Reassessing the conservation outlook for Madagascar's endemic Anatidae following the creation of new protected areas

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Abstract

Madagascar has three endemic species of Anatidae, all of which are classified by the International Union for Conservation of Nature (IUCN) as Endangered or Critically Endangered. Until recently there have been no protected areas within their ranges to secure key habitat. The creation of several new protected areas in Madagascar since 2010 has created an opportunity for better conservation management of these species, most obviously for Madagascar Pochard *Aythya innotata* which occurs at just a single site that has now been protected. We created distribution models for the other two species, Madagascar Teal *Anas bernieri* and Meller's Duck *A. melleri*, using survey data collected from 2004–2013 and MaxEnt software. Predicted ranges were compared with the locations of protected areas. Additionally, for each species, population monitoring was carried out at one site at which there has been conservation intervention. Our models predicted that breeding Madagascar Teal would occur near healthy mangroves (family: Rhizophoraceae) in areas with high mean temperature, but the total extent of predicted suitable habitat is just 820 km^2. Non-breeding Meller's Duck favour water surrounded by dense vegetation, in areas with low human population density. Meller's Duck occurs in at least nine protected areas, but most of these were set up for forest conservation and may not support many individuals. Since 2010, two wetland protected areas that could benefit Meller's Duck have been created, although one is small and the other, Alaotra, is heavily disturbed. The population of Meller's Duck at Alaotra is stable. Four new protected areas will benefit Madagascar Teal, covering more than half of the predicted breeding range for this species. The population at one of these protected areas, the

Manambolomaty delta, is increasing. Overall, we conclude that the conservation outlook for Madagascar Teal is improving, but the small range for this species means it is dependent on good management at protected areas where it does occur. Meller's Duck requires more attention, and the outlook for this species remains poor.

Key words: *Anas bernieri*, *Anas melleri*, Madagascar, population trends, species distribution model.

The protected areas created in Madagascar's colonial period and during the first republic (1896–1972) covered only 1.9% of the country's surface area and were gazetted mainly for forest conservation. This left Madagascar's wetlands largely without legal protection (Nicholl & Langrand 1989). In 2003, Madagascar announced an aim to triple the size of its protected area network (known as the Durban Vision; Norris 2006). This new policy provided an opportunity to establish wetland and marine protected areas, with a view to advancing the conservation of endemic and threatened aquatic species. Madagascar's wetlands are in general in very poor condition (Bamford *et al.* 2017) as a result of transformation of wetlands into rice fields, siltation and changes in water quality caused by deforestation and erosion, the presence of invasive non-native species, and over exploitation of resources including mangroves (family: Rhizophoraceae) for wood (Langrand & Goodman 1995; Young 1996a). Given this heavy destruction of Madagascar's wetlands, a study of the distribution, range and population trends for threatened endemic species was considered crucial in order to identify how well served threatened species are by the newly protected areas. Site surveys can provide some answers to these questions (*e.g.* Young *et al.* 2014), but this approach is not feasible for a country-wide perspective. Species distribution modelling may provide a solution.

Madagascar has three endemic species of Anatidae (Young *et al.* 2013a). Madagascar Pochard *Aythya innotata* are not discussed here as the species occurs at only one site (Bamford *et al.* 2015), making distribution modelling unnecessary. The site at which the pochard occurs has now been protected. The other two species, Madagascar Teal *Anas bernieri* and Meller's Duck *A. melleri*, have different ranges and occur in different habitat types, but both are classified as Endangered by the International Union for Conservation of Nature (IUCN 2016) because they are thought to be suffering long-term population declines. There are few data available for either species, and the evidence for this decline mostly comes from the rate of habitat destruction observed. Historically, neither species had the benefit of protected areas within their range to secure key habitat. The causes of their declines may be similar however (Young *et al.* 2013a), with both being threatened by habitat loss, hunting and fisheries bycatch mortality, and human disturbance (Wilmé 1994; Young *et al.* 2013a,b).

