Orange-bellied Parrot: A retrospective analysis of winter habitat availability, 1985-2015

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Front cover photo: The Spit Nature Conservation Reserve near Point Wilson in Port Phillip supported a large proportion of the Orange-bellied Parrot population in winter during the 1970s and 1980s. It is now rarely used by the species. *Tecticornia arbuscula* shrubland in the foreground and saltmarsh herbfield on the sand spits in the background. Photo Peter Menkhorst.

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Acknowledgements

We thank the many dedicated members of the Australian birding community who have participated in the regular winter searches for Orange-bellied Parrots over the last four decades. Without their sightings this project would not have been possible. We hope the insights gained from this analysis go some way towards repaying their commitment to the cause of Orange-bellied Parrot conservation.

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Summary

Background

The Orange-bellied Parrot *Neophema chrysogaster* is a small (41-50g), critically endangered, migratory parrot that breeds in south-western Tasmania and spends the non-breeding period (April-October) in coastal areas of south-eastern Australia. During winter, Orange-bellied Parrots inhabit low lying coastal regions of southeast mainland Australia and are rarely found more than one km from the coast. The number of individuals counted during coordinated winter surveys has declined from 70-90 individuals in the 1980s (with a peak of 122 in 1983) to fewer than 20 in each year since 2001 and fewer than 10 in the last 5 years.

This project aimed to assess whether a reduction in Orange-bellied Parrot non-breeding habitat has occurred since 1983 which may have contributed to the species decline.

Methods

Records from the Orange-bellied Parrot winter sightings database were combined with contemporaneous data from the Landsat Thematic Mapper, to develop a series of spatio-temporal models of Orange-bellied Parrot habitat for six time periods between 1983 and 2015. The pixel size of 25 m x 25 m in our habitat data provides a close approximation to the scale of habitat selection by the Orange-bellied Parrot. The models predict, on a continuous scale, the likelihood that a 25 m x 25 m pixel will support Orange-bellied Parrot habitat.

We used these models to explore shifts in Orange-bellied Parrot habitat availability and utilisation through time.

Results

The models were highly sensitive (correctly predicting habitat in 65.5% of pixels) and extremely specific (correctly predicting background absences with a mean of 99.7%). The study period model shows little change in the extent of habitat since 1983. This is broadly consistent with other data that suggest that while small areas of saltmarsh and intertidal habitats have been degraded or destroyed, these have not been significant, with most of the gross habitat loss occurring well before 1983.

Variability amongst the epochal models is likely explained by the declining Orange-bellied Parrot population (and hence bird observations) which has led to an overall reduction in usage of suitable habitat. That is, the model partly reflects the site proclivities of each diminished generation of surviving individuals, rather than habitat suitability per se. This may partly explain the extensive areas of apparently suitable habitat that seem to be underutilised, for example in Western Port, Corner Inlet and The Coorong.

Conclusions

We conclude that mainland winter habitat is unlikely to have declined significantly in a structural or compositional sense to explain the decline in Orange-bellied Parrot population. The population decline is more sensibly attributed to problems associated with small populations – genetic erosion, inbreeding depression, poor reproduction rate and disease. In the case of this migratory species an extra burden may be reduced opportunities for the social interaction that allows transfer of knowledge between generations about migration routes and the location of suitable habitat patches.

Introduction

The Orange-bellied Parrot *Neophema chrysogaster* is a small (41-50g), critically endangered, migratory parrot that breeds in south-western Tasmania and spends the non-breeding period (April-October) in coastal areas of south-eastern Australia (Forshaw and Cooper 2002; Commonwealth of Australia 2016). The population of Orange-bellied Parrot has been at low levels for many decades (Menkhorst et al. 1991) and the species has been the subject of intensive conservation management since the mid-1980s (Brown and Wilson 1984; Menkhorst et al. 1991; Commonwealth of Australia 2016). This management has included an annual program of coordinated searches of known and potential winter habitat carried out by volunteer birders and environment agency staff on a defined weekend in May, July and September each year (Starks et al. 1992; Orange-bellied Parrot Recovery Team 1996; Commonwealth of Australia 2016). The results of these surveys, plus details of incidental sightings, made at other times, are maintained in the Orange-bellied Parrot winter sightings database. The number of individuals counted during the winter surveys was relatively steady through the 1980s (Menkhorst et al. 1991, Starks et al. 1992) but has declined from 70-90 individuals in the 1980s (with a peak of 122 in 1983) to fewer than 20 in each year since 2001 and fewer than 10 in the last 5 years (Orange-bellied Parrot Recovery Team, unpublished data).

During winter, Orange-bellied Parrots inhabit low lying coastal regions of southeast mainland Australia and are rarely found more than one km from the coast. They feed on the seeds and growing tips of a range of herbaceous or shrubby saltmarsh plant species, species adapted to fore-dune habitat, and weeds growing in adjacent paddocks or along tracks. In South Australia, strandline plants, notably *Cakile maritima*, were important food plants during the 1980s and 1990s, but there are few recent records of the use of these species. Orange-bellied Parrots mostly forage from the ground and therefore prefer areas with clumps of the preferred food plants interspersed with patches of bare ground that provide access to their low-growing food. The one exception is when they feed on the shrub *Tecticornia arbuscula* which requires them to clamber amongst the foliage. Key food plant species are listed in Table 1.

There has been a series of studies to define and map the winter habitat of the Orange-bellied Parrot beginning with descriptive studies, mostly focussed on saltmarsh vegetation (Carr and Kinhill Planners 1979, Gibbons 1984, Loyn et al. 1986, Casperson 1995, Lee and Burgman 1999 and Ehmke and Tzaros 2009). Additional, studies have used aerial photography (McMahon et al. 1994) and biophysical and variables derived from other mapped features to provide spatial models of habitat distribution (Ehmke 2009, Ehmke and Herman 2013). These models have been important in focussing and refining monitoring efforts and habitat management programs. However, they provide only a snapshot of the situation for one short time period, and their utility is reduced by the coarse pixel size (minimum of one ha) of the modelled data.

Here we use records from the Orange-bellied Parrot winter sightings database combined with contemporaneous multi-spectral reflectance data from the Landsat Thematic Mapper to develop a series of spatio-temporal models of Orange-bellied Parrot habitat for six time periods (epochs) between 1985 and 2015. The pixel size of 25 m x 25 m in our habitat data provides a close approximation to the scale of habitat selection by the Orange-bellied Parrot (P.M. pers obs). We then use those models to explore shifts in Orange-bellied Parrot habitat availability and utilisation through time.

Specifically, we aimed to explore changes in extent of Orange-bellied Parrot habitat through time by:

1. Building a single model (study period model) using all observations of the species since 1983 and Landsat reflectance data over the same period – and then apply this model to 6 five year long summaries of Landsat reflectance data.
2. Building 6 independent models (epoch models) of the species each using only the observations of the species from within a 5 year epoch and summaries of the Landsat data within the corresponding epoch.

Table 1. Key food plants of the Orange-bellied Parrot when on mainland Australia. *Introduced species.

	Species Name	Food preference
	Acaena novae-zelandiae	secondary
*	*Arctotheca calendula*	secondary
	Atriplex cinerea	secondary
	Atriplex paludosa	secondary
*	*Atriplex prostrata (hastata)*	secondary
*	*Brassica fruticulosa*	primary
*	*Brassica sp.*	secondary
*	*Cakile maritima*	secondary
*	*Chenopodium album*	secondary
	Chenopodium glaucum	primary
*	*Diplotaxis tenuifolia*	secondary
	Eurychorda complanata	secondary
	Frankenia pauciflora	primary
*	*Galenia pubescens*	secondary
*	*Heliotropium europaeum*	secondary
*	*Plantago coronopus*	primary
*	*Poa annua*	secondary
*	*Polygonum arenastrum*	secondary
*	*Polygonum aviculare*	primary
*	*Rapistrum rugosum*	secondary
	Sarcocornia qinqueflora	primary
	Sporadanthus tasmanica	secondary
	Suaeda australis	primary
	Tecticornia arbuscula	primary
	Tecticornia halocnemoides	secondary
	Triglochin striatum	secondary

Modelling methods

Statistical modelling or regression is the process by which mathematical relationships are established between dependent and independent variables. These relationships can then be used to make predictions of the dependent variable in regions beyond our existing knowledge, provided we have useful and more extensive independent data. In this study, the presence or otherwise of Orange-bellied Parrot habitat is the dependent variable. It has only two states, ‘presence’ and ‘absence’ denoted by 1 or 0. Because we have no ‘true’ absence data, consequent of both the uncertainties of detection and the temporal and spatial extent of survey, ‘absences’ have been generated and supplied to the model as randomly generated points in both the geographic space and to a lesser extent in the spectral space. The independent variables for this model are variables derived from remote sensing, primarily the Landsat satellite platform. These data are considered to be useful independent variables for modelling the temporal and spatial extent of Orange-bellied Parrot habitat as they:

- are spatially explicit and extensive
- have been acquired regularly using the same sensors and spectral bands
- are rich in vegetation-relevant information particularly in herbaceous vegetation types (such as saltmarsh) where understorey is not obscured by shrub or tree canopies
- contain inter-annual and intra-annual variation reflecting the response of the vegetation to season and/or wetting and drying regimes
- resolve at scales useful for planning purposes
- are objective and free from human bias and error.

In essence, each model contrasts two competing spectral and physiographic signatures (one associated with temporally-defined Orange-bellied Parrot observations and the other defined by temporally-defined random background absences) to make predictions at every 25 m X 25 m pixel across our study area. An overview of the modelling processes and subsequent application of the resultant models is shown in Appendices A and B.

Study area

The spatial extent of the study area is shown in Figure 1. Within this region, the study area extends 10 km inland from the mainland coast between the mouth of the Murray River in South Australia to Jack Smith Lake in Gippsland, Victoria. This area includes the vast majority of mainland sightings of the Orange-bellied Parrot during the period modelled. The primary independent data used in this project is Landsat data acquired post 1987. Our modelling grain size – or the resolution at which we make predictions across our study area – is 25 m x 25 m.

