during that year; deployed in that year; or submitting a raft check in that year) for catchments in the central part of the mink control area. Note the scale of the vertical axis changes between catchments.

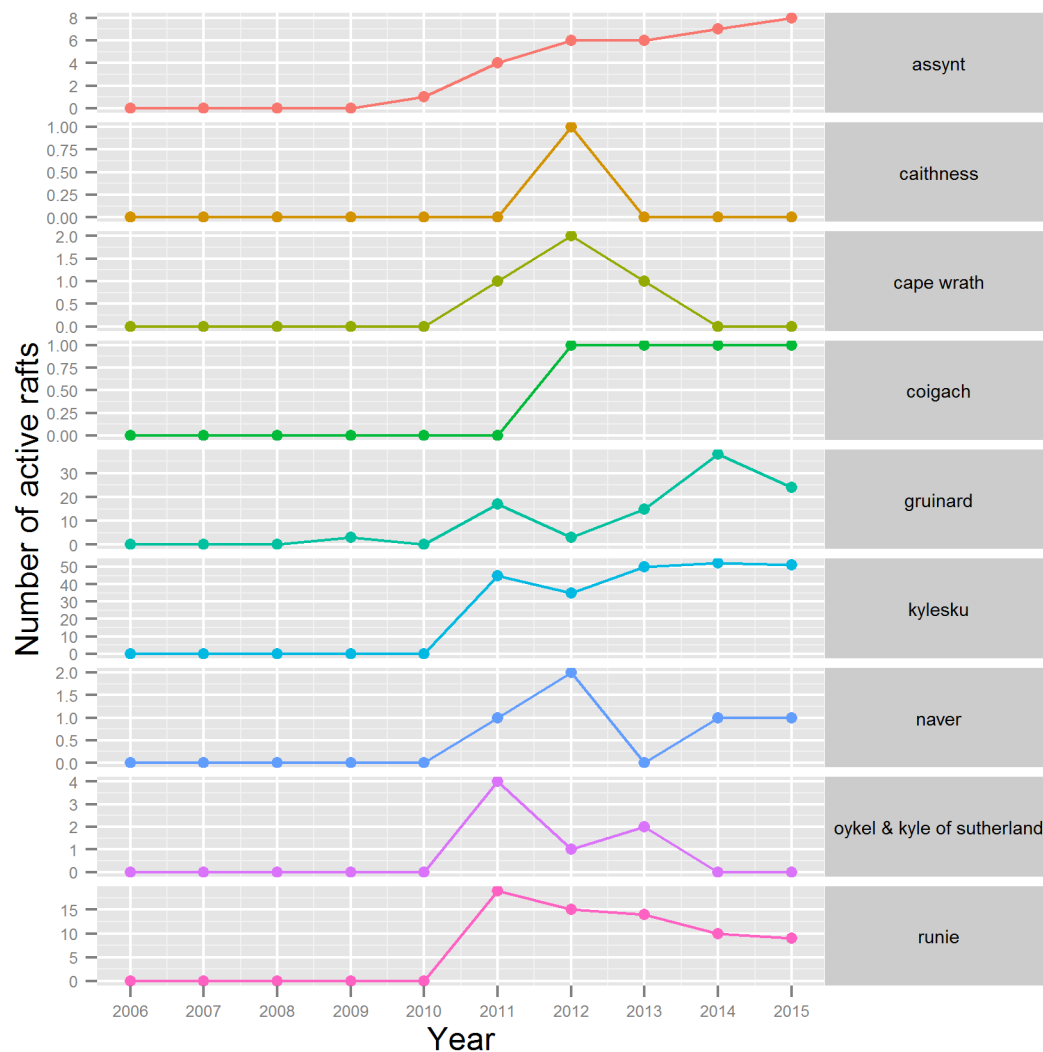


Figure 14: Active rafts (confirmed active before and after, or during that year; deployed in that year; or submitting a raft check in that year) for catchments in the north western part of the mink control area. Note the scale of the vertical axis changes between catchments.

## Number of raft checks

The following graphs illustrate annual trends in the number of raft checks recorded within specific river catchments. For illustrative purposes, catchments are assigned to being in southern, eastern, central or north western parts of the mink control area.