Madagascar Teal is found in the west coastal wetlands of Madagascar, from the far north of the island (at *c.* 12°S) to 23°S near the town of Toliary. It breeds in mature Black Mangrove *Avicennia marina* and spends the rest of the year on freshwater or brackish lakes (Young 2013; Young *et al.* 2013b). The species is never found more than a few kilometres from the coast, or at altitudes of more than a few metres above sea level (Young 2013). The teal was rediscovered in 1969 (Salvan 1970; Andriamampianina 1976), having been only rarely recorded anywhere in the country for nearly a century. Soon after, 120 individuals were recorded at lakes in the mid-western region of the country (Scott & Lubbock 1974). No more surveys were conducted until the early 1990s, by which time this species was known only in the central-western region (Langand 1990). Further populations have been discovered since then (*e.g.* Razafindrajao *et al.* 2001), but the overall population is estimated to number < 1,700 mature individuals (IUCN 2016).

Meller's Duck is found in wetlands in the highlands of central, east and northwest Madagascar, where this highly territorial species breeds predominantly in forested streams and rivers or in extensive marshland (Young 2013). It was introduced to Mauritius in around 1850 (Morris & Hawkins 1998) but the Mauritian population is now extinct (Young & Rhymer 1988). While there is hardly any information on which to determine population trends for Meller's Duck in Madagascar, numbers are thought to have been declining for the past four to five decades (Young 1996a; Young *et al.* 2013a). Although the species' range covers approximately half of Madagascar, and within that range it occurs on small rivers and wetlands which provide potentially a very large number of suitable sites, it is rarely seen in groups larger than single figures. The total population size is estimated at < 3,300 birds (IUCN 2016).

This paper aims to assess the current status of these two species, in order to help develop conservation strategies for them. Specific objectives are: 1) to describe trends in numbers at sites where there has been conservation intervention, 2) to utilise survey data to identify suitable habitat and predict the species' distribution, and 3) to compare the predicted distribution with the locations of the newly-protected areas.

Methods

Study sites

Monitoring of the Madagascar Teal population was carried out in the wetlands of the Manambolomaty Delta (18.96°S, 44.35°E) which cover an area of 630 km^2 (Fig. 1). The delta contains several different types of wetland habitats including freshwater ponds and lakes, estuaries, mangroves and marshes, all of which are utilised by Madagascar Teal, and the wetlands also provide important refuges for other aquatic fauna in western Madagascar (Rabearivony *et al.* 2010). In 1998, a conservation project for the teal was established in the Manambolomaty Delta (see Young *et al.* 2013a) with the objective of ensuring the long-term viability of this population by involving local communities in lake management and monitoring activities.