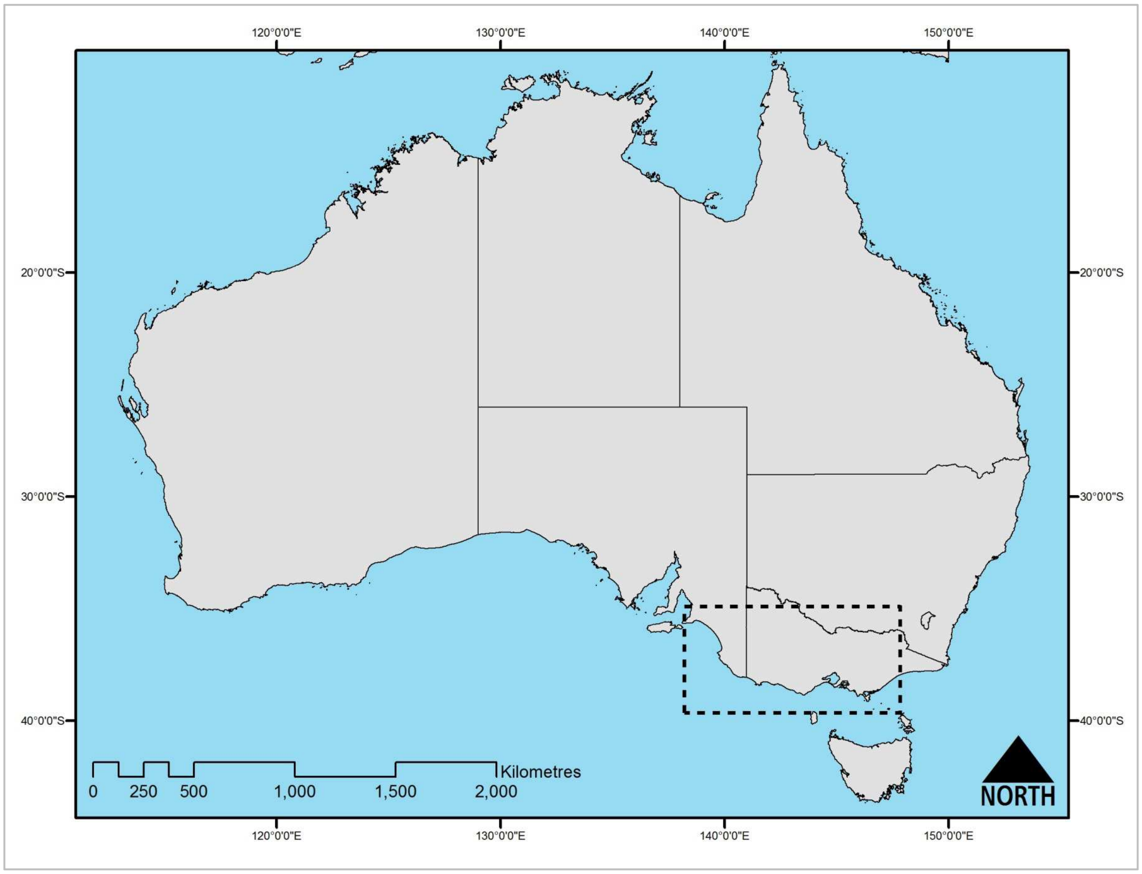

Figure 1. Study area includes coastal and near coastal areas of the Australian mainland coastline within the hatched inset.

Study period

The temporal extent of the study effectively extends from the calendar years 1983 to 2015. The temporal resolution of our predictions is summarised to 6 year epochs with overlap periods of one year (see Table 2).

Dependent data

Orange-bellied Parrot records

Location data were extracted from the winter sightings database which is maintained on behalf of the recovery team by Birdlife Australia. It is based upon an annual program of coordinated searches of known and potential habitat patches carried out by volunteer birders and environment agency staff on a defined weekend in May, July and September each year (Starks et al 1992; Orange-bellied Parrot Recovery Team 1996; Commonwealth of Australia 2016). The database also includes details of incidental sightings, made at other times and reported to the survey coordinator.

Sight records of OBPs for the years 1983 to 2015 inclusive, and the associated locational data, were extracted from the database. Records from outside the core wintering range, defined as from Corner Inlet, Victoria to Goolwa, South Australia (Figure 1), were excluded from further consideration because they are rare outliers.

Each record was scrutinised to check for inconsistencies between the written location and the mapped location. Discrepancies were referred to a selected expert who has been intimately involved in the winter monitoring project throughout the time period concerned (Peter Menkhorst for Victoria and

Bob Green for South Australia). The experts made a decision to either locate the record more precisely (in instances where they were confident in so doing) or to delete it from the modelled data. Each accepted record was then overlaid on high resolution aerial photography to check that it occurred within plausible habitat. For example, records that were over water were moved to the nearest plausible terrestrial habitat based on expert judgement, combined with an interpretation of the written locality data and other notes associated with the record. In many cases this was a straightforward move, for example from low on the beach along The Coorong to high on the beach in the zone where the food plant *Cakile maritima* grows and where OBPs were commonly found feeding during the late 20th century, or from a within a sewage pond at the Western Treatment Plant to the wheel ruts along the bund between two adjacent ponds, a common feeding site for the species in western Port Phillip during the 21st century. Records that could not be relocated with confidence were removed from the dataset. The purpose of these refinements was to ensure that the modelled data were suitable for spatial modelling at a 25 m resolution.

Accepted observations were then collated into 6 separate datasets, one for each epoch. The number of records by epoch that 'passed' the vetting process through to the subsequent modelling are shown in Table 2. Note that records from overlap years were added to both respective datasets.

Table 2. Numbers of Orange-bellied Parrot records by epoch and across the temporal extent of modelling.

Epoch Name	Temporal extent	No. of OBP records used
1985-1990	1983, 1984, 1985 1986, 1987, 1988, 1989, 1990	302
1990-1995	1990, 1991, 1992, 1993, 1994, 1995	253
1995-2000	1995, 1996, 1997, 1998, 1999, 2000	256
2000-2005	2000, 2001, 2002, 2003, 2004, 2005	210
2005-2010	2005, 2006, 2007, 2008, 2009, 2010	204
2010-2015	2010, 2011, 2012, 2013, 2014, 2015	146
Total records used	**Study period 1983-2015**	**1161**

Summaries of the Orange-bellied Parrot observation numbers (see Table 2) by epochal dataset are shown in the series of maps - Figures 3 to 7 inclusive. Figure 8 shows the total number of valid records used in this study irrespective of epoch.

Figure 2. The distribution of winter records of the Orange-bellied Parrot used in the model for the 1985-1990 epoch

Figure 3. The distribution of winter records of the Orange-bellied Parrot used in the model for the 1990-1995 epoch

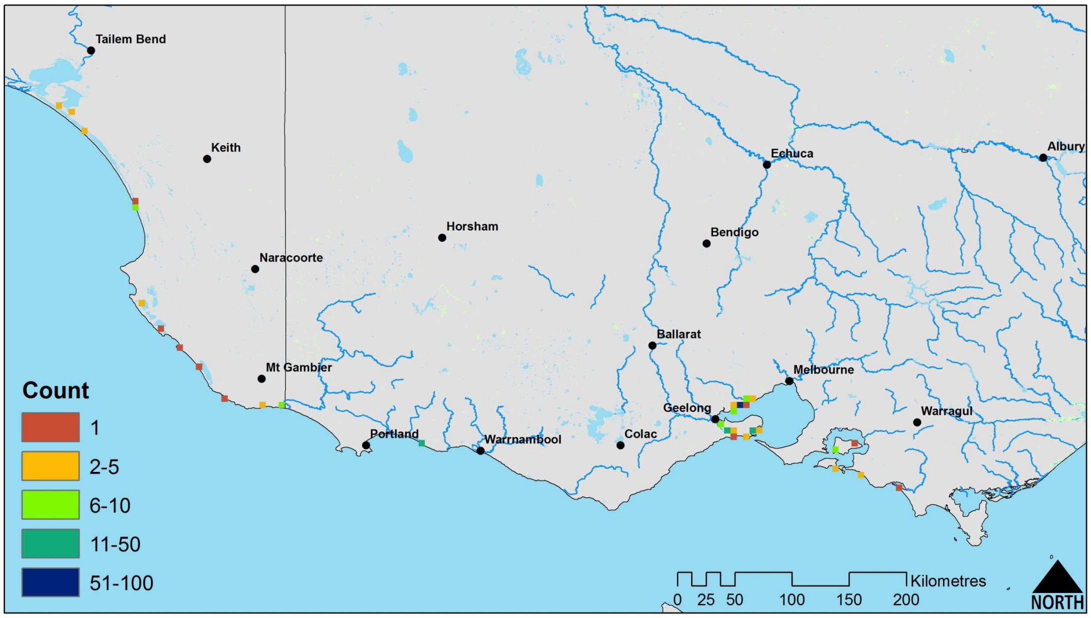

Figure 4. The distribution of winter records of the Orange-bellied Parrot used in the model for the 1990-1995 epoch

Figure 5. The distribution of winter records of the Orange-bellied Parrot used in the model for the 2000-2005 epoch

Figure 6. The distribution of winter records of the Orange-bellied Parrot used in the model for the 2005-2010 epoch

Figure 7. The distribution of winter records of the Orange-bellied Parrot used in the model for the 2010-2015 epoch

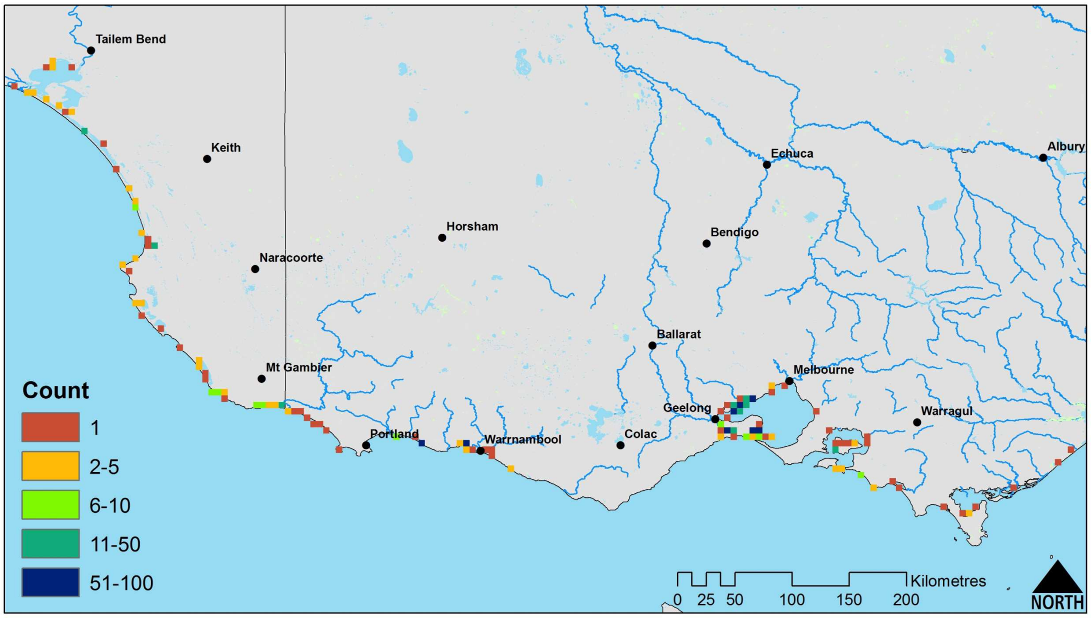

Figure 8. The distribution of all Orange-bellied Parrot records used in the models

The date and co-ordinate of each of the sets of observations were then used to extract the temporally (resolution = 5 year epoch) and spatially (resolution = 25 m) coincident independent data (see Appendix A and subsequent sections).

To build a useful model, we need presences and absences to discriminate between the variation within each of these classes as it is expressed in the independent data. Therefore, for modelling purposes we created a set of 35,000 'background absences' (sensu Liu et al 2013) which were allocated randomly across the entire study area. The use of random absences in the geographic space is a robust strategy when the target of the model is likely to be relatively narrowly defined in terms of the independent variables (Phillips and Dudik 2008).

Independent Data

Independent satellite-derived data

Spectral reflectance data from the 'thematic mapper' sensor mounted on the various Landsat missions[1], and indices derived from these reflectance data, were used as inputs to the spatio-temporal models. Using the Geosciences Australia data-cube and the National Computing Infrastructure, we created 36 independent datasets from the Landsat chrono-sequence for each epoch. From the set of 'cloud-free' images we derived median (and therefore stable) data for Bands 1, 3, 4, 5 and 7 (see Table 4) for each of the summer, winter and autumn seasons at every 25 m x 25 m pixel in the study area. Various standard Landsat indices were then derived from the median images (Appendix C). While the winter and autumn image sets were used in the modelling at their 'native' 25 m spatial resolution, the set of summer images was resampled to 250 m to supply landscape context data to each model. These data were supplied as independent variables because landscape configuration is likely to be a component of OBP feeding and roosting site selection (Ehmke 2009). A complete list of the independent data is provided in Appendix C.

