Impacts of Deforestation on the Conservation Status of Endemic Birds in the North Maluku Endemic Bird Area from 1990-2003

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Abstract

Satellite imagery has become a powerful tool to analyze land-use trends across large portions of the globe, including remote areas where access is logistically or political impossible. Due to the rapid pace of deforestation, the high biodiversity contained within, and the difficulty of access and standardized field surveys, the tropics are a key front for using remote sensing to identify target areas for conservation action and, more recently, to inform species-level trends. This study focuses on deforestation in eastern Indonesia, which has some of the highest rates of forest clearing in the world from mining, plantation expansion, timber extraction, and shifting agriculture. Forest loss on the highly biodiverse islands of the North Maluku district in eastern Indonesia was examined from 1990 to 2003 and the conservation status of 39 restricted-range avian species found in the area was re-assessed from these trends. Of the land area available for analysis, forests declined from 86% to just under 70% in these thirteen years, with much of this occurring in the lowlands (below 400m). Consequently, those species with large amounts of their range at low elevations were disproportionately affected, with 10 out of 25 endemic species being under more threat than currently listed by the IUCN Red List and only 3 being considered safer than currently listed.

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Introduction

The remote islands of the northern Moluccas are some of the most biodiverse in the world in terms of species' endemism. However, the crush of deforestation which is running throughout the tropics has recently begun to move into these islands, threatening the unique species found only here. Using remote sensing techniques, it is possible to determine the extent and speed at which this deforestation, driven by logging, mining, biofuel development, among other threats, is moving. The extent of habitat remaining and the spatial patterns of deforestation can be used as surrogates for determining population trends of key taxa, as surveys are extremely difficult to conduct in these far-flung locations. In this paper, we use remote sensing to examine deforestation from 1990 to 2003 in the northern Moluccas and determine the extent of habitat available for the many range-restricted avian species found in this area. We can then re-assess the IUCN Red List status of many of these species as well as make predictions given annual deforestation rates, about the future prospects for these species.

The hotspot concept, first developed by Norman Myers in 1988 (Myers 1988) and updated through the years since then (Myers 1990, Myers et al. 2000), was intended to draw attention to those areas of the world "featuring exceptional concentrations of endemic species and experiencing exceptional loss of habitat" (Myers et al. 2000). Initial work led to the recognition of 25 hotspots that were concentrated on terrestrial flora and fauna, including the islands of Wallacea in eastern Indonesia (Myers et al. 2000). More recent work has expanded this concept to include 34 terrestrial hotspots (Mittermeier et al. 2005).

The Wallacea hotspot encompasses the entire land area between Java and Borneo to the west and the island of New Guinea to the east. This includes the large island of Sulawesi, the islands of the Moluccas to the east, and the islands of the Lesser Sundas and Timor Leste to the south (Mittermeier et al. 2005, Figure 1). Politically, the area is mostly Indonesian, although Timor Leste (the eastern half of the island of Timor) has recently gained independence. All of these islands are extremely diverse in size, topography, and climate, as well as geologic history. These islands are unique in the South-East Asian region in their oceanic origins and lack of historical connection to either the Asian mainland or to Australia and New Guinea. Thus, they lie between these two major biogeographical realms; the Oriental realm to the west and the Australasian realm to the east, and Wallacea represents a transition zone between the two (Stattersfield et al. 1998). Due to the unique origins and geography, the area is a bastion of endemism, with an estimated 1,500 plants, 126 mammals, 265 birds, and 99 reptiles endemic to the islands (Whitten et al. 2005). This high degree of endemism leads to a diverse suite of important conservation targets across the region. BirdLife International has recognized 10 Endemic Bird Areas (EBA) within Wallacea, including the area of concentration for this study, the North Maluku EBA (Stattersfield et al. 1998).

The North Maluku EBA consists of the northernmost islands in the Moluccas (Maluku in Indonesian), centered around the island of Halmahera (18,000 km^2) (Stattersfield et al. 1998, Figure 1). Other key islands in this EBA include Morotai, Bacan, and Obi, as well as a number of smaller islands to the West of Halmahera (including Ternate, the capital of the Indonesian territory of North Maluku) (Stattersfield et al. 1998). Many of these islands are volcanic in origin, and are thus fairly mountainous. Compared to many other islands in Wallacea, however, Halmahera is relatively low, reaching a maximum elevation of 1,635m, with very little habitat at the upper elevations. Because of this geography, few endemic montane species have developed on Halmahera, unlike the neighboring islands of Buru and Seram, which are much smaller, but contain much more habitat at higher elevations and a corresponding number of endemic montane species (Stattersfield et al. 1998).

The land cover of these islands is dominated by tropical lowland evergreen and semi-evergreen rainforest, with smaller areas of limestone forest and tropical montane rain forest above 700 m (Stattersfield et al. 1998). Overall, the North Maluku EBA contains 43 restricted-range species (i.e. species with total historical ranges of less than 50,000 km^2), 26 of which are confined entirely to these islands (Stattersfield et al. 1998). Out of the 218 EBAs world-wide, North Maluku ranks tenth in the number of restricted-range species present, and 15th in the number of restricted-range species endemic to the EBA (Stattersfield et al. 1998). Four species are endemic to Halmahera, while two species are confined entirely to Obi and Bacan (one found only on Obi; Stattersfield et al. 1998). Since the islands are relatively low in stature, most birds have large elevation ranges, with a few exceptions, including the endemic *Habroptila wallacii*, a flightless rail confined to sago swamp forests on Halmahera (Stattersfield et al. 1998).

Little is known about many of the species of this EBA, and only one BirdLife-sponsored survey in the mid-1990s has provided much of the current range and population estimates for these species (Poulsen and Lambert 2000). As the definition of a hotspot as threatened suggests, though, the incredible diversity of flora and fauna in Wallacea is under extreme threat. Only 7% of the area is under protection (24,387 km^2 out of 338,494 km^2), and much less is functionally so (Whitten et al. 2005). Recent work by BirdLife International, along with many local partners has encouraged more protection for the North Maluku EBA, which had no protected areas until 2004, when the Aketajawe-Lolobata National Park was established (Whitten 2008). Only 50,774km^2 of the original vegetation in the hotspot is intact (Conservation International 2008).

The North Maluku EBA has been spared much of the destruction that the rest of Wallacea and Indonesia as a whole has experienced. However, the area is under increasing pressure for resource extraction, with most of the lowland forests under timber concessions, and multiple mines opening up on Halmahera (Whitten et al. 2005). Up to 90% of the land area of these islands is under logging concessions (Marsden 1998). Halmahera and Ternate islands were also the site of religious fighting between Christians and Muslims from 1999 through the early part of this century, which kept outside surveys from occurring more regularly (Conservation International 2008).

The Red List was developed by the World Conservation Union (IUCN) over the last 40 years, and has moved from an expert-based ranking system to a much more rigorous, data-driven ranking system (Rodrigues et al. 2006). The List has become a key tool for conservation worldwide, mainly due to the rigorous data collection efforts, and the increased availability of data on range size, population size, population trends, habitat preferences, and other key data (Rodrigues et al. 2006). The continued update of this list is vital to its eventual use and dissemination. Re-assessment of all species is a continuing process, and this study will contribute to the knowledge of an important part of the world for avian conservation.

Due to the remoteness of the study region, obtaining ground-based population estimates to review the Red List status of the range-restricted birds is difficult. My project uses remote sensing of satellite imagery to determine the amount of forest remaining in the North Maluku EBA. Then, the amount of habitat remaining is used as a surrogate for the on-the-ground work. The relationship between species endangerment and habitat area has shown to be predictable based on the species-area curve, and previous studies have used the extent of remaining forests to predict the number of threatened birds in insular Southeast Asia (Brooks et al. 1997, Brooks et al. 1999). However, these studies were based on early deforestation data at coarse resolutions. The extent of current deforestation is increasing extremely rapidly in tropical areas, thus this study seeks to develop finer-scale measures of deforestation measures over a longer time period to more accurately predict the rate of deforestation and its subsequent impacts on the range-restricted species of North Maluku.

While much previous work has used satellite imagery to examine habitat changes through time (Skole and Tucker 1993, Rignot et al.1997, Sanchez-Azofeifa 2001, Defries et al. 2002, Seto et al. 2004, Harper et al. 2007), only recently has this method been extrapolated to explicitly reviewing populations and trends in birds (Buchanan et al. 2005, Buchanan et al. 2007). Most of these studies deal with tropical forests, where deforestation patterns are much easier to distinguish, due to high productivity and more uniform forest cover of the wet, tropical forests. As the North Maluku EBA is also predominately tropical forest, many of the methodologies of these studies are relevant to my current study. Linking habitat remaining to Red List criteria is a more recent innovation, used mostly by Buchanan et al. (2005, 2007). However, earlier work compared the extent of remaining habitat across four archipelagos of Southeast Asia and used the species-area curve relationship to predict accurately the number of bird and mammal species that should be considered threatened (Brooks et al. 1997, Brooks et al. 1999). Our study is the first to explicitly examine the trends in endemic birds within the North Maluku EBA based on examination of deforestation at high resolution.

For our study, we will use satellite imagery to classify the extent and pattern of deforestation at two time periods in North Maluku during the 1990s and early 2000s. We will then use the altitudinal preferences of the restricted-range species of North Maluku to build distribution ranges for each time period, to examine the extent of deforestation affecting each individual species. The amount of habitat remaining, as well as the amount of habitat that has been lost during this time period, and that is expected to be lost over the course of three generations, will enable us to re-assess the status of each species in the IUCN Red List.

Methods

Data and Preprocessing

Land cover change in the North Maluku EBA was assessed using Landsat Thematic Mapper (30 meter resolution) images acquired from the United States Geological Service's Global Visualization Viewer (Glovis) and downloaded from the Earth Explorer (USGS 2008). Twelve images were obtained for two time periods: from December 1990 and October 1991 for time period one (Landsat TM 5) and various dates in 2003 and 2004 for the second time period (Landsat ETM+ 7) (Table 1 in Appendix). The images for path 109, row 58 were not included in the analysis because two time periods were not available. Images were selected to limit cloud cover in the study area and if two multi-temporal images for the same location were similar in cloud cover, the image most closely corresponding to the same season for the other time period was chosen. Exact anniversary dates were not possible to obtain, yet all images in each time period were collected within one year of each other. All analysis was performed in Erdas Imagine 9.2, ArcGIS 9.3, and some scripting models were run through PythonWin 2.5.2 (Leica Geosystems 2008, ESRI 2008, Hammond 2006).

Before classifying land cover change, all images were standardized through radiometric correction to eliminate errors from the sensor (Chander et al. 2007, NASA 2008). Additionally, a standard dark object subtraction technique was used to convert all image values to on-ground reflectance, which allowed for more direct comparison and multi-image classifications (Song 2001).

For each image (or mosaic of images), Landsat TM band 1 (in the blue portion of the electromagnetic spectrum) was used to mask out the majority of cloud and haze from each image (Stibig et al. 2003). This process involved setting a threshold based on visual analysis of each image and masking out those areas above the reflectance threshold. Each image differed in threshold value, depending on the amount and type of clouds (low, puffy or high, wispy clouds). A similar procedure was performed using Landsat TM band 5 to remove, as accurately as possible, the shadows cast by clouds (Stibig et al. 2003). The threshold values for this analysis also differed by image and were set more conservatively than the thresholds for the cloud masks, due to the interference with shady sides of large mountains. Any remaining areas influenced by clouds or cloud shadows were removed during the classification process.