Meller's Duck population monitoring was conducted at Lake Alaotra and its

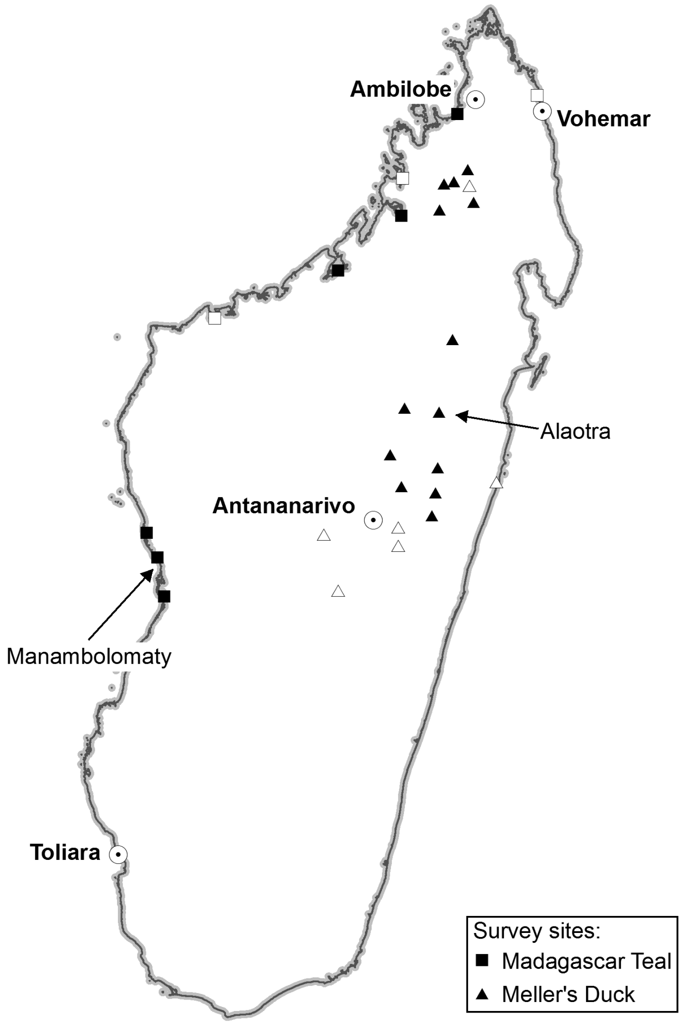

Figure 1. Study sites and other locations referred to in the text. For the survey sites, filled symbols represent sites where the target species was recorded, and unfilled symbols show sites where it was not recorded.

surrounding marshes (17.50°S, 48.50°E) in an area covering 500 km². Lake Alaotra, the largest lake in Madagascar, is surrounded by steep, deforested hills and erosion of the slopes causes substantial sedimentation in the lake. Alaotra is home to several threatened species, including the Alaotra Gentle Lemur *Hapalemur alaotransis* (classed as Critically Endangered by IUCN) which is endemic to the marshes at Alaotra. Alaotra is one of the most threatened ecosystems in Madagascar (Mutschler 2003). Conservation activities at the lake were started in 1995, and include education and awareness programmes, establishing fishermen's groups to regulate activities and monitoring of biodiversity including waterfowl.

In preparation for the distribution surveys, we visited sites throughout the historical range of the two species for collecting count data. For the Madagascar Teal, these ranged from Toliary in the south to Ambilobe in the north, with some sightings also from the northeastern part of the Vohemar district (Young 2013). For Meller's Duck, the historical range covers highland wetlands in the north, east and northwestern regions of the country. Locations of the survey sites are shown in Figure 1.

Distribution surveys

Field work was undertaken from 2002–2006 for Madagascar Teal and 2004–2008 for Meller's Duck, with some extra data collected in 2012 and 2013 for both species. Survey locations were selected opportunistically and informally, sometimes as part of survey work with other objectives, using 1:500,000 scale Foiben-Taosarintan'i Madagascar (FTM) maps and Google Earth images. Most sites were visited only once during the study period. Survey effort varied with the size of the site, ranging from two hours at small ponds to three days at large lakes. The total number of ducks of each species was recorded for each site on each occasion.

Population monitoring

The more detailed monitoring of teal at the Manambolomaty Delta was carried out monthly in at least five months every year from 1999–2012. Counts of birds were made using binoculars and a telescope. Counts commenced between 06:00–12:00 h and the duration of the count was recorded, varying from 15 min to 6 h depending on conditions. A total of 13 locations were monitored during this period, although not all locations were surveyed every year. The number of locations surveyed in each year ranged from 6–13; the number of years in which each location was surveyed ranged from 3 years to all 13 years of the monitoring period.

At Alaotra, biannual monitoring of waterbirds was conducted during July and February (during the dry season and rainy season respectively) from July 1998 to July 2012. In 1998 monitoring was initiated at five locations around the lake, with a sixth site monitored from 2003 onwards. The marsh at one location was converted to rice agriculture in 2001 so monitoring was transferred to a new location nearby. Counts of birds were direct counts using binoculars and telescope. Visits were made by canoe or on foot. Observations began at 05:45 h and ended at 10:00–11:00 h.

Predicted range maps

The survey methods used during the study meant that presence-only modelling was the only appropriate method for distribution modelling. Predicted occurrence maps of Madagascar Teal and Meller's Duck were created using MaxEnt software (Phillips *et al.* 2006). Both species utilise slightly different habitat during their breeding and non-breeding seasons, often gathering in larger lakes during the non-breeding season which coincides with the dry season. Madagascar Teal may be constrained by the availability of both breeding and non-breeding habitat (Young *et al.* 2013a), but the model here is based on sightings from the breeding season only. Meller's Duck is also likely to be limited by the availability of both breeding and non-breeding habitat, but there are few breeding records for this species, meaning that it was not possible to develop a satisfactory model of the birds' distribution across breeding habitat. Only sightings made during the dry (non-breeding) season therefore were included in the model.