Altitude data

The composite national 25 m (bare earth) digital elevation model[2] derived from over 200 individual LiDAR surveys undertaken between 2001 and 2015 covers part of the study area including most of the coastline and low lying coastal areas. In regions of the study area with no LiDAR coverage (notably the far western coastal area including the mouth of the Murray River) the LiDAR data was mosaicked with the 1 second Space Shuttle Radar Telemetry Mission Level 2 Derived Digital Surface Model for Australia (Gallant et.al. 2011).

Other independent variables considered

Other independent datasets were examined for use in the modelling. Terrain models derived from the Space Shuttle Radar Topography Mission (Geoscience Australia 2016) were considered but this product remains too coarse for reliably defining small scale shallow surface depressions (Bhang and Swartz 2008). Rainfall and evaporation models were also considered, however, gridded epoch specific rainfall and temperature data were not readily available for this project. In addition, phenological patterns associated with rainfall events and wetland filling events, particularly in treeless landscapes are well reflected in the spectral data. The use of the Landsat derived spring season data within epochs was excluded from the modelling as it provided no significant additional model improvement over the use of the other seasons.

Building the modelling datasets

All spatially and temporally valid Orange-bellied Parrot sighting locations were taken to each of the independent datasets (see Appendix C) to extract spatially-coincident and temporally-relevant spectral and altitudinal data. In addition, all of the independent data, irrespective of epoch, were extracted at each of the random absence sites. As such, the absence data could be deployed to the modelling over the entire study period (1985-2015) or to any individual epoch. Following this extraction process, presence and absence sites, along with their set of potential predictors, were placed in a database for formulating modelling datasets. Six separate epochal datasets were created. Each of these contained the Orange-bellied Parrot observation data exclusive to one of the six epochs accompanied by the coincident and contemporaneous independent data, plus the random set of background absences

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[1] http://landsat.gsfc.nasa.gov/?p=3229

[2] See http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_22be4b55-2485-4320-e053-10a3070a5236 for associated metadata

accompanied by independent data specific to the same epoch[3]. A seventh dataset, which we shall henceforth refer to as the 'study period' dataset, included all Orange-bellied Parrot observation data with their coincident and contemporaneous independent data, plus the random absence data points repeated for each of their epochal manifestations (ie. 35,000 sites X 6 epochs = 210,000 background absence data points).

For each of the seven models, two independent ensemble models were built; one that subsampled from all of the available presence and absence data and one that was restricted to sub-sampling from 90% of the presence and absence data. The latter model was tested by assessing its capacity to predict the 10% of the data held out of the modelling process. This testing indicated the underlying performance of the final model, that is, the degree to which it can be reliably generalised.

Modelling process

We used the 'CLUS'[4] system (Struyf et al. 2011) to create seven ensemble regression-tree models using a strategy of bagging (stratified-random bootstrapping of the dependent dataset of presences and absences), and random forests (supplying a random set of the independent data to decision nodes for partitioning). The goal of regression trees more generally is to predict the target (or dependent variable) based on the recursive partitioning of several input (independent) variables. Each leaf in a predictive tree represents a value of the target variable given the values of the input variables represented by the path from the root to the leaf (Friedman 2001). Here we invoke predictive clustering trees (sensu. Kocev et al. 2007), a particular type of regression tree that generalizes learning trees as cluster hierarchies. Each decision node within the tree is supplied with a random sub-set of the independent variables from which a partitioning test is applied, a method known as Random Forests. Random Forests (Breiman 2001) is an ensembling method that utilises the average value from a group ('forest') of trees, thereby overcoming the inherent inaccuracies in seeking a single parsimonious model. Bootstrap aggregating (or bagging), which is similar to model averaging (Breiman 1996), was used to further improve the accuracy of predictions.

Following the removal of 10% of each dataset for validation purposes, the remaining 90% of the data was used to develop the regression-tree models. Each of the 20 'bags', or subsamples, was created by randomly sub-sampling both presences (where available) and absences from 20 strata delimited within the independent variable Normalised Difference Vegetation Index (NDVI see table 2). NDVI was divided into 20 sampling strata based on equal intervals from the range determined by intersection with the entire set of presence and absence data. The resultant suite of 20 ensemble models was averaged to produce a consensus model through model voting.

Bagged random forests are well suited to modelling large sets of independent variables, many of which may be highly correlated. While over-fitting is often seen as a problem in statistical modelling, predictions of regression trees for independent data sets are not compromised by using a large number of variables and are generally superior to other methods (e.g. generalised linear models, generalised additive models, and multivariate adaptive regression splines; Elith et al. 2006).

Model Application and post processing

The relationships between the dependent and independent data formulated by the consensus or ensemble models within each of the six epochs were applied to the relevant independent data to create spatially explicit expressions of each model, each comprising two layers or maps – specifically the mean likelihood of Orange-bellied Parrot habitat presence (expressed at the 25 m pixel scale) and

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[3] For example the 1990-1995 epoch included 35,000 random background absences and 253 presences.

[4] Clus is free software (licensed under the GPL) and can be obtained from this website: https://dtai.cs.kuleuven.be/clus/index.html

the standard deviation of likelihood determined from each of the twenty random forest models (see Appendix A).

For the study period model, we used the relationships revealed in the model and applied these to the independent data for each epoch (see Appendix A). Thus, this model was used to create a further 12 maps – 6 mean likelihood surfaces – one for each epoch – and a further 6 standard deviation surfaces.

All 12 mapped predictions were filtered using a water mask using a water detect algorithm created for each epoch to remove all predictions that occurred in lakes and near-shore environments.

Model results and discussion

Model fitting

The models predict, on a continuous scale, the likelihood that a 25 m pixel will support Orange-bellied Parrot habitat. These predictions, along with measures of 'within model' uncertainty, can be made across broad geographic regions given the appropriate geographically-constrained and, where necessary, temporally-constrained, independent inputs. In general, the models predict habitat to be associated with intertidal or near intertidal areas close to waterbodies. The models, perhaps erroneously, predict all open beaches within the study area to be potential habitat although the many observations of birds in such habitats may only be incidental to the availability of nearby wetland habitat.

Treated as a regression problem the R^2 or general 'fit' of each of the models is summarised in Table 3. All of the models fitted to the training data perform extremely well with approximately 80-90 % of the variance predicted from the set of independent variables. However, when each of the ensemble models were evaluated against the 'hold out' or test dataset, the model performance falls significantly. This probably reflects:

- the tendency of regression trees to over-fit sparse dependent data to independent data that will invariably have an extremely high number of unique variable combinations at 25 m resolution. Each OBP observation site is likely to be different within the broad variable space. Further, the set of random absences, although numerous, is unlikely in any tractable number of bootstrap iterations of the model to fully describe all possible spectral combinations that constitute absence'. …
- a very high of degree of spectral (both local and contextual) variation between field observations of OBPs (for example sand dunes vs intertidal wetlands) combined with the comparatively small number of observations of the birds within any given epoch.
- A disproportionately high number of Orange-bellied Parrots in unusual locations in some epochs.
- The inevitable problems that arise with modelling using random background absence data, including the significant number of random absence sites that will likely sample potential habitat for OBPs (i.e. false absences), and the unknown extent of the variable space that will be poorly assigned to either presence or absence.

Table 3. Coefficients of determination for the test and training data for each epoch model and the study period model.

Model (epoch/period)	Coefficient of determination (R^2), training data	Coefficient of determination (R^2), test data
1985-1990	0.896	0.620
1990-1995	0.844	0.712
1995-2000	0.821	0.565
2000-2005	0.824	0.493
2005-2010	0.780	0.406
2010-2015	0.828	0.600
Study period (1985-2015)	**0.815**	**0.578**

If we examine the utility of the model as a classification problem, model performance is appropriately measured as the number of correctly classified presences and absences. To ascertain from our continuous likelihood outputs whether a site should be classified as habitat or otherwise we need to select a threshold that optimises the correct assignation of presences (above the threshold) and absences (below the threshold). In this study we have used a threshold derived from the study period model that approximates the maximisation of sensitivity and specificity (Max SSS (Liu et al 2016)) to show the classification error rate (See Table 4).

Table 4. Classification error rate

Model (epoch/period)	Test or training	Sensitivity - % correctly predicted habitat	Specificity - % correct background absences
1985-1990	Training data	93.9%	99.9%
1990-1995	Training data	97.0%	99.9%
1995-2000	Training data	89.9%	99.9%
2000-2005	Training data	87.4%	99.9%
2005-2010	Training data	91.0%	99.9%
2010-2015	Training data	92.5%	100.0%
Study period (1985-2015)	**Training data**	**85.0%**	**99.8%**
1985-1990	Test Data	72.0%	99.6%
1990-1995	Test Data	84.6%	99.6%
1995-2000	Test Data	84.6%	99.6%
2000-2005	Test Data	64.7%	99.6%
2005-2010	Test Data	58.3%	99.7%
2010-2015	Test Data	75.0%	99.8%
Study period (1985-2015)	**Test Data**	**65.5%**	**99.7%**

The apparent importance of each independent variable in each of the seven models is shown in Appendix 1. ‘Importance’ is here expressed as the proportion of the total number of partition tests to which the specific variable was deployed. Care should be taken in interpreting these data as many of the input data are highly correlated, such that if one was removed from the analysis, another analogous variable would likely significantly change its ranking. The variables selected can only be indicative of the underlying ecosystem drivers and are only here used in the pursuit of model accuracy, as opposed to implying causation. Further to this, the frequent use of a co-variate to partition the data, does not imply a positive or negative correlation with the data, it merely implies its usefulness towards accurate prediction. Not surprisingly, given the Orange-bellied Parrot’s well documented preference for overwintering feeding habitat in intertidal saltmarshes and adjacent vegetation, altitude is consistently the most frequently used variable in every model.

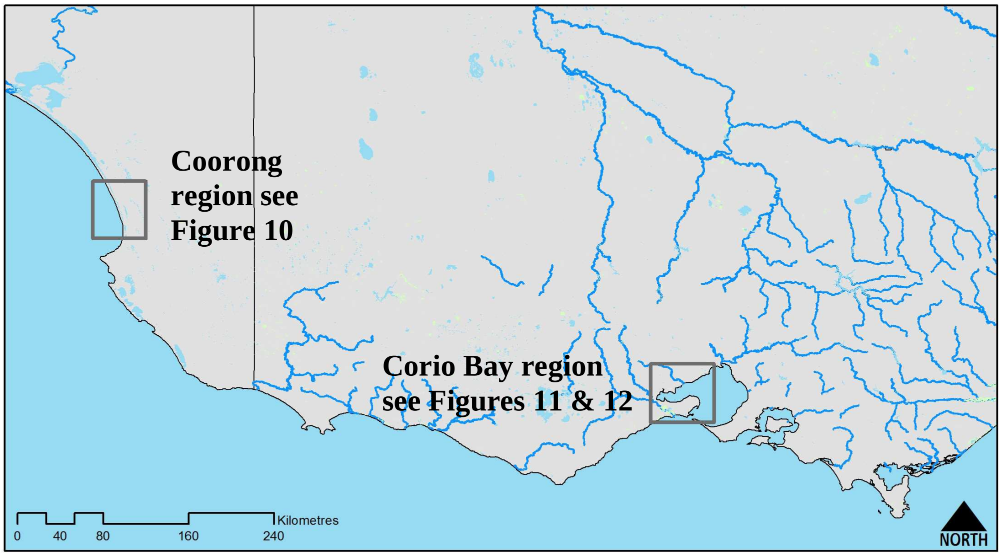

Figure 9. Study area showing the coastal regions where spatially explicit versions of the applied model are shown. Refer also to Figures 10, 11 & 12.