Land Cover Classification

Supervised classification was performed on the corrected and cloud-masked images using Erdas Imagine. Four different land cover types were identified: 1) primary forest, 2) disturbed forest (or other vegetation), 3) bare ground, and 4) any remaining cloud and cloud shadow effects. Areas that corresponded to each of these land cover types were identified and a unique signature file was built for each image. A minimum of 10 signatures for each land cover was used for classification (at least 40 distinct signatures per image). However, depending on the amount of area each land cover represented, up to 50 signatures for one land cover type and 200 signatures per image were used in the analysis. These signatures were then run through a variety of parametric and non-parametric classification models, including maximum likelihood, mahalanobis distances, and parallelepiped. While many of the classifications produced similar results, the cleanest and most accurate classifications were achieved most often using parallelepiped models. Since this process uses a non-parametric envelope to group pixels with similar characteristics, it was able to provide the broad land cover groups required for the analysis, while reducing the speckle inherent in the parametric methods. Any pixels not classified through parallelepiped were classified using a maximum likelihood model.

After classification, each image was filtered to remove areas less than 1ha. All images for each time period were then mosaicked together to produce a land cover map representing the four categories. Each time period classification was then visually examined and compared with the original Landsat images to determine areas where the classification confused land classes. This effect was most common on very illuminated slopes, where areas of primary forest were often classed as secondary growth. Additionally, areas near clouds were often misclassified similarly due to the increased reflectance from the underside of the cloud layers. Some areas of primary forest misclassified as secondary growth, primarily along cloud edges and illuminated mountainsides were edited to obtain a more accurate product.

An accuracy assessment was performed for each final land cover image to determine how closely the images match the classifications. For each image, 500 random points were distributed across the classified land area and visual interpretation was made to determine extent of agreement between the classified images and the raw satellite imagery.

For the final analysis, the cloud and cloud shadow classes were combined for each time period and one total cloud mask was produced with these categories set to represent no data. This cloud mask was re-applied to each land cover mosaic for each time period to obtain images of analyzable areas and the final land cover images were produced (Figure 2).

To compare land cover changes at different elevations, two digital elevation models (DEM) were obtained from the Shuttle Radar Topography Mission and mosaicked together to completely cover the study area (Jarvis et al. 2008). This file was subsequently resampled to 30m resolution to match the cell size of the Landsat images and clipped to the extent of the land cover images.

Range-restricted Avian Species Analysis

Forty-three range-restricted bird species are found in the North Maluku EBA, and 39 of them were used in the analysis. Of those four species excluded, the Invisible Rail (*Habroptila wallacii*) and the Olive Honeyeater (*Lichmera argentauris*) are not associated with forests, while the Spice Imperial-Pigeon (*Ducula myristicivora*) and the Island Whistler (*Pachycephala phaionota*) are both highly vagile, small-island specialists, which only reach the area occasionally.

Elevation ranges, generation times, degree of forest dependence, and population densities of each species were obtained from BirdLife International (BirdLife International unpublished data). The elevation range of each species was supplemented with comparisons to Coates and Bishop (1997) and Poulsen and Lambert (2000) to obtain the best estimates for usual occurrence of each species. Generation times were calculated either from more well-known congeners, or extrapolated from mean age at first breeding and either mean annual survival or maximum longevity in the wild. Population densities were taken from a limited number of papers from Wallacea, and were extrapolated for some species from congeners in other areas of Asia (Marsden 1998, Poulsen 1998, Poulsen et al. 1999, Hill and Lill 1998, Smyth et al. 2002, Craig 1996, Kawakami and Higuchi 2003, McCallum et al. 2000).

Each species' elevation range was evaluated for the amount of primary forest in 1990/1 and 2002/3 to determine how much forest was lost between dates. The islands for which a species was evaluated was based on distributions from Coates and Bishop (1997), and nearby, smaller islands were included unless the species was specifically mentioned as being endemic to certain larger islands.

Results

Land Cover Classification

Overall, I was able to analyze 72% of the land area of the North Maluku EBA for deforestation and during these 13 years, the extent of primary forest declined by approximately 17%, with correspondingly sharp increases in secondary growth and non-forested areas (Table 1). Most of this deforestation occurred in the lowlands (traditionally defined as those areas below 300 m), with over 35% of the forest that existed below 100m in 1990 having disappeared by 2003 (Table 2). Much of the remaining lowland forest in 2003 appeared to be mangrove forests along the coasts and major rivers.

The quality assessment showed an overall good fit for each image (Appendix II, Tables B and C), resulting from the simplified classification (three classes) and the dominance of primary forest in both time periods. While this method was not independent of the classifications, it does show the accuracy of the classifications with respect to the signatures derived from the original images. A more intensive accuracy assessment would have to include baseline data collected in the field.

Range-restricted Avian Species Analysis

Since the majority of the deforestation occurred in the lowlands, it would stand to reason that those species that are restricted to lower elevations would be the ones most widely affected. The Pink-headed Imperial-pigeon (*Ducula rosacea*) (maximum elevation 120m) and the Dusky Friarbird (*Philemon fuscicapillus*) (maximum elevation 120m) had the lowest maximum elevation of any species and correspondingly had the most loss of habitat over their range, with losses of 35.9% and 34.6%, respectively (Tables 3 and 4). Overall, 30 out of the 39 species analyzed lost between 18% and 23% of their original habitat, with only a few higher-elevation species losing less than 12% of the original forest cover (Tables 3 and 4).

For the IUCN Red List, one of the key measures of endangerment used is the trend of population lost within 10 years or in three generations, whichever is longest (IUCN 2008). Factoring in this criterion for each species, we find that those species that are long-lived join those species that have a high rate of deforestation within their range as the most threatened, as they will be facing massive forest losses in three generations. Both *D. rosacea* and *P. fuscicapillus* are among these species, ranking 2nd and 3rd, respectively. However, under this measure, the most threatened species in the North Maluku EBA is the White Cockatoo (*Cacatua alba*), which has a very long generation time (~ 13 years) and a maximum elevation of only 900m. At present deforestation rates, this species could lose over 65% of its habitat in the next 40 years. Six other species are estimated to lose over 35% of their forest habitat in the next three generations, including three species (Paradise-Crow (*Lycocorax pyrrhopterus*), Long-billed Crow (*Corvus validus*), and Moluccan Goshawk (*Accipiter henicogrammus*)) that are currently listed under the safest threat level of the IUCN (Locally Common). Of these seven species, *C. validus*, *A. henicogrammus*, and the Chattering Lory (*Lorius garrulus*) are all highly-dependent on forest, while the remaining four species (*C. alba*, *D. rosacea*, *P. fuscicapillus*, and *L. pyrrhopterus*) are found in higher densities in forests, but will tolerate some disturbance.

On the opposite spectrum, a number of species that are currently listed as Near Threatened, Vulnerable, or Endangered, come in at the bottom of the list with the least amount of habitat loss. These species, including Moluccan Woodcock (*Scolopax rochussenii*), Carunculated Fruit-Dove (*Ptilinopus granulifrons*), and Moluccan Cuckoo (*Cacomantis heinrichi*), have low populations due to high-altitude specialization (*S. rochussenii* and *C. heinrichi*) or endemism to a single small island (*P. granulifrons*), so even a small decline in population would be worrying to the future survival of these species.

For each species, two factors were examined to determine the best category of endangerment. The trend in forest loss (Tables 5 and 6) and the amount of area currently occupied (Tables 3 and 4) were both examined. For forest loss, the cut-offs for each level were: >50% for endangered, >30% for vulnerable, and near 30% for near threatened (IUCN 2008). The dependence of each species on forest was also taken into account, and thus some species (like Paradise-crow (*Lycocorax pyrrhopterus*) and Cinnamon-bellied Imperial-pigeon (*Ducula basilica*)) were not listed under the category they reach, but should be watched closely for evidence of declines.

In examining total range, it was also necessary to modify the IUCN Red List due to both forest dependence, and the fact that not all areas could be examined (due to clouds and/or missing images). Thus, the modified categories used were:

Under 5,000km^2 and forest dependence of high = endangered

Under 5,000km^2 and forest dependence of medium = vulnerable

Under 15,000km^2 and forest dependence of high = vulnerable

Under 15,000km^2 and forest dependence of medium = near threatened

Under 20,000km^2 and forest dependence of high = near threatened.

All species were taken to inhabit the total range of non-analyzable area, making the estimates conservative. Overall, the results showed good correlations with existing knowledge, while providing new information for species that are thought to be common. Since it is not possible to determine total ranges for species that occur outside of the EBA, this measure was not examined for those species, and only species endemic to the EBA have a final suggested status change (Table 7).

Discussion

Spatial Patterns of Deforestation

Deforestation in Indonesia has been a well-studied affair over the past 50 years, as deforestation rates have continued to increase from the 1950s until the present day. In 1950, the majority of Indonesia was still estimated to be densely forested, but forest cover fell from 162 million ha to 98 million ha in the next 50 years, as deforestation rates increased from 1 million ha per year in the 1980s to 1.7 million ha per year in the 1990s, and have since increased to over 2 million ha per year (FWI/GFW 2002). One estimate of forest loss over the entirety of Indonesia in the 1990s was 22.3 million ha (Stibig et al. 2007). Lowland forests, in particular, have been harvested at unsustainable rates, with Sulawesi having already lost most of it by 2000, Sumatra expected to lose it by 2005 and Kalimantan province on Borneo expected to lose most lowland forest by 2010 at 2000 deforestation rates (FWI/GFW 2002). By 2000, Indonesia was estimated to have retained about 58% of its original forest cover, and deforestation rates were the highest of any tropical ecosystem in the world (Laurance 2007). By 2005, only 48.8% (88 million ha) of Indonesia was forested, a 10% loss in just five years (FAO 2005). Of this, only a little over half (~55%) was considered primary, undisturbed forest, down from ~61% in 1990 (FAO 2005).

Similar data just for North Maluku is less well-known. Brooks et al. (1999) estimated that Halmahera was 86% forested in 1990 based on data that they obtained from the World Conservation Monitoring Centre and the Center for International Forestry Research. This estimate corresponds well to the estimate from this study (86.44% forest cover for the whole EBA). Other studies have looked at Maluku as a whole (which includes the North Maluku EBA, the larger islands of Buru, Seram, Wetar and Taliabu, and many smaller islands south of the EBA), and estimated that between 1985-1997 between 0-13% of the forest was lost (FWI/GFW 2002).

Similarly to the pattern of deforestation in the rest of Indonesia, lowland forests have been the most impacted in the study area. The northeastern peninsula and portions of central Halmahera, the isthmus of Bacan, and northwestern and far eastern Obi have seen the largest reductions of forest cover during the study period (Figures 2 and 3). The reasons for forest reduction vary over the area, with mining being a key component of deforestation on the northeastern peninsula of Halmahera and plantation development being a key driver in the eastern portions of Obi.

Exploitation and development of forest resources continues at a break-neck pace in Indonesia, while conservation efforts lag far behind. Currently, only 18.6% of forest across all of Indonesia has been set aside for conservation (FAO 2005). In the North Maluku EBA, this total is even smaller, with only one national park on Bacan and one newly established national park on Halmahera (WDPA 2009). Additionally, another national park has been proposed for higher elevations on Obi (WDPA 2009). However, information on the boundaries and enforcement of these parks is often severely lacking and it is unclear just how much protection these areas provide to the forest and species contained within. Other more well-known and studied national parks in Indonesia have had large amounts of exploitation, usually with the cooperation of corrupt bureaucrats (Barber and Schweithelm 2000).

Drivers of Deforestation in North Maluku

As in the other islands of the Indonesia archipelago, many different sources of deforestation are combining to create very high rates of habitat loss. The complexity and variety of sources will make slowing or halting deforestation very difficult for future policy-makers. Although, all forest land in Indonesia is controlled by the government, which issues concessions for logging (FAO 2005). In general, the area is experiencing pressure from four sources: commercial logging, subsistence (shifting) agriculture, mining, and plantation development. Additional pressure may come from large-scale fires, which have devastated large portions of other Indonesian islands, but which have so far spared the islands of North Maluku (Barber and Schweithelm 2000). Conversion of primary forest into shrub or grassland, and the opening of forests through road-building, selective logging, and fragmentation will increase the chances of fire in North Maluku.

