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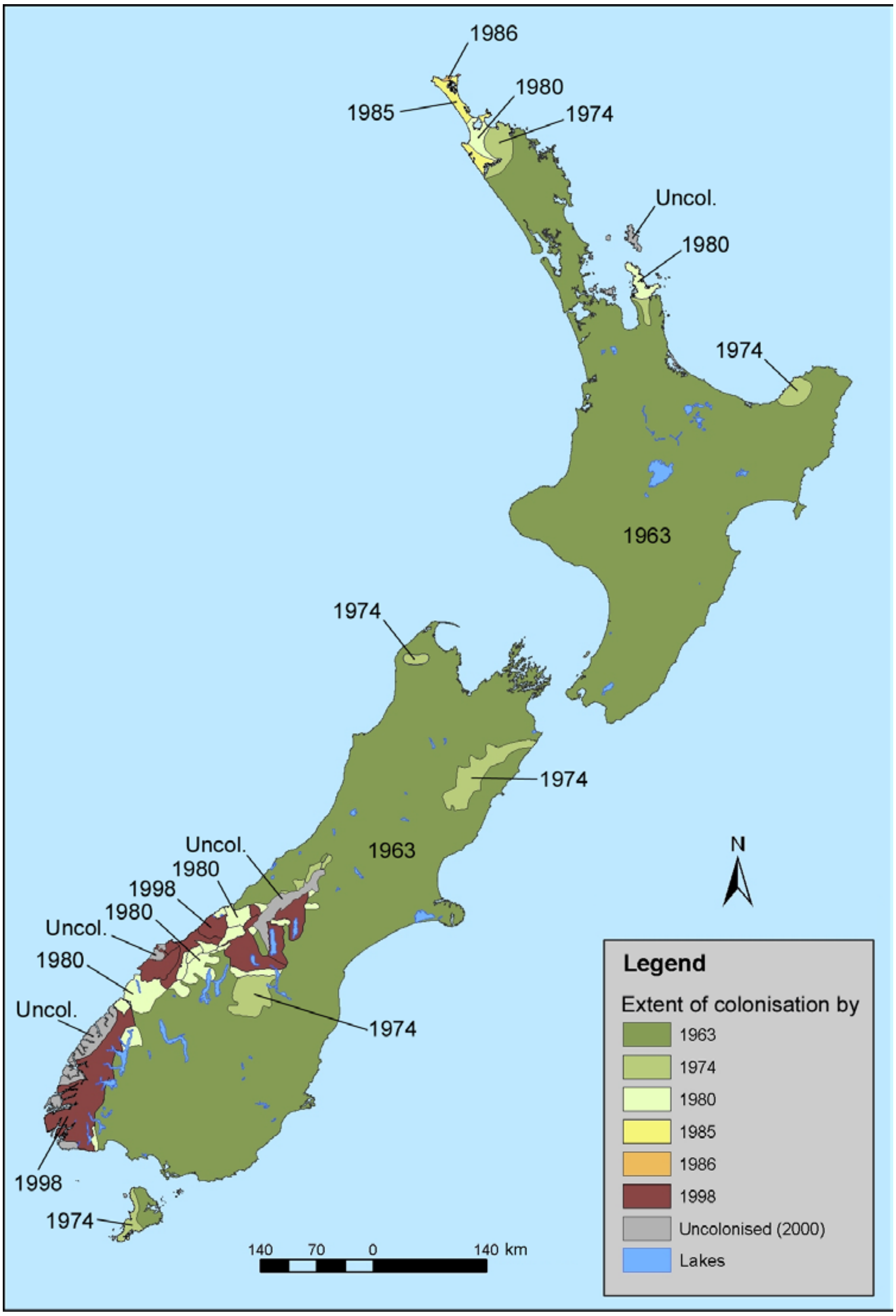
Figure 3. Extent of colonisation of mainland New Zealand by brushtail possums.



covering present and future possum population monitoring data (i.e. recording, reporting, collating, archiving). Some of the 'outstanding' data will be difficult to locate and a considerable amount will be in formats other than the two we have used. Consequently, it may not be cost-effective to collect these data. Such problems provide further support for the need to institute a set of explicit guidelines or an SOP for recording and reporting results of trap-catch monitoring surveys before any further data collection is undertaken (see Section 5.6).

5.2 THE DATABASE

All possum monitoring data and control operation information is stored in a relational database, which is linked to spatial information in a GIS. The relational database contains four tables for: possum population *survey* data; individual trap-*line* data; *control* operation information; and *GIS* data for *control* areas (see Fig. 1). The table with GIS data for control areas contains polygon identification information that links the control operation information to one or more polygons in a GIS coverage that describes the spatial extent of the control. However, some possum monitoring surveys in uncontrolled populations were not associated with any control operation(s).

The process of establishing links between possum population surveys and control operations in the same area (which included obtaining accurate information on operational area boundaries) was the most difficult and time-consuming part of this project. Because the data were collected from many sources, with several different data-organisation styles and data formats, the links often had to be created by tedious, individual hand-checking of names, dates, and spatial locations as mapped in the GIS layer. Often there were discrepancies in key data, and these required further follow-up by telephone or email, or had to be abandoned. It is clear that a much more efficient approach would be to design a system to capture the required data in a standardised format that would establish the required links, provide a common data platform, and identify missing and erroneous data during the data-entry process.

5.3 COLONISATION HISTORY

Possums were liberated successfully at numerous sites within mainland New Zealand and on numerous offshore islands from 1858 onwards (Pracy 1974). The subsequent spread of possums was accelerated by additional liberations of New Zealand-bred possums. By the 1960s possums occurred over > 90% of the mainland (Cowan 1990). Figure 3 shows the extent of colonisation of New Zealand (at various times) by possums, with those most recently colonised locations highlighted. With the exception of high alpine areas (snow and ice fields), the only possum-free areas remaining are confined to the southwest of the South Island, and a number of offshore islands (e.g. Great Barrier Island). It is likely that within the next 10–20 years all the available possum habitat of mainland New Zealand will have been colonised by possums.

The map of colonisation history was used as a spatial predictor in the following GRASP modelling. We included colonisation history because it was expected that areas that either had not been colonised or were relatively recently colonised by possums might have lower indices of population density than areas where possums had been established for longer periods. However, all the models are fully data-defined and no assumptions were made about the relative importance of colonisation history (or any spatial predictor variable) in predicting TCIs (or any other response variables). While the colonisation history map has greater temporal resolution for more recent colonisations (e.g. Northland, south Westland, and Fiordland), this should not adversely affect the models because the effects of time since colonisation might be expected to decrease to insignificant levels after c. 20–25 years. Therefore, the lack of any detail for colonisation history before 1963 is unlikely to have affected the effects of colonisation history as a spatial predictor of present possum densities.

5.4 SPATIAL PREDICTIONS OF POSSUM RELATIVE ABUNDANCE

5.4.1 Uncontrolled model

The trap-catch data used for the uncontrolled model came from 10 of 13 DOC conservancies and from the Southland and Wellington Regional Councils. TCIs from 1421 actual trap lines and 250 'pseudo' lines (see Section 4.4.1) were included in these analyses. The uncontrolled model constructed using GRASP accounted for 50% of the variation in the pre-control TCIs. Seven factors had significant correlations with TCI (Fig. 4).