Study period model applied to 1985-1990 Study period model applied to 1990-1995 Study period model applied to 1995-2000 Study period model applied to 2000-2005 Study period model applied to 2005-2010 Study period model applied to 2010-2015

Epoch model 1985-1990 Epoch model 1990-1995 Epoch model 1995-2000 Epoch model 2000-2005 Epoch model 2005-2010 Epoch model 2010-2015

Figure 10. Top Row of images - study period model applied to the spatial data delimited by epoch for a portion of the Coorong Lakes, South Australia. Left to right: Study period model applied to epoch 1985-1990 specific spatial data; study period model applied to epoch 1990-1995 specific spatial data; study period model applied to epoch 1995-2000 specific spatial data; study period model applied to epoch 2000-2005 specific spatial data; study period model applied to epoch 2005-2010 specific spatial data; study period model applied to epoch 2010-2015 specific spatial data. Bottom row of images - individual within-epoch models: Left to right: epoch 1985-1990; epoch 1990-1995; epoch 1995-2000; epoch 2000-2005; epoch 2005-2010; epoch 2010-2015.

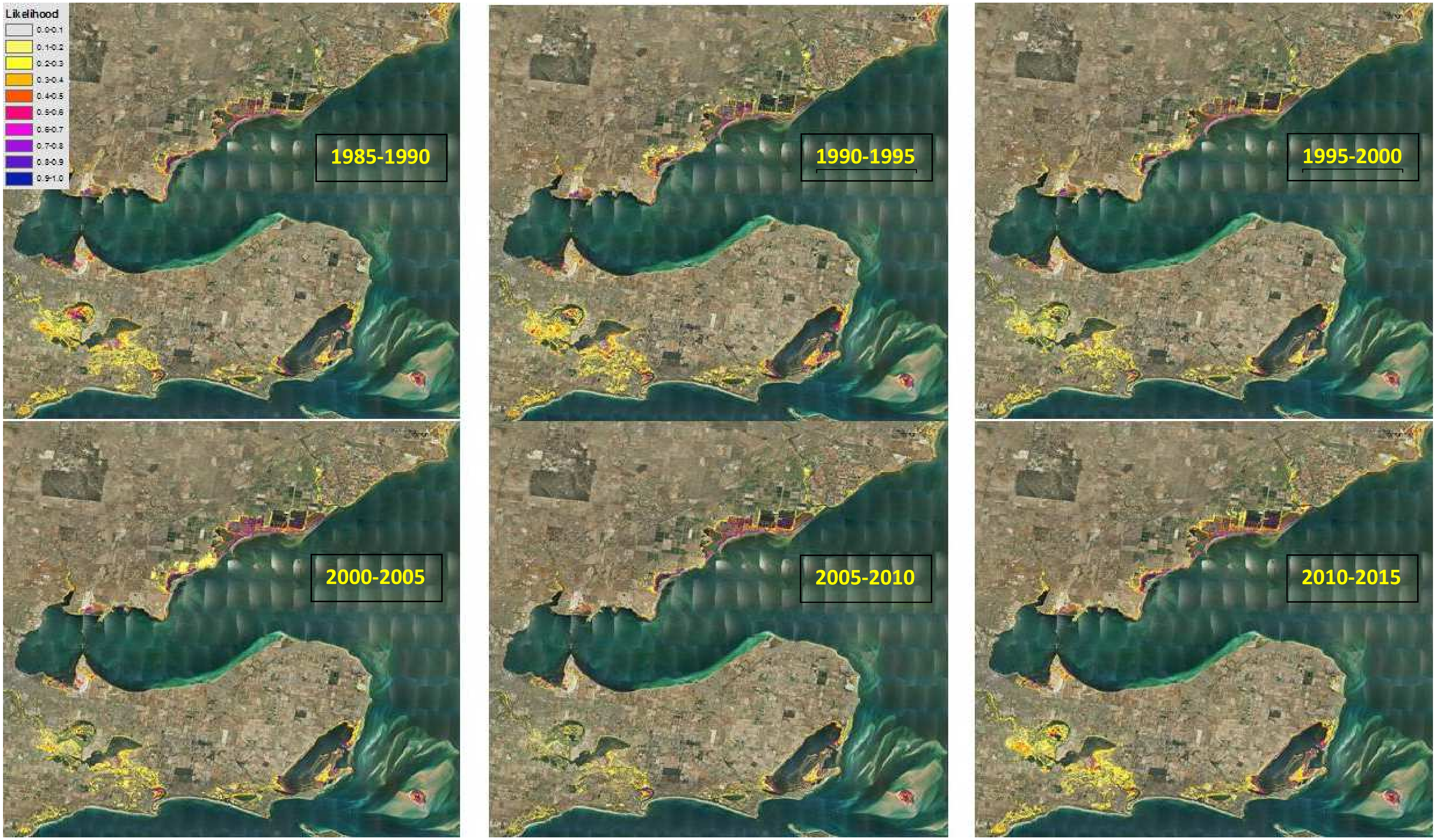

Figure 11. Study Period model applied to the spatial data delimited by epoch for coastal areas associated with Corio Bay and neighbouring coastline, Victoria . Clockwise starting from the top left: Study period model applied to epoch 1985-1990 specific spatial data; study period model applied to epoch 1990-1995 specific spatial data; study period model applied to epoch 1995-2000 specific spatial data; study period model applied to epoch 2000-2005 specific spatial data; study period model applied to epoch 2005-2010 specific spatial data; study period model applied to epoch 2010-2015 specific spatial data.

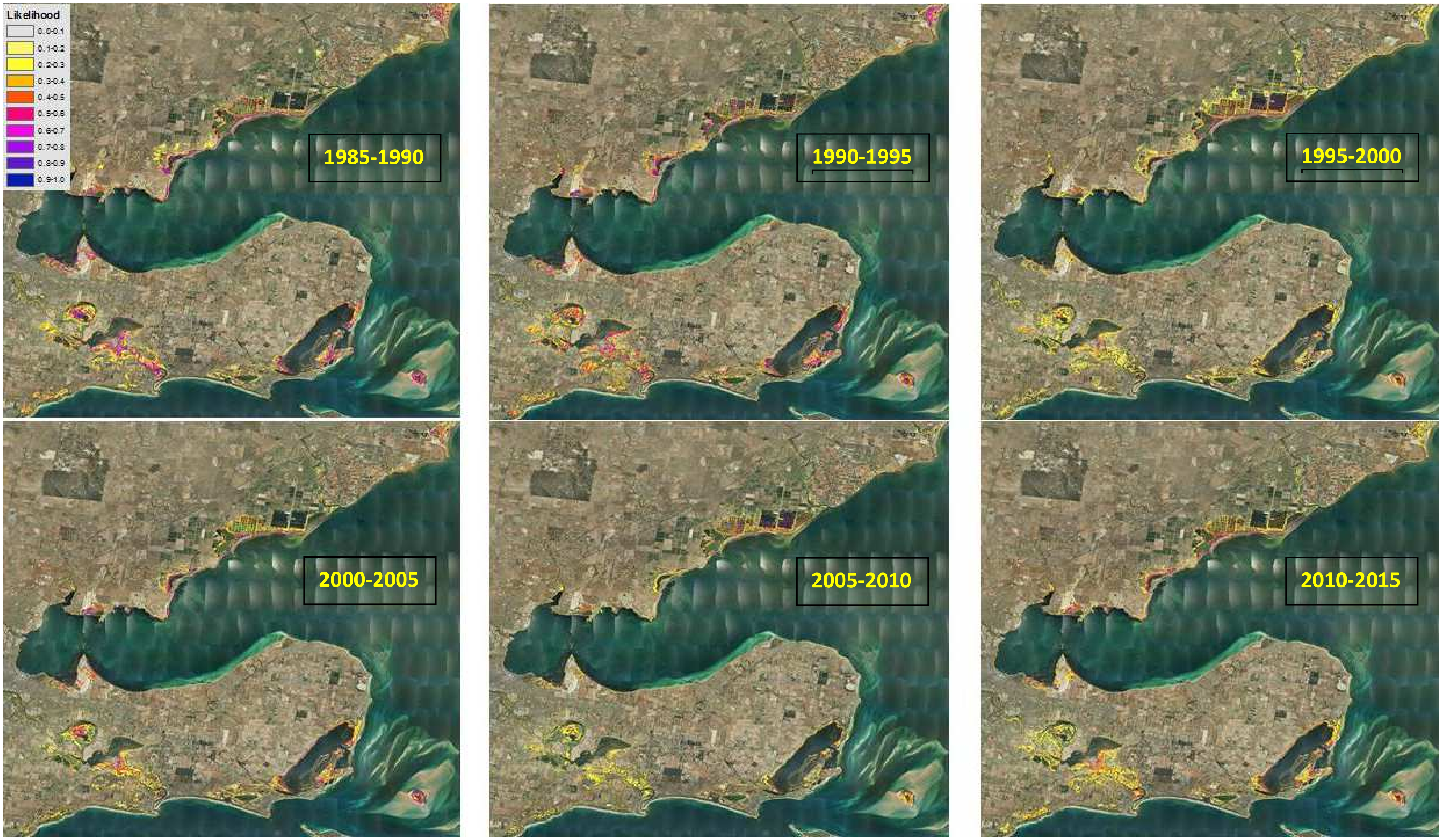

Figure 12. Individual within-epoch models for coastal areas associated with Corio Bay and neighbouring coastline, Victoria. Clockwise starting from the top left: Epoch 1985-1990; epoch 1990-1995; epoch 1995-2000; epoch 2000-2005; epoch 2005-2010; epoch 2010-2015.

Temporal Change

Definitive conclusions about the absolute extent, and degree of change in extent, of Orange-bellied Parrot habitat over time cannot be made using this or any other modelling approach that uses sampling effort-biased, presence-only models. In particular, the model cannot account for those elements of habitat and niche that are poorly rendered in reflectance data, such as the subtle ramifications of extinction debt, predation levels, interspecific competition for food resources, some forms of weed invasion and human visitation levels. These factors may well have changed significantly over time. However, some trends in the interpretation of the models when applied and visualised are worth further discussion. Maps of the 12 'mean likelihood prediction' outputs are shown for two regions of the study area: a section of The Coorong wetlands in South Australia (Figure 10) and Corio Bay and surrounding wetlands in Victoria (Figures 13 and 14). Figure 9 shows the location of both these areas as inset boxes. These two regions were selected because they are representative of the habitats utilized by wintering Orange-bellied Parrots and contain a large proportion of the records used in the models. The model predictions have been superimposed on a 'fixed' aerial image from 2009 and 2011 respectively.