Habitat variables were prepared in ArcGIS v10 using the Spatial Analyst extension (ESRI 2012). The variables included in each analysis are shown in Table 1, and were all prepared at 1 km resolution. Variables included were: water cover (lakes and rivers) as determined from remote sensing data; vegetation cover relevant to each species (*i.e.* forest cover for Meller's Duck; mangrove cover for Madagascar Teal); a measure of vegetation thickness (the Normalised Difference Vegetation Index, NDVI); human population density as a measure of disturbance; and basic climate information (Table 1). Models for both species covered the entire country. Presence records were filtered so that the minimum distance between sightings was 1 km to match the resolution of the habitat data. The small number of presence records for both species made further compensation for spatial bias unfeasible (see Merow *et al.* 2013), a common problem with rare species. Models were constrained to use only linear relationships. MaxEnt allows the user to set a regularisation multiplier to reduce over-fitting of the model, but after a few trials we kept this multiplier set to the default of 1 because higher values led to models that predicted very large areas of species occurrence. The software was set to create response curves for each variable and to perform jack-knife measurement of the importance of each variable. Cross-validation was used to test the models, with the number of replicate models set to ten. The final model presented in each case is the average value of all ten models. Good habitat for each species was defined as areas where the final model prediction was ≥ 60% probability of suitability for the species.

Population trends analysis

Count data for both species were modelled using Generalized Linear Models. Statistical analyses were carried out in R 3.2.3 (R Core Team 2015). We tested log-linear models but the results were unsatisfactory as our data were zero-inflated and over-dispersed. Instead we used negative binomial models using the package MASS (Venables & Ripley 2002), which produced a better fit. For each species, counts were modelled with year, site and duration of the count as explanatory variables. Site was fitted as a categorical variable, Year was fitted as a continuous variable to establish an overall trend and then as a categorical variable. Duration was standardised to have mean = 0 and s.d. = 1. The trend for year was plotted with the other variables held stable. The 95% confidence intervals for the predictions were calculated from the standard errors of the predictions.

Table 1. Habitat variables included in MaxEnt models for Madagascar Teal and Meller's Duck.

Variable	Description	Madagascar Teal	Meller's Duck
Wetland area (proportion)	Spatial Analyst software was used to calculate flow accumulation from Digital Elevation Model (DEM) data (Jarvis *et al.* 2008). This was used to create a feature set of rivers and streams. This was combined with the LandSat Global Inland Water dataset (Feng *et al.* 2015) to create an overall water cover feature. Both datasets from 2000.	×	×
Population density (people km^{-2})	Taken from CIESIN *et al.* (2004). Data from 2010.	×	×
Mean temperature (°C)	Annual mean temperature (1970–2000), taken from www.WorldClim.org (Hijmans *et al.* 2005).	×	×
Annual precipitation (cm)	Total annual precipitation (1970–2000), taken from www.WorldClim.org (Hijmans *et al.* 2005).	×	×
Dry season NDVI (October) Rainy season NDVI (February)	NDVI long-term mean (2001–2013) taken from FEWS Net, available at www.earlywarning.usgs.gov/fews and resampled to $1km^2$ resolution.	×	×
Elevation (m a.s.l.)	Taken from DEM data (Jarvis *et al.* 2008).	×	×
Slope (% incline)	Calculated from DEM data (Jarvis *et al.* 2008) using Spatial Analyst.		×
Forest cover (%)	Calculated from Madagascar vegetation map (Moat & Smith 2007). Data from 2003–2006.		×
Mangrove cover (%)	Calculated using Giri *et al.* (2011). Data from 1997–2000.	×	

Results

Predicted ranges

Spatial filtering to 1 km resolution resulted in 15 presence records for Madagascar Teal and 33 for Meller's Duck. The habitat preference model for Madagascar Teal during the breeding season was most strongly affected by two variables (variable percentage contributions to the model are given in parentheses): positive effects of mangrove cover (76%) and mean annual temperature (22%). There were also weaker contributions to the model of annual precipitation (negative, 1.4%) and dry season NDVI (positive, 0.1%). The remaining variables made no contribution to the model. On a Receiver Operating Characteristics (ROC) curve, the mean Area Under Curve (AUC) was 0.994 ± 0.003, indicating an excellent model performance.