TCI varied with the survey month (SSMONTH), with trap-catch rates being highest in December–February and lowest in April–October. Possum populations are typically at their lowest ebb (in terms of the number of free-ranging individuals—i.e. excluding pouch young) in late winter. The pattern for survey month also reflects a generally lower level of activity during winter months (Cowan & Clout 2000). Although possums are largely arboreal, they spend about 10–15% of their time on the ground in forest habitats, and they tend to be more active on moonlit nights and less active in heavy or persistent rain (Cowan & Clout 2000), which helps to explain the seasonal TCI effect.

For the type of trap set (SETTYPE), raised sets had markedly lower TCIs than ground sets, and this forms the basis for the correction factor graph (see Fig. 8). The relative width of each of the bars indicates that there were considerably more data from surveys where ground-set traps were used. In the mean annual temperature (MAT) GAM graph, MAT ranges from c. –3°C to c. 15°C. TCI increases strongly from the lowest MAT until a MAT of c. 10°C, and after this shows little increase with MAT. There appears to be a relatively complex relationship between TCIs and mean annual solar radiation (MAS), which we cannot explain. In the minimum winter temperature (TMIN) GAM graph, TMIN ranges from –8°C to 6°C and TCI increases linearly with increasing TMIN. TCI varied with distance to pasture (see GAM graph for DISTPAST in Fig. 4), being lowest on forest–pasture margins and increasing with increasing distance from the pasture, with an inflexion between c. 500 and c. 3000 m from the pasture. This result is somewhat different from what we expected since forest–pasture margins were typically considered as preferred habitat for possums and as having relatively high population densities (e.g. Coleman et al. 1980) and therefore TCIs might be expected to be higher. More recently, Byrom & Nugent (unpubl. data) found no evidence of higher possum densities near forest–pasture margins and suggested that previous findings could reflect altitudinal or other gradients. One possible explanation for the lower TCIs around forest–pasture margins is the effect of localised hunting pressure from fur trappers. Hence the DISTPAST graph may be showing the combined effect of hunting pressure and habitat preference. TCI increased linearly with the time since colonisation (TCOLONISE).

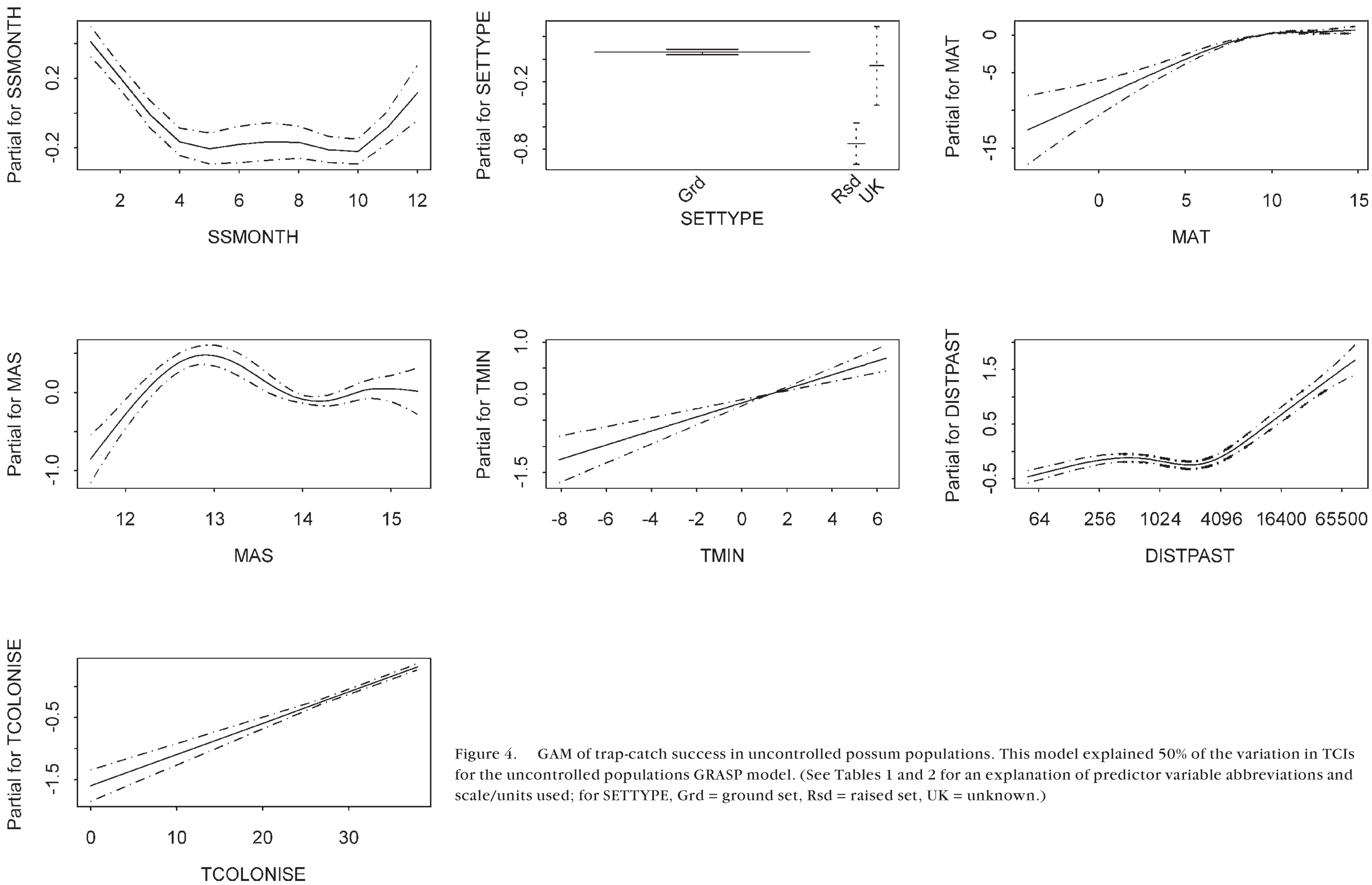


Figure 4. GAM of trap-catch success in uncontrolled possum populations. This model explained 50% of the variation in TCIs for the uncontrolled populations GRASP model. (See Tables 1 and 2 for an explanation of predictor variable abbreviations and scale/units used; for SETTYPE, Grd = ground set, Rsd = raised set, UK = unknown.)

Figure 5 shows the relative contributions of each of the spatial and other factors to the uncontrolled population model. All predictor variables available for the model are shown, but only those with a statistically significant relationship with TCI have horizontal bars (the length of the bar is proportional to the amount of deviance explained: the drop contribution is the amount of deviance explained when each variable is dropped from the full model (see Section 4.1); the alone contribution bars show the amount of deviance explained by each variable alone). It is unclear why some predictor variables (e.g. land cover, LANDCOV) did not show a significant relationship with TCI. However, it is possible that other predictor variables (e.g. MAT, TMIN, DISTPAST) accounted for much of the pattern that might be expected from land-cover. In addition, all of the neighbourhood land-cover variables include information from the LCDB.