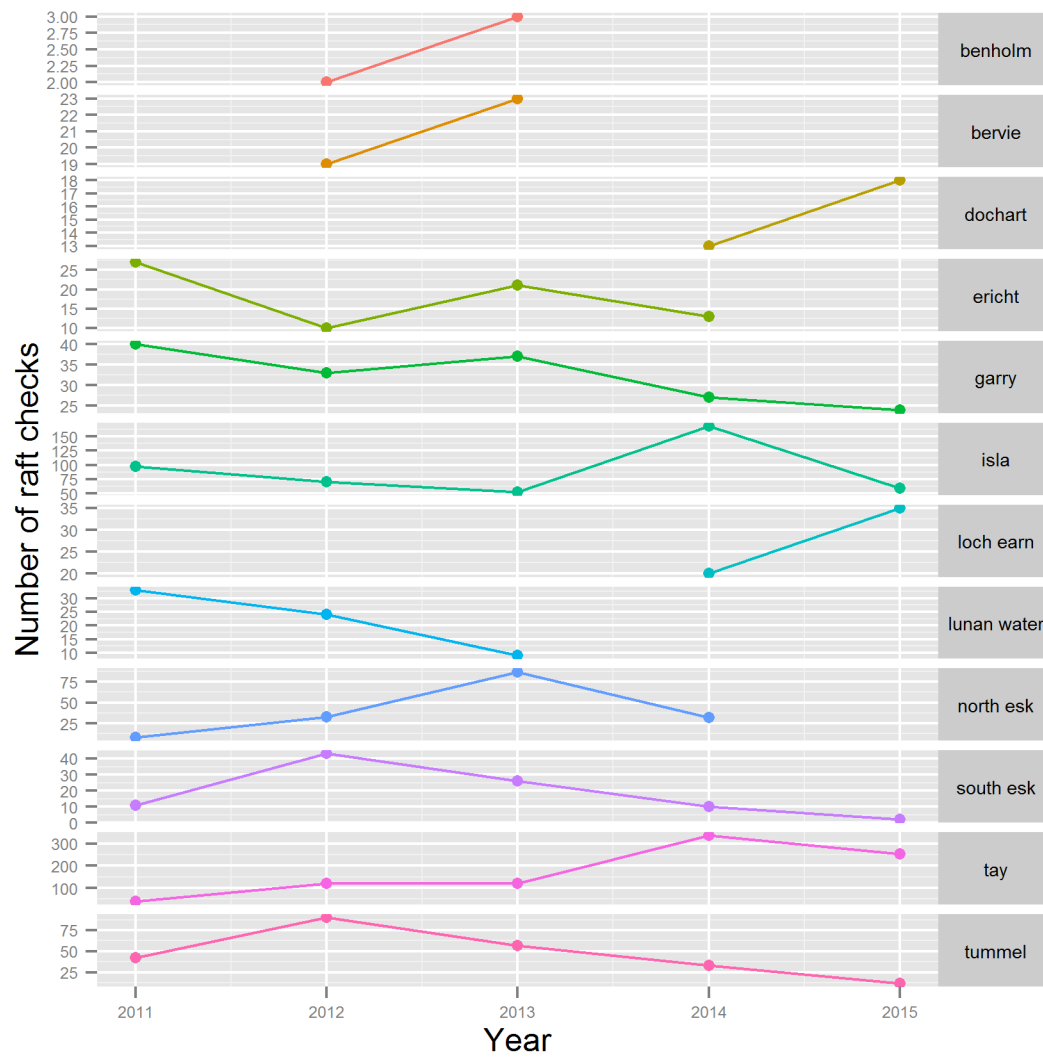


Figure 15: The number of raft checks per year for catchments in the southern part of the mink control area. Note that the scale on the vertical axis changes for each catchment.

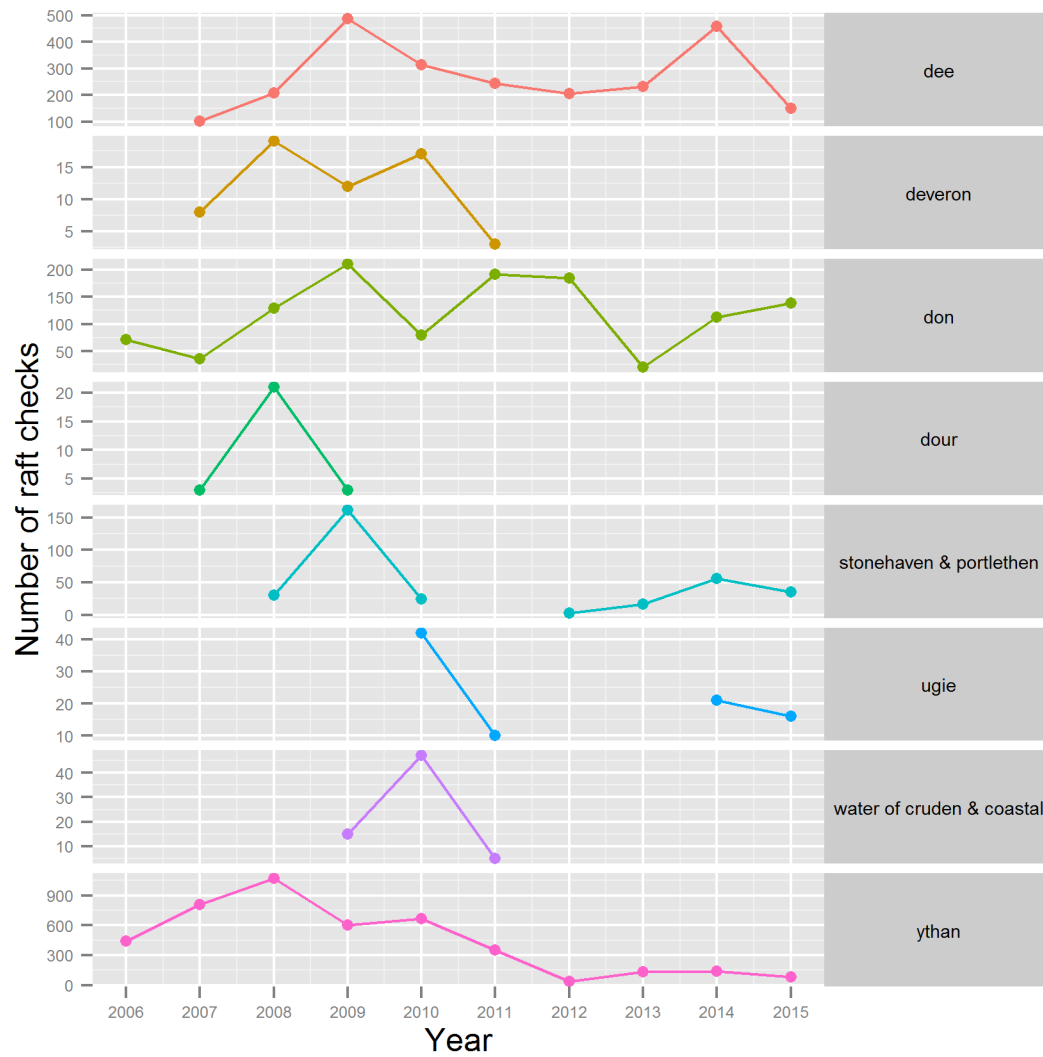


Figure 16: The number of raft checks per year for catchments in the eastern part of the mink control area. Note that the scale on the vertical axis changes for each catchment.