The main variables in the model for Meller's Duck, all with positive effects, were elevation (41%), water cover (30%) and dry season NDVI (13%). There were also smaller, negative, effects for wet season NDVI (4%), human population density (4%) and mean temperature (3%). The model had AUC = 0.956 ± 0.030.

Predicted distribution maps for both species are shown in Figure 2. Prior to 2010, the majority of breeding habitat for Madagascar Teal was unprotected. Since then, four new protected areas that will benefit this species have been established (Mahavavy-Kinkony, Manambolomaty, Menabe-Antimena and Mangoky-Ihotry). However, three significant areas of predicted good habitat remain unprotected: Ankazomborona, Loza Bay and the Mahajamba Delta. Overall, there was 820 km^2 of predicted suitable habitat (area where the model predicted suitability for the species greater than 0.6), and of this the proportion protected has increased from 3% to 56% since 2011.

Dry season habitat for Meller's Duck occurs within several long-established protected areas, notably Marotandrano Special Reserve, Zahamena National Park, Ranomafana National Park, Andringitra National Park, and Kalambatritra Special Reserve. Five new protected areas have recently been established that could benefit this species, especially in the northern highlands (Bemanevika and the Tsaratanana-Marojejy corridor) and at Lake Alaotra. The model predicts several small, scattered areas of suitable habitat that are currently unprotected but only one large continuous area of unprotected good habitat: the forests east of Lake Tsiazompaniry in Anosibe. Of the 4,800 km^2 of predicted suitable habitat (model prediction > 0.6), the proportion protected has increased from 9% to 46%.

Population trends

Models of count data were significantly better fits to the data than null models, both for Madagascar Teal (Likelihood Ratio = 1377, d.f. = 115, $P < 0.001$) and for Meller's Duck (LR = 136, d.f. = 33, $P < 0.001$). The population trends by year are shown in Figure 3. For Madagascar Teal, an initial slight decline has been followed by a steady increase since 2003. By 2011, the population was 136% higher than it had been in 1999, although this was followed by a slight decline again in 2012. With fewer data, the