We ran the uncontrolled GRASP model to predict possum TCIs for surveys using ground-set traps in January (Fig. 6) and June (Fig. 7). Despite the ad hoc and uneven sampling of areas and habitats, overall, the broad patterns produced by the uncontrolled model appear to make biological sense. For example, predicted uncontrolled possum densities are generally higher in the North Island compared with the South Island, and are generally higher in lower altitude podocarp-dominated forests compared with beech forest. While there is some supporting evidence for trends such as declining density with increasing altitude, this pattern is more likely to be driven by altitudinal zonation of palatable vegetation than by actual physical variables such as temperature and rainfall (Efford 2000), although these may influence the

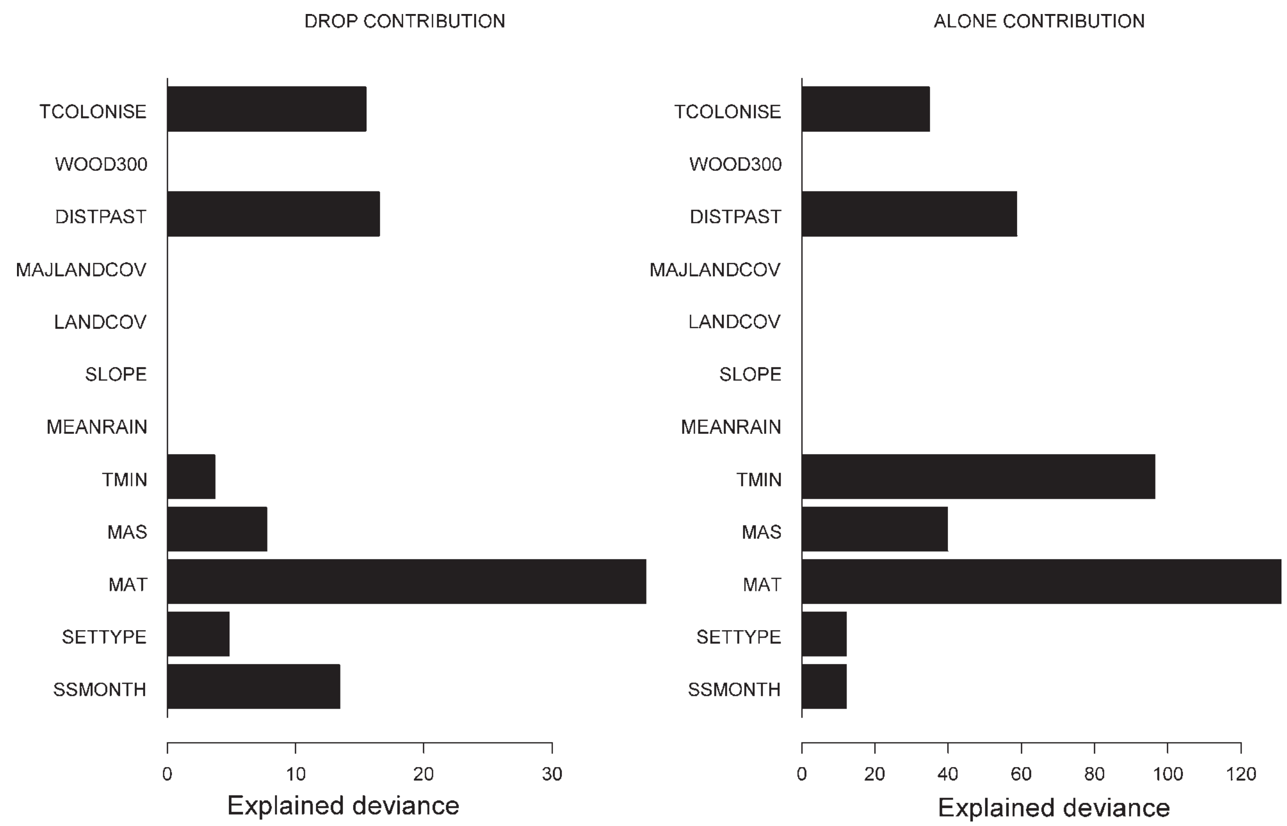


Figure 5. Contributions of spatial predictor variables to the model for uncontrolled possum populations; see Section 4.1 for an explanation of drop and alone contributions. (See Tables 1 and 2 for an explanation of abbreviations and scale/units used.)