Commercial logging of forests is by far the biggest threat to the forests of North Maluku. Much of the increase in commercial logging, which began in the late 60s and peaked in the 90s, was driven by government corruption during the Suharto regime. From 1967 to 1977, the amount of area logged increased from 4 million ha to 28 million ha and by 1985 there were 585 20-year logging concessions outstanding, which covered an area of 63 million ha (1/3 of the land area of Indonesia (FWI/GFW 2002). In 1998, over 3 million ha of Maluku were under logging concession, though how much of this area was actively being logged is unknown (FWI/GFW 2002). In addition to the massive amounts of forest under legal logging concessions, illegal logging by many different groups is a major driver of deforestation over many parts of the country. Some estimates contend that illegal logging provides 50-70% of the wood needed by the forest industry in Indonesia (FWI/GFW 2002).

While clear-cutting by commercial loggers represents a huge threat, it is not the only logging practice that threatens the biodiversity of the islands. Selective logging of large trees has been implicated in loss of nesting habitat for parrot species, as well as opening the forest to cage-bird trappers, which also represents a dire threat to parrots. Additionally, selective logging itself has been shown to significantly lower bird diversity on neighboring islands, especially insectivorous, terrestrial, and flocking species (Marsden 1998).

Shifting agriculture has played a significant role in deforestation on many of the islands of Indonesia. Around 2 million ha of forest was estimated lost between the 1960s and 1999 due to the transmigration program, which facilitated immigration from the extremely populous main island of Java to outer islands (FWI/GWP 2002). Additional estimates put deforestation due to shifting agriculture and small-scale farming at around 4 million ha between 1985 and 1997 (~20% of forest loss) (FWI/GWP 2002). In addition to subsistence farming, small agroforestry plots to grow cash crops are also common in Indonesia, producing spices, coffee, rubber, benzoin, cocoa and fruit for export (FWI/GWP 2002). These plots are often at small scales (0.01-5 ha), and, if they are embedded in a matrix of primary forest and native shade tree species, can hold high numbers of species, though this declines as the plots move closer to monoculture systems (Scales and Marsden 2008, Waltert et al. 2004).

In our study area, small-scale agriculture appears to be a major driver of deforestation, especially of those areas already cleared in 1990. Obtaining accurate classification of deforested or secondary growth land in the first time period was made more difficult by the scale of the change (often less than the pixel size). This appears to be due to small plots created in a matrix of primary forest, which made analysis of these areas difficult, and possibly underestimated the amount of degraded forest in the initial time period.

Another major driver of deforestation in Indonesia is the development of plantation crops, predominately oil palm expansion, but also coffee, rubber, and even timber plantations. The FAO (2005) estimated that plantations (excluding timber) covered about 4% of the land area of Indonesia. Palm oil production is increasing by 9% yearly worldwide, 80% of which comes from Malaysia and Indonesia (Fitzherbert et al. 2008). Indonesia lost an estimated 1.7-3 million ha of forest to oil palm alone between 1990 and 2005 (Fitzherbert et al. 2008). The majority of these plantations are in the western part of Indonesia due to the ready infrastructure and labor force, though more recent expansion has driven development to eastern Indonesia, particularly Irian Jaya (FWI/GFW 2002). Other forms of plantation agriculture are currently more extensive than oil palm, but expansion is very slow and probably not the source for much of the more recent deforestation (FWI/GFW 2002). All of these plantations, however, decrease the amount of diversity in an ecosystem, even to levels less than secondary forest. They also fragment the landscape and act as barriers to dispersal and movement for many species (Fitzherbert et al. 2008).

Due to the remoteness of the North Maluku EBA, it has not been a huge site of oil palm expansion, and little development of plantation-style agriculture is readily noticeable for the time periods examined. Indeed, Maluku province as a whole had no verified large oil palm plantations through 1998 at least (Barber and Schweithelm 2000). However, as forest land becomes scarcer in the eastern islands, the pressure and incredible growth of oil palm is sure to reach these islands, and threaten any remaining lowland forest.

A more recent development and one that so far has been limited to Halmahera within the study area is mining. Gold was discovered on the northern peninsula of Halmahera in the mid-1990s and a mine was built at Gosowang to begin extraction (Carlile et al. 1998). This initial mine operated from 1999-2002 before being closed, but additional mines have continued to spring up nearby to extract gold from the same deposit. In 2004, a mine was opened at Toguraci and another mine (which also extracts silver) was opened at Kencana in 2005 (Newcrest Mining 2009). In addition to these legal gold mines, many small, illegal gold mines using mercury extraction have sprung up recently as well, which threatens not only the ecology of the area, but also the health and safety of the local populace (Newcrest Mining 2009). All of these mines have been the site of numerous protests by the local inhabitants over environmentally destructive practices.

More recently, nickel mines have sprung up on many areas of Halmahera. PT Antam is the largest mining company in Indonesia and they currently operate three nickel mines on the northeast peninsula of Halmahera (PT Antam 2009). The locations of these mines correspond very closely to large areas of deforestation present on the peninsula, and could be a direct or indirect source (i.e. through encouraging settlement in the area) of deforestation that have occurred during the analysis time period. Additionally, another nickel mine is set to begin operations soon (Eramet 2009), and the initial development of housing for employees, as well as site-preparation may be responsible for much of the deforestation in the lower part of the central hub of Halmahera. This mine (Weda Bay nickel mine) is located in the newly established Aketajawe-Lalobata National Park.

Species-Level Analysis

Two previous studies have examined the distribution patterns of endangered birds in insular Southeast Asia to attempt to predict whether deforestation alone can predict endangerment (Brooks et al. 1997, Brooks et al. 1999). Their results showed that the islands of the Greater Sundas (Sumatra, Java, Borneo) and northern Wallacea (including North Maluku and Sulawesi, among other islands) contained relatively fewer endemic species than predicted and that many of these species were found in montane areas (Brooks et al. 1997). However, as much of the current habitat destruction is occurring in the lowlands, the endemic species of these islands should be less vulnerable to endangerment through deforestation (Brooks et al. 1997). North Maluku, however, is somewhat unique in this regard, in having very few endemic montane species (mostly due to the lack of large areas above 1000 m), thus we would expect that the species in these islands may be more susceptible to the clearance of lowland forests than others in the Wallacea region.

Under the IUCN Red List, there are 9 categories under which a species is assigned: Not Evaluated (NE), Data Deficient (DD), Least Concern (LC), Near Threatened (NT), Vulnerable (VU), Endangered (EN), Critically Endangered (CR), Extinct in the Wild (EW), and Extinct (EX) (IUCN 2008). All of the species analyzed in the North Maluku EBA are listed in one of four categories (LC, NT, VU, and EN) increasing in threat level. Each level is based on a combination of five criteria: declining population; small geographic range size or fragmentation or decline of the geographic range; small population size or rapid decline; extremely small population or restricted distribution; or a quantitative analysis of extinction risk (IUCN 2008).

Currently, 12 species found in the North Maluku EBA are listed under a category of threat by the IUCN (i.e. NT, VU, or EN). Of those species, I did not analyze *H. wallacii*, since it is restricted to lowland sago swamps, which is a more detailed land cover analysis than was feasible in this study. Each of the 11 remaining species will be discussed in turn below.

Species Currently Listed as Near Threatened, Vulnerable, or Endangered

Moluccan Megapode (*Eulipoa wallacei*) – Current Status: Vulnerable;

Current Population Estimate: 20,000 - 50,000

Forest Loss 1990-2003: 18.26%

Forest Loss in 3 Generations: 19.78%

Forest Dependence: High

This species is found on many of the larger islands of the Moluccas, generally above 750m, but it descends to communal nesting areas on the coast, where it is generally persecuted through egg-collecting by locals (Coates and Bishop 1997). The species has become extinct on many islands and is found in large concentrations only on Halmahera and Haruku (outside of North Maluku) (BirdLife International 2008a).

While this species is on the lower end of the forest loss scale, the predominate pressure on the population appears to be from exploitation at the communal breeding sites. The good news is that if protection of those sites can be improved, the forest habitat should be sufficient for its long-term survival. Both measures of endangerment examined here point to the species being vulnerable within the North Maluku EBA. Its status elsewhere is unknown.

Moluccan Woodcock (*Scolopax rochussenii*) – Current Status: Endangered

Current Population Estimate: 2,500 – 10,000

Forest Loss 1990-2003: 10.27%

Forest Loss in 3 Generations: 16.15%

Forest Dependence: High

This little-known species is endemic to the islands of Obi and Bacan, where it is a high-altitude specialist. The population is assumed to be very small, as no specimens or sightings have been verified since 1980 (BirdLife International 2008b).

As a high-altitude specialist, this species appears to be much better off than many of the other restricted-range species. If, as is thought (BirdLife International 2008b), the population is bigger than currently thought, then the species may be eligible for down-listing, but more complete surveys would be required to justify this action. Our analysis shows that it should remain listed as endangered.

Chattering Lory (*Lorius garrulus*) - Current Status: Endangered

Current Population Estimate: 46,000 – 295,000

Forest Loss 1990-2003: 19.54%

Forest Loss in 3 Generations: 40.46%

Forest Dependence: High

Human pressure, particularly due to the cage bird trade, is a major threat to this species, and coupled with large amounts of habitat loss, this makes *L. garrulus* one of the most threatened in the EBA. It is considered one of the most important cage birds in eastern Indonesia, although legal exportation has largely ceased since 2003 (BirdLife International 2008c). Illegal capture, however, is still done on a large scale, particularly on Halmahera, where recent surveys have indicated around 10,000 birds a year from 4 species, including *L. garrulus*, are poached (ProFauna 2008). Selective logging of large trees is another potential threat to this species, as these trees are necessary for breeding cavities (BirdLife International 2008c).

This species can occur at high densities and the amount of forest loss within its range is in the middle of the range for all species. However, its longer generation time leads to a very high potential clearance in three generations, which along with the high pressure on the adults themselves and their nesting trees would lead to a high level of endangerment. This species has recently been downgraded to vulnerable based on a slowing of the pet trade in Indonesia, and our analysis shows that based on percent area change, vulnerable is the best category for the species.

Moluccan Cuckoo (*Cacomantis heinrichi*) - Current Status: Near Threatened

Current Population Estimate: 10,000 – 20,000

Forest Loss 1990-2003: 5.70%

Forest Loss in 3 Generations: 5.99%

Forest Dependence: High

This species is another little known species that seems to be restricted mostly to higher elevations on Halmahera and Bacan, although recent survey work has found the species at slightly lower elevations on Bacan (BirdLife International 2008d). Due to it primarily high-altitude range, it is fairly protected against the current issues affecting the forest in North Maluku, with by far the lowest habitat loss within its range as any species in the North Maluku EBA. However, this is a very tiny range in total, and based solely on the area occupied and it high dependence on forest, it qualifies to be up-listed to vulnerable, and possibly even endangered. Better knowledge of the altitudinal range limits of the species would be necessary to say definitely one way or the other.

Purple Dollarbird (*Eurystomus azureus*) - Current Status: Near Threatened

Current Population Estimate: 2,500 – 10,000

Forest Loss 1990-2003: 21.11%

Forest Loss in 3 Generations: 29.47%

Forest Dependence: High

This species is found mostly in the lowlands and, though it does seem to tolerate disturbance well, it seems to be out-competed in disturbed areas by its congener (*Eurystomus orientalis*) (BirdLife International 2008e). Thus, while the total forest loss is not great compared to other species in the analysis, it would seem that it does face a high level of threat from habitat loss along with competition. In addition, the total area occupied by this species is shrinking, and combined with competition in open areas by it congener, and its high dependence on forest, leads to the conclusion that this species should be up-listed to vulnerable from its current status of near threatened.