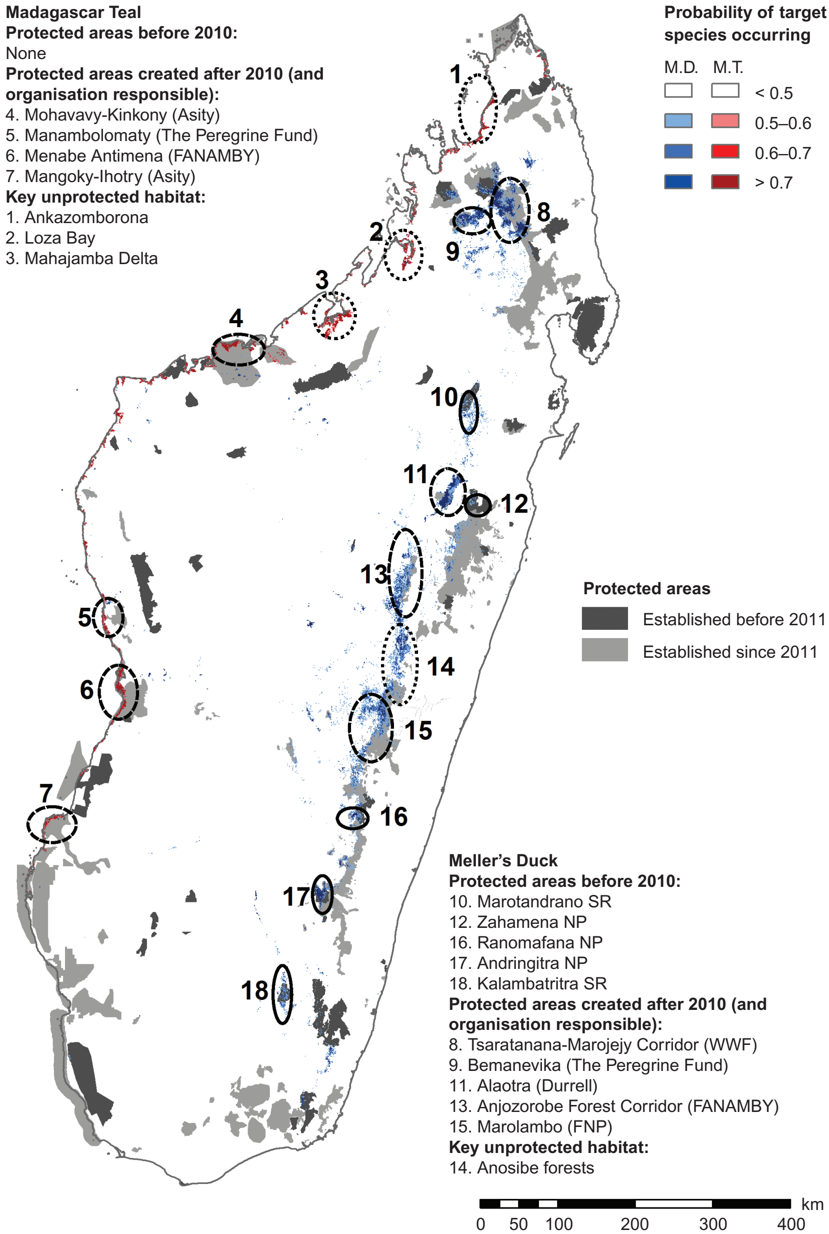

Figure 2. Predicted occurrence of Meller's Duck (blue) and Madagascar Teal (red), with protected areas and key areas of occurrence that are unprotected highlighted. SR = Special Reserve, NP = National Park. "Organisation Responsible" refers to the non-governmental organisation (NGO) that set up the reserve and supports management.