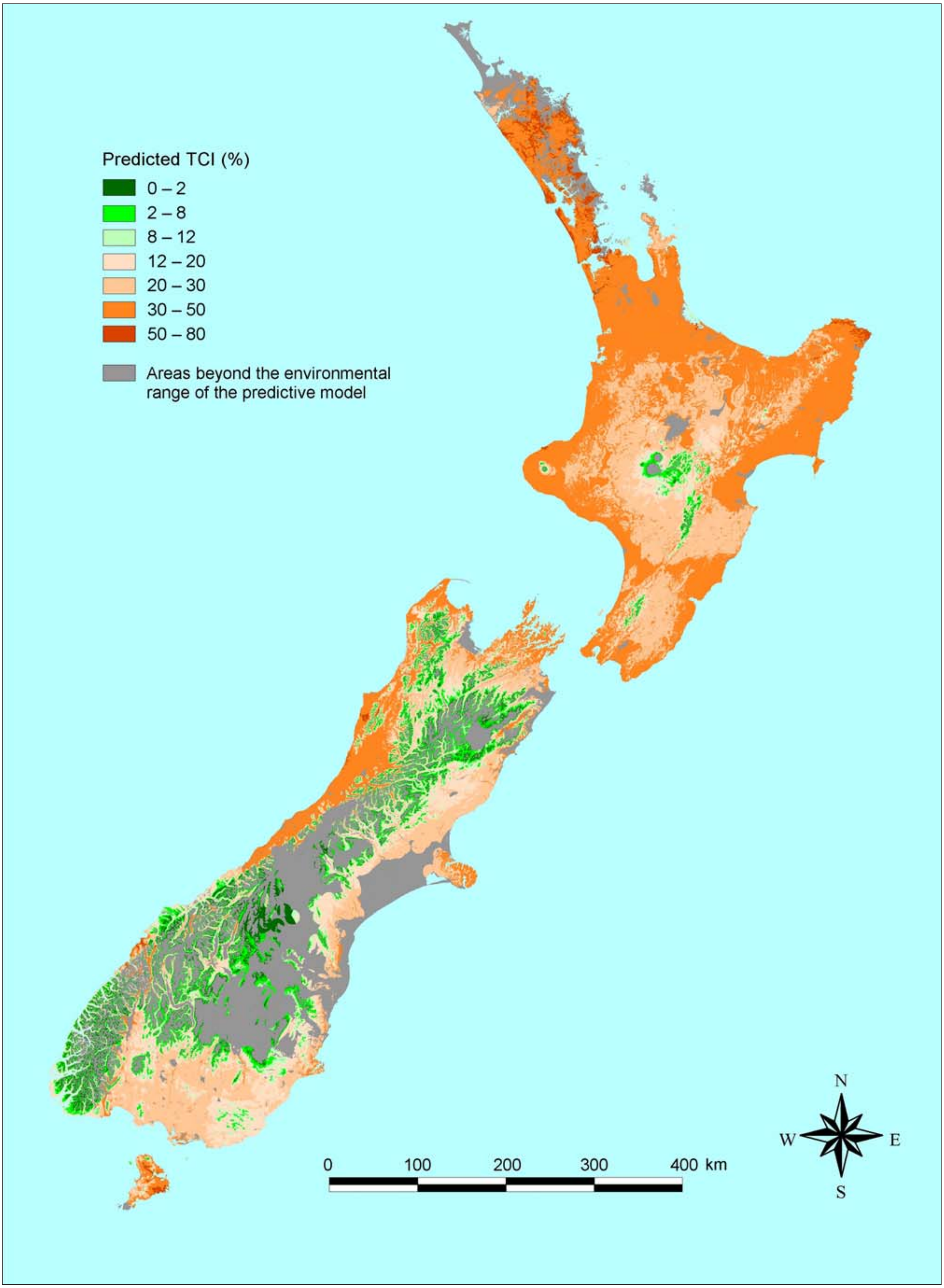


Figure 6. Predicted trap-catch rates, TCI (%), for possums in uncontrolled populations for surveys using ground-set traps in January.

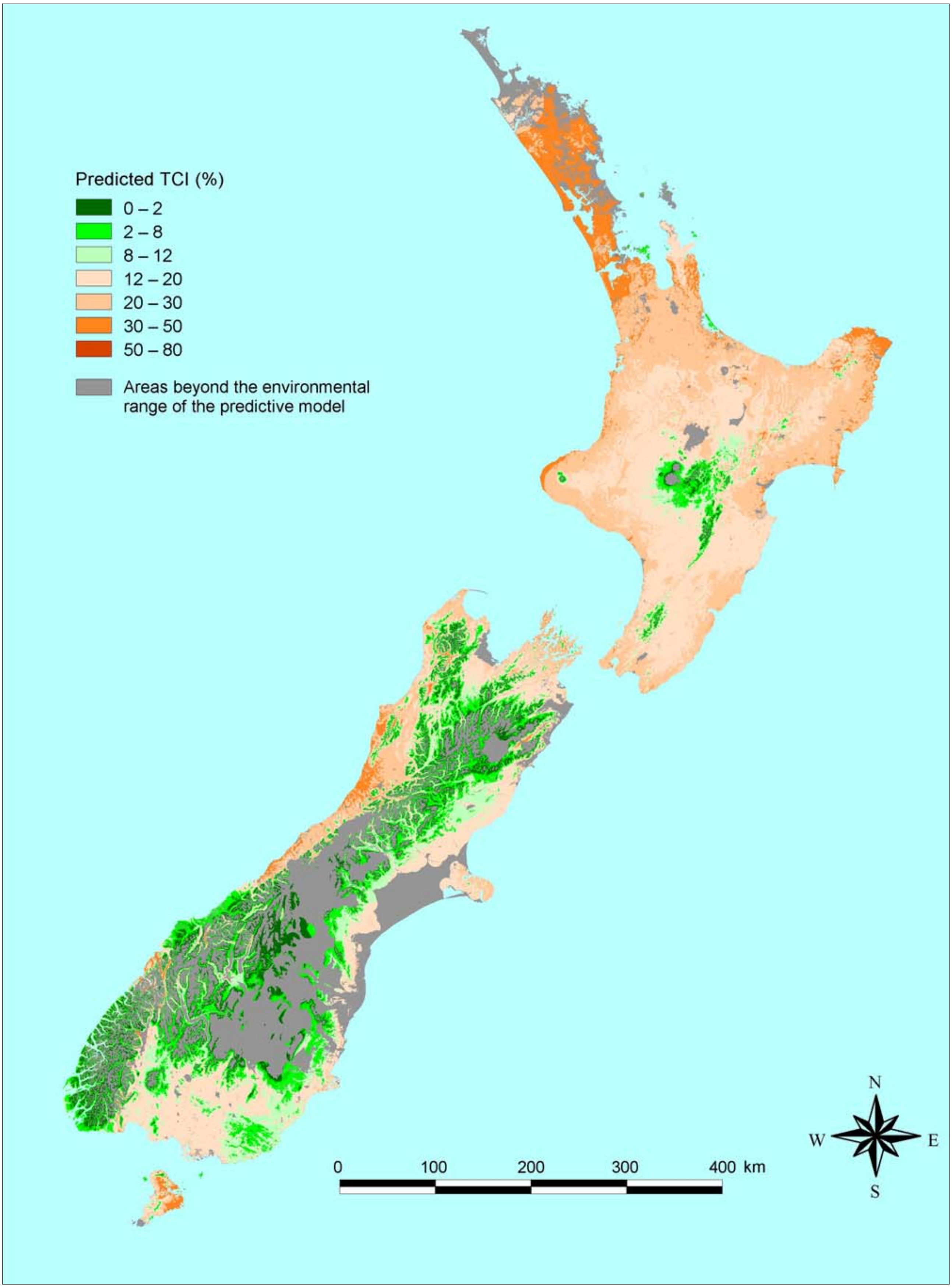


Figure 7. Predicted trap-catch rates, TCI (%), for possums in uncontrolled populations for surveys using ground-set traps in June.

vegetation zonation. Despite the apparent importance of some individual climatic variables for predicting uncontrolled TCIs (see Figs 4 and 5), direct climatic effects on density are contradicted by the actual occurrence of high possum densities at both high and low latitudes, and in both the wet west and the drier east (Efford 2000).

Relatively high or moderate densities are also predicted for many areas of clear farmland where this is unlikely to be so (e.g. as in the Waikato). Therefore, Figs 6 and 7 should be viewed in conjunction with Fig. 2 (which highlights those areas and habitats from which the TCI data used for the uncontrolled possum population model were derived and/or relate to) and interpreted with caution. We believe that considerable improvement in the predictions from the uncontrolled model would be obtained if there were more data available from areas and/or habitats that are poorly represented.

5.4.2 Effects of season, habitat, and trap-set type on trap-catch indices

Figure 8 provides a graphical means for converting between TCI values for January and June, and for converting between raised-set and ground-set trapping. These correction graphs are derived from parts of the GAM in Fig. 4 showing the individual effect of each variable for explaining TCIs. The derivation of the formulae used to make these corrections is given in Appendix 2. The GRASP analyses used all the uncontrolled-possum-population TCIs, distributed across different environments and land-cover categories, obtained both with raised and ground sets, and at different times of the year. The resulting statistical model teases apart the different influences on trap-catch rates and finds the residual effect of each variable while holding the other variables constant. Therefore, the graph for trap-set type in Fig. 4 shows the effect of trap-set height (i.e. ground or raised) on TCIs, by holding all other variables (e.g. environmental, land cover, and seasonal effects) constant. An inspection of the shape of the response of TCI to survey month (Fig. 4: SSMONTH) reveals the effect of survey month (i.e. season) on TCI is relatively constant over winter months, but changes quickly over summer months, reaching its highest level in January before declining sharply to May. As a result, the upper 'correction graph' presented in Fig. 8 can be used to convert between TCIs obtained over all of the winter period (rather than for June alone) and January, or vice versa.