Blue-capped Fruit-dove (*Ptilinopus monacha*) - Current Status: Near Threatened

Current Population Estimate: Unknown

Forest Loss 1990-2003: 20.29%

Forest Loss in 3 Generations: 16.91%

Forest Dependence: Medium

This species is another lowland specialist, although it favors smaller islands and coastal areas more than primary rainforest (BirdLife International 2008f). Thus, it is likely to not have experienced as much habitat loss as perceived, especially as it frequents mangroves and disturbed forest. Based on our analysis, this species is one of three candidates to be down-listed, in this case from near threatened to locally common.

Carunculated Fruit-dove (*Ptilinopus granulifrons*) - Current Status: Vulnerable

Current Population Estimate: 2,500 – 10,000

Forest Loss 1990-2003: 16.03%

Forest Loss in 3 Generations: 13.36%

Forest Dependence: Medium

This species is endemic to the smaller island of Obi, where it is mostly a lowland specialist, rarely getting above 550m (BirdLife International 2008g). Obi has experienced quite a bit of forest clearing in the lowlands and the only protected area proposed for the island is above this species' range, thus this species could be considered highly threatened. Our analysis showed, however, that vulnerable is the best category for this species, especially since it does withstand some degradation. If forest clearing in the lowlands of Obi increases at the rate of some of the other islands, this species could be endangered.

Pink-headed Imperial-pigeon (*Ducula rosacea*) - Current Status: Near Threatened

Current Population Estimate: Unknown

Forest Loss 1990-2003: 35.94%

Forest Loss in 3 Generations: 59.52%

Forest Dependence: Medium

This species is a wide-ranging small island specialist, which is found on only a few islands in the North Maluku EBA (BirdLife International 2008h). It was analyzed only for the island of Bacan, as it exact range in the EBA is unknown. As a coastal specialist, its habitat is declining in the EBA and is expected to continue to do so. How important the EBA is to the overall global population is unknown, so while *D. rosacea* has the highest amount of habitat lost of any species, determining its exact status is more problematic. Based on habitat loss, it could be considered threatened in the EBA (or at least on Obi), but until its exact range is determined, it may be impossible to tell.

White Cockatoo (*Cacatua alba*) - Current Status: Vulnerable

Current Population Estimate: 43,000 – 183,000

Forest Loss 1990-2003: 20.15%

Forest Loss in 3 Generations: 65.35%

Forest Dependence: Medium

While currently listed as vulnerable and still common over parts of its range, this species faces a multitude of threats and could be a good candidate for up-listing to endangered. The species is found on many of the islands in the middle of EBA, and is found up to about 900m (BirdLife International 2008i). Capture for the cage bird trade was a huge problem in the 1990s, though it has been controlled more recently (BirdLife International 2008i). However, illegal capture over and above the 10 pair quota is still rampant on Halmahera, where it was estimated that at least 200 birds were captured in 2007 (ProFauna 2008). Similarly to *L. garrulus*, this species faces problems due to the selective logging of large trees, upon which it depends for roosting and nesting (BirdLife International 2008i).

While this species currently has a relatively large population, there has been a recent decline, possibly related to unsustainable trapping for the live bird trade in the 1990s and possibly related to habitat destruction. These declines would be expected to continue into the future at current deforestation rates. *C. alba* does tolerate some habitat modification, so declines may not be quite as sharp as expected from straight habitat loss, although it will probably disappear from many of the smaller islands in the EBA, if it has not already. The closely related Seram Cockatoo (*Cacatua moluccensis*) was found over a wide area on the neighboring island of Seram, and while densities were lower in logged and secondary forest, the species was still present in fairly large numbers even in degraded forest (Kinnaird et al. 2003).

Based on our analysis, the declines expected over the next three generations of this species are expected to be over 65%, which would put this species firmly in the endangered category. Even allowing for its medium dependence on forest, this species faces a multitude of threats and should be up-listed.

<u>Sombre Kingfisher (*Todiramphus funebris*) - Current Status: Vulnerable</u>

Current Population Estimate: 2,500 – 10,000

Forest Loss 1990-2003: 19.75%

Forest Loss in 3 Generations: 23.55%

Forest Dependence: Medium

This species is endemic to the island of Halmahera, where it is found primarily in the lowlands at very low population densities (BirdLife International 2008j). It does tolerate some disturbed habitats and will use coconut plantations and other secondary forests to a small extent (BirdLife International 2008j).

Since it is a lowland specialist, this species is expected to undergo some decline as deforestation spreads in the area. Its ability to utilize some disturbed habitat should help it from declining too rapidly. And with its shorter generation time, it falls in the middle of the pack among the species analyzed here for habitat loss. Because of these reasons, this species is actually a good candidate for down-listing to near threatened status from vulnerable.

Dusky Friarbird (*Philemon fuscicapillus*) - Current Status: Vulnerable

Current Population Estimate: 2,500 – 10,000

Forest Loss 1990-2003: 34.64%

Forest Loss in 3 Generations: 48.93%

Forest Dependence: Medium

Among all of the species analyzed, this very little-known species may be the most threatened, however, its life-history causes much confusion and combined with its tolerance for degraded forests, it is recommended that this species remain listed as vulnerable . *P. fuscicapillus* is found on the island of Morotai, and possibly on the island of Halmahera (it was analyzed for both islands, though its status on Halmahera is unclear), at very low elevations (only up to 120m) (BirdLife International 2008k). Due to this range, it is expected to have incurred heavy declines and will decline even further as more and more lowland forest is cleared. This species does tolerate degraded forest and perhaps even severely degraded forest and has been described as "common" in the past (BirdLife International 2008k).

The mimicry of this species with Dusky-brown Oriole (*Oriolus phaeochromus*) makes population estimates and surveys difficult and perhaps unreliable. This mimicry also creates difficulty in assessing its habitat needs. A key priority should be determining the extent to which it will use degraded forest, and whether the densities are sufficient for its survival prospects.

Other Species of Interest

In addition to those species highlighted above that are already listed under a category of threat, other species that are currently considered common are also good candidates to be up-listed. This analysis was restricted to those species that are endemic to the EBA, since species with extralimital ranges cannot be accurately analyzed. A few noteworthy species in this category are mentioned at the end of the section.

Seven species that are listed as locally common are candidates for up-listing either to near threatened, or to vulnerable. These species include the Long-billed Crow (*Corvus validus*) and the Moluccan Goshawk (*Accipiter henicogrammus*), both of which should be up-listed to vulnerable based on the current deforestation rates extrapolated out to three generations. Both of these species are highly-dependent on forest and have long generation times, which leads to a much higher threat level. Two other species, Wallace's Standardwing (*Semioptera wallacii*) and Halmahera Cuckooshrike (*Coracina parvula*), should be up-listed to vulnerable based on the total area occupied. And three species, Long-whiskered Owlet-nightjar (*Aegotheles crinifrons*), Dusky-brown Oriole (*Oriolus phaeochromus*), and Scarlet-breasted Fruit-dove (*Ptilinopus bernsteinii*), should be up-listed to near threatened based on the total area occupied.

A number of species that have extralimital ranges are facing large declines within the EBA: Rufous-necked Sparrowhawk (*Accipiter erythrauchen*), Violet-necked Lory (*Eos* *squamata*), White-eyed Imperial-pigeon (*Ducula perspicillata*), and Drab Whistler (*Pachycephala griseonota*),. Of these species, the raptor (*A. erythrauchen*) is of the most interest, due to its high dependence on primary forest. *A. erythrauchen* is also found outside of the EBA on the islands of Buru and Seram. *E. squamata* is similar to *C. alba* and *L. garrulus* in facing threats not only from habitat loss, but from the huge illegal trade in cage birds between Halmahera and the Philippines (ProFauna 2008).

Applicability of Remote Sensing to Species-level Analysis

The recent explosion of remote sensing capabilities, including more satellites, higher-resolution satellites, lower costs in obtaining images (many are now free), and more trained personnel, has allowed access to any part of the world for almost any practical use. Large, remote areas where on-the-ground surveys are expensive and impractical can now be augmented (or in some cases replaced) by examination of satellite images to determine areas of best habitat suitability and, in turn, the threat that many of the species face from habitat destruction. While this technology can never truly replace local knowledge, especially in areas where more direct human impacts can be seen, including hunting or capturing birds for the pet trade, it can offer a low-cost alternative. Key to this analysis, however, is accurate determination of species' range limits, not only elevation preferences, but also the islands on which each species occurs. One of the more challenging aspects of this analysis was in fact this latter point. Knowledge of species' ranges on many of the smaller islands in the North Maluku archipelago was often lacking, and thus, determining suitable habitat and range limitations for each species was often problematic.

Naturally, some areas of the world are much easier to work in and would be much more conducive to this type of analysis. My study area was in the wet tropics of insular Southeast

Asia, which offers benefits and challenges. The greatest benefit is the fact that islands, by definition, have sharply defined boundaries. This fact provides us with a more definitive range estimate, because the spatial distribution of species is primarily along an elevational gradient with little directional components. Another key advantage of this study site is the near uniformity of the land cover, with most of the land covered in wet, tropical forest. Very few species (with the notable exception of *H. wallacii*) are restricted to a certain land cover type. Thus, the entire habitat can be mapped as one unit without further analysis of land cover type.

Of course, those advantages are contrasted by a few disadvantages of working in the tropics. The primary issue is with cloud cover. Much of the tropics (especially mountainous areas) are almost perpetually covered in clouds (or in haze from evaporation from the forest). Previous studies of land cover in insular Southeast Asia at a even coarser scale than this study have found that it requires up to two years of imagery mosaicked together to obtain completely cloud-free images (Stibig et al. 2003). Finding single cloud-free images is extremely difficult, although this problem should begin to become a little easier as more sensors come online and more images become available. For my study, I was able to examine around 73% of the terrestrial ground in the area, which may tend to be the average over a tropical area with Landsat imagery.

Besides masking areas from analysis, reflectance from clouds also distorts values and makes accurate classification much more difficult. Similarly, topography offers similar challenges to classification, with hills facing the sun showing up much brighter, while those facing away from the sun often in shadow, particularly for extremely mountainous terrain. While these issues did plague this analysis, the islands of the North Maluku EBA are generally not quite as steep as many other tropical islands.

Both cloud cover and topography effects can be mitigated somewhat through the use of alternative methods of land cover classification. Analysis of radar imagery is a particularly exciting development in this sense, particularly its use at large scales (see ALOS project at http://www.eorc.jaxa.jp/ALOS/en/index.htm). Radar can penetrate cloud cover, allowing a researcher to classify all of the land area under consideration. It does have some of the same limitations as Landsat imagery, however, in the classification process (and the reliance on a user's particular skill level). Additionally, no historical time-series exists for radar, so comparisons have to be made between Landsat data from an earlier time period, and radar for recent land cover changes, which may also prove to be challenging, and increase the uncertainty and error to the analysis.

One final challenge to this project in classification was in the scale of change. Landsat images were used in this analysis to obtain the best combination of high-resolution, ease of classification, and most importantly, a consistent temporal record. Recent advances in high-resolution imagery (eg. GeoEye, Quickbird) are pushing the limits of sub-meter resolution, however, they are extremely difficult to classify and analyze in a land cover change analysis. With pixel sizes of 30m, Landsat offers a much easier classification, but trades off the ability to detect small changes across the landscape. During the first time period analyzed in this study, much of the deforestation was on a very small scale (less than a hectare), so while quite a bit of change was occurring, it was difficult to accurately capture the change. By 2003, much of this small-scale change due to shifting agriculture and urban expansion began to consume much larger areas, and was much more detectable. Additionally, more large-scale landscape level changes due to logging, mining, and plantation development were occurring at this second time period. All of these are found at scales of square kilometers and are much more apparent in the classified image.

Additionally, Landsat images have a consistent, long-term record, with images going back to the 1970s. Thus, one can compare these images, which were collected with a standard methodology much more easily and accurately. Recently, USGS has made all of its archived images free to the general public as well, which is very important when attempting to perform large-scale land cover changes at high resolution. As more and more options become available, and image costs decrease further, other sources may become more feasible (eg. radar). However, to look at a time-series of images at high resolution and low cost over a large study area, Landsat is the best option.

