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Contraction in the range of Malleefowl (*Leipoa ocellata*) in Western Australia: a comparative assessment using presence-only and presence–absence datasets

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Abstract. As human impacts on habitat increase in their intensity and scale it is increasingly important that we are able to characterise and monitor changes in the distribution of threatened species. The Malleefowl (*Leipoa ocellata*) is listed as vulnerable in Australia and the National Recovery Plan suggests that its range has contracted by 45% in Western Australia (WA). We quantified changes in the range of Malleefowl in WA and determined the relative influence that various threatening processes, such as land clearing and agricultural development, may have had on its range. We also investigated whether presence-only data (from existing survey and reporting) could reliably assess the status of Malleefowl by comparing presence-only data with presence–absence data. To obtain a presence–absence dataset we interviewed long-term residents within our study area of 64 000 km^2 about the occurrence of Malleefowl. The range of Malleefowl has contracted in WA but this contraction is less substantial than previously claimed. The contraction in range within the agricultural landscapes of south-western WA is associated with the extent of land clearing, the number of years since commencement of agricultural activity, and the number of sheep within a landscape. To conserve Malleefowl, we believe landscapes developed for agriculture in recent decades must be protected to ensure they do not develop attributes found in landscapes that have been heavily cleared and occupied since the early 1900s.

Introduction

Many species of Australia's terrestrial fauna have experienced contractions in range and decreases in abundance (Burbidge and McKenzie 1989; Morton 1990; Garnett and Crowley 2000). These have not occurred evenly across the continent, with agricultural landscapes and arid areas in particular suffering a substantial loss of species (Burbidge and McKenzie 1989; National Land and Water Resources Audit 2001; McKenzie and May 2003). Both these landscapes are important habitat for Malleefowl (*Leipoa ocellata*). Species persisting in these landscapes are subject to a variety of threatening processes including competition with introduced herbivores (Hobbs *et al*. 1993), predation by introduced predators (Short 1998) and inappropriate fire regimes (Woinarski and Recher 1997; Burbidge 2003). Those occupying agricultural landscapes are subject to the additional stressor of destruction and fragmentation of their habitat (Saunders 1989; Hobbs *et al*. 1993). These threatening processes typically interact with each other (Caughley 1994).

The Malleefowl is a large (~2 kg), sedentary, ground-dwelling bird that uses fermentation and solar radiation to incubate its eggs in mounds (Frith 1956). The historical range of Malleefowl in Western Australia (WA) covered a broad arc from north of Carnarvon to east of Esperance with the species recorded over most of the southern half of the state (Benshemesh 2000; Barrett *et al*. 2003). Nationally, the species is listed as Vulnerable under the *Environment Protection and Biodiversity Conservation Act* 1999 (Commonwealth) based on the belief that the range of the species has contracted by at least 20% over the last three generations (i.e. 20–30 years) and that this rate of contraction is likely to continue (Benshemesh 2000; Garnett and Crowley 2000). In WA, the Malleefowl is listed as 'fauna that is rare or is likely to become extinct' under Schedule 1 of the *Wildlife Conservation* (*Specially Protected Fauna*) *Notice* 2005 (WA).

Despite the wealth of research conducted on this species (e.g. Frith 1962; Booth 1985; Brickhill 1987; Benshemesh 1992; Priddel and Wheeler 2003) there is uncertainty about the extent or even the reality of range contraction in the WA Wheatbelt with claims for both decreases (Benshemesh 2000) and increases in range (Serventy and Whittell 1976). Like many bird species, the pattern of contraction for Malleefowl has been more ambiguous than the clear and widespread contractions exhibited by various mammal species (e.g. Short and Turner 1993) so ascertaining its status is problematical, particularly on a regional scale.

Early records suggest Malleefowl were common across their range in WA (Crossman 1909; Carter 1917; Ashby 1921; Carnaby 1933) but numbers declined significantly as land was developed for agriculture in the twentieth century (Storr 1991). Soon after European settlement, Malleefowl disappeared from coastal heaths of the south-west (Carter 1923) and areas of the central Wheatbelt (Milligan 1904; Crossman 1909; Ogilvie-

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Grant 1910). Land clearing (Frith 1962), grazing (Frith 1962), predation by Red Foxes (*Vulpes vulpes*) (Ashby 1922; Priddel and Wheeler 1996) and altered fire regimes (Benshemesh 1992) are all cited as threatening processes. However, there is also suggestion of population increases in some areas. Serventy and Whittell (1976) stated that Malleefowl numbers increased in the WA Wheatbelt from about 1945 to 1975 and that the species had recolonised areas where it had apparently disappeared. They attributed this resurgence to the abundance of a novel food source: grain from farming operations.

Ideally, long-term structured census data (Hone *et al.* 2005) would be used to quantify and determine causes for range contraction of Malleefowl, but this information is not available over broad scales. As a result, Malleefowl researchers have been restricted to conducting detailed studies on individual populations (e.g. Frith 1962; Benshemesh 1992; Priddel and Wheeler 2003) or providing broad-scale estimates at coarse geographical scales (e.g. Benshemesh 2000). A revised recovery plan for Malleefowl (J. Benshemesh, unpubl. data) avoids making estimates of range contraction altogether and presents regional maps of occurrence instead. It has been suggested that there is potential for using presence-only datasets, such as museum collections, atlases (Dunn and Weston 2008) and community databases (Shaffer *et al.* 1998; Reutter *et al.* 2003), to understand spatial patterns of species occurrence (Graham *et al.* 2004; Elith *et al.* 2006). The collection and utilisation of these data are becoming increasingly common (Lunney *et al.* 2000) and global systems are being established for their storage (e.g. Roberts *et al.* 2005). The shortcomings of these data (e.g. spatial bias, false absence) are well established (Austin 2002), but if such shortcomings are addressed, these types of data are likely to provide valuable insight into the status of Malleefowl.