Across the entire study area within-epoch models visually appear to be quite volatile and subject to change from epoch to epoch, whereas the study period models appear to be quite stable when applied to each of the epochs. These impressions are borne out if we round-up the continuous likelihood scores to two decimal places and plot this against the number of hectares predicted (see Figures 15-19). Individual epoch models, when plotted in this way, seem to differ widely in the general context of decline in the extent of habitat over time (compare the two right-hand columns in Figure 15, and Figures 16 and 17, and 18 and 19), whereas the study period model, when applied to each of the epochal datasets, is quite stable and expresses very little discernible trend in terms of hectares of habitat over time (compare the two left hand columns in Figure 15, and Figures 16 and 17, and 18 and 19). Figures 18 and 19 focus on the application of models to the 1985-1990 epoch and to the 2010-2015 epoch and further reinforce this pattern. If we believe that all of the places that the Orange-bellied Parrot has been observed over the last 35 years broadly circumscribe the mainland habitat of the species, and that the independent data are useful in distinguishing this habitat from non-habitat, the study period model implies that a significant or measurable decline in Orange-bellied Parrot habitat is not credible. This is broadly consistent with other data that suggest that while saltmarsh and intertidal habitats have suffered significant loss in small, specific areas (Boon et al. 2011), losses in the context of the study area have not been significant, with most of the gross losses in extent occurring well before 1983 (Carr and Kinhill Planners 1979). Fluctuations in the individual epoch models are more likely explained by the combination of:

- changing patterns of the habitat preference (Orange-bellied Parrot recovery team unpublished data) of cohorts of birds, especially as bird numbers decline (as opposed to declining extent of habitat)
- declining numbers of birds and therefore diminished geographic reach/expression of the 'homing' instincts of the entire population.
- declining numbers birds and consequently low detectability

Given the propensity of birds to return to previous overwintering locations (Starks et al. 1992), and assuming an absence of competition for food resources (given the very low population numbers at any site), each temporal model could be seen to reflect not only the inherent suitability of the set of locations but, at least in part, the proclivities and homing instincts of each generation of surviving individuals, rather than habitat suitability per-se. Indeed, this may in part explain why there has always been extensive areas of underutilised but apparently suitable habitat in Corner inlet, Western Port and The Coorong, for example. In this context, localised and/or temporary losses of habitat elements (such as that caused by changes in the salinity and water levels of estuaries) may be important and should be examined further.

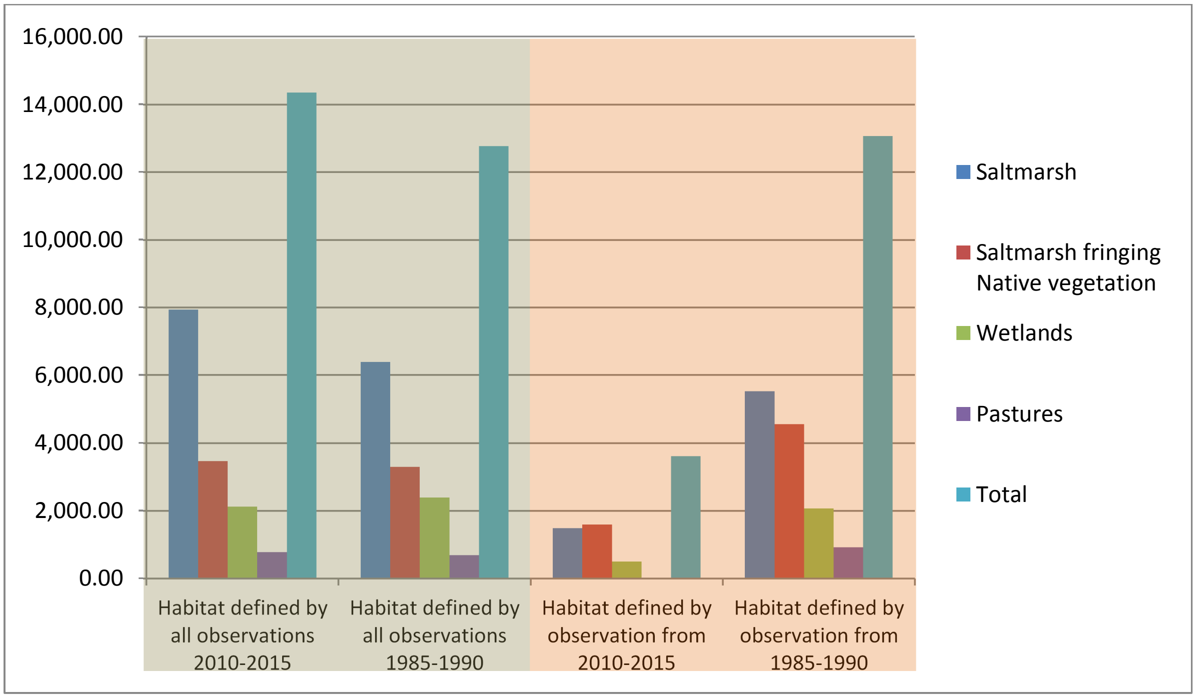

Figure 15. Area estimates (ha) by land-cover type. A pixel is classified as Orange-bellied Parrot habitat if its likelihood of being so is greater than 0.5. The two left-hand summaries show areas derived from the study period applied to the bookend epochs and the two right-hand summaries show the within epoch summaries for the bookend epochs.

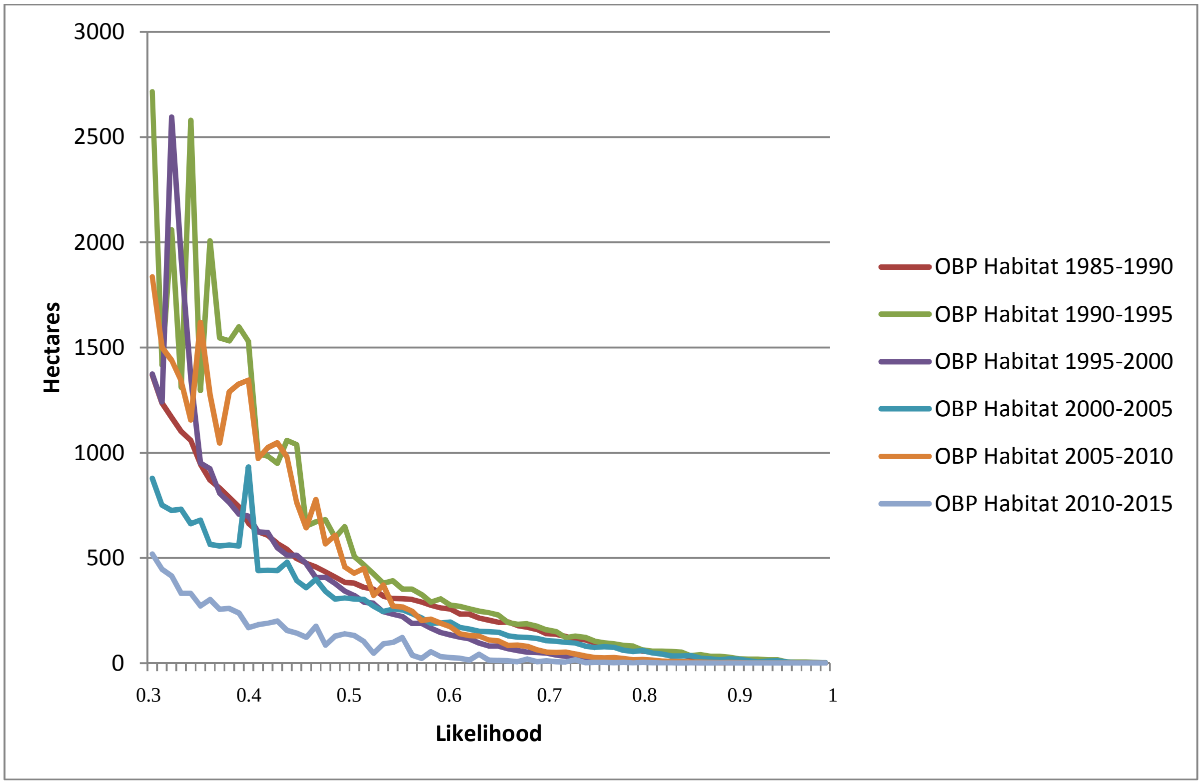

Figure 16. Epoch models applied and mapped across the study area with the number of hectares plotted at each 0.01 increment of Orange-bellied Parrot habitat likelihood above 0.03.

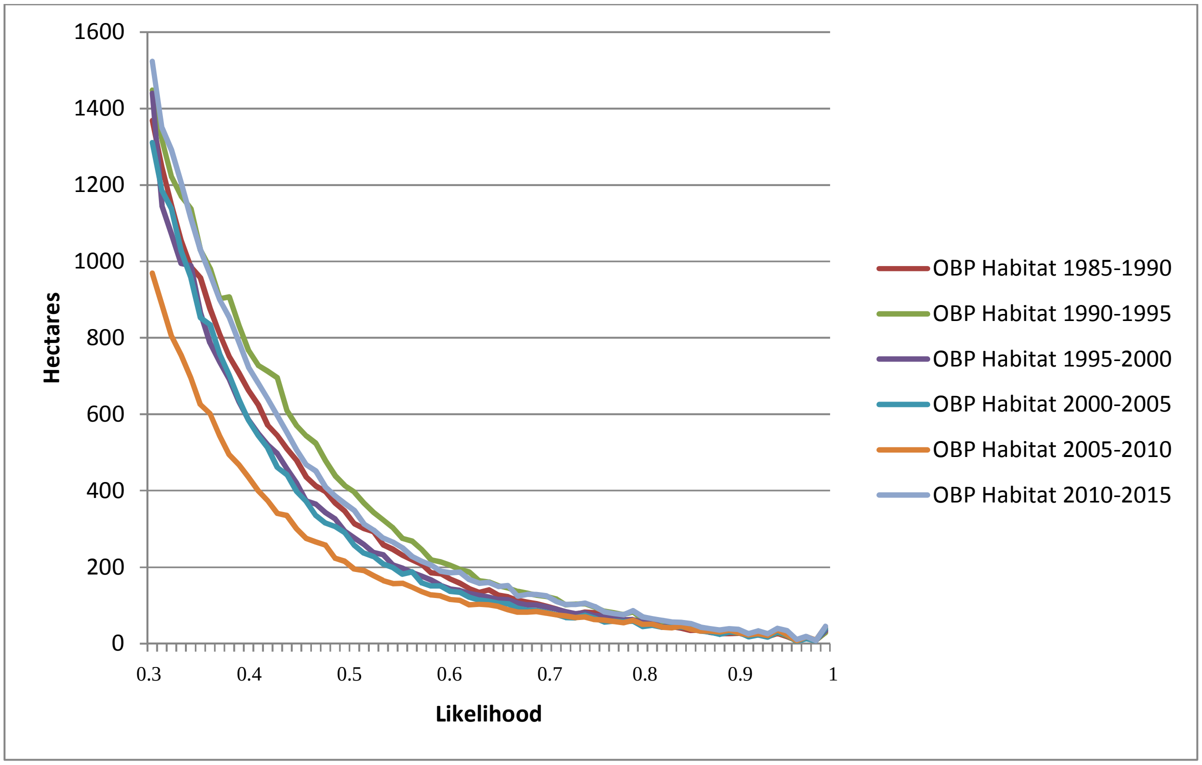

Figure 17. Study period model applied to independent data from each of the epochs. The number of hectares is plotted at each 0.01 increment of Orange-bellied Parrot habitat likelihood above 0.03.