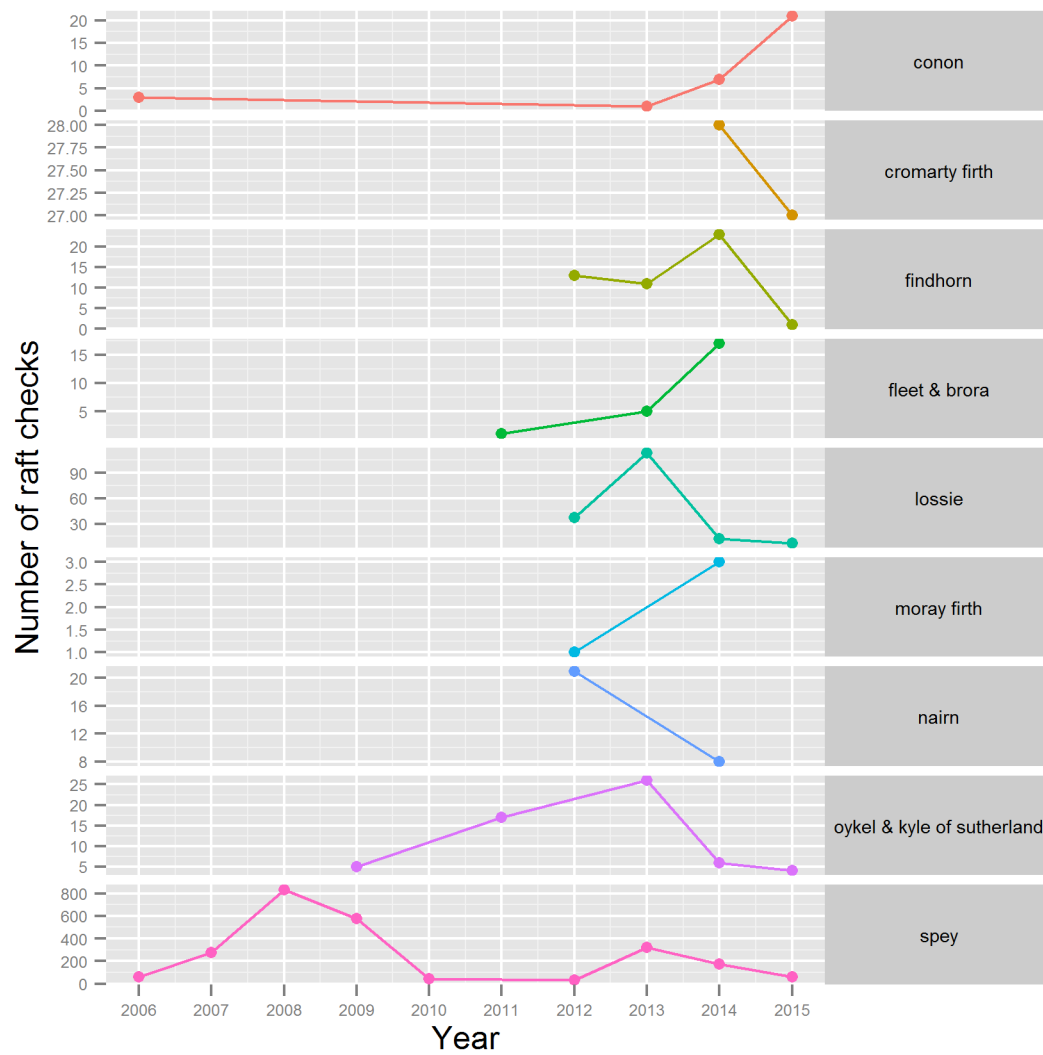


Figure 17: The number of raft checks per year for catchments in the central part of the mink control area. Note that the scale on the vertical axis changes for each catchment.

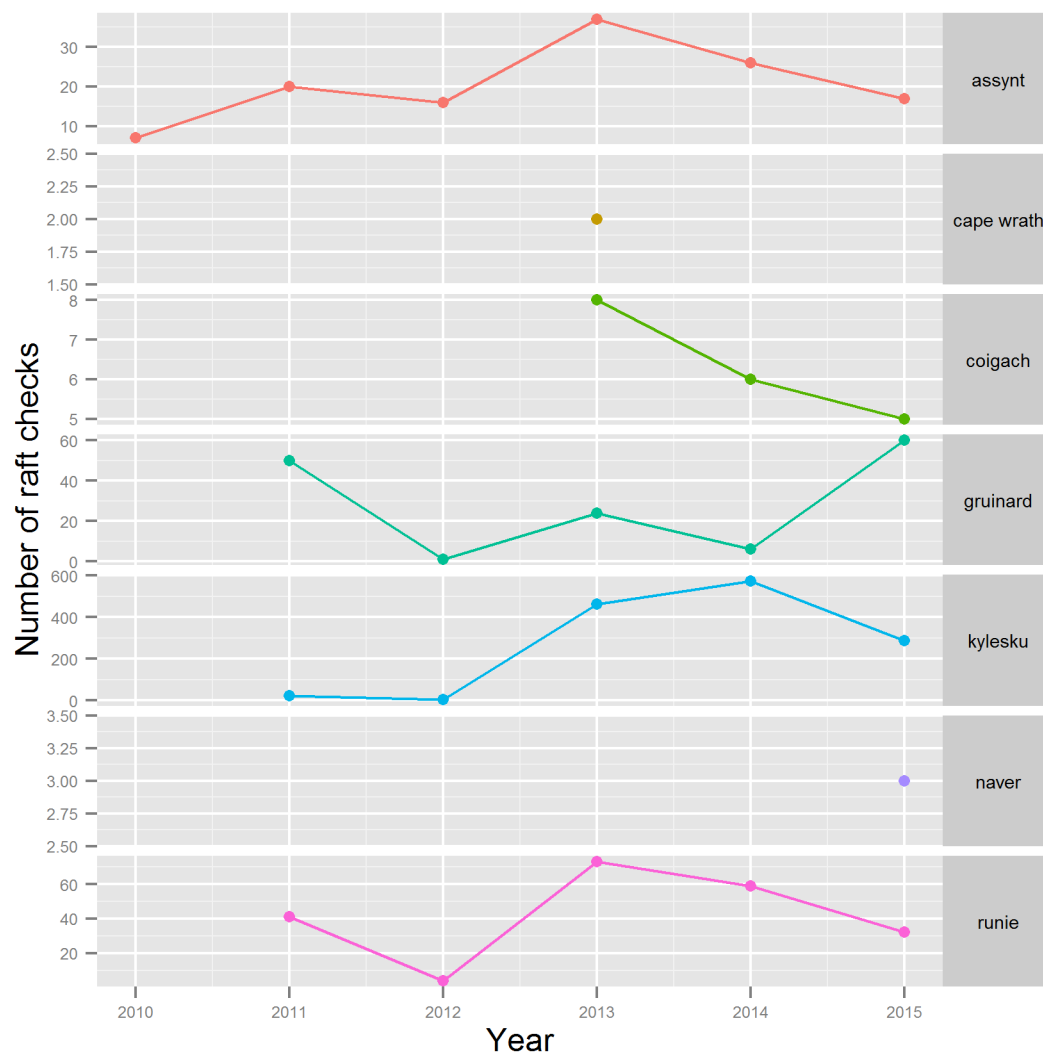


Figure 18: The number of raft checks per year for catchments in the north western part of the mink control area. Note that the scale on the vertical axis changes for each catchment.

## Appendix II - Mink detection rate data

Table 1: Summary table for a generalised linear mixed model (GLMM) analysing the relationship between mink detection rate (per raft check) and the year of mink control (of a river catchment). Data are for the rivers Dee, Spey and Ythan. The top row shows the number of observations (raft checks) and groups (individual rafts) in the data, as well as the residual degrees of freedom for the model, and the variance and standard deviation for the random effects (raft id – included to account for non-independence). The rest of the table shows the parameter estimates, standard errors (both on the logit scale), Z & P values for the fixed effects in the model, which included catchment and an interaction between year of control and catchment.

Observations: 9086	Groups: 399	Residual d.f. 9079	Variance: 1.57	St. dev: 1.25
	Estimate	S.E.	Z value	P value
Intercept	-1.33	0.24	-5.67	< 0.0001
Year of control	-0.35	0.05	-7.27	< 0.0001
Catchment (Spey)	-1.12	0.44	-2.58	0.01
Catchment (Ythan)	-0.55	0.30	-1.85	0.06
Year of control : Spey	0.00	0.10	0.02	0.99
Year of control : Ythan	0.15	0.06	2.54	0.01

The following figures show trends in mink detection per calendar year for river catchments under mink control. For illustrative purposes river catchments have been broadly categorised to southern, eastern, central and north western parts of the mink control area.