We assessed the conservation status of Malleefowl in WA by investigating the sensitivity of a presence-only dataset to false absences and compared outcomes from presence-only and presence–absence estimates. We also determined the relative influence that various threatening processes may have had on the distribution of Malleefowl in the WA Wheatbelt. We sought to answer the following questions:

(1) Can we use presence-only data to assess reliably the status of a species?
(2) Has the Malleefowl undergone a contraction of range in WA, and more specifically, within the WA Wheatbelt?
(3) Is there a relationship between changes in the range of Malleefowl and landscape-scale environmental predictors within the WA Wheatbelt?

Our approach is general and might be applied to any species where appropriate, comparable data with a current and historical component are available, such as species from bird atlas programs, museum collections or other distributional databases (as maintained by most state conservation agencies).

Materials and methods

Study area

Land-use in WA (~2 600 000 km^2) consists primarily of extensive grazing of natural vegetation in semi-arid and arid areas, with intensive agriculture (e.g. dryland cropping, grazing of modified pastures) largely confined to south-western areas where mean annual rainfall exceeds 300 mm (Fig. 1; Bureau of Rural Sciences 2006). Climatic conditions vary greatly across the state, from mean annual rainfall <200 mm in the arid interior to >1200 mm in the mesic south-western corner (Bureau of Meteorology 2007). Excluding urban areas in the south-west of the state, human population densities are low, particularly to the north and east of the Wheatbelt region (<1 person km^{-2}; Australian State of the Environment Committee 2001), where extensive pastoralism is the dominant land-use.

The WA Wheatbelt extends from north of Geraldton to east of Esperance in south-western WA. Land-use consists largely of cropping (wheat, barley) and grazing of sheep (Saunders and Ingram 1995) (Fig. 1). Over 93% of the native vegetation has been removed in ~100 years (Saunders and Ingram 1995) resulting in a highly fragmented landscape, consisting of small and isolated islands of native vegetation in a matrix of cropping and grazing lands. These remnants are believed to be continuing to degrade owing to a variety of processes associated with agricultural production, including grazing by livestock (Hobbs *et al.* 1993), weed invasion (Hobbs *et al.* 1993) and altered fire regimes (Bowman 2003). These processes, combined with the influence of introduced predators, have led to most bushland remnants becoming unsuitable for many threatened species (Saunders *et al.* 2003).

Presence-only analysis of range contraction of Malleefowl

Data on Malleefowl occurrence

We supplemented a presence-only dataset of Malleefowl occurrence in WA from the National Recovery Plan (NRP) for Malleefowl (Benshemesh 2000) with a new, large dataset of locations obtained from community organisations and government agencies: the Malleefowl Preservation Group and other community Malleefowl groups, the WA Department of Environment and Conservation, the Western Australian

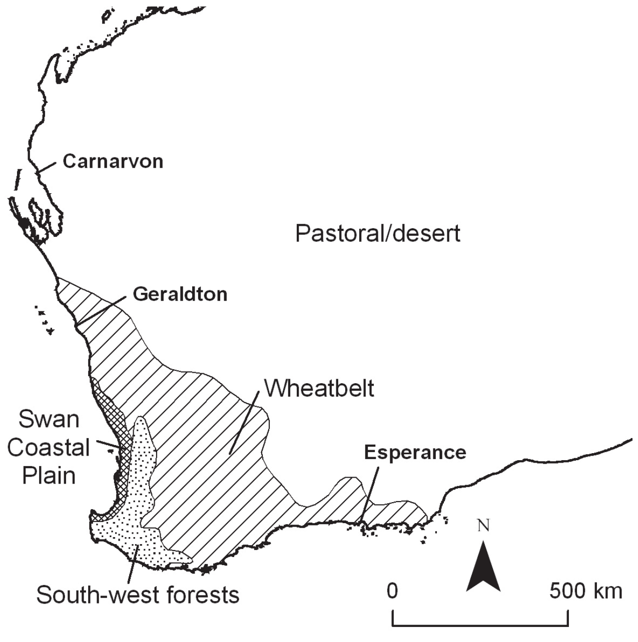

Fig. 1. Broad land-use categories within southern WA.

Museum, and Birds Australia (Blakers *et al.* 1984; Barrett *et al.* 2003). Records included *ad hoc* sightings of individual birds, recently active mounds and road kills. The combined dataset (*n* = 3466 records) contained 1172 presence-only records of Malleefowl occurrence from the NRP and 2294 from the supplementary dataset. Data were biased towards recent times (range 1837–2006, mean = 1991, Fig. 2) and were accurate to within 10 km or less.

Range contraction

In the NRP, estimates of range contraction were determined by quantifying the number of one-degree grid-cells (~100 × 100 km) in which Malleefowl had been recorded before 1981 (the mean year for the dataset) but not recorded after this time. We applied the same methodology to our combined dataset for WA and compared the estimate to that determined using the NRP data only. An analysis grid was created for WA using a GIS with the origin of the grid (top left corner) situated at 14°11′28″S, 112°55′5″E, allowing for optimum coverage of the mainland. All cells where the mainland occupied less than 25% of the area were removed from the analysis. The approach of assessing the decline used in the NRP has been modified in a revised recovery plan (J. Benshemesh, unpubl. data). The grid-based approach documented in this study has been removed and replaced with simple distribution maps. Explicit estimates of range contraction are avoided.

We plotted the data using a GIS and classified each cell within the grid into one of four categories: (1) Malleefowl never recorded; (2) only recorded in or before 1981; (3) only recorded after 1981; and (4) recorded before and after 1981. We quantified the number of cells within each category and compared our findings to those of the NRP.

We investigated the certainty of cell classification by quantifying how many sightings points were used to classify each individual cell into each class. If cells contained two sightings or less pre- or post-1981, they were identified as having low certainty. We determined the number and distribution of low certainty cells to provide a measure of confidence in the analysis.