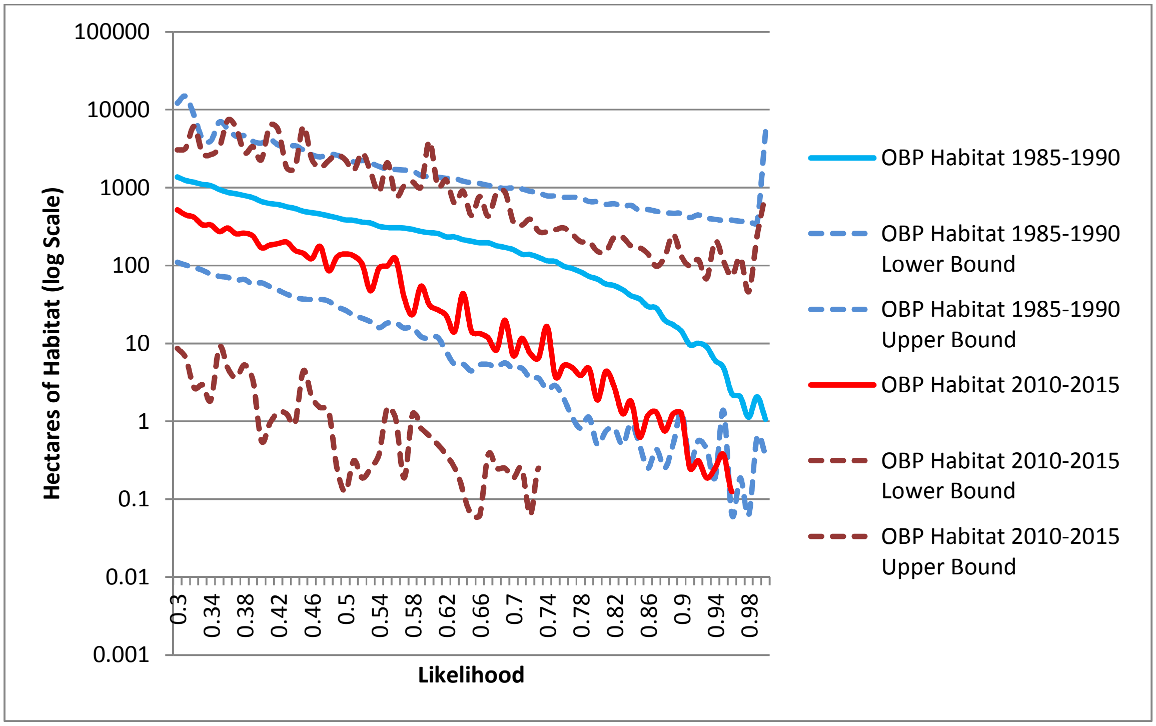

Figure 18. Epoch model for 1985-1990 and epoch model for 2010-2015. Models applied and mapped across the study area with the number of hectares plotted at each 0.01 increment of Orange-bellied Parrot habitat likelihood above 0.03. Within model uncertainty is also plotted as one standard deviation above and below the mean.

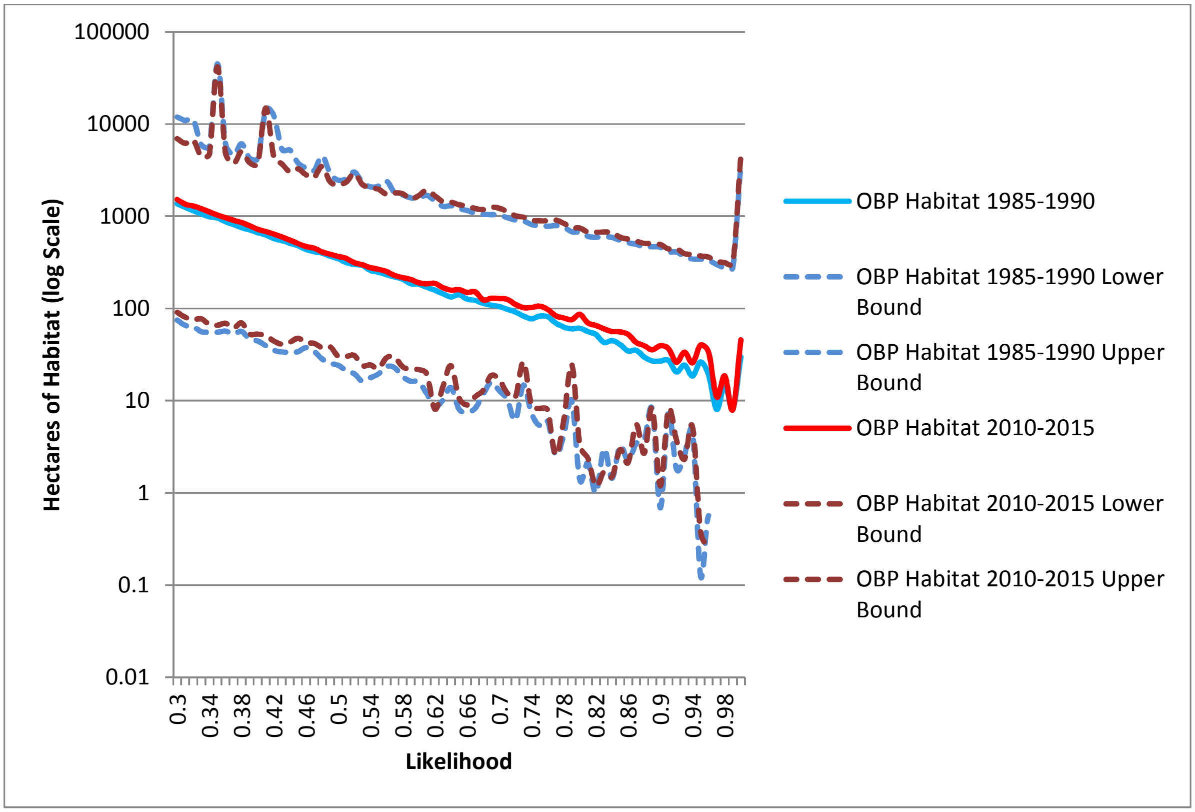

Figure 19. Study period model applied to independent data from epochs 1985-1990 and 2010-2015. The number of hectares is plotted at each 0.01 increment of Orange-bellied Parrot habitat likelihood above 0.03. Within model uncertainty is also plotted as one standard deviation above and below the mean.

Conclusion

The minimal decline in apparent extent of habitat is not sufficient to explain the decline in the Orange-bellied Parrot population, a conclusion in general agreement with the population modelling study of Drechsler et al. (1998) who found that density-independent factors such as habitat quality, which act regardless of population size, are likely to be more important than density-dependant factors such as habitat area.

We conclude that mainland winter habitat, in the sense of this study, is unlikely to have declined significantly in a structural or compositional sense (although this cannot be definitively determined). The Orange-bellied Parrot population decline is more sensibly attributed to problems associated with small populations – genetic erosion, inbreeding depression, poor reproduction rate, low survivorship and disease. In the case of this migratory species, an extra burden may be reduced opportunities for the social interaction that allows transfer of knowledge between generations about migration routes and the location of suitable habitat patches.

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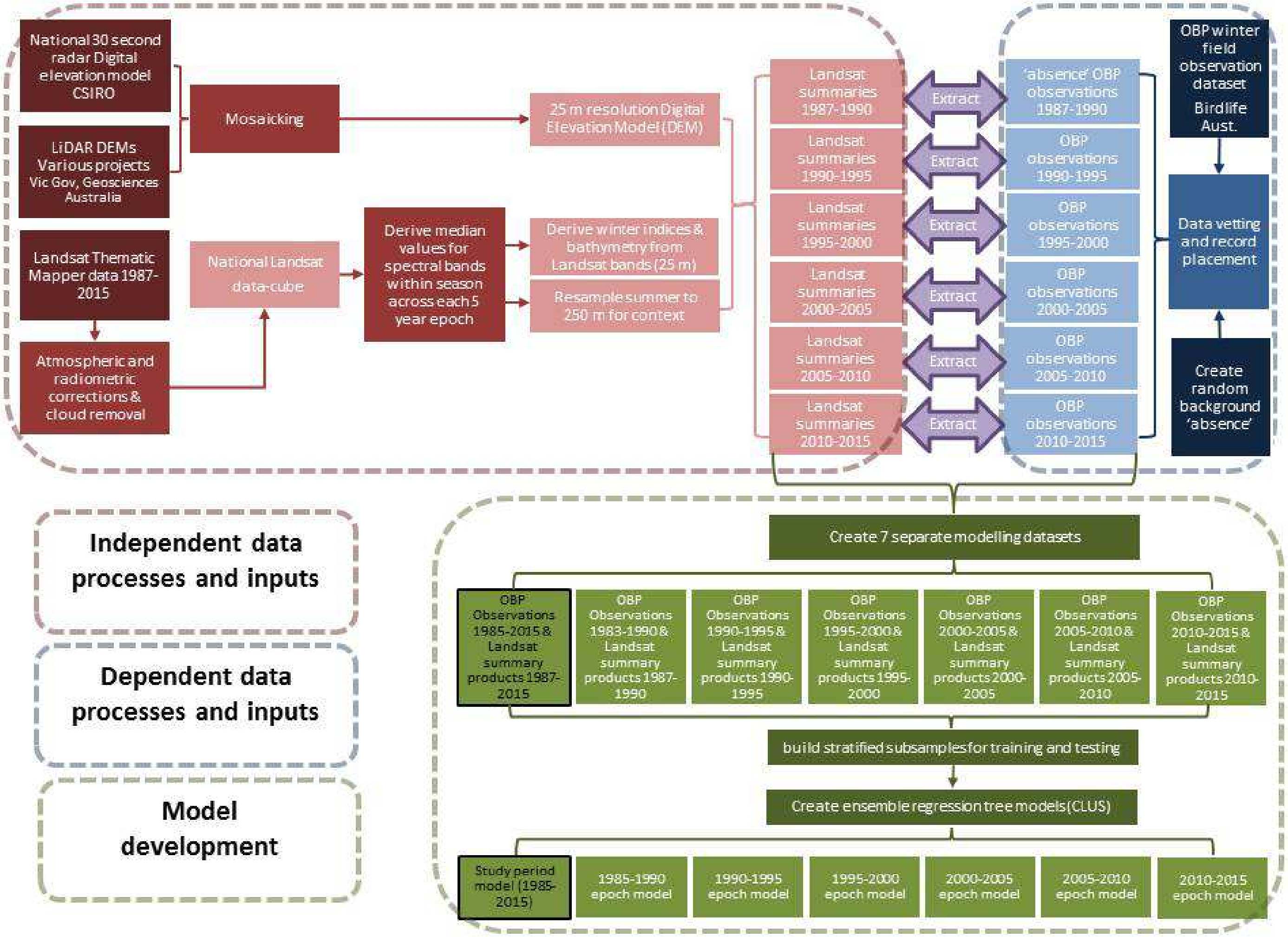
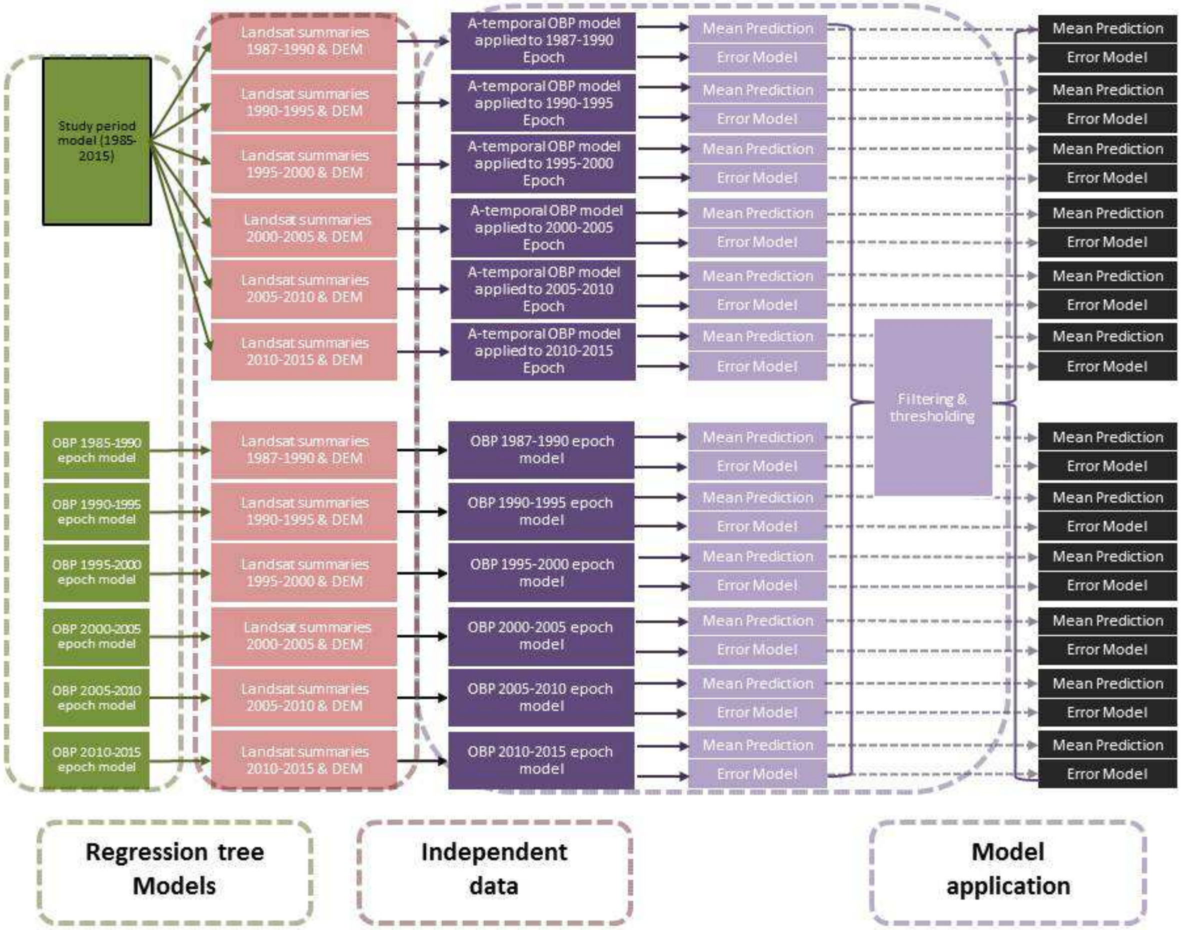
Appendix A: Modelling processes showing data inputs and outputs