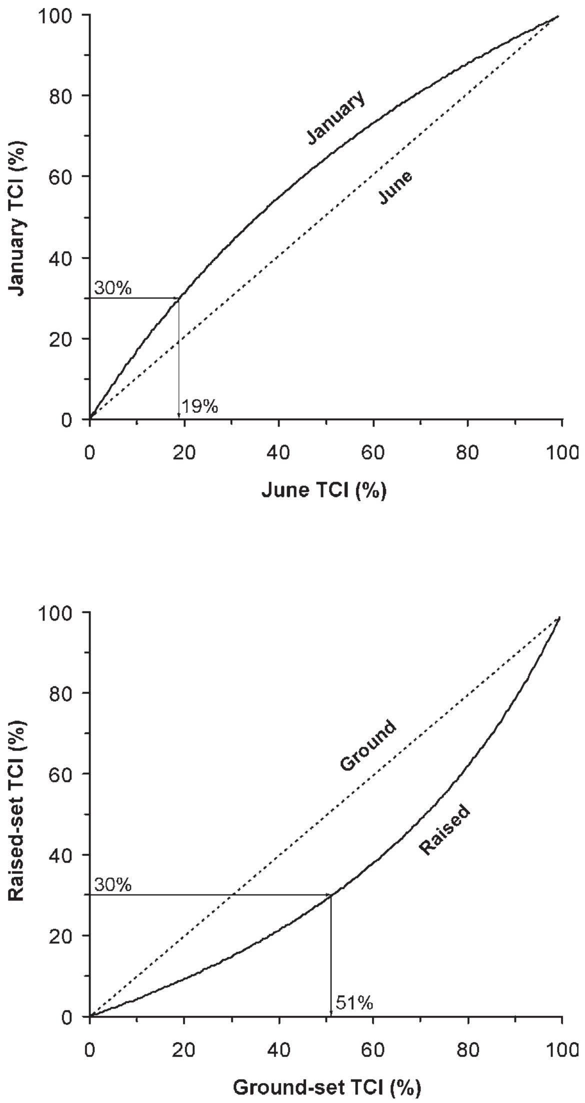


Figure 8. Correction graphs for removing the effects of season and trap-set type on TCI. These graphs are derived from the GAM in Fig. 4.

As an example, the upper graph in Fig. 8 predicts that a TCI of c. 30% in January is equivalent to a TCI of c. 19% in June (approximately winter). Similarly, in the lower graph a TCI of c. 30% using raised sets is equivalent to a TCI of c. 51% obtained for a similar survey using ground-set traps. Conversions such as these can be made equally well in either direction. One of the advantages of such an approach to correcting individual-factor effects on TCIs is that corrections done in this way will always be between 0 and 100% (whereas corrections based on multiplicative or additive factors could result in corrected trap-catch rates below 0% or above 100%).

5.4.3 Post-control models

Pre-maintenance control model

The pre-maintenance control model was developed using DOC West Coast data only, since neither the Canterbury nor West Coast Regional Councils undertook any pre-maintenance control surveys. From a total of 435 trap lines in all the post-control surveys, only 283 lines could be associated with previous control operations and were, therefore, used in the pre-maintenance control model. Most of the remaining trap lines were from uncontrolled areas and had, therefore, previously been included in the model for predicting TCIs in uncontrolled populations.

The pre-maintenance control model constructed using GRASP accounted for 30% of the variation in TCIs. Five factors had significant correlations with TCI (Fig. 9). TCI increased non-linearly with mean annual temperature (MAT). TCI increased with mean annual rainfall (MEANRAIN) up to c. 6000 mm but thereafter declined. TCI also increased with increasing distance to pasture (DISTPAST) although, unlike the relationship in the uncontrolled model (Fig. 4), the relationship here is linear. TCI also varied with survey month (SSMONTH) and followed a pattern similar to that noted for the uncontrolled model and partly explained by a generally lower level of possum activity in winter months (Cowan & Clout 2000). Other factors such as seasonal variation in trappability and a decline in actual possum numbers may also contribute to this trend.

For the variables describing the relationships with previous control, there was only a weak negative relationship between TCI and the distance to the edge of previous control (DISTPREVCON). Given that all the trap lines are located within areas where control has been undertaken, this result may partly reflect the rate at which possums are able to disperse back into an area following control. Intuitively, we expected to find a relationship between TCI and the time to previous control (TPREVCONT) but the analyses did not reveal any significant relationship with this variable. Figure 10 shows the relative contributions of each of the spatial and other factors to the pre-maintenance control model.

The lack of a significant effect for the time to previous control on predicting pre-maintenance control TCIs was surprising, since it is reasonable to expect possum populations to recover over a period of several years following a control operation. To investigate 'time to previous control' as a potential predictor variable more carefully, we examined the effects of control and time since control on TCIs for DOC control operations in the West Coast