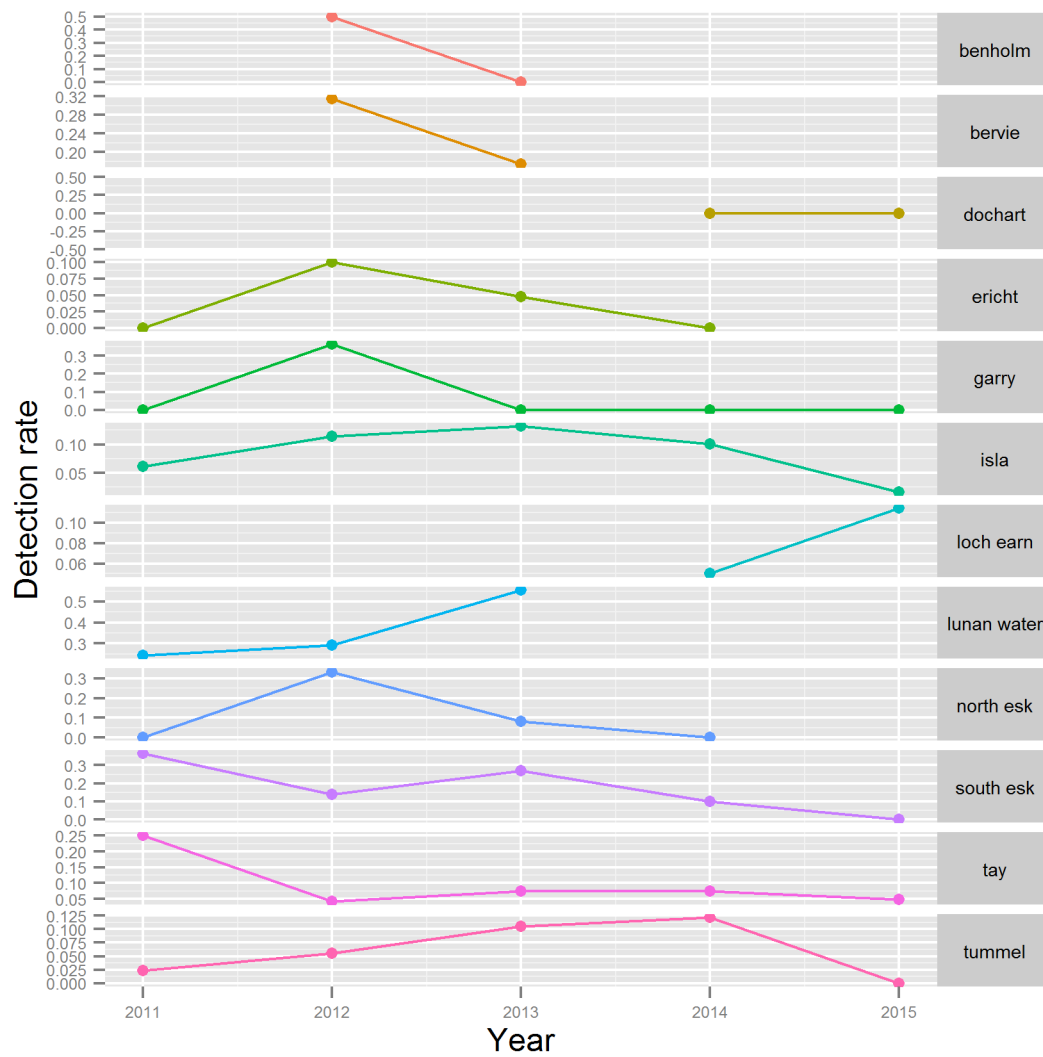


Figure 19: The detection rate (presence of mink prints / raft check) per year for river catchments in the southern part of the mink control area. Note the scale of the vertical axis changes between catchments.

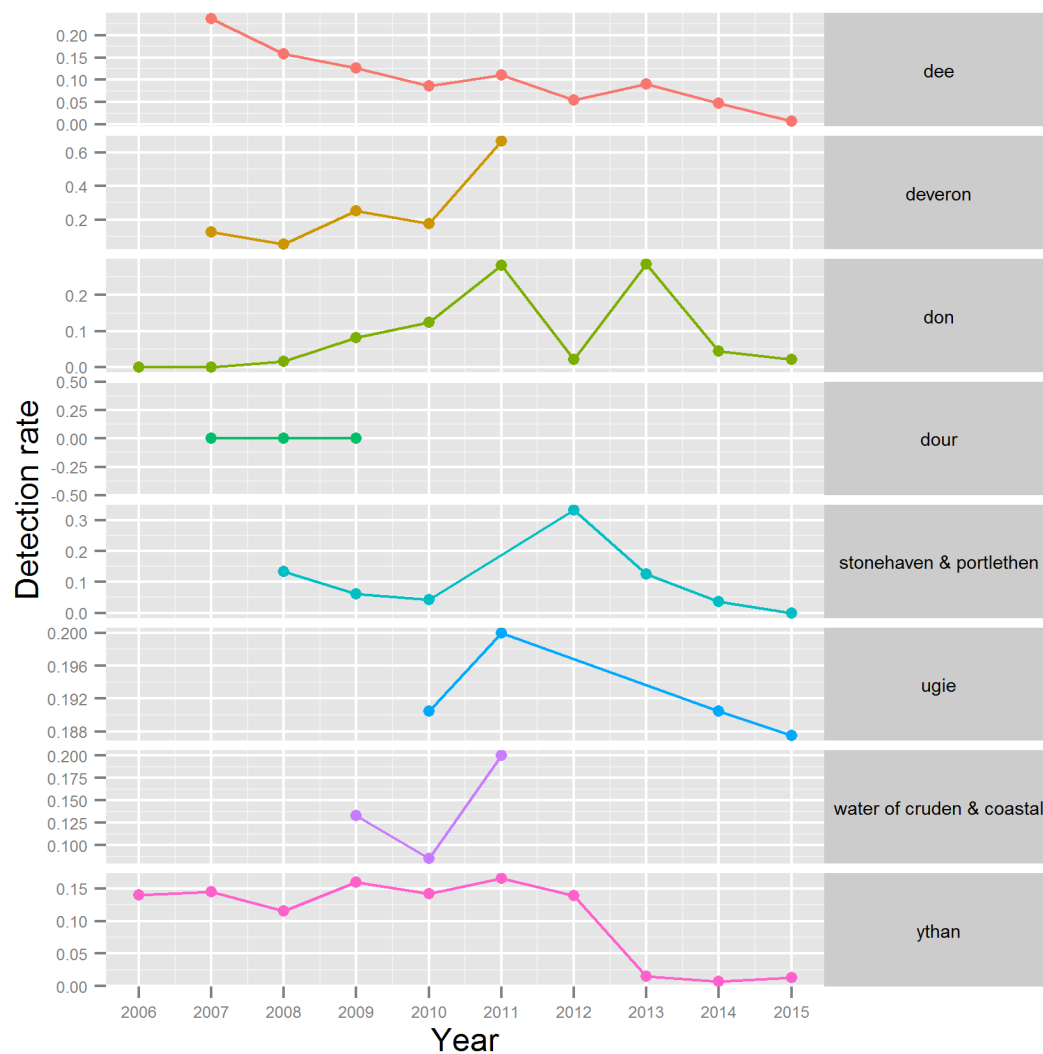


Figure 20: The detection rate (presence of mink prints / raft check) per year for river catchments in the eastern part of the mink control area. Note the scale of the vertical axis changes between catchments.