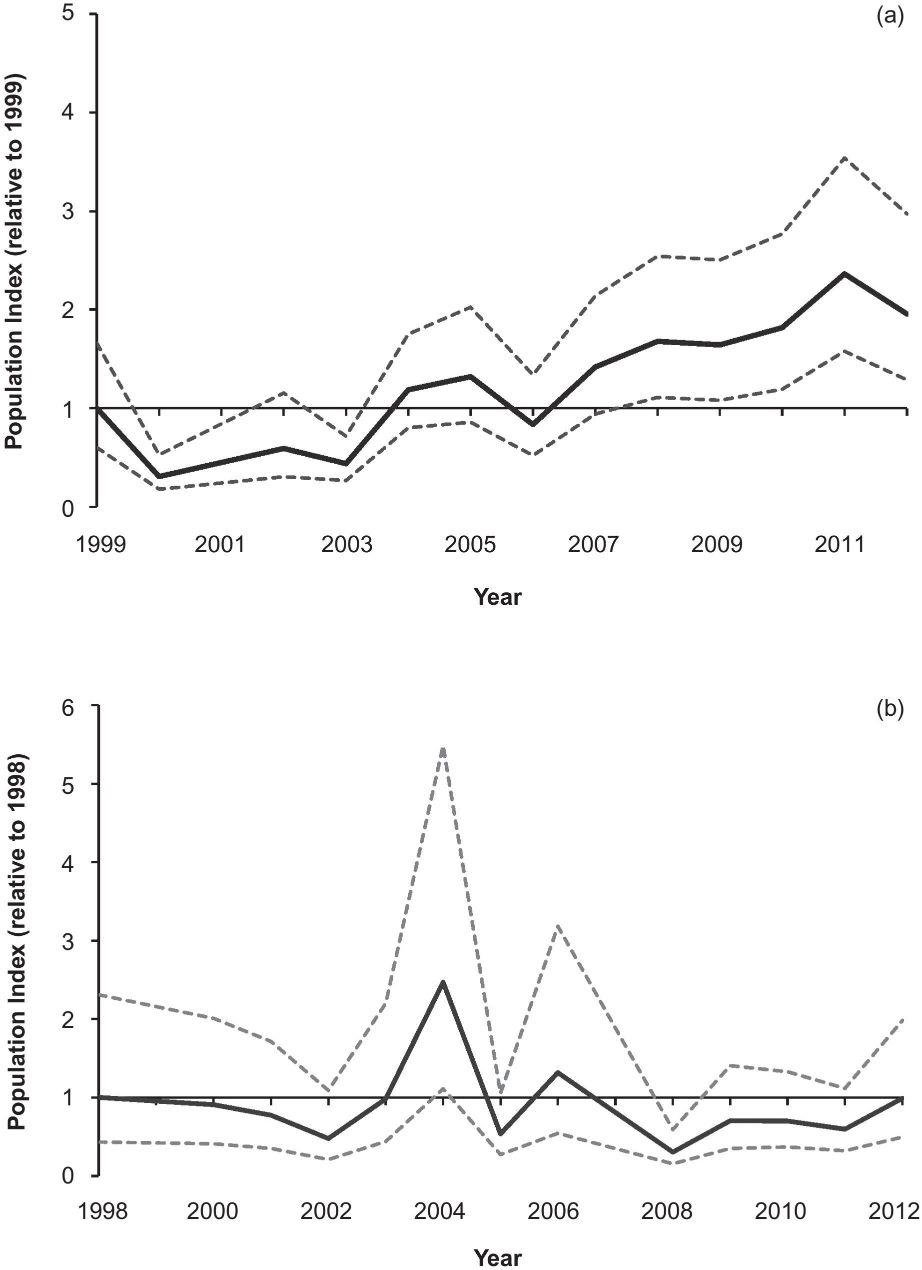

Figure 3. Population trends for a) Madagascar Teal in Manambolomaty, and b) Meller's Duck in Alaotra. Continuous lines = annual population estimate from the model; dashed lines = 95% confidence intervals.

model fit for Meller's Duck had wider confidence intervals and no trend was detectable in the data. The population appears stable based on the limited data available.

Discussion

Our species distribution models broadly confirm previous *ad hoc* distribution maps for these two species (*e.g.* Young 2013), but our maps suggest that there is little suitable habitat within the simplified ranges shown in those *ad hoc* distribution maps. Breeding habitat for Madagascar Teal was predicted to occupy an area of just 820 km^2 along the west coast, constrained nearly entirely by the availability of mangroves. The vegetation map used (Giri *et al.* 2011) generally only includes mature mangroves in its classification (Jones *et al.* 2014), and an effect of dry season NDVI indicates that even among mature mangroves the healthiest stands are being selected (*e.g.* Chellamani *et al.* 2014). Even this small figure may overestimate the suitable habitat, given that Madagascar Teal nest only in Black Mangrove and not in other species, a distinction that the vegetation map does not make. Madagascar Teal is also known to be sensitive to human disturbance (Young *et al.* 2013b), requiring undisturbed wetlands not just for breeding but also for moulting during the dry months.

Dry season habitat for Meller's Duck was associated with wetlands at cooler, high elevations and with high dry season NDVI – generally, areas that are forested or have dense evergreen bush – and in areas with low human population density. We did not record any ducks in the eastern coastal regions, and this was reflected in our model which did not predict any suitable habitat in this region, contrary to previous distribution maps. The eastern wetlands have a high human population density and correspondingly high disturbance, meaning that there is little suitable habitat remaining for Meller's Duck on the east coast (Young 2013). Human disturbance is one of the most important factors affecting freshwater biodiversity in Madagascar (Bamford *et al.* 2017). Apart from the exclusion of the east coast wetlands, the results from our model are similar to previous studies such as Young (1996b) and Langrand (1990), but additionally suggest that the northern highlands may be an important area for this species.

Interpretation of the models needs to be undertaken with caution, as there was no independent dataset available to test the models against. The small sample size limited modelling to linear relationships, but some responses may in reality be non-linear, particularly responses to NDVI. Furthermore, the models cover a fairly short, and already slightly out of date, temporal period and so make no allowance for future changes in habitat associated with climate change or other habitat changes. The effects of climate change, particularly on coastal mangroves, are poorly understood in Madagascar (Ward *et al.* 2016) and may cause substantial changes within protected areas, rendering them unsuitable for some of the species that live there. Despite these limitations, our results do highlight conservation measures that will benefit these species in the short term at least.