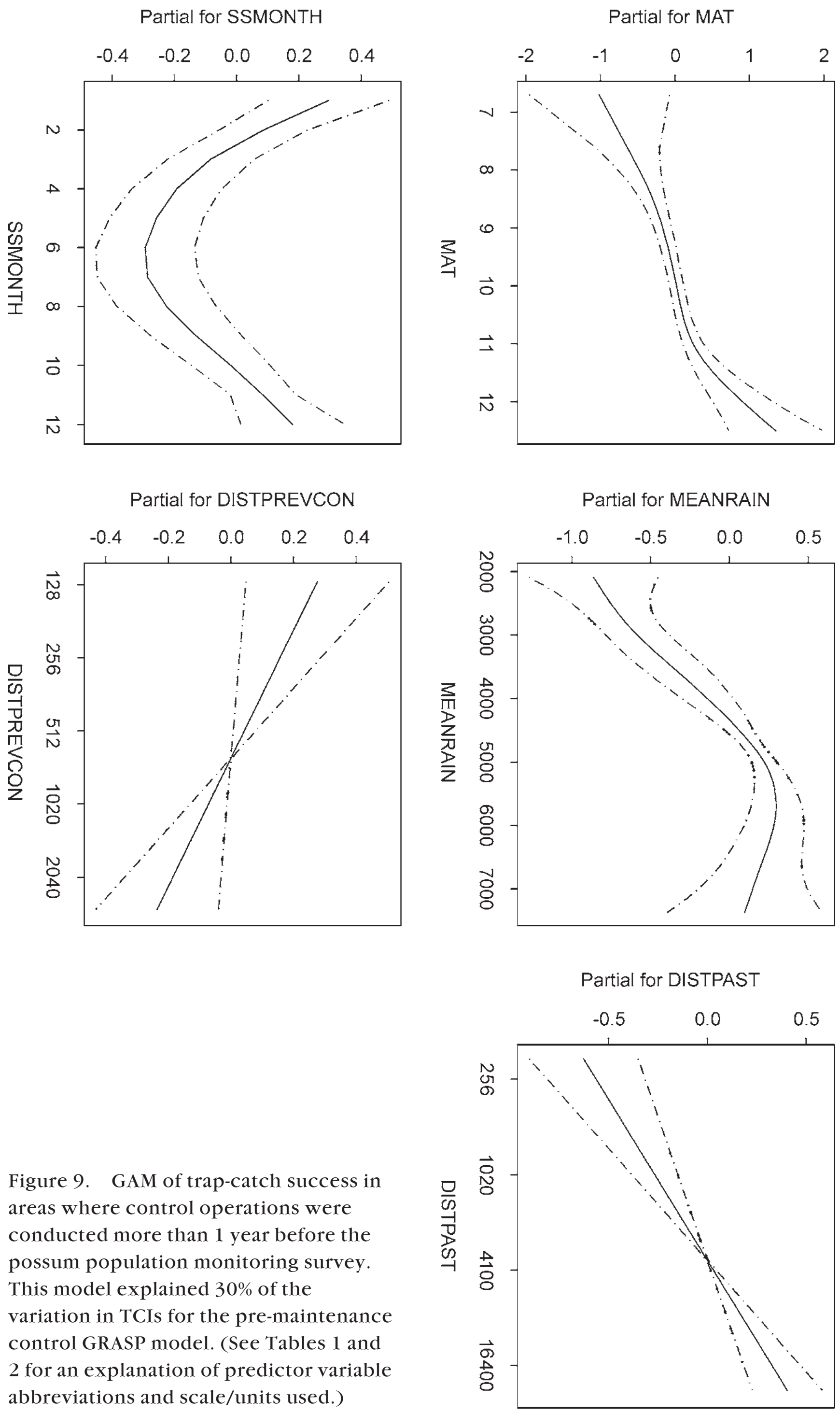


Figure 9. GAM of trap-catch success in areas where control operations were conducted more than 1 year before the possum population monitoring survey. This model explained 30% of the variation in TCIs for the pre-maintenance control GRASP model. (See Tables 1 and 2 for an explanation of predictor variable abbreviations and scale/units used.)

Conservancy in more detail. Figure 11 shows the overall TCIs obtained from surveys of uncontrolled possum populations, immediate post-control surveys, and surveys conducted at different times following control. Typically, the latter surveys were conducted as pre-control surveys before further control. A considerable amount of DOC-funded possum control and monitoring on the West Coast is undertaken in areas relatively recently colonised by possums. Hence, in addition to analysing all the data for this area, we also repeated the analyses for data collected from trap-catch surveys in areas colonised before 1980 (essentially to remove the potential effect of ‘time since colonisation’).

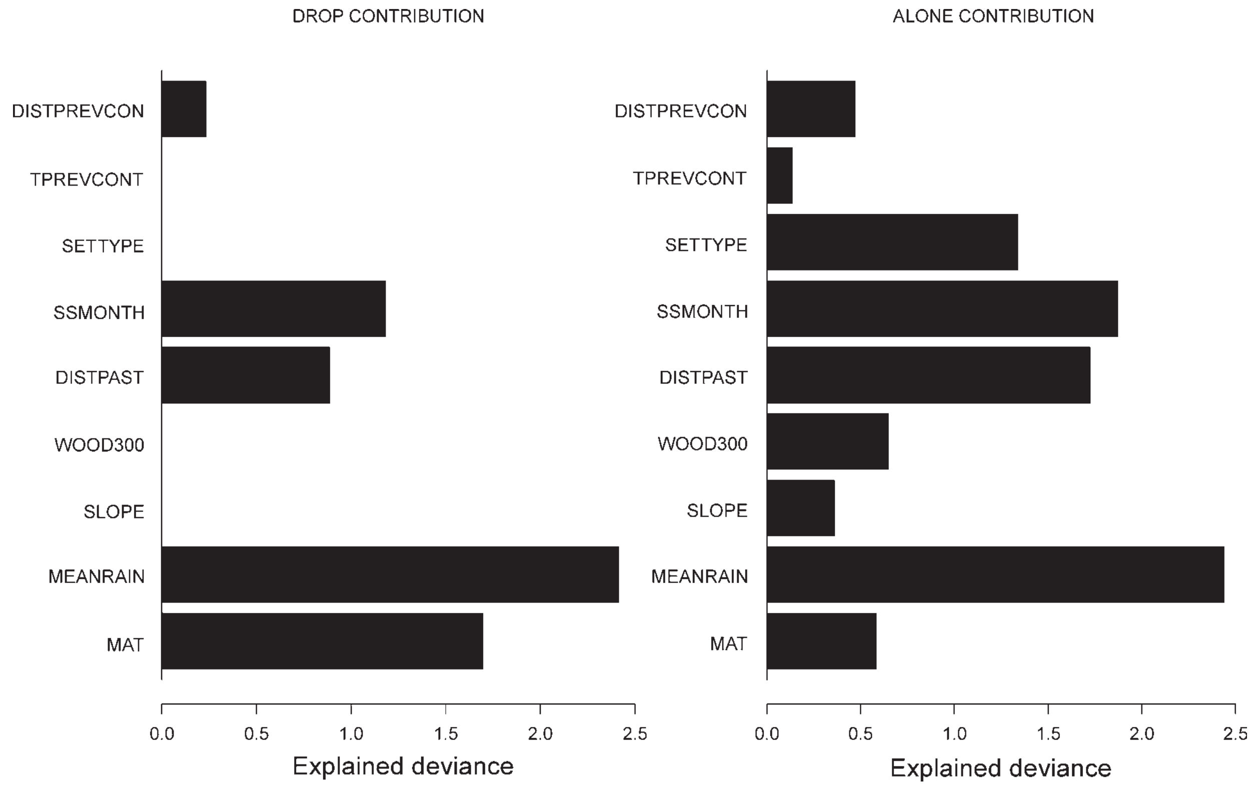


Figure 10. Contributions of predictor variables to the model of trap catch in areas with control operations more than 1 year before the survey; see Section 4.1 for an explanation of drop and alone contributions. (See Tables 1 and 2 for an explanation of predictor variable abbreviations and scale/units used.)

TCIs for surveys carried out immediately after control were significantly lower than surveys conducted on uncontrolled possum populations (Fig. 11). This was more noticeable for the data from areas colonised before 1980. The complete data set, which included surveys of populations that had colonised areas since 1990, undoubtedly sampled some of these populations before they had reached peak densities. Unexpectedly, there is only weak evidence in Fig. 11 to suggest that possum abundance increases consistently over a number of years following control. While there is a weak trend of increasing TCIs with time since control up to c. 3 years post-control, there were no clear patterns in TCIs obtained between 4 and 6 years after control (both for all data and for data from areas colonised before 1980).

Several factors make these results difficult to interpret. From Fig. 11 it is apparent that there is considerable variability in the data (including that from areas that were colonised before 1980), therefore the lack of any clear trends may simply be an artefact of the sample we are dealing with. The possum monitoring surveys used here differ in several respects, most notably in their control history, but also in time and location. The many locations from which survey data were obtained represent a wide range of climatic and habitat variation. If specific populations were monitored at regular intervals following control, we might reasonably expect to see clearer evidence of increasing TCIs with time since control. Although there was a significant difference between uncontrolled and post-control TCIs for areas possums had colonised c. 20 years or more previously (and had sufficient time to reach peak (c. equilibrium densities)), there was still no evidence of any gradual increase following control.