Appendix B: Application of 7 models to independent data to create spatially explicit predictions with uncertainty



Appendix C: A list of independent (predictor) variables created for each epoch

Variable	Pixel resolution	Seasons	Statistics	Derivation post atmospheric and radiometric corrections (see also Appendix A.)
B1 = reflectance in the blue spectrum (0.45-0.52 µm)	250 m	Summer (December 1 - March 30)	Median for epoch	Area weighted resampling of 25m summer median data
B2 = Reflectance in the green spectrum (0.52-0.60 µm)	250 m	Summer (December 1 - March 30)	Median for epoch	Area weighted resampling of 25m summer median data
B3 = reflectance in the red spectrum (0.63-0.69 µm)	250 m	Summer (December 1 - March 30)	Median for epoch	Area weighted resampling of 25m summer median data
B4 = Reflectance in the near infrared (0.76-0.90 µm)	250 m	Summer (December 1 - March 30)	Median for epoch	Area weighted resampling of 25m summer median data
B5 = Reflectance in the mid-infrared (1.55-1.75 µm)	250 m	Summer (December 1 - March 30)	Median for epoch	Area weighted resampling of 25m summer median data
B7 = Reflectance in the far infrared (2.08-2.35 µm)	250 m	Summer (December 1 - March 30)	Median for epoch	Area weighted resampling of 25m summer median data
B1 = reflectance in the blue spectrum (0.45-0.52 µm)	25 m	Winter (June 30–September 30), Autumn (31 March – 20 July)	Median for epoch	
B2 = Reflectance in the green spectrum (0.52-0.60 µm)	25 m	Winter (June 30–September 30), Autumn (31 March – 20 July)	Median for epoch	
B3 = reflectance in the red spectrum (0.63-0.69 µm)	25 m	Winter (June 30–September 30), Autumn (31 March – 20 July)	Median for epoch	
B4 = Reflectance in the near infrared (0.76-0.90 µm)	25 m	Winter (June 30–September 30), Autumn (31 March – 20 July)	Median for epoch	
B5 = Reflectance in the mid-infrared (1.55-1.75 µm)	25 m	Winter (June 30–September 30), Autumn (31 March – 20 July)	Median for epoch	
B7 = Reflectance in the far infrared (2.08-2.35 µm)	25 m	Winter (June 30–September 30), Autumn (31 March – 20 July)	Median for epoch	
Enhanced Vegetation Index	25 m	Winter (June 30–September 30), Autumn (31 March – 20 July)	Median for epoch	= (B4 – B3) / (B4 + 6*B3 – 7.5*B1 + 1)
Normalised Difference Burn Ratio	25 m	Winter (June 30–September 30), Autumn (31 March – 20 July)	Median for epoch	= (B4 - B7) / (B4 + B7)
Normalised Difference Vegetation Index	25 m	Winter (June 30–September 30), Autumn (31 March – 20 July)	Median for epoch	= (B4 – B3) / (B3 + B4)
Soil Adjusted Total Vegetation Index	25 m	Winter (June 30–September 30), Autumn (31 March – 20 July)	Median for epoch	= [[(B5-B3) / (B5-B3+0.5)] * 1.5] - (B7/2)
Specific Leaf Area Vegetation Index	25 m	Winter (June 30–September 30), Autumn (31 March – 20 July)	Median for epoch	= B4 / (B3 + B7)
Normalised Difference Moisture Index	25 m	Winter (June 30–September 30), Autumn (31 March – 20 July)	Median for epoch	= (B4 – B5) / (B4 + B5)
Normalised Difference Wetness Index	25 m	Winter (June 30–September 30), Autumn (31 March – 20 July)	Median for epoch	= (B4 – B5) / (B4 + B5)
Normalised Difference Soil Index	25 m	Winter (June 30–September 30), Autumn (31 March – 20 July)	Median for epoch	= (B3 – B5) / (B3 + B5)
Digital Elevation model (height [m] above sea level)	75 m	Not applicable	Not applicable	Composite of LiDAR and space shuttle Radar DSM's

Appendix D: Ranked variable importance 1985-1990 Epoch Model

Variable	Bag count	Forest Count	Forest %Tests
DIGITAL ELEVATION MODEL_300	20	141	11.82
Median_Autumn_85_90_NDSI	18	60	5.03
Median_Winter_85_90_EVI	16	59	4.95
Median_Summer_225_85_90_Band5	19	55	4.61
Median_Winter_85_90_Band1	18	54	4.53
Median_Summer_225_85_90_Band4	19	52	4.36
Median_Autumn_85_90_Band1	19	51	4.27
Median_Autumn_85_90_Band4	16	45	3.77
Median_Winter_85_90_Band4	15	40	3.35
Median_Autumn_85_90_Band3	15	38	3.19
Median_Winter_85_90_SLAVI	16	37	3.1
Median_Autumn_85_90_NDMI	17	32	2.68
Median_Winter_85_90_NDMI	17	32	2.68
Median_Autumn_85_90_Band5	15	30	2.51
Median_Autumn_85_90_NDVI	16	29	2.43
Median_Summer_225_85_90_Band1	17	28	2.35
Median_Autumn_85_90_Band2	16	27	2.26
Median_Autumn_85_90_NDWI	13	27	2.26
Median_Autumn_85_90_NDBR	14	27	2.26
Median_Winter_85_90_Band3	15	26	2.18
Median_Autumn_85_90_SATVI	13	25	2.1
Median_Autumn_85_90_EVI	16	25	2.1
Median_Autumn_85_90_SLAVI	15	24	2.01
Median_Winter_85_90_Band2	12	23	1.93
Median_Winter_85_90_NDSI	10	23	1.93
Median_Winter_85_90_SATVI	13	22	1.84
Median_Autumn_85_90_Band7	10	20	1.68
Median_Winter_85_90_Band5	12	20	1.68
Median_Winter_85_90_NDBR	14	18	1.51
Median_Summer_225_85_90_Band3	10	18	1.51
Median_Summer_225_85_90_Band7	20	17	1.42
Median_Summer_225_85_90_Band2	8	15	1.26
Median_Winter_85_90_Band7	11	14	1.17
Median_Winter_85_90_NDWI	10	12	1.01
Median_Autumn_85_90_BATHY	9	11	0.92
Median_Winter_85_90_NDVI	8	10	0.84

Ranked variable importance 1990-1995 Epoch Model

Variable	Bag count	Forest Count	Forest %Tests
DIGITAL ELEVATION MODEL	20	134	14.36
Median_Autumn_90_95_NDSI	20	72	7.72
Median_Summer_225_90_95_Band4	18	64	6.86
Median_Summer_225_90_95_Band5	20	49	5.25
Median_Autumn_90_95_Band4	19	47	5.04
Median_Summer_225_90_95_Band1	18	46	4.93
Median_Autumn_90_95_Band1	19	41	4.39
Median_Autumn_90_95_NDBR	17	33	3.54
Median_Winter_90_95_Band1	17	32	3.43
Median_Summer_225_90_95_Band2	16	29	3.11
Median_Autumn_90_95_NDMI	16	24	2.57
Median_Summer_225_90_95_Band7	19	24	2.57
Median_Winter_90_95_NDMI	10	23	2.47
Median_Winter_90_95_SLAVI	13	23	2.47
Median_Winter_90_95_NDSI	13	21	2.25
Median_Autumn_90_95_Band5	14	20	2.14
Median_Autumn_90_95_NDVI	10	18	1.93
Median_Winter_90_95_NDVI	10	18	1.93
Median_Winter_90_95_Band7	13	17	1.82
Median_Autumn_90_95_Band2	11	16	1.71
Median_Autumn_90_95_SATVI	12	16	1.71
Median_Winter_90_95_Band5	12	16	1.71
Median_Winter_90_95_EVI	10	16	1.71
Median_Winter_90_95_Band4	10	14	1.5
Median_Autumn_90_95_Band7	11	13	1.39
Median_Winter_90_95_Band2	10	13	1.39
Median_Summer_225_90_95_Band3	10	13	1.39
Median_Winter_90_95_NDWI	9	12	1.29
Median_Winter_90_95_NDBR	11	12	1.29
Median_Autumn_90_95_NDWI	11	11	1.18
Median_Winter_90_95_Band3	8	10	1.07
Median_Autumn_90_95_Band3	8	9	0.96
Median_Autumn_90_95_SLAVI	8	9	0.96
Median_Autumn_90_95_EVI	6	8	0.86
Median_Winter_90_95_SATVI	6	8	0.86