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Figures and Tables

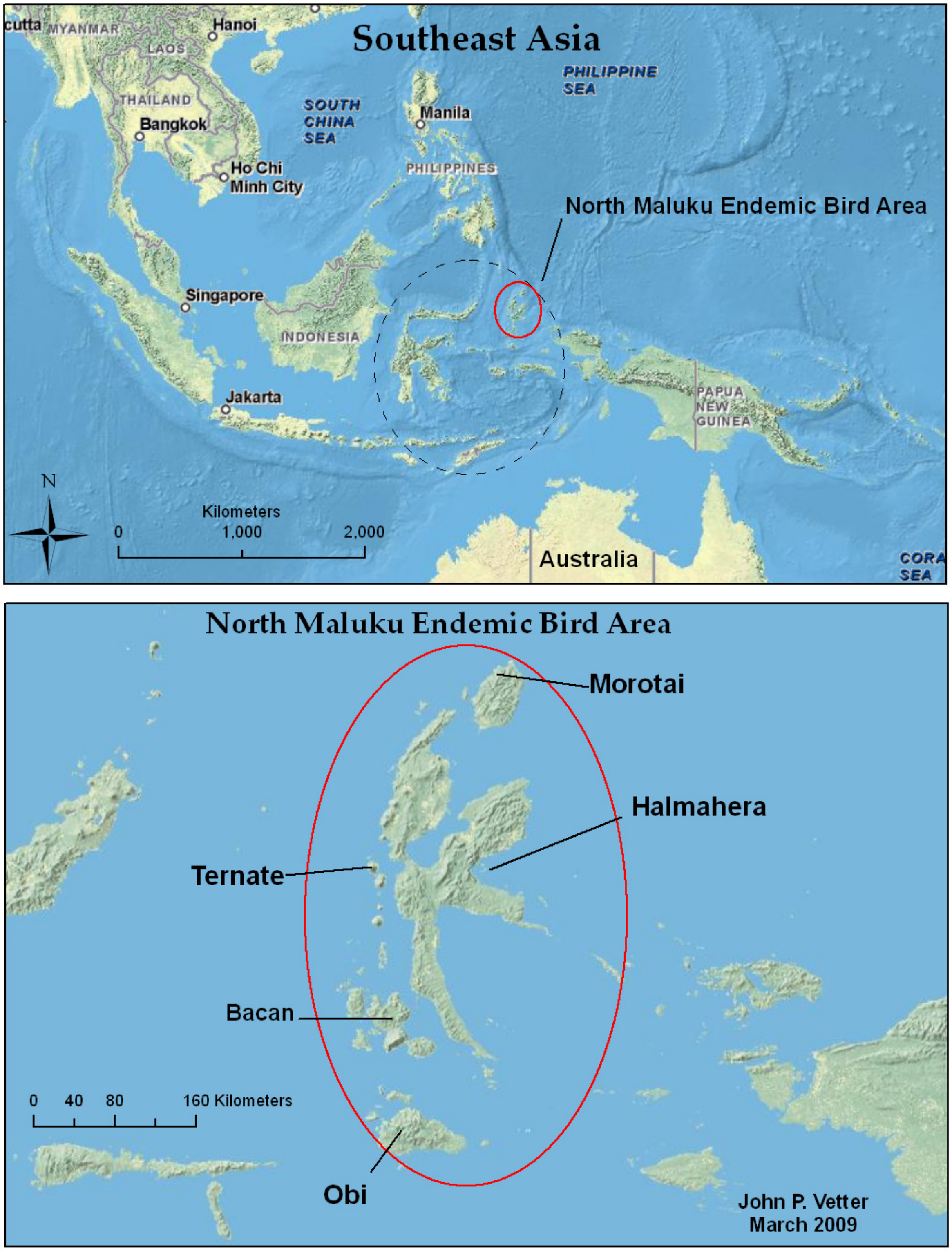

Figure 1 – Location of the North Maluku Endemic Bird Area in insular Southeast Asia.

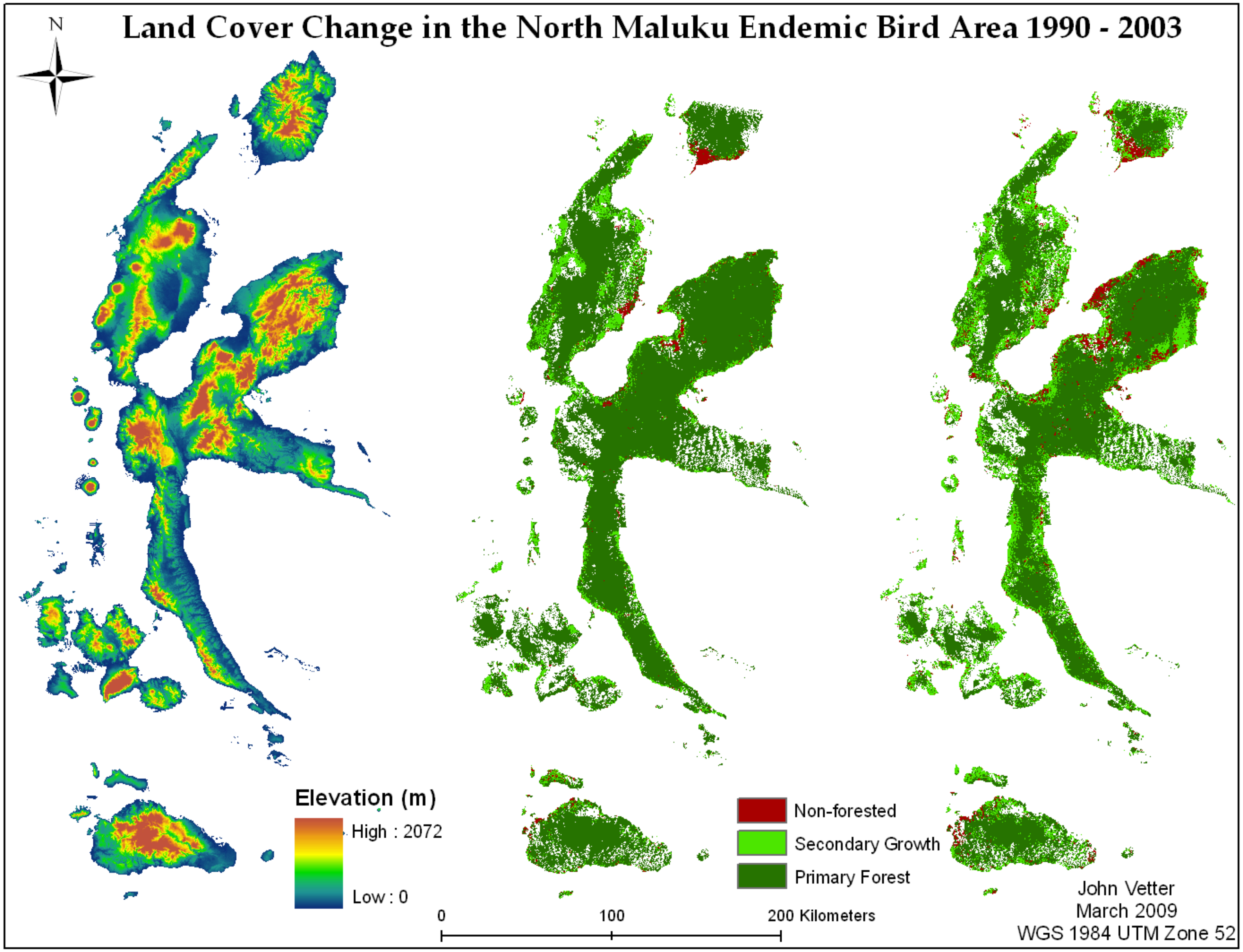

Figure 2 – Land Cover for 1990/1 and 2002/3 in the North Maluku EBA. White areas over terrestrial areas represent clouds.

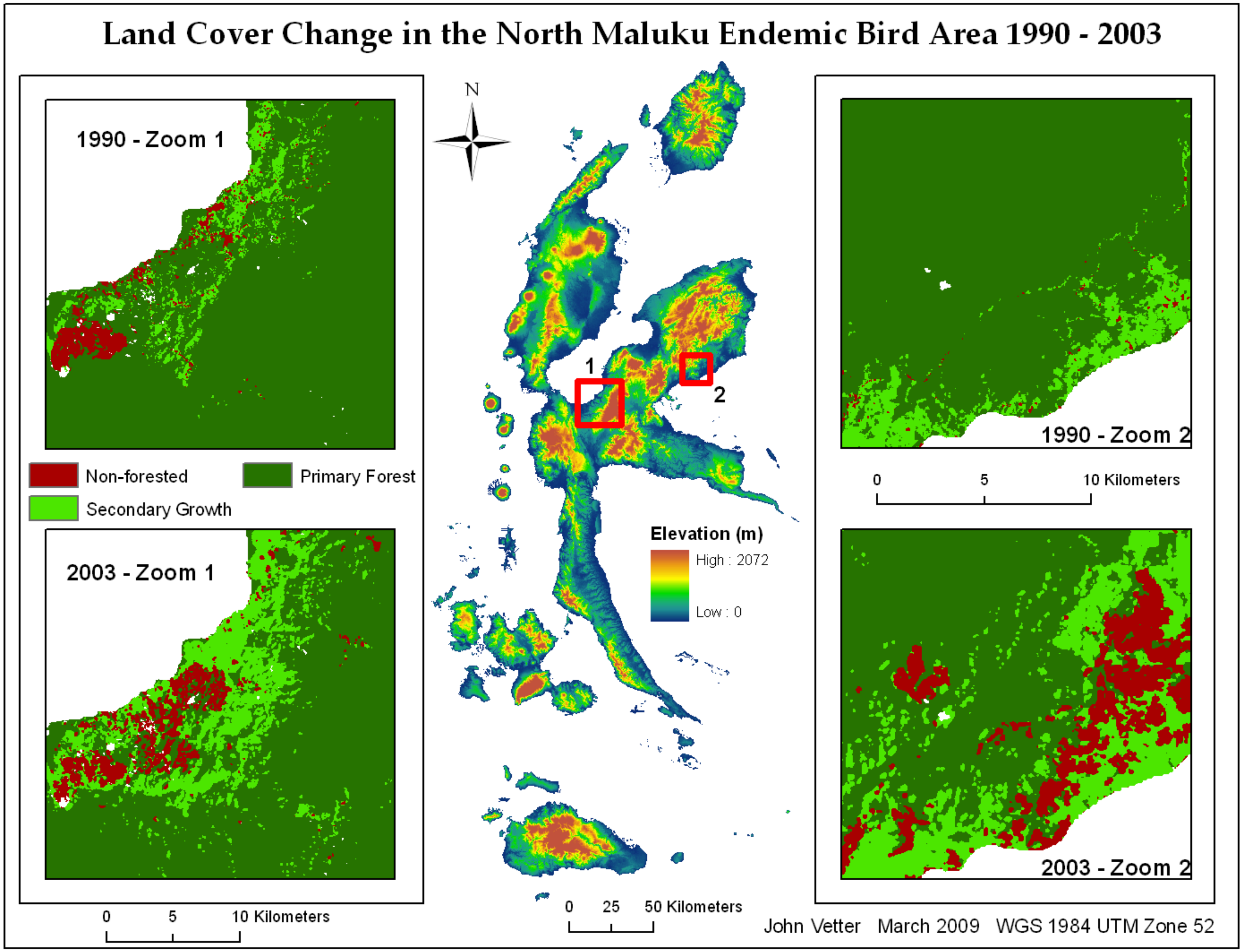

Figure 3 – Closer look at two areas experiencing rapid land cover change from 1990 to 2003 in the North Maluku EBA.

Table 1 – Total area of the North Maluku EBA under different land cover types and percentages of each land cover in the total analyzed area (area that was free from cloud cover).