Presence–absence analysis of range contraction of Malleefowl in the Wheatbelt

Grid development and classification

We assessed the status of Malleefowl in the WA Wheatbelt using a grid-based approach similar to that described above for the analysis of WA as a whole. The grid was centred on three areas that contained towns with community-based Malleefowl interest groups: Ongerup (southern Wheatbelt), Merredin (central Wheatbelt) and Wubin (northern Wheatbelt). We presumed this gave greater consistency of observer effort, reducing the likelihood of including false absences. The grid was positioned to span several gradients including degree and history of clearing, and vegetation and land-use type. We used a grid with cells 25 × 25 km, giving 102 cells.

An initial estimate of Malleefowl status made use of presence-only data from the supplementary dataset described above. Cells were classified into four categories based on the presence or apparent absence of Malleefowl pre- and post-1989 (mean year of records intersecting the Wheatbelt grid), as described above. If Malleefowl were not recorded in an area: (1) they may have been truly absent; (2) the area may not have been searched for Malleefowl; or (3) community knowledge of Malleefowl occurrence for the area may not have been previously collated.

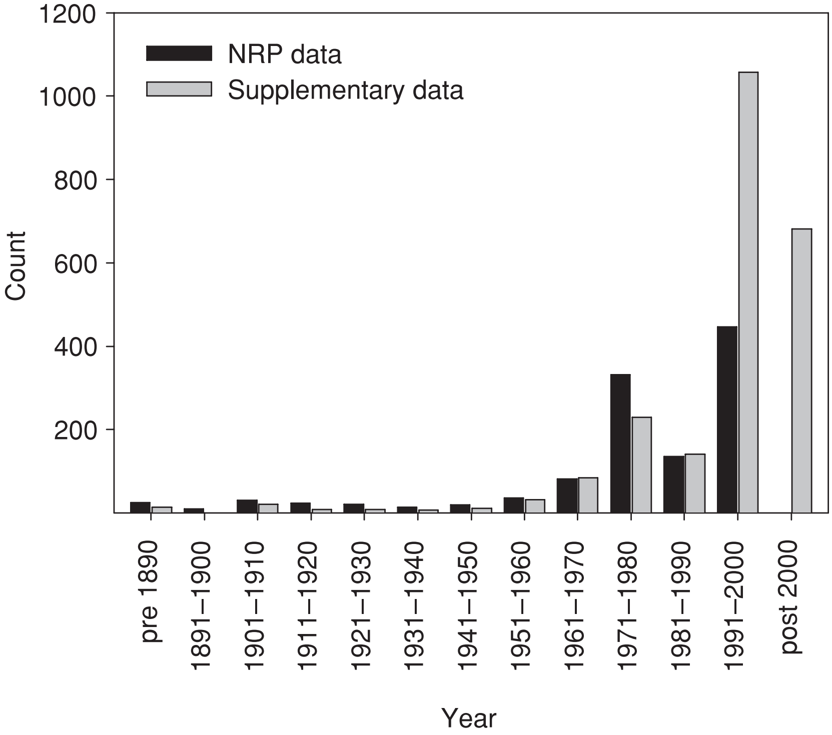

Fig. 2. The distribution through time of records of Malleefowl for WA.

We added reliable absence to the presence-only dataset by a targeted postal and phone survey of land managers, which was conducted from December 2005 to April 2006. This verification process queried all grid-cells where there were no records of Malleefowl either pre- or post-1989. The survey asked whether respondents had seen evidence of Malleefowl occurrence (birds, active and inactive mounds) within cells pre-1989, post-1989 or both. Respondents (primarily landholders and natural resource management officers) were selected for survey if they had a thorough knowledge of the grid-cell in question, had greater than 20 years experience or residence of the area, and were able to identify Malleefowl reliably. A cell was only considered an absence after three absence records were obtained. A single positive in recent or historical times was sufficient to confirm any cell as a presence in that time. After completion of the survey, we used the information to reclassify all grid-cells into one of the four categories described above.

Regression analysis

We developed seven landscape-scale variables for modelling the range contraction of Malleefowl (Table 1). We included variables that were potentially of importance to the contraction in range of Malleefowl based on the literature and our knowledge of their ecology. Threatening processes that were not readily quantifiable on a spatial basis (e.g. presence of the introduced Red Fox) were excluded from analysis as were those acting at a smaller temporal or spatial scale than that of the grid (e.g. fire regimes).

Variables 1 (ALIEN) and 2 (FARMING) were created by digitising maps from Jarvis (1986), which documented when land was alienated for agricultural purposes, and when different land-use types (e.g. extensive pastoralism, extensive mixed farming) began within an area, respectively. Each cell was assigned a date of alienation and a date of commencement of farming. Where multiple dates existed for a cell, the modal date was used.

Variables 3 and 4 (AVGSHPHA, AVGCRLHA) were developed using values for mean total number of sheep per statistical local area (SLA) and mean total hectares of land under cereal production respectively (Australian Bureau of Statistics 1998) for the years 1983 to 1997. Variable 5 (POPSQKM01) quantified the density of human population (individuals km^{-2}) for each cell based on population statistics for 2001 for each SLA (Australian Bureau of Statistics 2003).

The vegetation variables (FRAG_INDEX, VEG_HA) were based on the extent of woody perennial vegetation at 2004 (Landmonitor 2004). They excluded areas of vegetation modelled as at risk of salinity (Evans and Caccetta 2000), as much of the vegetation in these areas was unlikely to be suitable for Malleefowl (e.g. saline flats).

We used generalised additive models (GAMs) to investigate the relationship between contraction of range of Malleefowl and the various environmental predictors. We considered GAM to be the most appropriate method for this analysis as it does not require *a priori* knowledge of the shape of the response curves (Hastie and Tibshirani 1990). We examined the pattern of range contraction of Malleefowl by contrasting cells within the grid where Malleefowl were present before and after 1989 with cells where Malleefowl were present before 1989 only (i.e. binomial distribution). Cells where Malleefowl never occurred were excluded from analysis.