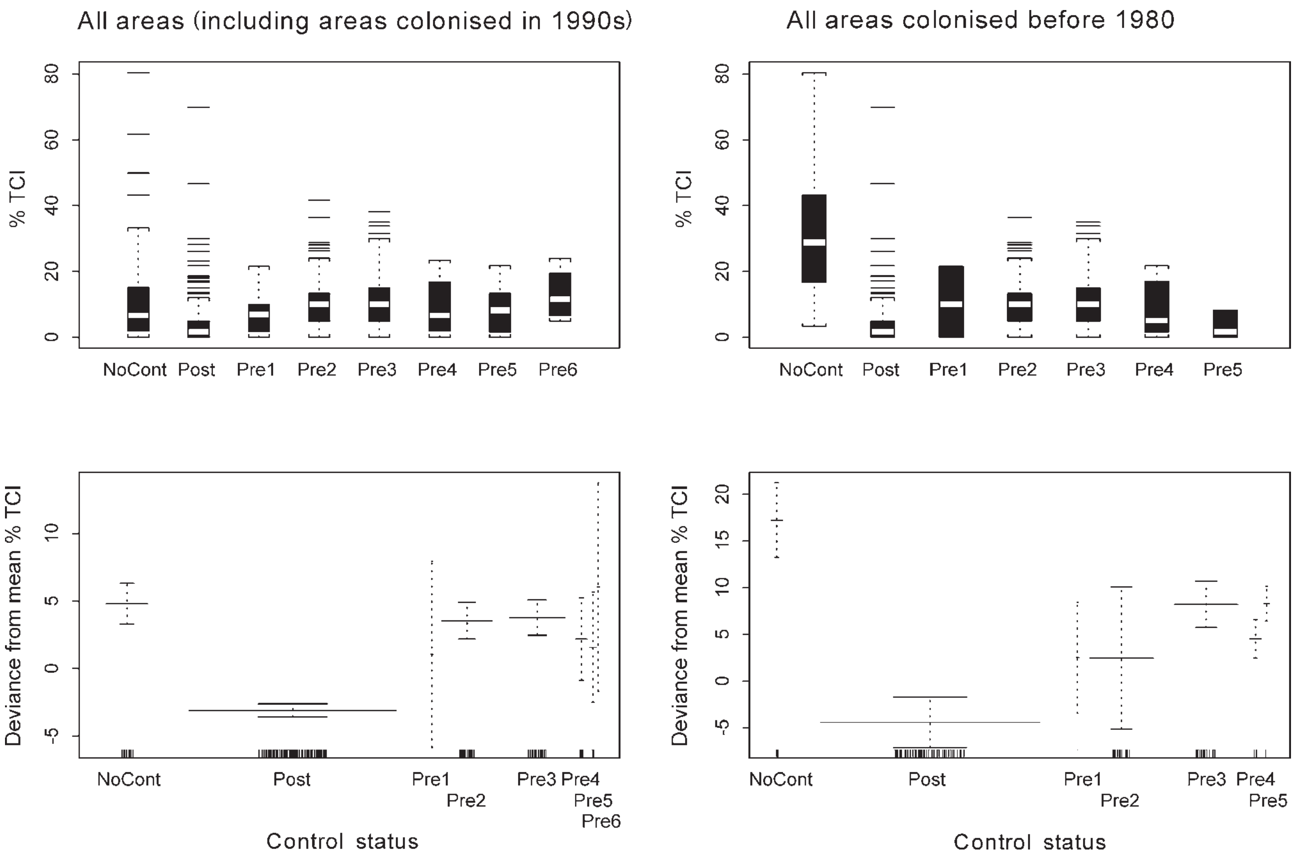


Figure 11. Effects of control and time since control on TCIs obtained from surveys conducted by DOC in the West Coast Conservancy since 1996. The upper graphs show the overall TCIs under different control status, from areas with no history of control (NoCont), to immediate post-control surveys (Post), to pre-control surveys conducted 1–6 years following previous controls (Pre1, Pre2, etc.). The symbols in the upper graphs indicate the distribution of the data: the solid bar denotes the quartiles of the data, with the mean in the centre of the bar and the median indicated by the white bar embedded in the solid bar; the whiskers show the approximate 95% range, with extreme outliers shown as individual bars. The lower graphs show ANOVA results for the effects of control status on TCIs: the wide horizontal bars show the deviance from the mean TCI for each control history (± SEs); the relative sample sizes for each control history are indicated by the width of the horizontal bar and the number of hatch marks along the x-axis.

Another factor that could account for the lack of any clear trend in these data is the coverage of areas from which survey data were available and the actual timing of the monitoring surveys. For example, it is conceivable that those areas where surveys were carried out 1–3 years after control might be more likely to have had less effective control and/or greater reinvasion from adjacent uncontrolled areas (hence the need to survey and apply maintenance control or repeat wide-scale control). Conversely, those areas where surveys were carried out 4–6 years after control might be more likely to have had more effective control and/or little or no reinvasion (hence the greater interval between control and monitoring). This highlights some of the potential problems associated with using monitoring data collected in relation to specific control operations.

A more effective way to address this particular question (i.e. monitoring population recovery following control) would be to establish permanent survey areas (trap-line locations could be fixed or random) in areas where initial (or knockdown) control operations were planned. Immediate post-control surveys as well as subsequent monitoring surveys conducted at regular intervals (e.g.