Land Cover (km^2)	1990/1	% of total	2002/3	% of total	% change
Non-forested	524.295	2.44%	1170.239	5.45%	3.01%
Secondary Growth	2386.841	11.12%	5337.601	24.86%	13.74%
Primary Forest	18557.73	86.44%	14961.02	69.69%	-16.75%
Total	21468.86		21468.86		
Total Area of North Maluku		29568.92	**% Area Analyzed**		72.61%

Table 2 – Total area under different land cover types by elevation and the percentage of primary forest that was lost from 1990 to 2003.

Elevation Range (m)	1990 Land Cover (km^2)			2003 Land Cover (km^2)			% Loss of Primary Forest
	Non-forested	Secondary Growth	Primary Forest	Non-forested	Secondary Growth	Primary Forest	
0 - 100	432.17	1669.54	4425.45	757.94	2911.08	2858.15	35.42%
100 - 200	52.42	415.66	3697.32	242.41	1090.39	2832.61	23.39%
200 - 300	24.33	165.39	2795.89	81.79	605.50	2298.31	17.80%
300 - 400	5.16	76.92	2032.81	32.68	315.56	1766.64	13.09%
400 - 500	2.45	32.68	1638.61	18.32	163.17	1492.26	8.93%
500 - 600	1.32	11.89	1363.26	11.32	95.66	1269.50	6.88%
600 - 700	1.52	6.23	1054.41	10.24	64.64	987.28	6.37%
700 - 800	0.40	3.27	666.17	5.69	40.97	623.19	6.45%
800 - 900	0.37	1.97	397.14	3.95	24.86	370.67	6.66%
900 - 1000	0.97	1.63	221.85	2.18	12.55	209.71	5.47%
1000 - 1100	1.99	0.91	131.68	2.26	7.33	125.00	5.07%
1100 - 1200	0.70	0.25	67.03	0.79	2.81	64.38	3.95%
1200 - 1300	0.12	0.18	32.08	0.28	1.15	30.95	3.54%
1300 - 1400	0.05	0.19	15.24	0.20	0.71	14.58	4.36%
1400 - 1500	0.14	0.07	6.54	0.08	0.57	6.10	6.68%
1500 - 1600	0.15	0.03	3.81	0.08	0.38	3.53	7.42%
1600 - 1700	0.02	0.00	2.60	0.01	0.20	2.41	7.28%
1700 - 1800	0.00	0.00	1.95	0.00	0.06	1.89	3.18%
1800 - 1900	0.00	0.00	1.68	0.00	0.00	1.68	0.00%
1900 - 2000	0.00	0.00	1.48	0.00	0.00	1.48	0.00%
2000 - 2100	0.00	0.00	0.71	0.00	0.00	0.71	0.00%
Total	524.29	2386.81	18557.70	1170.20	5337.58	14961.02	19.38%

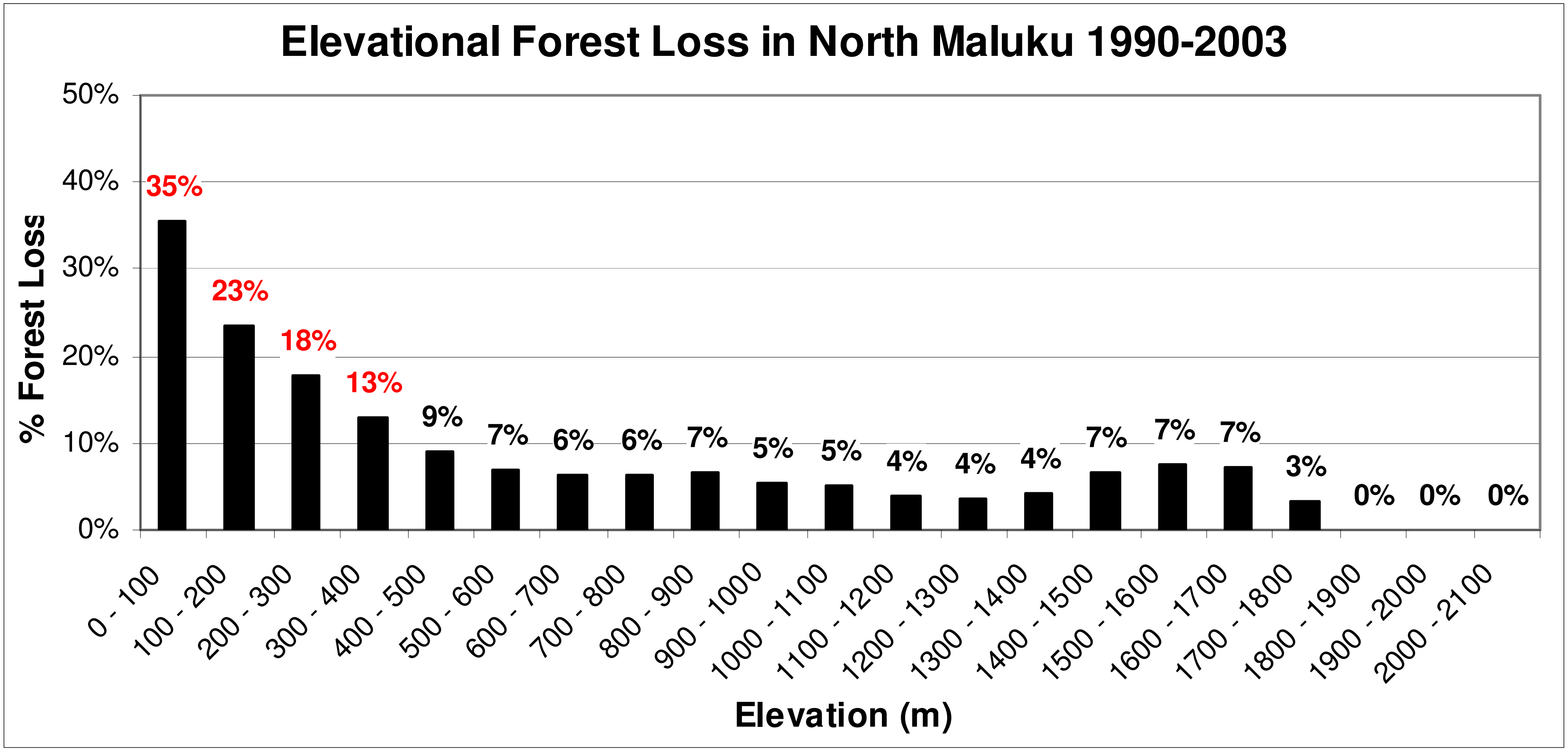

Figure 4 – Graphical illustration of deforestation at 100m elevation ranges. Maximum elevation represents the higher end of a 100m interval (eg. 200 = % deforestation from 100 – 200m).

Table 3 – The area and amount of analyzed forest lost in the elevation range of each restricted-range species endemic to the North Maluku EBA, and the suggested status based on the size of area occupied (* - *Cacomantis heinrichi* falls into the endangered category for range size, however, it does not meet criteria for decline, and is thus kept as vulnerable).

	Total Area in Range	Total Area Analyzed	Forest Cover		% Lost 1990 - 2003	Total Possible Range in 2003	Forest Dependence	Projected Status
			1990	2003				
Philemon fuscicapillus	6789.88	5846.85	4076.26	2664.12	34.64%	3607.14	Medium	VU
Centropus goliath	23154.68	16676.77	13814.81	10536.02	23.73%	17013.93	Medium	LC
Oriolus phaeochromus	14153.43	12491.59	10474.12	8141.17	22.27%	9803.00	Medium	NT
Eurystomus azureus	18966.31	16142.33	13731.79	10833.50	21.11%	13657.47	High	VU
Todiramphus diops	27463.79	19905.44	17007.74	13504.75	20.60%	21063.10	Medium	LC
Corvus validus	27963.08	20282.39	17382.47	13854.74	20.29%	21535.42	High	LC
Ptilinopus monacha	27963.08	20282.39	17382.47	13854.74	20.29%	21535.42	Medium	LC
Ptilinopus hyogastrus	22628.84	19059.51	16430.17	13116.90	20.17%	16686.23	Medium	LC
Lalage aurea	28207.00	20466.14	17565.30	14026.05	20.15%	21766.90	Medium	LC
Cacatua alba	19965.47	17010.72	14594.23	11653.80	20.15%	14608.56	Medium	NT
Pitta maxima	28351.53	20575.28	17673.91	14127.93	20.06%	21904.18	Medium	LC
Accipiter henicogrammus	22826.67	19214.09	16580.42	13258.03	20.04%	16870.60	High	NT
Zosterops atriceps	22010.63	18727.22	16183.41	12961.75	19.91%	16245.16	Medium	LC
Todiramphus funebris	16178.67	14346.49	12310.37	9879.59	19.75%	11711.77	Medium	NT
Melitograis gilolensis	21864.74	18591.69	16153.02	12977.40	19.66%	16250.46	Medium	LC
Ducula basilica	29280.93	21262.70	18355.07	14767.11	19.55%	22785.34	Medium	LC
Lorius garrulus	29298.66	21276.38	18368.44	14779.78	19.54%	22802.06	High	LC
Lycocorax pyrrhopterus	29554.60	21460.35	18549.27	14952.85	19.39%	23047.09	Medium	LC
Aegotheles crinifrons	20581.59	17684.67	15414.66	12551.63	18.57%	15448.56	High	NT
Ptilinopus granulifrons	1571.90	1225.32	1103.78	926.86	16.03%	1273.43	Medium	VU
Coracina parvula	12299.16	10998.91	10462.41	9121.02	12.82%	10421.27	High	VU
Ptilinopus bernsteinii	12799.24	10922.83	10524.70	9381.33	10.86%	11257.74	Medium	NT
Scolopax rochussenii	1033.26	816.14	807.34	724.46	10.27%	941.57	High	EN
Semioptera wallacii	8498.78	7390.55	7235.61	6627.88	8.40%	7736.11	High	VU
Cacomantis heinrichi	199.22	156.10	151.94	143.28	5.70%	186.40	High	VU*
Habroptila wallacii	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Table 4 – The area and amount of analyzed forest lost in the elevation range of each restricted-range species with ranges that include areas outside of the North Maluku EBA.

	Total Area in Range	Total Area Analyzed	Forest Cover		% Lost 1990 - 2003	Total Possible Range in 2003	Forest Dependence	Projected Status
			1990	2003				
Ducula rosacea	572.64	417.30	309.47	198.26	35.94%	353.60	Medium	VU
Loriculus amabilis	22001.70	18550.48	15925.86	12643.28	20.61%	16094.51	Medium	LC
Eos squamata	27779.35	20144.30	17245.13	13726.26	20.41%	21361.30	Medium	LC
Myiagra galeata	28207.00	20466.14	17565.30	14026.05	20.15%	21766.90	Low	LC
Ducula perspicillata	28658.46	20801.63	17899.10	14337.91	19.90%	22194.74	Medium	LC
Dicaeum erythrothorax	29069.36	21102.04	18197.17	14617.97	19.67%	22585.29	Low	LC
Pachycephala griseonota	29463.05	21401.76	18491.61	14897.70	19.44%	22958.99	Medium	LC
Ninox squamipila	21254.91	18080.09	15653.05	12657.11	19.14%	15831.92	Medium	LC
Coracina atriceps	21254.91	18080.09	15653.05	12657.11	19.14%	15831.92	Medium	LC
Accipiter erythrauchen	23798.19	20253.15	17697.97	14387.72	18.70%	17932.76	High	NT
Monarcha pileatus	17348.63	15394.75	13353.50	10879.48	18.53%	12833.37	Medium	NT
Megapodius freycinet	13997.52	10201.25	9432.68	7709.76	18.27%	11506.02	High	VU
Eulipoa wallacei	19879.65	17177.91	14994.28	12256.62	18.26%	14958.36	High	VU
Coracina ceramensis	2469.39	2009.41	1810.93	1558.83	13.92%	2018.82	Medium	VU
Lichmera argentauris	N/A	N/A	N/A	N/A	N/A			
Ducula myristicivora	N/A	N/A	N/A	N/A	N/A			
Pachycephala phaionota	N/A	N/A	N/A	N/A	N/A			

Table 5 – The percent forest loss that is expected to occur within the next 3 generations or 10 years and the status for each endemic species due to this change (* - These species fit the criteria for vulnerable, but are not entirely dependent on forest, so they have been left under their current status.).