Before modelling, all variables that were highly correlated ($r > 0.75$) were identified and the variable least relevant to Malleefowl (i.e. least direct, see Austin and Meyers 1996) removed. Vegetation variables were log-transformed before modelling to reduce the relative influence of any outlying cells containing very large amounts of native vegetation.

We produced the GAM model using GRASP (Lehmann *et al.* 2002) in the statistical package R (http://www.r-project.org/, accessed June 2006). The model was fitted with a backwards stepwise selection method, using Bayesian information criterion (BIC). We chose BIC as it is known to impose heavier penalties on including additional terms in a model than Akaike's information criterion (Burnham and Anderson 2002). It was our intent to create a model with fewer terms to remove unnecessary complexity in interpretation.

Finally, to assist in interpreting the outputs of the GAM, we plotted the distribution of Malleefowl records with respect to environmental predictors as histograms. We used the area under the curve (AUC) of a receiver operating characteristic (ROC) plot to measure the discriminatory ability of the model as described by Lehmann *et al.* (2002).

Results

Status of Malleefowl in WA

Malleefowl were observed at least once in 91 of 244 (37%) one-degree cells within WA, using all data. Of those cells, only 64 contained Malleefowl after 1981, representing a contraction in

Table 1. Variables included in the regression analysis of Malleefowl range contraction within the WA Wheatbelt
Data were for 102 cells, each of 625 km^2

Variable	Name	Description	Mean ± s.d.	Minimum–Maximum
1	ALIEN	Date when cell experienced agricultural alienation	1944 ± 21	1900–1984
2	FARMING	Date of commencement of agriculture within cell, including pastoralism and cropping	1906 ± 18	1850–1939
3	AVGSHPHA	Average total number of sheep per hectare per cell (1983–97)	1.29 ± 0.66	0.37–3.45
4	AVGCRLHA	Proportion of land under cereal production (1983–97)	0.32 ± 0.08	0.11–0.45
5	POPSQKM01[A]	Human population density (individuals km^{-2}; as at 2001)	0.32 ± 0.23	0.06–1.06
6	FRAGINDEX	Area of woody perennial vegetation (ha) within cell divided by number of remnants within cell	54 ± 183	4–1395
7	VEG_HA[A]	Sum of area of woody perennial vegetation within grid-cell (ha)	6817 ± 8386	817–50712

[A] log$_e$ transformed before analysis.

Table 2. Change in occupancy of cells for Malleefowl in WA using a one-degree cell size

NRP, National Recovery Plan (Benshemesh 2000)

	WA		Wheatbelt	
	NRP dataset	All data	NRP dataset	All data
Occupied pre-1981	87	91	30	30
Occupied post-1981	47	64	25	30
% range contraction	46%	30%	17%	0%

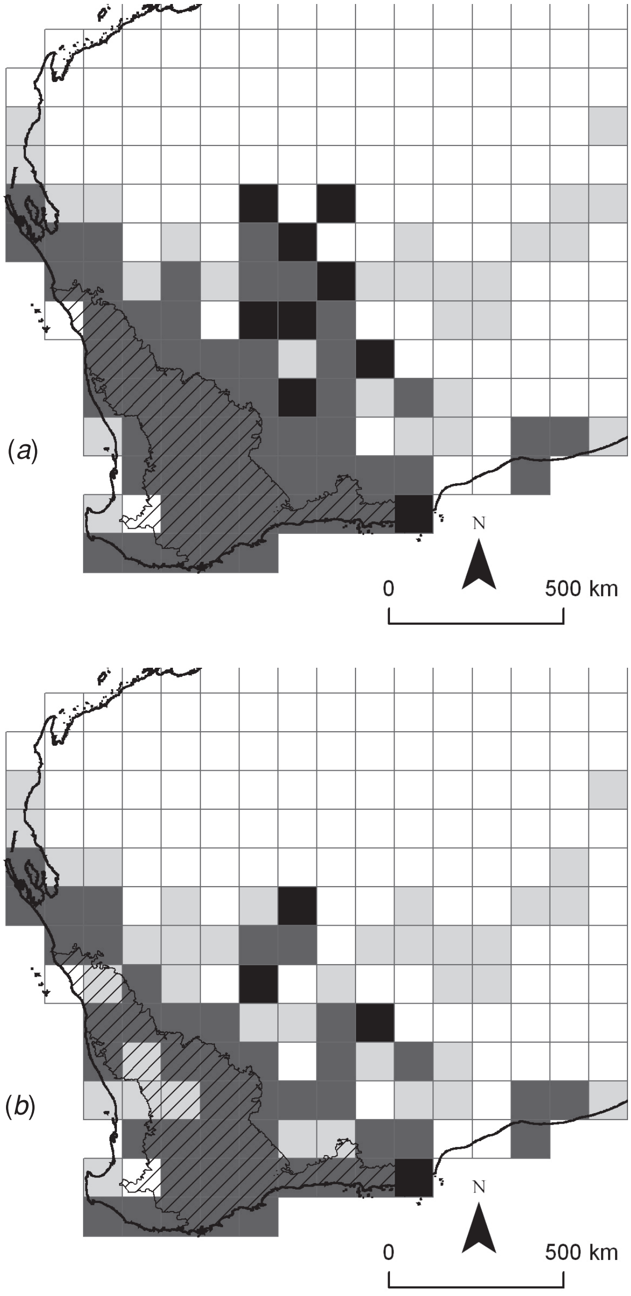

Fig. 3. Occurrence of Malleefowl in WA for: (*a*) the combined dataset; (*b*) NRP dataset. Dark grey, present pre- and post-1981; light grey, present pre-1981; black, present post-1981; hatched area, Wheatbelt of WA.

range of 29.7% (Table 2). Using the NRP data only, an estimate of range reduction of 46% was obtained. No contraction of range was observed within the WA Wheatbelt when using all data, in contrast to a 17% contraction determined using NRP data only. These findings are plotted spatially in Fig. 3.