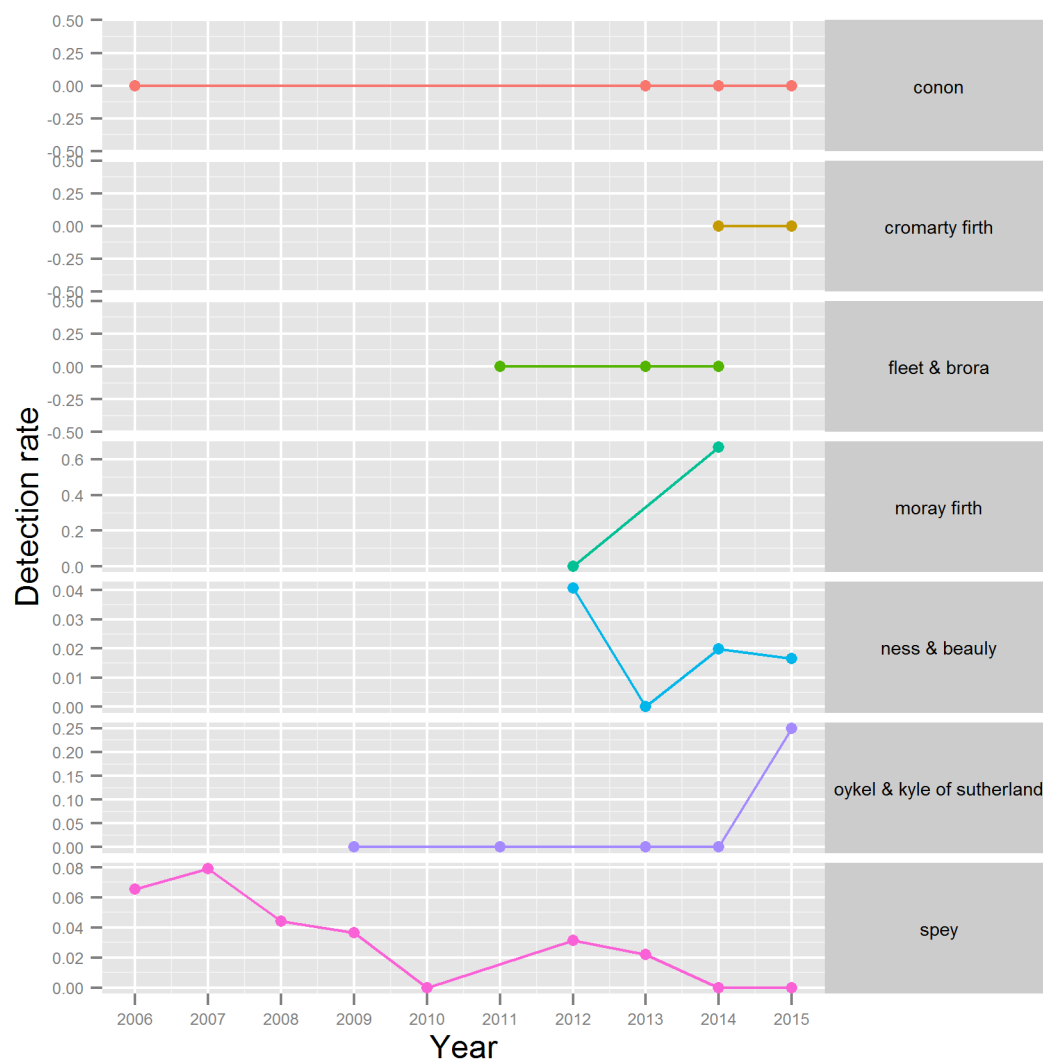


Figure 21: The detection rate (presence of mink prints / raft check) per year for river catchments in the central part of the mink control area. Note the scale of the vertical axis changes between catchments.