	% Lost 1990 - 2003	% Forest Loss in 3 Generations or 10 years	Forest Dependence	Current IUCN Red List Status	Suggested status based on change
Cacatua alba	20.15%	65.35%	Medium	VU	EN
Philemon fuscicapillus	34.64%	48.93%	Medium	VU	VU
Lorius garrulus	19.54%	40.46%	High	EN	VU
Lycocorax pyrrhopterus	19.39%	38.29%	Medium	LC	LC*
Corvus validus	20.29%	37.02%	High	LC	VU
Accipiter henicogrammus	20.04%	35.95%	High	LC	VU
Ducula basilica	19.55%	32.38%	Medium	LC	LC*
Eurystomus azureus	21.11%	29.47%	High	NT	NT
Melitograis gilolensis	19.66%	28.51%	Medium	LC	LC
Centropus goliath	23.73%	26.01%	Medium	LC	LC
Aegotheles crinifrons	18.57%	25.07%	High	LC	LC*
Todiramphus diops	20.60%	24.57%	Medium	LC	LC
Oriolus phaeochromus	22.27%	24.20%	Medium	LC	LC
Todiramphus funebris	19.75%	23.55%	Medium	VU	LC
Lalage aurea	20.15%	22.06%	Medium	LC	LC
Zosterops atriceps	19.91%	21.76%	Medium	LC	LC
Pitta maxima	20.06%	20.82%	Medium	LC	LC
Ptilinopus monacha	20.29%	16.91%	Medium	NT	LC
Ptilinopus hyogastrus	20.17%	16.80%	Medium	LC	LC
Semioptera wallacii	8.40%	16.59%	High	LC	LC
Scolopax rochussenii	10.27%	16.15%	High	EN	LC
Coracina parvula	12.82%	14.58%	High	LC	LC
Ptilinopus granulifrons	16.03%	13.36%	Medium	VU	LC
Ptilinopus bernsteinii	10.86%	9.05%	Medium	LC	LC
Cacomantis heinrichi	5.70%	5.99%	High	NT	LC
Habroptila wallacii	N/A	N/A	N/A	VU	

Table 6 - The percent forest loss that is expected to occur within the next 3 generations or 10 years for each non-endemic species within the North Maluku EBA.

	% Lost 1990 - 2003	% Forest Loss in 3 Generations or 10 years	Forest Dependence	Current IUCN Red List Status
Ducula rosacea	35.94%	59.52%	Medium	NT
Accipiter erythrauchen	18.70%	33.55%	High	LC
Eos squamata	20.41%	33.08%	Medium	LC
Ducula perspicillata	19.90%	32.95%	Medium	LC
Pachycephala griseonota	19.44%	32.50%	Medium	LC
Loriculus amabilis	20.61%	22.79%	Medium	LC
Coracina atriceps	19.14%	21.77%	Medium	LC
Myiagra galeata	20.15%	21.03%	Low	LC
Monarcha pileatus	18.53%	20.09%	Medium	LC
Eulipoa wallacei	18.26%	19.78%	High	VU
Megapodius freycinet	18.27%	19.62%	High	LC
Ninox squamipila	19.14%	19.55%	Medium	LC
Dicaeum erythrothorax	19.67%	16.39%	Low	LC
Coracina ceramensis	13.92%	15.83%	Medium	LC
Lichmera argentauris	N/A	N/A	N/A	LC
Ducula myristicivora	N/A	N/A	N/A	LC
Pachycephala phaionota	N/A	N/A	N/A	LC

Table 7 – Suggested change in status for all restricted-range species that are endemic to the North Maluku EBA.

	IUCN Red List Status	Status Based on Change	Status Based on Area	New Status	Change (Y/N)
Cacatua alba	VU	EN	NT	EN	**Y**
Scolopax rochussenii	EN	LC	EN	EN	N
Philemon fuscicapillus	VU	VU	VU	VU	N
Lorius garrulus	EN	VU	LC	VU	*Y*
Corvus validus	LC	VU	LC	VU	**Y**
Accipiter henicogrammus	LC	VU	NT	VU	**Y**
Eurystomus azureus	NT	NT	VU	VU	**Y**
Semioptera wallacii	LC	LC	VU	VU	**Y**
Coracina parvula	LC	LC	VU	VU	**Y**
Ptilinopus granulifrons	VU	LC	VU	VU	N
Cacomantis heinrichi	NT	LC	VU	VU	**Y**
Aegotheles crinifrons	LC	LC*	NT	NT	**Y**
Oriolus phaeochromus	LC	LC	NT	NT	**Y**
Todiramphus funebris	VU	LC	NT	NT	*Y*
Ptilinopus bernsteinii	LC	LC	NT	NT	**Y**
Habroptila wallacii	VU	N/A	N/A	N/A	N/A
Lycocorax pyrrhopterus	LC	LC*	LC	LC	N
Ducula basilica	LC	LC*	LC	LC	N
Melitograis gilolensis	LC	LC	LC	LC	N
Centropus goliath	LC	LC	LC	LC	N
Todiramphus diops	LC	LC	LC	LC	N
Lalage aurea	LC	LC	LC	LC	N
Zosterops atriceps	LC	LC	LC	LC	N
Pitta maxima	LC	LC	LC	LC	N
Ptilinopus monacha	NT	LC	LC	LC	*Y*
Ptilinopus hyogastrus	LC	LC	LC	LC	N

Appendix I – Reference Tables

Table A – Dates and locations of images used in the analysis.

Images Used in Land Cover Analysis			
Landsat Path	Landsat Row	Date of TM image	Date of ETM image
109	58	N/A	5/23/2003
109	59	10/21/1991	1/15/2003
109	60	10/21/1991	7/23/2003
109	61	10/21/1991	5/23/2003
110	58	12/4/1990	11/3/2002
110	59	12/20/1990	5/27/2002
110	60	12/4/1990	5/27/2002

Table B – Accuracy assessment for the 1990/1 TM5 images. (Ref 1 – Non-forested, Ref 2 – Secondary Growth, Ref 3 – Primary Forest). Columns represent raw image data, while the rows represent the classified image classes.

1990/1	Non-forested	Secondary Growth	Primary Forest	Total	User's Accuracy
Non-forested	8	0	0	8	8/8 = 100%
Secondary Growth	1	51	4	56	51/56 = 91.1%
Primary Forest	4	33	399	436	399/436 = 91.5%
Total	13	84	403	500	
Producer's Accuracy	8/13 = 61.5%	51/84 = 60.7%	399/403 = 99.0%		458/500 = 91.6%
Kappa Statistic = 0.6978					

Table C – Accuracy assessment for the 2002/3 TM7 images. (Ref 1 – Non-forested, Ref 2 – Secondary Growth, Ref 3 – Primary Forest). Columns represent raw image data, while the rows represent the classified image classes.

2002/3	Non-forested	Secondary Growth	Primary Forest	Total	User's Accuracy
Non-forested	23	4	1	28	23/28 = 82.1%
Secondary Growth	1	83	28	112	83/112 = 74.1%
Primary Forest	3	19	338	360	338/360 = 93.9%
Total	27	106	367	500	
Producer's Accuracy	23/27 = 85.2%	83/106 = 78.3%	338/367 = 92.1%		444/500 = 88.8%
Kappa Statistic = 0.7400					

Appendix II – Species Range Maps

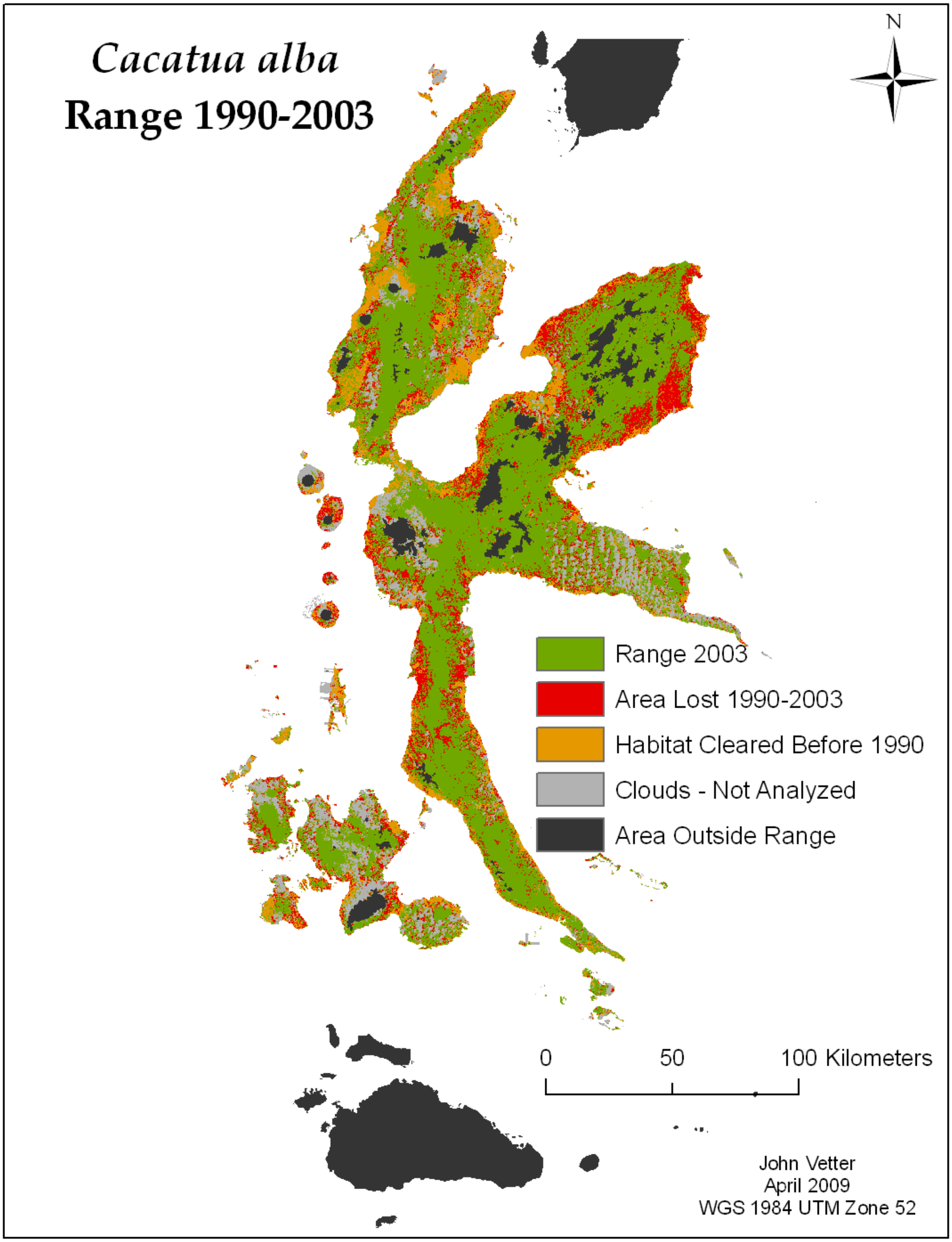

Figure A – Map of the range from 2003 (Green) and 1990 (Green plus Red) for the White Cockatoo (*Cacatua alba*). Gray areas are clouds and orange areas were secondary growth or unforested in 1990. Black areas are outside the species range.