Nine and four cells contained points after 1981 only, using both the combined dataset and NRP dataset respectively (Table 3). These cells could represent an expansion of the Malleefowl's range or a false absence pre-1981. In addition, the classification of 58% of cells from the 'before 1981 only' and 'after 1981 only' categories was identified as uncertain, as they contained two or fewer records pre- or post-1981. All but one of these cells occurred in remote, uncleared areas to the north-east of the WA Wheatbelt (Fig. 4). Eleven out of 37 one-degree cells (30%) that had been identified as range contractions using the NRP dataset were misdiagnosed, as determined using the combined dataset.

Status of Malleefowl in the WA Wheatbelt

Grid classification

Initial classification of 102 grid-cells in the WA Wheatbelt using presence-only data can be seen in Fig. 5*a*. Most of the grid-cells contained Malleefowl both before and after 1989. Cells never containing Malleefowl were largely confined to the western edge of the grid. There were 22 cells (22%) containing Malleefowl after 1989 only, and 13 cells (13%) containing Malleefowl before 1989 only.

Comparison of presence-only and presence–absence datasets

The landholder survey converted the presence-only dataset into a presence–absence dataset. The extent and pattern of range contraction for Malleefowl within the WA Wheatbelt was very different when comparing estimates based on the two methods. The classification of 38 of 102 grid-cells changed (Fig. 5*b*). Of 44 cells containing apparent absences before 1989, 34 (77%) were found to be false absences. Six of 35 cells (17%) containing apparent absences after 1989 were found to be false absences also. Using the presence-only dataset, there was no clear pattern of range contraction or expansion across the grid (Fig. 5*a*). In contrast, when using the presence–absence dataset, the contraction in range of Malleefowl was largely confined to the western margin of the grid, while Malleefowl were still present in the east (Fig. 5*b*). Findings from the landholder survey resulted in all cells containing records only after 1989 to be re-assigned as areas containing Malleefowl both in recent and historical times suggesting no evidence for range expansion (Fig. 5*b*).

Table 3. Classification and certainty of grid-cells based on Malleefowl occurrence records within WA

All data and NRP dataset split pre- and post-1981

Category	All data	No. of certain cells (%)	NRP dataset	No. of certain cells (%)
Never present	153	n/a	159	n/a
Before 1981 only	27	11 (41)	37	17 (46)
After 1981 only	9	4 (44)	4	1 (25)
Before and after 1981	55	54 (98)	44	38 (86)

Regression modelling of Malleefowl range contraction

Variable 6 was removed owing to correlation with variable 7 ($r = 0.8$). Three variables were selected in the final model: ALIEN (date cell experienced agricultural alienation), VEG_HA (log of area of woody perennial vegetation within cell) and AVGSHPHA (average number of sheep per hectare).

This model explained 82.2% of the variation associated with Malleefowl presence or absence within cells in the WA Wheatbelt. Of the three variables, VEG_HA accounted for the most deviance (75.9 based on a univariate GAM), followed by ALIEN (71.5) and AVGSHPHA (23.6). A summary of the GAM model including the direction of effect for predictor variables is included in Table 4. Drop and alone contributions of predictors to the model are presented in Table 4 also. Histograms showing the distribution of the response variable with respect to each predictor are shown in Fig. 6. Malleefowl had contracted from most of the cells that had 3% native vegetation cover or less (<log 3.35), and all cells with less than 2% vegetation cover (<log 3.18). Malleefowl were present in all but one cell cleared after 1937 and present in most cells with sheep density below 2 ha^{-1}.

Validation of the model (i.e. plotting observed response values against predicted response values) resulted in an AUC value of 0.989, indicating that the model was able to discriminate effectively between areas of Malleefowl range contraction and stability.

Discussion

The purpose of this study was to determine the conservation status of Malleefowl in WA and in the Wheatbelt in particular, given contradictory information on range contraction and expansion. A critical step was to assess the reliability of presence-only data previously used to justify claims about range contraction. We also aimed to understand which processes or events have impacted on Malleefowl occurrence in the WA Wheatbelt.

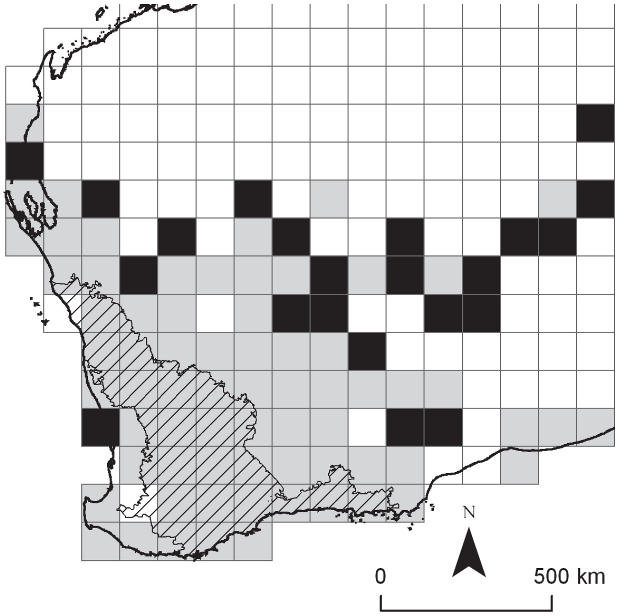

Fig. 4. Uncertainty in classification of grid-cells based on estimates using the combined dataset. Grey, areas considered certain (i.e. classification informed more than two data points pre- or post-1981); black, areas considered uncertain (i.e. classification informed by two data points or fewer pre- or post-1981); hatched area, WA Wheatbelt. Cells where Malleefowl were not recorded are excluded.