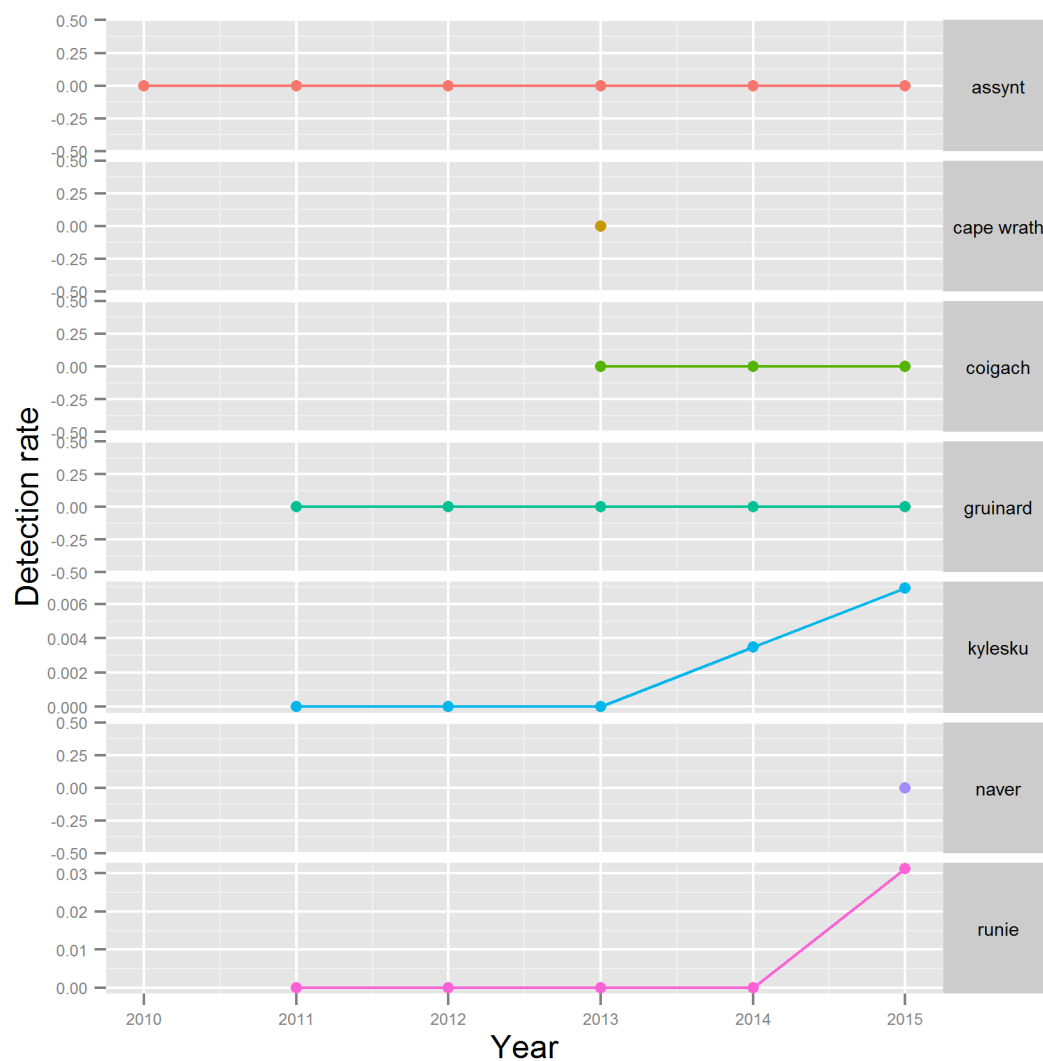


Figure 22: The detection rate (presence of mink prints / raft check) per year for river catchments in the north western part of the mink control area. Note the scale of the vertical axis changes between catchments.