Ranked variable importance 1990-1995 Epoch Model

Variable	Bag count	Forest Count	Forest %Tests
DIGITAL ELEVATION MODEL	20	134	14.36
Median_Autumn_90_95_NDSI	20	72	7.72
Median_Summer_225_90_95_Band4	18	64	6.86
Median_Summer_225_90_95_Band5	20	49	5.25
Median_Autumn_90_95_Band4	19	47	5.04
Median_Summer_225_90_95_Band1	18	46	4.93
Median_Autumn_90_95_Band1	19	41	4.39
Median_Autumn_90_95_NDBR	17	33	3.54
Median_Winter_90_95_Band1	17	32	3.43
Median_Summer_225_90_95_Band2	16	29	3.11
Median_Autumn_90_95_NDMI	16	24	2.57
Median_Summer_225_90_95_Band7	19	24	2.57
Median_Winter_90_95_NDMI	10	23	2.47
Median_Winter_90_95_SLAVI	13	23	2.47
Median_Winter_90_95_NDSI	13	21	2.25
Median_Autumn_90_95_Band5	14	20	2.14
Median_Autumn_90_95_NDVI	10	18	1.93
Median_Winter_90_95_NDVI	10	18	1.93
Median_Winter_90_95_Band7	13	17	1.82
Median_Autumn_90_95_Band2	11	16	1.71
Median_Autumn_90_95_SATVI	12	16	1.71
Median_Winter_90_95_Band5	12	16	1.71
Median_Winter_90_95_EVI	10	16	1.71
Median_Winter_90_95_Band4	10	14	1.5
Median_Autumn_90_95_Band7	11	13	1.39
Median_Winter_90_95_Band2	10	13	1.39
Median_Summer_225_90_95_Band3	10	13	1.39
Median_Winter_90_95_NDWI	9	12	1.29
Median_Winter_90_95_NDBR	11	12	1.29
Median_Autumn_90_95_NDWI	11	11	1.18
Median_Winter_90_95_Band3	8	10	1.07
Median_Autumn_90_95_Band3	8	9	0.96
Median_Autumn_90_95_SLAVI	8	9	0.96
Median_Autumn_90_95_EVI	6	8	0.86
Median_Winter_90_95_SATVI	6	8	0.86

Ranked variable importance 1995-2000 Epoch Model

Variable	Bag count	Forest Count	Forest %Tests
DIGITAL ELEVATION MODEL	20	178	17.73
Median_Summer_225_95_00_Band4	18	61	6.08
Median_Autumn_95_00_Band1	20	50	4.98
Median_Autumn_95_00_EVI	17	41	4.08
Median_Summer_225_95_00_Band7	19	38	3.78
Median_Winter_95_00_Band2	15	37	3.69
Median_Winter_95_00_EVI	19	37	3.69
Median_Summer_225_95_00_Band5	19	36	3.59
Median_Autumn_95_00_Band4	12	32	3.19
Median_Autumn_95_00_Band5	15	30	2.99
Median_Summer_225_95_00_Band3	18	25	2.49
Median_Autumn_95_00_Band2	13	24	2.39
Median_Winter_95_00_Band5	16	24	2.39
Median_Winter_95_00_NDBR	11	23	2.29
Median_Autumn_95_00_Band3	14	22	2.19
Median_Winter_95_00_NDVI	15	22	2.19
Median_Winter_95_00_NDWI	13	22	2.19
Median_Autumn_95_00_NDSI	13	21	2.09
Median_Summer_225_95_00_Band1	13	21	2.09
Median_Autumn_95_00_NDMI	13	20	1.99
Median_Winter_95_00_Band1	10	19	1.89
Median_Winter_95_00_Band4	12	19	1.89
Median_Autumn_95_00_NDVI	11	18	1.79
Median_Autumn_95_00_SLAVI	12	18	1.79
Median_Winter_95_00_Band3	11	18	1.79
Median_Winter_95_00_Band7	12	18	1.79
Median_Winter_95_00_NDMI	10	18	1.79
Median_Autumn_95_00_NDBR	12	17	1.69
Median_Autumn_95_00_Band7	11	16	1.59
Median_Autumn_95_00_NDWI	11	16	1.59
Median_Summer_225_95_00_Band2	10	15	1.49
Median_Winter_95_00_SLAVI	12	14	1.39
Median_Autumn_95_00_SATVI	10	13	1.29
Median_Winter_95_00_SATVI	7	10	1
Median_Winter_95_00_NDSI	5	5	0.5

Ranked variable importance 2000-2005 Epoch Model

Variable	Bag count	Forest Count	Forest %Tests
DIGITAL ELEVATION MODEL	20	140	14.85
Median_Autumn_00_05_SLAVI	20	62	6.57
Median_Autumn_00_05_Band4	18	45	4.77
Median_Autumn_00_05_NDSI	16	44	4.67
Median_Autumn_00_05_Band1	16	42	4.45
Median_Winter_00_05_NDSI	15	32	3.39
Median_Summer_225_00_05_Band2	18	32	3.39
Median_Autumn_00_05_Band2	15	31	3.29
Median_Autumn_00_05_SATVI	12	29	3.08
Median_Summer_225_00_05_Band4	19	28	2.97
Median_Autumn_00_05_EVI	12	27	2.86
Median_Autumn_00_05_NDBR	17	26	2.76
Median_Summer_225_00_05_Band5	16	26	2.76
Median_Winter_00_05_Band2	14	25	2.65
Median_Autumn_00_05_NDVI	13	23	2.44
Median_Summer_225_00_05_Band1	14	23	2.44
Median_Winter_00_05_Band7	13	22	2.33
Median_Autumn_00_05_Band3	13	21	2.23
Median_Winter_00_05_Band5	13	21	2.23
Median_Summer_225_00_05_Band3	14	21	2.23
Median_Autumn_00_05_NDMI	13	20	2.12
Median_Winter_00_05_SLAVI	10	20	2.12
Median_Winter_00_05_Band3	13	19	2.01
Median_Winter_00_05_Band4	12	19	2.01
Median_Summer_225_00_05_Band7	20	19	2.01
Median_Winter_00_05_Band1	10	17	1.8
Median_Autumn_00_05_Band7	13	16	1.7
Median_Winter_00_05_EVI	11	16	1.7
Median_Autumn_00_05_NDWI	9	14	1.48
Median_Winter_00_05_NDWI	7	12	1.27
Median_Autumn_00_05_Band5	10	11	1.17
Median_Winter_00_05_NDBR	8	11	1.17
Median_Winter_00_05_NDVI	8	10	1.06
Median_Winter_00_05_NDMI	8	9	0.95
Median_Winter_00_05_SATVI	4	6	0.64

Ranked variable importance 2005-2010 Epoch Model

Variable	Bag count	Forest Count	Forest %Tests
DIGITAL ELEVATION MODEL	20	157	16.22
Median_Autumn_05_10_NDVI	20	62	6.4
Median_Autumn_05_10_Band4	18	61	6.3
Median_Summer_225_05_10_Band4	20	57	5.89
Median_Autumn_05_10_Band1	17	38	3.93
Median_Summer_225_05_10_Band1	15	35	3.62
Median_Summer_225_05_10_Band5	18	35	3.62
Median_Winter_05_10_NDWI	18	32	3.31
Median_Autumn_05_10_NDSI	16	31	3.2
Median_Summer_225_05_10_Band7	20	29	3
Median_Winter_05_10_Band1	14	28	2.89
Median_Autumn_05_10_EVI	15	26	2.69
Median_Autumn_05_10_SATVI	11	25	2.58
Median_Autumn_05_10_Band3	14	23	2.38
Median_Autumn_05_10_SLAVI	14	23	2.38
Median_Winter_05_10_NDVI	9	22	2.27
Median_Autumn_05_10_Band2	15	20	2.07
Median_Winter_05_10_NDMI	11	19	1.96
Median_Autumn_05_10_Band5	13	18	1.86
Median_Winter_05_10_SATVI	11	18	1.86
Median_Summer_225_05_10_Band2	10	18	1.86
Median_Winter_05_10_Band5	12	17	1.76
Median_Winter_05_10_Band7	12	16	1.65
Median_Winter_05_10_NDSI	11	15	1.55
Median_Winter_05_10_NDBR	12	15	1.55
Median_Summer_225_05_10_Band3	11	15	1.55
Median_Autumn_05_10_NDMI	12	14	1.45
Median_Autumn_05_10_NDBR	11	14	1.45
Median_Winter_05_10_EVI	9	14	1.45
Median_Winter_05_10_Band3	11	13	1.34
Median_Winter_05_10_Band4	7	13	1.34
Median_Autumn_05_10_Band7	10	12	1.24
Median_Autumn_05_10_NDWI	8	12	1.24
Median_Winter_05_10_Band2	7	10	1.03

Ranked variable importance 2010-2015 Epoch Model

Variable	Bag count	Forest Count	Forest %Tests
DIGITAL ELEVATION MODEL	20	93	15.84
Median_Summer_225_10_15_Band1	20	43	7.33
Median_Autumn_10_15_Band1	17	39	6.64
Median_Autumn_10_15_SLAVI	17	39	6.64
Median_Summer_225_10_15_Band5	17	30	5.11
Median_Winter_10_15_EVI	14	25	4.26
Median_Summer_225_10_15_Band4	16	24	4.09
Median_Winter_10_15_NDWI	15	21	3.58
Median_Autumn_10_15_NDVI	11	18	3.07
Median_Autumn_10_15_NDSI	12	18	3.07
Median_Autumn_10_15_NDBR	12	17	2.9
Median_Winter_10_15_NDMI	10	15	2.56
Median_Autumn_10_15_Band3	10	14	2.39
Median_Autumn_10_15_Band4	10	14	2.39
Median_Summer_225_10_15_Band7	18	14	2.39
Median_Winter_10_15_Band1	10	13	2.21
Median_Winter_10_15_Band7	5	13	2.21
Median_Autumn_10_15_Band2	9	12	2.04
Median_Autumn_10_15_Band7	8	11	1.87
Median_Winter_10_15_Band4	9	11	1.87
Median_Autumn_10_15_Band5	8	10	1.7
Median_Winter_10_15_Band3	7	10	1.7
Median_Autumn_10_15_NDMI	7	8	1.36
Median_Autumn_10_15_NDWI	7	8	1.36
Median_Winter_10_15_NDSI	8	8	1.36
Median_Winter_10_15_SLAVI	7	8	1.36
Median_Summer_225_10_15_Band3	5	8	1.36
Median_Autumn_10_15_SATVI	6	7	1.19
Median_Autumn_10_15_EVI	6	7	1.19
Median_Winter_10_15_Band2	4	6	1.02
Median_Winter_10_15_NDBR	5	6	1.02
Median_Winter_10_15_Band5	5	5	0.85
Median_Summer_225_10_15_Band2	5	5	0.85
Median_Winter_10_15_NDVI	4	4	0.68

Ranked variable importance 1985-2015 Study Period Model

Variable	Bag count	Forest Count	Forest %Tests
DIGITAL ELEVATION MODEL	20	324	14.19
Median_Autumn_SLAVI	20	149	6.52
Median_Autumn_NDBR	19	95	4.16
Median_Autumn_Band1	20	88	3.85
Median_Summer_225_Band4	20	73	3.2
Median_Summer_225_Band5	20	72	3.15
Median_Autumn_Band2	19	67	2.93
Median_Autumn_NDWI	20	66	2.89
Median_Winter_Band1	20	65	2.85
Median_Winter_EVI	20	62	2.71
Median_Autumn_Band4	20	61	2.67
Median_Winter_Band3	18	61	2.67
Median_Summer_225_Band1	18	60	2.63
Median_Summer_225_Band7	20	59	2.58
Median_Autumn_NDVI	20	58	2.54
Median_Autumn_Band5	20	56	2.45
Median_Autumn_NDMI	16	56	2.45
Median_Winter_Band4	18	53	2.32
Median_Summer_225_Band2	18	53	2.32
Median_Autumn_NDSI	16	51	2.23
Median_Winter_Band5	19	51	2.23
Median_Autumn_Band3	17	50	2.19
Median_Autumn_Band7	18	50	2.19
Median_Autumn_EVI	18	50	2.19
Median_Summer_225_Band3	17	47	2.06
Median_Winter_Band2	18	45	1.97
Median_Winter_NDMI	20	44	1.93
Median_Autumn_SATVI	17	43	1.88
Median_Winter_SLAVI	19	42	1.84
Median_Winter_NDVI	19	41	1.8
Median_Winter_NDBR	17	40	1.75
Median_Winter_Band7	18	39	1.71
Median_Winter_SATVI	16	31	1.36
Median_Winter_NDSI	15	28	1.23

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