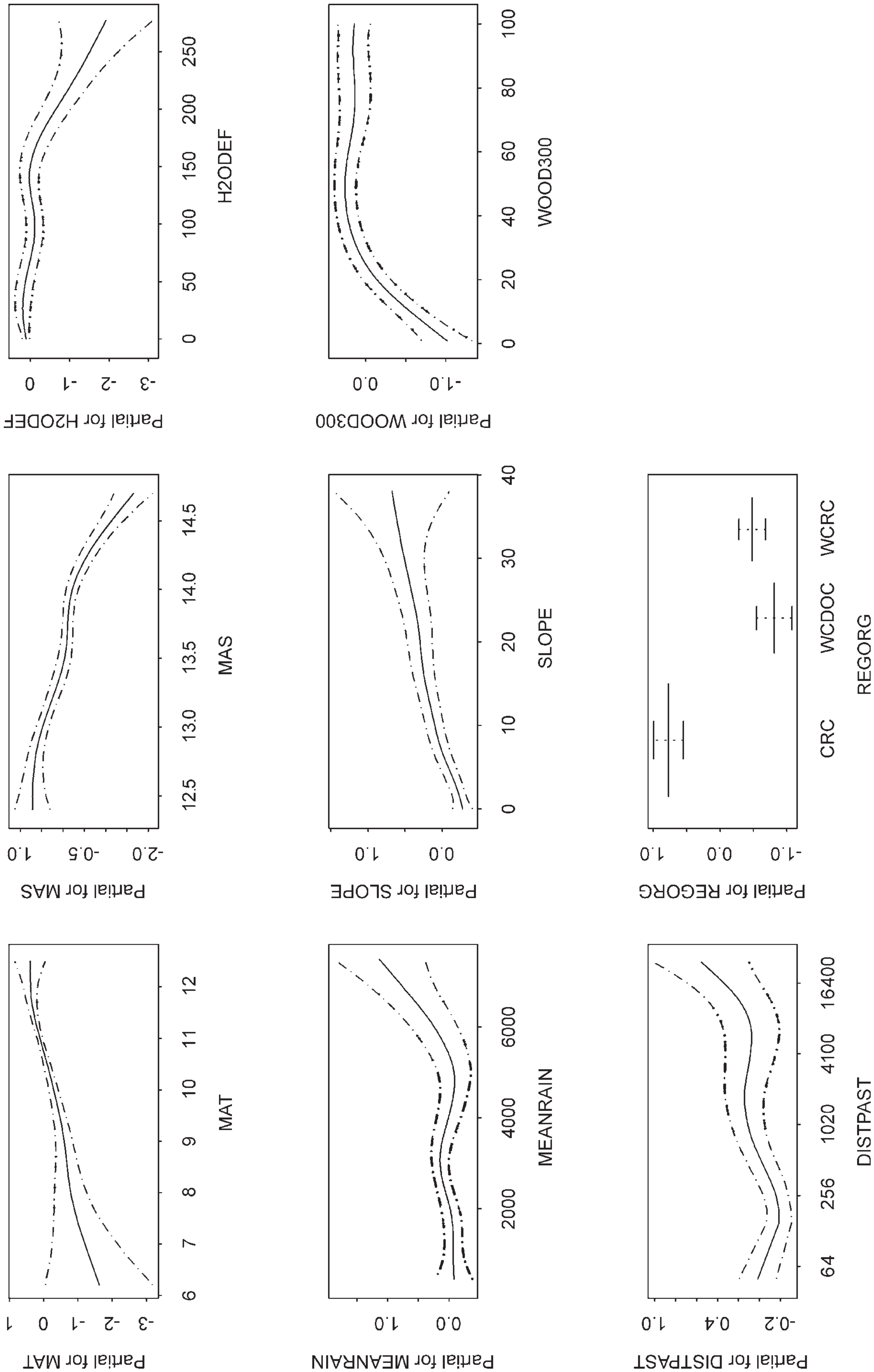


Figure 12. GAM of trap-catch success in post-control possum populations. This model explained 20% of the variation in TCIs for the post-control GRASP model. (See Tables 1 and 2 for an explanation of predictor variable abbreviations and scale/units used; for REGORG, CRC = Canterbury Regional Council, WCDOC = West Coast Conservancy (DOC), WCRC = West Coast Regional Council.)

annual or 2-yearly) would provide more reliable temporal sequence data that could be analysed for the effects of time since control. This approach, if applied to sufficient areas with differing control histories, might also offer the possibility of assessing patterns and rates of population recovery in relation to control strategies. Some of the desired data is being collected in an ongoing DOC-funded project (no. 2083; see Nugent et al. 2001).

Post-control model

The post-control model was limited to the Canterbury and West Coast regions. In these areas there was a total of 3792 trap lines from 325 surveys (see Fig. 14) and a total of 96 control operations or operational areas. Of these, 2320 trap lines had both location and other required information. Of these lines, 1692 were post-control trap lines with the required information and were included in the post-control models.

The post-control model constructed using GRASP accounted for 20% of the variation in TCIs. Eight factors had significant correlations with TCI (Fig. 12). There was a positive non-linear relationship between TCI and mean annual temperature (MAT), and there were negative non-linear relationships between TCI and mean annual solar radiation (MAS) and the annual water deficit (H2ODEF). TCI also increased with increasing mean annual rainfall (MEANRAIN) up to c. 3000 mm, then declined slightly to 5000 mm before increasing again. There was a relatively weak positive relationship between TCI and slope (SLOPE), and a stronger positive relationship with the amount of

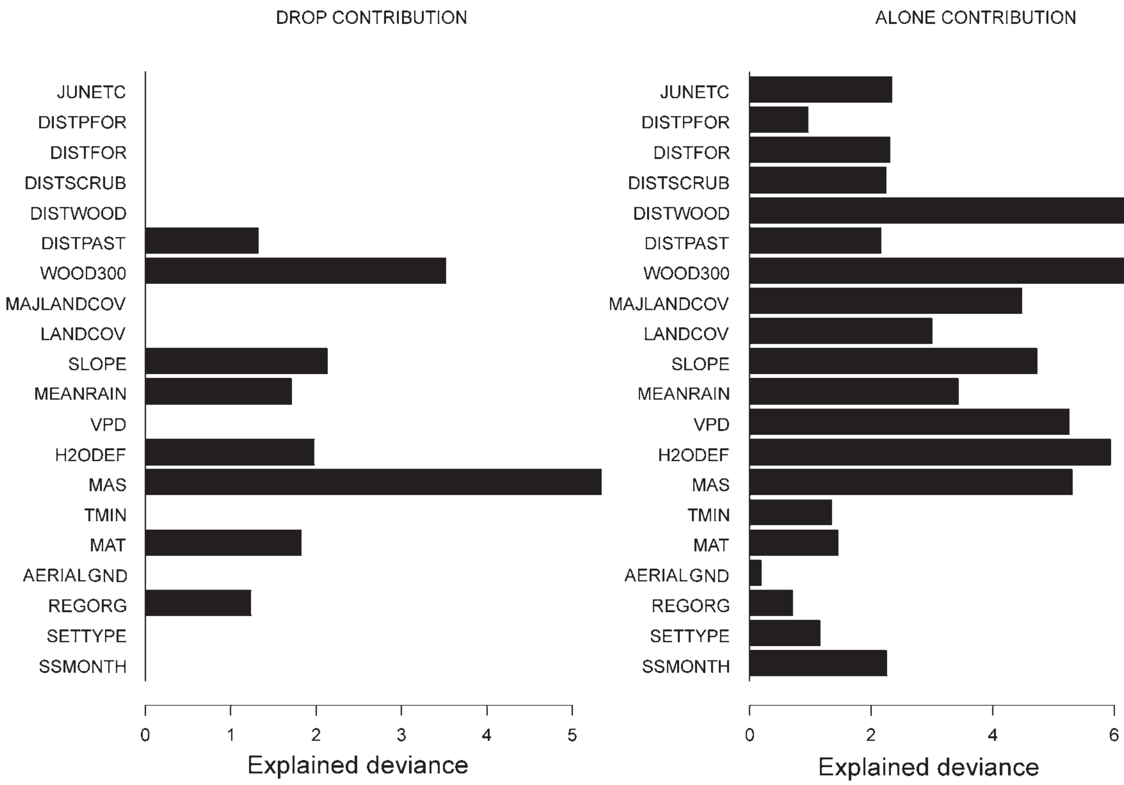


Figure 13. Contributions of predictor variables to the model for post-control possum populations; see Section 4.1 for an explanation of drop and alone contributions. (See Tables 1 and 2 and Fig. 12 for an explanation of predictor variable abbreviations and scale/units used.)

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