## Appendix III – Prioritising coverage of female capture locations

The following figures show maps of female mink capture locations and the currently active rafts network for 18 of the main river catchments within the mink control area.

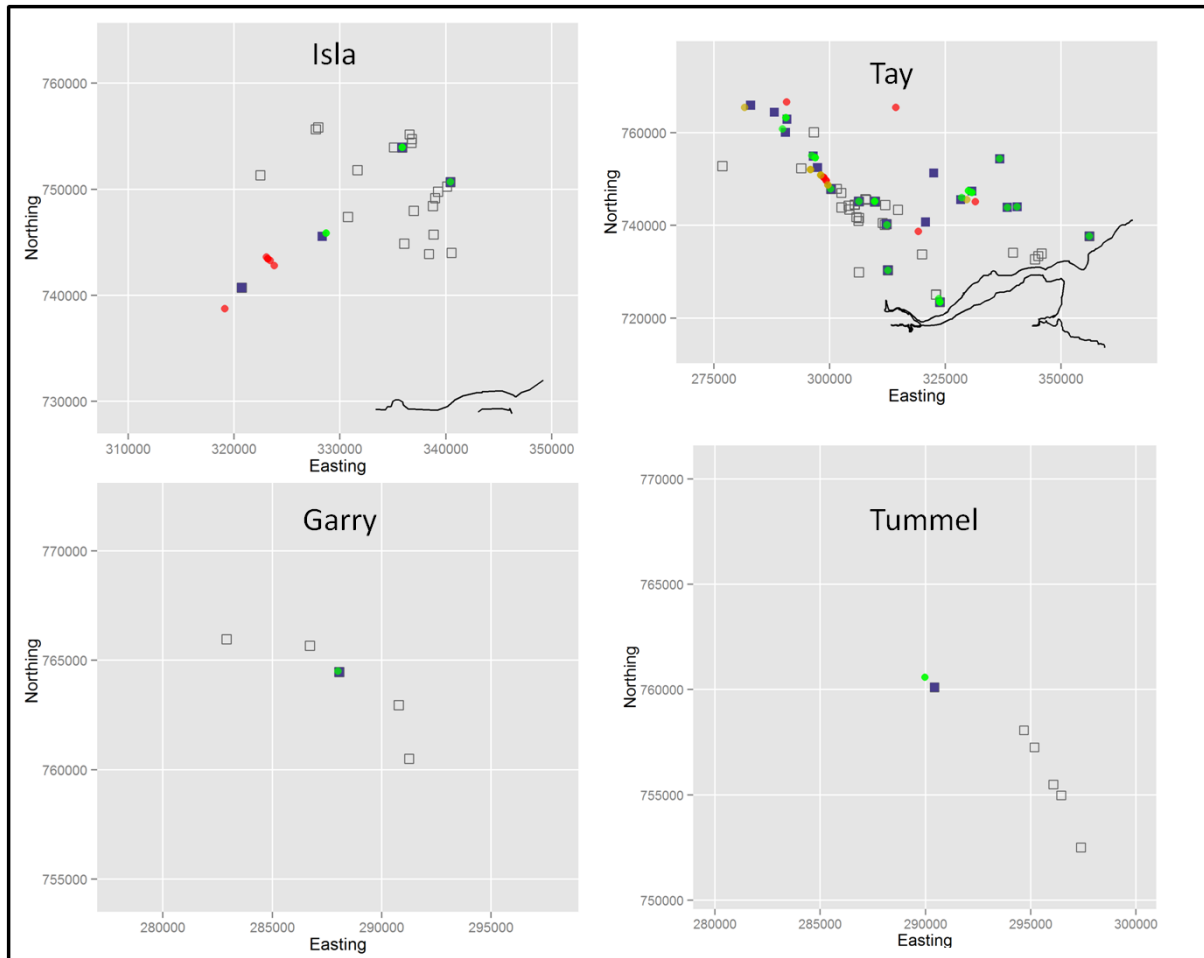
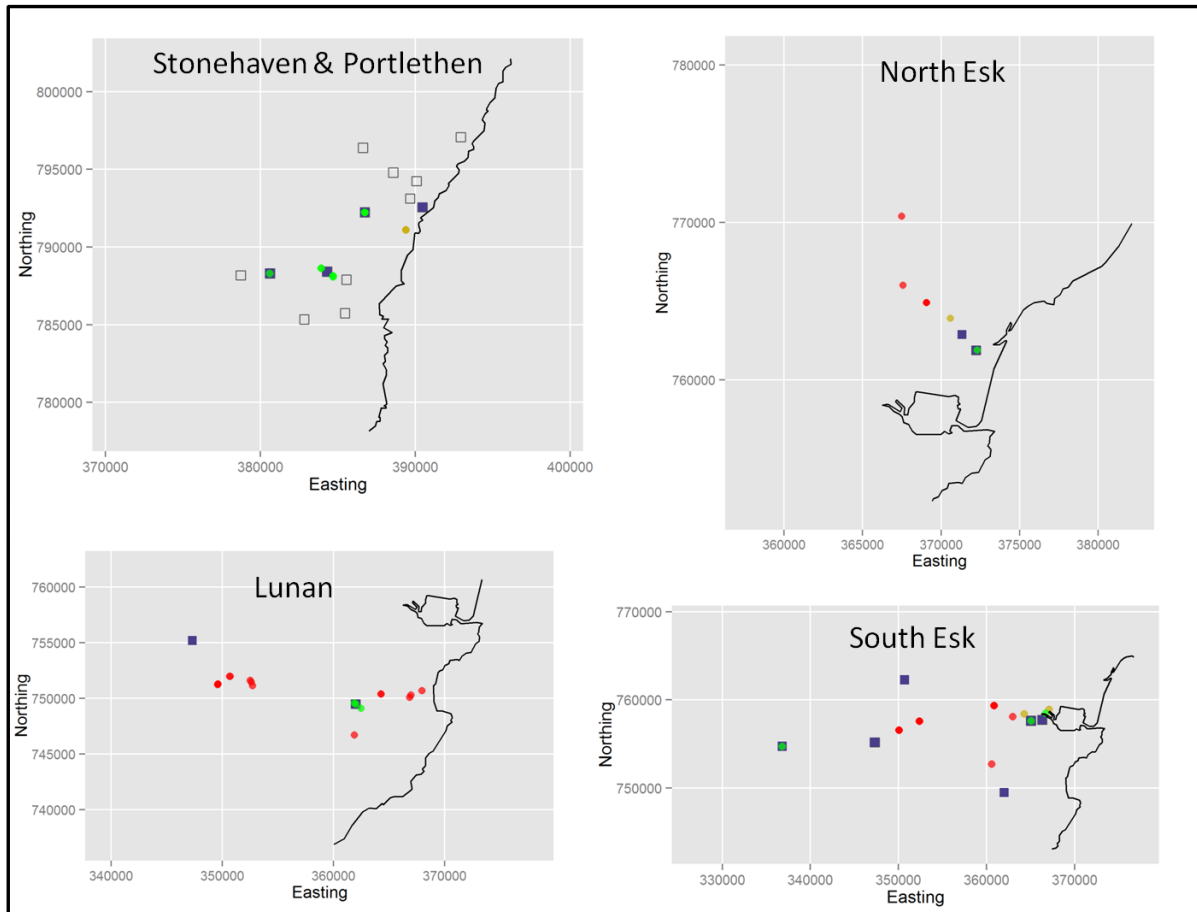