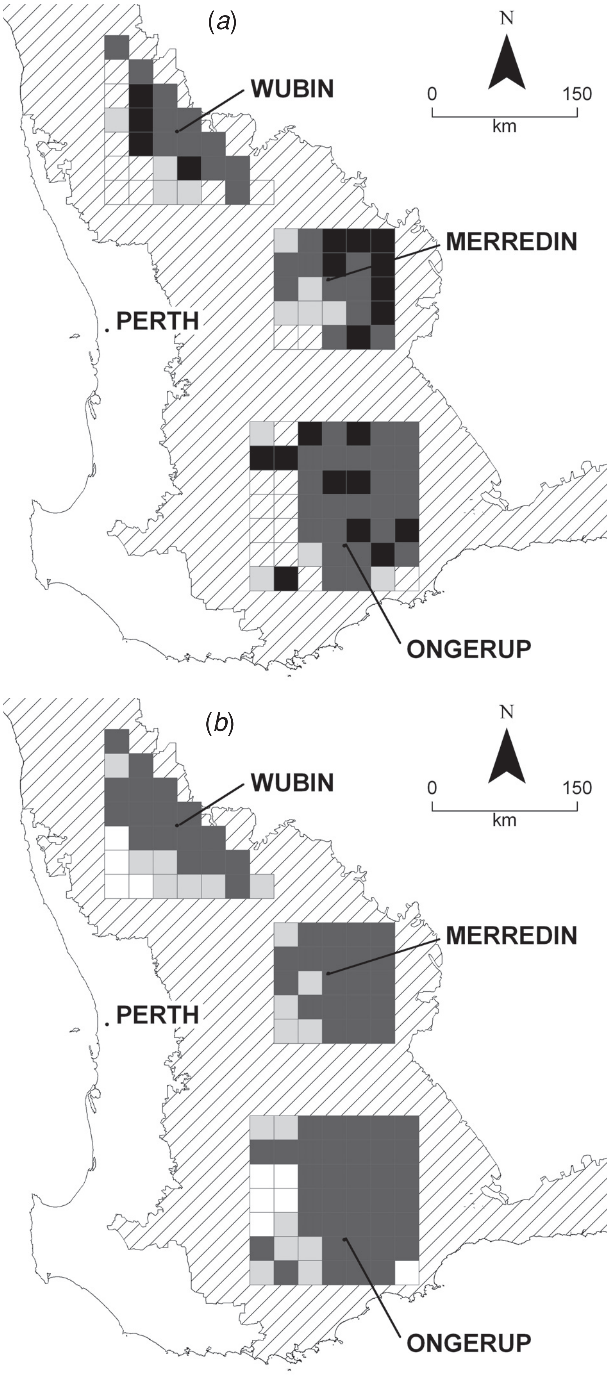

Fig. 5. The change in status within each 25 × 25-km cell within the WA Wheatbelt resulting from verification via landholder survey: (*a*) before survey; and (*b*) after survey. White, Malleefowl never present; dark grey, present pre- and post-1989; light grey, present pre-1989 only; black, present post-1989 only; hatched area, WA Wheatbelt.

An assessment of the contraction range of Malleefowl

Based on a coarse resolution analysis for all of WA, we determined that Malleefowl had experienced a contraction of range of ~30%. Contraction occurred primarily within arid areas to the east of the Wheatbelt (Fig. 3*a*) with some contraction in the deep south-west of WA and on the western margin of the Wheatbelt. However, there was a substantial degree of uncertainty to the scale of decline in remote areas of the state because of the low observer densities (Fig. 4).

Malleefowl have persisted across much of the WA Wheatbelt but have suffered a range contraction in western and central portions. The species still occurs in the eastern half of the Wheatbelt. The contraction in the range of Malleefowl was best predicted by three variables: the amount of remaining vegetation, the length of time an area had been subject to agricultural land use, and numbers of sheep.

Contraction of the range of Malleefowl was most strongly associated with the amount of vegetation remaining within an area (i.e. habitat loss), with the length of time of agricultural development and sheep density contributing less to the model. Malleefowl have been lost from most cells where little vegetation remains (i.e. less than 3%). The negative effect of habitat loss on avifauna has been well established (e.g. Saunders and Ingram 1995; Ford *et al.* 2001) and so it was not surprising to observe a negative relationship between extent of clearing of native vegetation and presence of Malleefowl. Furthermore, the same qualitative relationship has been observed for Malleefowl elsewhere in Australia (Frith 1962).

The correlation between contraction of range of Malleefowl and the length of time an area had been subject to agricultural land-use provides evidence that actions associated with agricultural activity may be having a negative impact on Malleefowl populations. Our analysis showed that Malleefowl had not disappeared from any grid-cells where agricultural development had started after the 1930s. This suggests a 70-year time lag before the effects of agricultural development result in the complete loss of Malleefowl from an area. This may be explained by the impact that agricultural development has on the size of Malleefowl populations, where the effect is immediate, but it takes many generations for the population to decline to the point where it becomes locally extinct (Priddel and Wheeler 2003; Priddel *et al.* 2007). It may also be possible that remnants

Table 4. Summary of the final GAM model for Malleefowl range contraction within the WA Wheatbelt, selected by a backward stepwise procedure

Drop contribution shows change in deviance when the variable was dropped from the final model, alone contribution shows change in deviance where new models are created with only one variable

Selected variable	*P*-value	Direction of the effect	Drop contribution	Alone contribution
VEG_HA	<0.001	–	64.8	75.9
ALIEN	<0.001	–	43.3	71.5
AVGSHPHA	<0.001	+	54.9	23.6
Null deviance	202.4	Residual deviance		36.1
Degree of freedom (d.f.)	90	Residual d.f.: all variables		78