Prior to 2010 there were no protected areas within the breeding range of Madagascar Teal, and very few within the dry season range either. Kirindy-Mitea National Park contains two shallow lakes, which shelter approximately a few tens of Madagascar Teal during the dry season, but the park contains no breeding habitat. Since 2010, four protected areas have been created that could benefit breeding Madagascar Teal: Mangoky-Ihotry, Menabe Antimena, Manambolomaty and Mahavavy Kinkony. Between them, these Protected Areas cover more than 50% of the teal's predicted breeding range. Provided they are adequately managed – and in Madagascar that is not a certainty – they represent a major step forward in the conservation of Madagascar Teal.

Meller's Duck occurs in at least five protected areas that were established before 2010 in the highlands. However these areas are primarily for forest protection, and the small rivers and streams that they contain are home to only small numbers of Meller's Duck (Young *et al.* 2013b). Whilst nearly half of the predicted suitable habitat is now protected, the same problems apply to some of the protected areas created since 2010. Two newly-protected areas may be more useful for Meller's Duck conservation, as they contain more substantial wetland areas: Bemanevika and Alaotra. Bemanevika may contain the most suitable, and least disturbed, habitat, but this site covers only *c.* 500 ha of wetlands. The Alaotra Protected Area covers a much larger area of wetlands, over 300 km^2, but this area is highly disturbed (Mutschler 2003; Bamford *et al.* 2017). If, contrary to our model, the species does still occur in the east coast wetlands, no new protected areas have been created which would help to reinforce its presence in that region.

Monitoring of Madagascar Teal at Manambolomaty shows that the population is increasing at this site, suggesting that this site at least is adequately managed for this species. While we cannot rule out that this increase may be due to immigration from more disturbed areas, we do know that birds from this site emigrate to other wetlands along the west coast of Madagascar (Razafindrajao *et al.* 2012). Conservation work at Manambolomaty has worked to make anthropogenic use of the wetlands more sustainable, and our results suggest that this work is effective.

Monitoring of Meller's Duck in Alaotra and its surrounding marshes show that the population is apparently stable over more than ten years of monitoring. This result may mask the seriousness of the situation at Alaotra, as many of the birds recorded there during the dry season will not breed there. The Alaotra wetlands constitute one of the most threatened habitats in Madagascar (Mutschler 2003; Bakoariniaina *et al.* 2006). Due to intense human pressure, conservation interventions at this site do not appear to be having any beneficial effect for the Meller's Duck. Despite this, Alaotra is still likely home to the largest number of Meller's Ducks in Madagascar, with several hundred birds seen each year, and it is a critical site for this species.

Conclusion

Overall, our results suggest good news for Madagascar Teal. Since 2010 several protected areas have been created, covering more than half of its breeding range, which should, if managed correctly, benefit the species. Monitoring at one of these sites shows a population increase, and monitoring at other sites should be a priority to determine if this increase is occuring more widely. Further detail on nesting habitat requirements for the species is required, although survey work in dense, mature mangroves is not straightforward. However, the total area of breeding habitat is small and non-protected habitat is being cleared rapidly (authors' pers. obs.). Protection of all remaining suitable habitat is in theory achievable and would further improve the outlook for this species, but would require an organisation willing to pay for it – none of the new protected areas in Madagascar have been government funded.

The situation for the Meller's Duck is less promising. The species does occur in several protected areas, and several new ones have been created since 2010 resulting in nearly half of its dry season habitat being protected. However, it does not occur at high density across most of its range. Furthermore, little is known about the species' breeding habitat requirements, so we cannot judge how much protected breeding habitat there might be or how many pairs that could support. There are only two wetland protected areas in its range, one of which is small and the other is large but severely degraded. The non-breeding population at this latter site is stable. This species undoubtedly requires far more conservation attention but first requires more detailed research so that the species' breeding requirements and limiting factors are known in sufficient detail to form a conservation plan.

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