Figure 23: Maps illustrating the current coverage of female capture locations by active rafts on the rivers Lunan, Tay, Garry and Isla. The traffic light colour coding follows: green = good (raft < 1km); amber = caution (raft < 2 km); red = danger (raft > 2km). Active rafts are shown as squared. Those that are the closest raft to a female capture location are coloured blue.



**Figure 24:** Maps illustrating the current coverage of female capture locations by active rafts on the rivers North Esk, South Esk, Lunan and the Stonehaven & Portlethen area. The traffic light colour coding follows: green = good (raft < 1km); amber = caution (raft < 2 km); red = danger (raft > 2km). Active rafts are shown as squared. Those that are the closest raft to a female capture location are coloured blue.

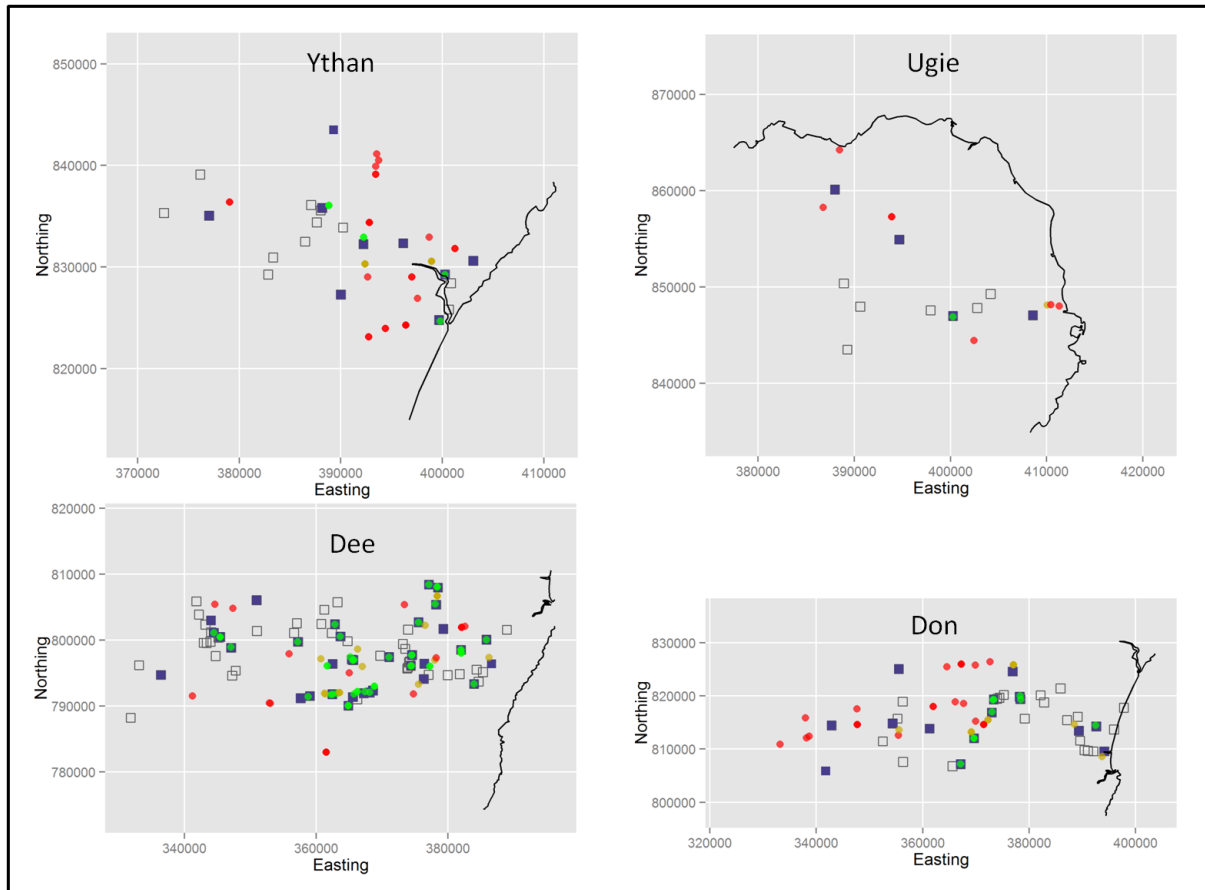
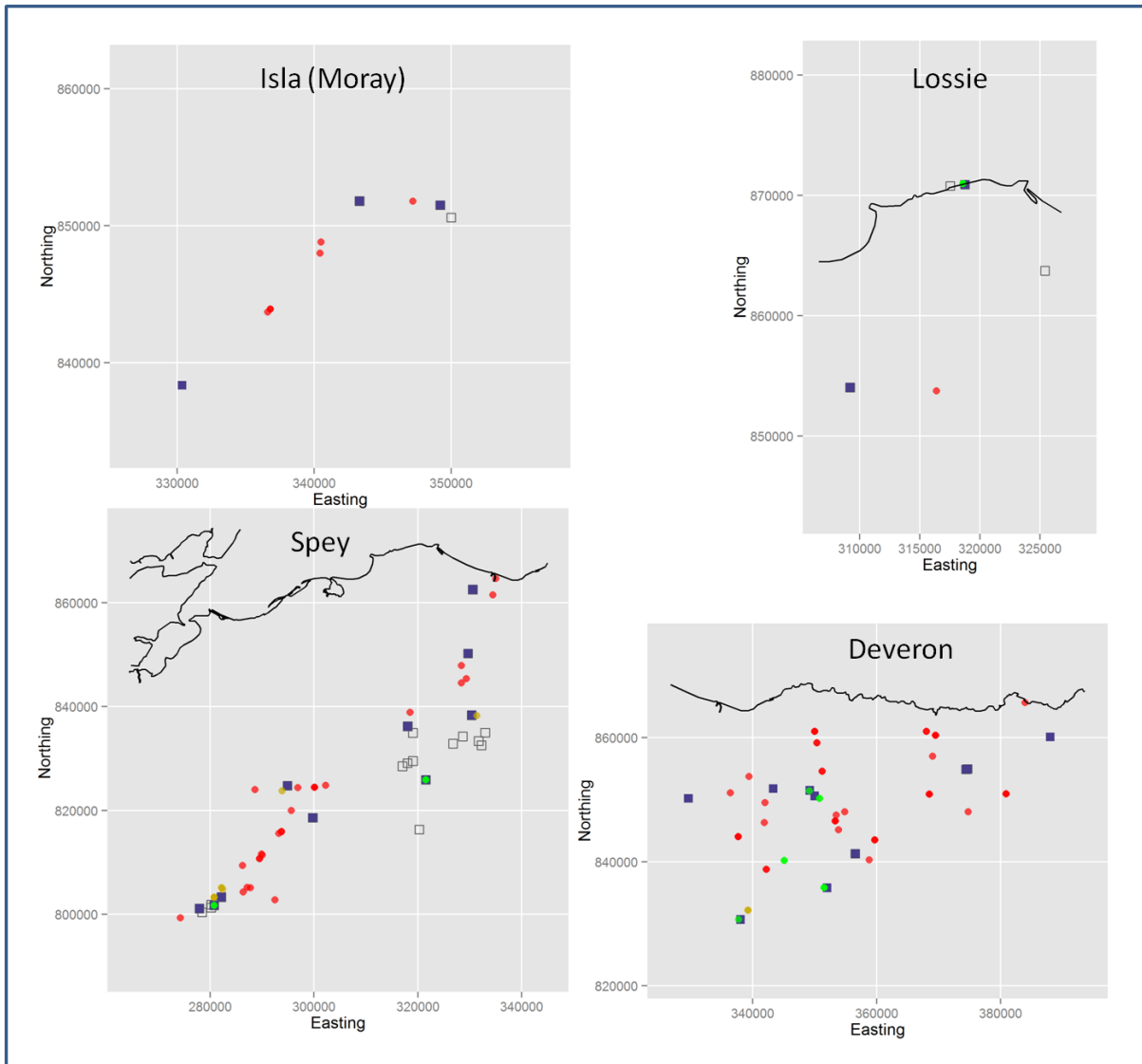
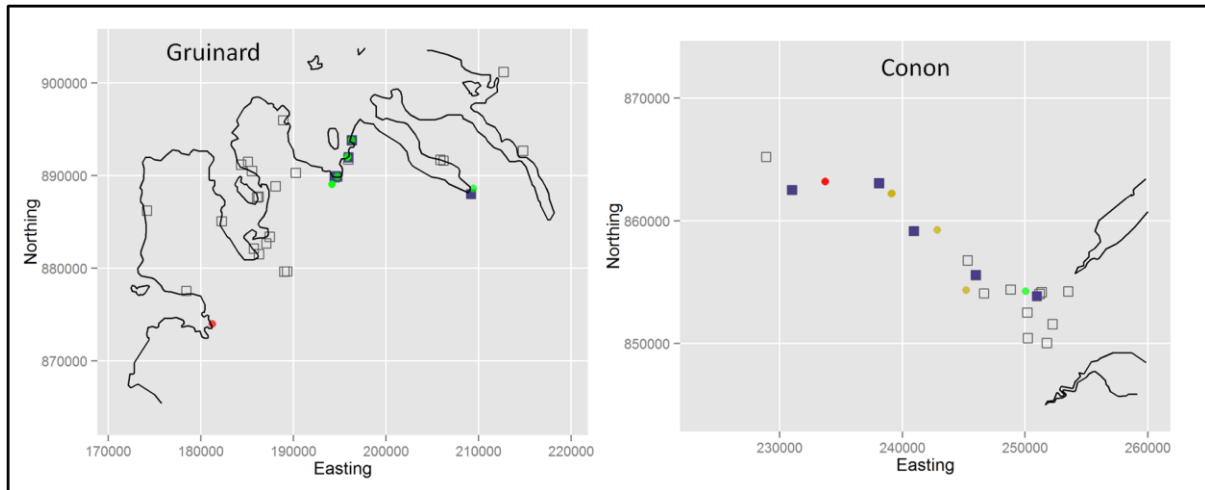


Figure 25: Maps illustrating the current coverage of female capture locations by active rafts on the rivers Dee, Don, Ythan and Ugie. The traffic light colour coding follows: green = good (raft < 1km); amber = caution (raft < 2 km); red = danger (raft > 2km). Active rafts are shown as squared. Those that are the closest raft to a female capture location are coloured blue.



**Figure 26: Maps illustrating the current coverage of female capture locations by active rafts on the rivers Deveron, Spey, Isla and Lossie. The traffic light colour coding follows: green = good (raft < 1km); amber = caution (raft < 2 km); red = danger (raft > 2km). Active rafts are shown as squared. Those that are the closest raft to a female capture location are coloured blue.**



**Figure 27: Maps illustrating the current coverage of female capture locations by active rafts on the rivers Conon and Gruinard. The traffic light colour coding follows: green = good (raft < 1km); amber = caution (raft < 2 km); red = danger (raft > 2km). Active rafts are shown as squared. Those that are the closest raft to a female capture location are coloured blue.**