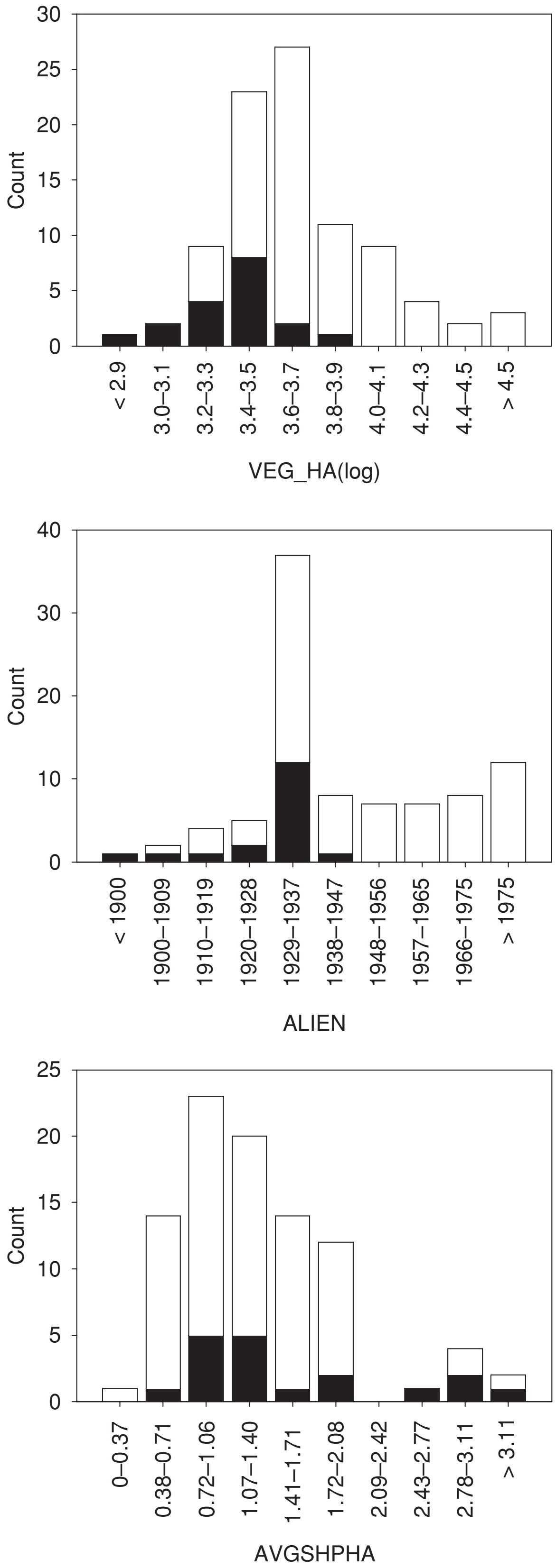

Fig. 6. Histograms of the response variable with respect to each predictor variable. Black, Malleefowl absence; white, Malleefowl presence.

degrade as their agricultural age increases, rendering habitat less suitable for Malleefowl, causing local extinctions. However, it may also be possible that the nature and pattern of clearing changed in the 1940s and beyond in a manner that benefited Malleefowl.

The effects of agricultural land-use on remnant vegetation are many and varied (see Hobbs and Hopkins 1990). These include the depletion of seed stores and removal of above-ground vegetative material through grazing by stock, and alteration of vegetation community composition. The longer an area has been used for agricultural operations, the poorer the condition of the remnant vegetation is likely to be (Saunders *et al.* 2003; Spooner and Lunt 2004). Therefore it is reasonable to deduce that agriculture, via the processes mentioned above, has and will continue to have a negative impact on the persistence of Malleefowl within the WA Wheatbelt compounding long after clearing has finished.

Our analysis indicates a correlation between the contraction in range of Malleefowl and time since commencement of agriculture. However, it is possible that this variable is acting as a surrogate for natural differences such as habitat or soil-type. Timbered areas with heavier soils were cleared earlier as they were the most productive, with mallee and areas on deep sand cleared several decades later (Burvill 1979). These differences were not included in the model but may have contributed to the pattern of contraction of Malleefowl range. Similarly, at least some areas cleared in later years had more retained vegetation and more substantial corridors of native vegetation linking remaining natural vegetation.

Contraction of Malleefowl range was associated with higher sheep densities, potentially reflecting the negative impact of sheep grazing on Malleefowl habitat. The impacts of grazing on Malleefowl persistence have been noted in eastern Australia (e.g. Frith 1962; Priddel *et al.* 2007) and recognised to have profound negative effects on remnant bushland within the WA Wheatbelt (Hobbs and Hopkins 1990; Yates *et al.* 2000; Saunders *et al.* 2003). The increased likelihood of Malleefowl range contraction in areas with high sheep numbers suggests that grazing of remnant vegetation is a threat to the species' persistence in the WA Wheatbelt also.

Generally, where sheep numbers are lower, wheat production is higher ($r = -0.66$). Therefore the correlation between Malleefowl range contraction and the number of sheep in an area may, in part, also be a reflection of the Malleefowl's reliance on wheat as a food source, as suggested by several authors (Serventy and Whittell 1976; Brickhill 1987; Storr 1991).

We were limited to detecting large changes in the distribution of Malleefowl and not changes in density. Although we did find anecdotal evidence of a decrease in Malleefowl density throughout the Wheatbelt during the last century via our landholder survey and the literature (e.g. Saunders and Ingram 1995), considerable uncertainty still remains regarding trends in Malleefowl density. We may speculate that there has been a decrease in density of Malleefowl in remaining habitat in addition to a contraction in its range, but adequate quantification of such a change would require temporally structured monitoring of multiple populations over the long-term (Benshemesh 2000).

Two known threats to Malleefowl (predation by Red Foxes and too-frequent fire), were excluded from this analysis as they could not be adequately quantified across the study area. There is a possibility that variables contained within our analysis are correlated with these threats. For example, it may be possible that Fox predation is more intense in areas with less vegetation or greater densities of sheep but it was outside the scope of this study to investigate such interactions. We suggest that studying the role of such threats within the context of this study would be a worthwhile pursuit.

Presence-only v. *presence–absence data*

The differences between the presence-only and presence–absence estimates of range contraction were substantial (Fig. 5). In the presence-only assessment, over 20% of cells contained recent Malleefowl records (post-1981) but no historical records (before or including 1981), apparently signifying a range expansion for the species; a pattern that would contradict claims that the range of the species has contracted (Benshemesh 2000). However, subsequent to the survey, all of these cells were found to have been occupied by Malleefowl both in recent and historical times, illustrating that the species had not undergone a range expansion. In addition, the presence-only data appeared to show the Malleefowl population to be contracting and expanding in many areas, making it difficult to determine an overall trend. Conversely, the presence–absence analysis showed the species contracting in several areas, and expanding in none, an overall trend of contraction. This comparison shows the vulnerability of presence-only data to false absence. We suggest that presence-only data is not suitable to assess the status of a species at this scale and reliable presence–absence data are critical to making assessments of conservation status.

Ideally, to confirm contraction of range or assess species status, presence–absence surveys should be carried out over broad spatial scales at two or more time periods but this is typically unfeasible (Araújo and Guisan 2006). Aerial surveys may be used to apply this approach for large, conspicuous species residing in open habitats (e.g. Emu (*Dromaius novaehollandiae*) and Australian Bustard (*Ardeotis australis*); Grice *et al.* 1985, 1986), but for most species such approaches are not suitable. We demonstrated a method of obtaining a presence–absence dataset that made best use of existing presence-only data: we verified all areas of apparent absence via landholder survey. This method was effective because it was quick, inexpensive and easy. It did not require us to query areas of presence, and avoided the onerous task of surveying vast areas for Malleefowl to obtain absence data. Brickhill (1987) conducted a similar survey of local knowledge of Malleefowl presence in New South Wales and found the reliability of some survey observations to be questionable. That is, many areas claimed to contain Malleefowl were found to contain inactive mounds only, as respondents had not visited the actual location (i.e. a farmland remnant) for many years. Most of our survey responses were based on sightings of actual birds rather than solely observations of mounds and so the potential for bias of our estimate of range contraction due to this issue is limited. Despite the assumption that a landholder's knowledge of an area was correct, we believe this method would be appropriate for use in populated areas, particularly for those species such as Malleefowl that are conspicuous and easy to identify.

The role of presence-only data in the assessment of range contraction

The addition of new presence data (2294 records) to the NRP dataset (1172 records) resulted in a substantial reduction in the estimate of Malleefowl range contraction for WA. Many areas initially identified as areas of contraction using NRP data (11 out of 37 one-degree cells), particularly in the central Wheatbelt, were proven to be incorrect, illustrating the vulnerability of a presence-only analysis to variable observer effort. In this study, Malleefowl range contraction was limited to remote rangeland and desert areas of very low human population density (<1 person km^{-2}, Fig. 3). The likelihood of the species being present but undetected in these areas is high. Furthermore, 'uncertain' cells were largely confined to sparsely populated areas (Fig. 4). Hence, the pattern of range contraction may be wholly, or in part, a function of the density of people, and therefore observer effort.

The dataset we collated in this study represents the best available dataset of Malleefowl occurrence for WA, and expanded the NRP dataset by nearly 2300 records, but this additional effort largely acted to consolidate our knowledge in areas of known occurrence. The new data provided little new information for sparsely populated areas such as the arid zone of WA and consequently, both the NRP estimate and ours were uncertain for these areas as they were informed by very few scattered records. We suggest that supplementing a presence-only dataset with additional records is likely to provide only limited insight into a species' distribution, particularly in remote areas.

Presence-only assessments of status may be misleading owing to the fact that they are highly sensitive to differences in observer effort. However, over broad scales more detailed data is unlikely to be available. Presence-only datasets are often: (1) collected over long periods, (2) collected by experts and enthusiasts, and (3) collected at a fairly fine resolution. Where the time or resources, or both, available to researchers are limited, it is important to maximise the use of existing data to form useful management recommendations. In this study, we illustrated how this may be achieved by verifying apparent absences. The approach effectively incorporates presence-only datasets into a presence–absence analysis, thereby making a useful contribution to understanding patterns in species occurrence.

Summary and conservation implications

We used the Malleefowl to demonstrate methods for utilising presence-only datasets to assess range contraction and to illustrate several major issues associated with doing so. Presence-only data are highly sensitive to false absences and bias in observer effort, both in time and space. Consequently, conservation decisions and assessments of status based on presence-only data are potentially misleading. Effort should be directed towards verifying presence-only datasets before using them for such purposes. We suggest that to adequately assess the status of a species, a presence–absence dataset represents the minimum requirement. This is a general issue affecting any analysis of decline based on presence only records (e.g. atlas data, museum collections, distributional databases). Inevitably the weaknesses of such datasets must be balanced against the fact that they often represent the only data available in most cases – there is no simple solution.

The range of Malleefowl in the WA Wheatbelt has contracted and it is possible that it will continue to do so. The known threat of introduced predators (Priddel and Wheeler 1996; Priddel *et al*. 2007) must be addressed to reduce the likelihood of such a contraction continuing. Our study suggests to reduce further the likelihood of contraction, clearing of native vegetation should stop. In areas where Malleefowl have already been lost, re-establishment of native vegetation will be necessary to support the species. In areas where sufficient native vegetation remains, active management to restore or retain habitat value will be required (Yates *et al*. 2000) as changes caused by agricultural practices (e.g. fragmentation, grazing) are likely to be long-term and persistent (Foster *et al*. 2003) and may not be fully evident yet. Future research should be directed towards investigating how landscapes change as they age following agricultural development and how this relates to the persistence of Malleefowl.

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