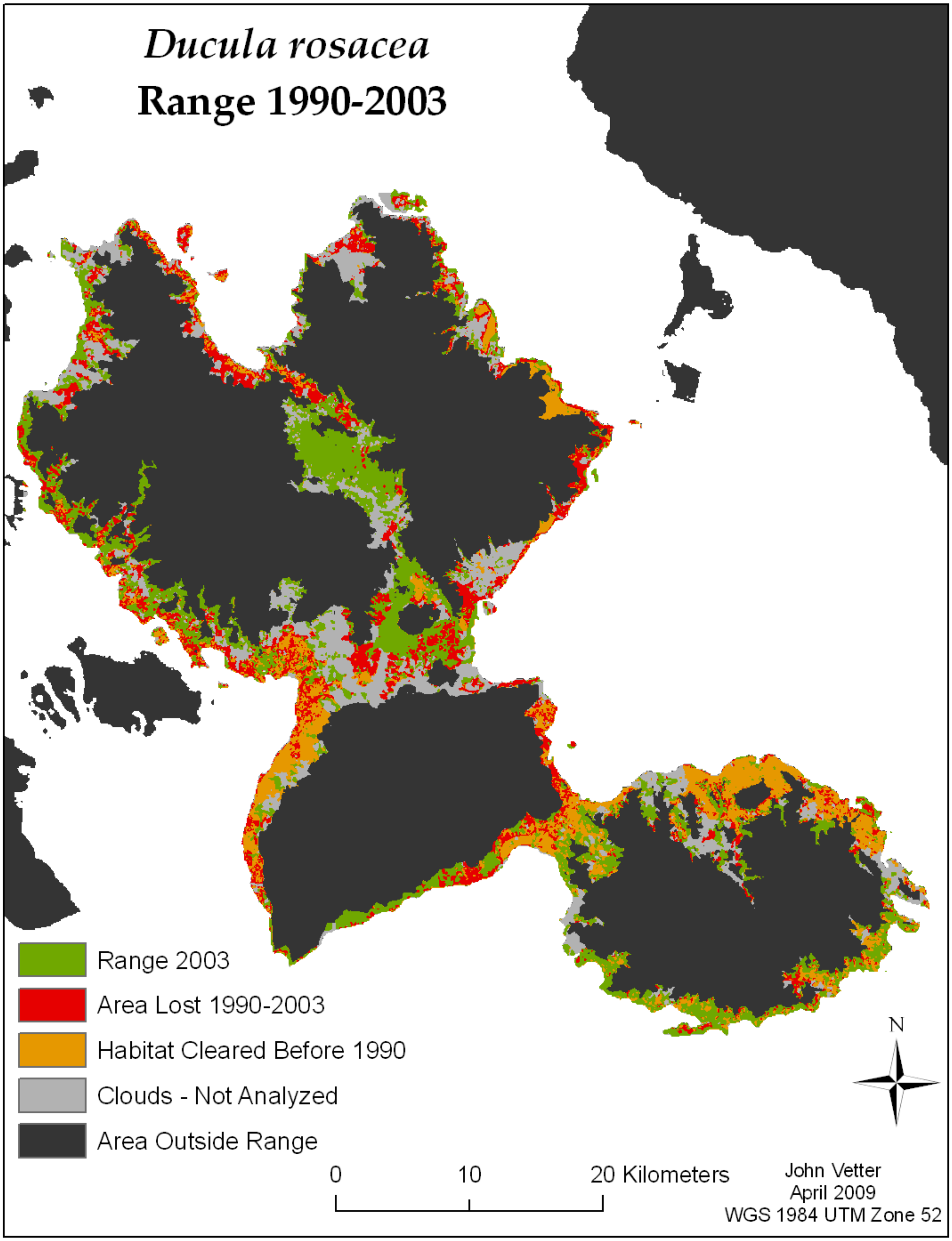

Figure B – Map of the range from 2003 (Green) and 1990 (Green plus Red) for the Pink-headed Imperial-Pigeon (*Ducula rosacea*). Gray areas are clouds and orange areas were secondary growth or unforested in 1990. Black areas are outside the species range.

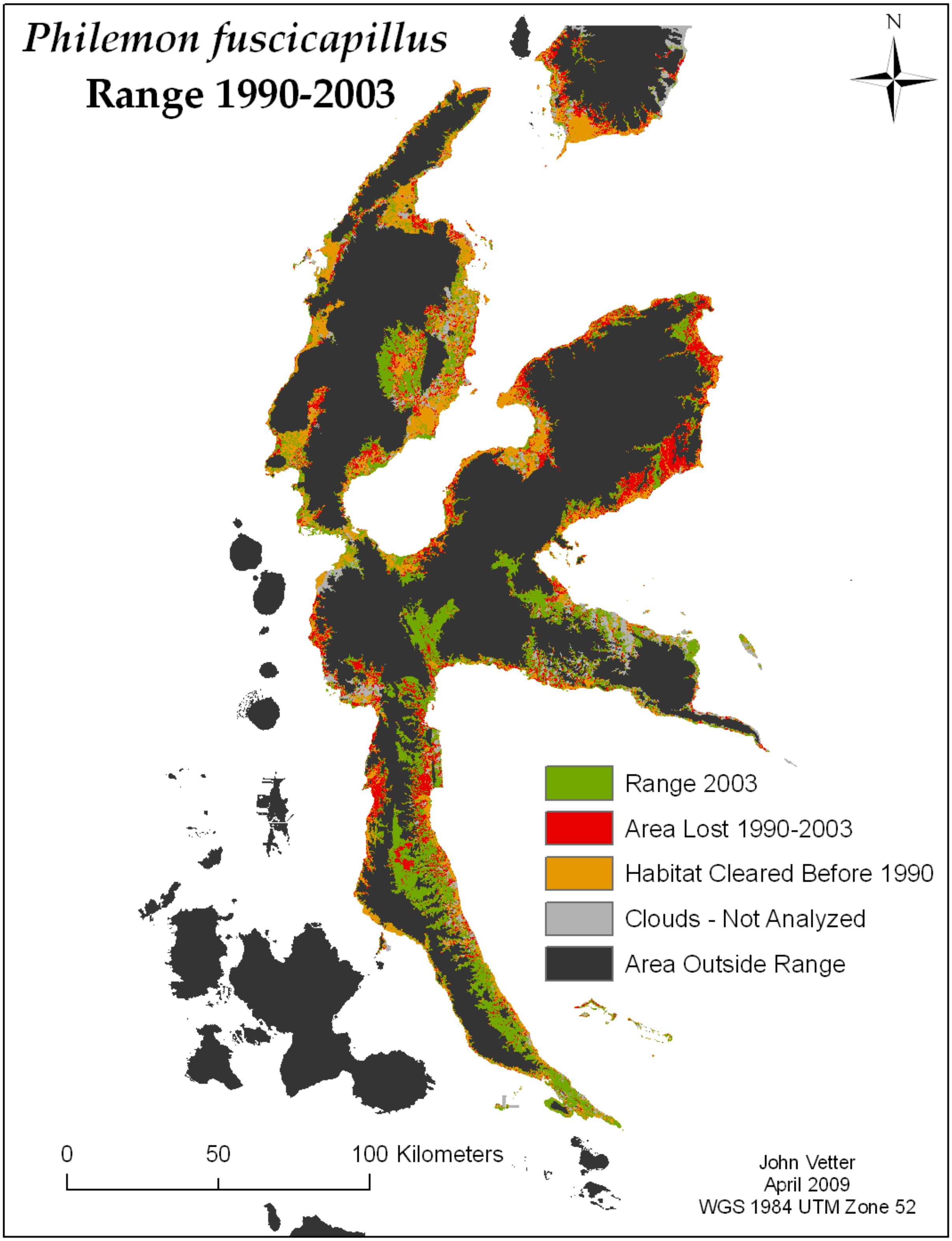

Figure C – Map of the range from 2003 (Green) and 1990 (Green plus Red) for the Dusky Friarbird (*Philemon fuscicapillus*). Gray areas are clouds and orange areas were secondary growth or unforested in 1990. Black areas are outside the species range.

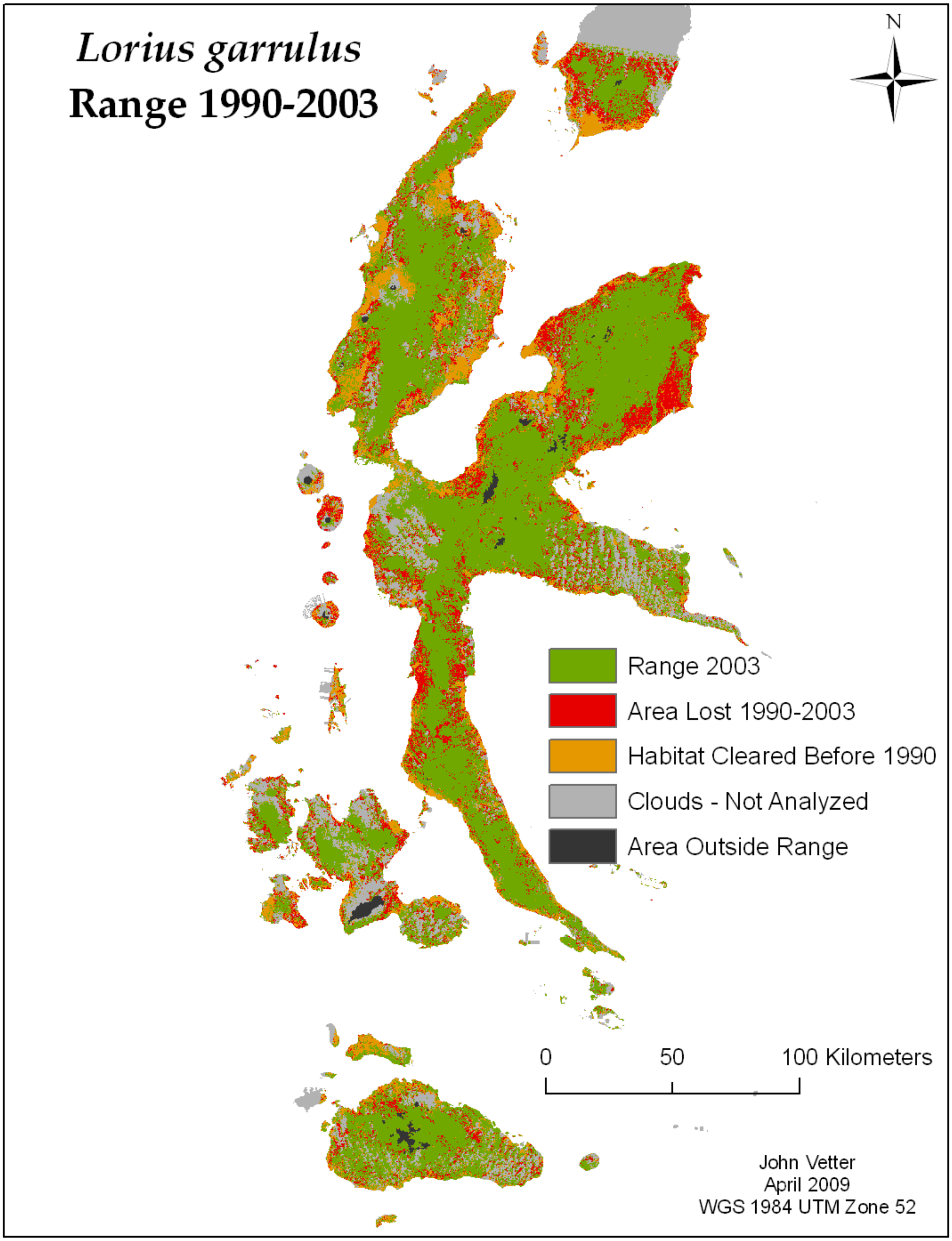

Figure D – Map of the range from 2003 (Green) and 1990 (Green plus Red) for the Chattering Lory (*Lorius garrulus*). Gray areas are clouds and orange areas were secondary growth or unforested in 1990. Black areas are outside the species range.

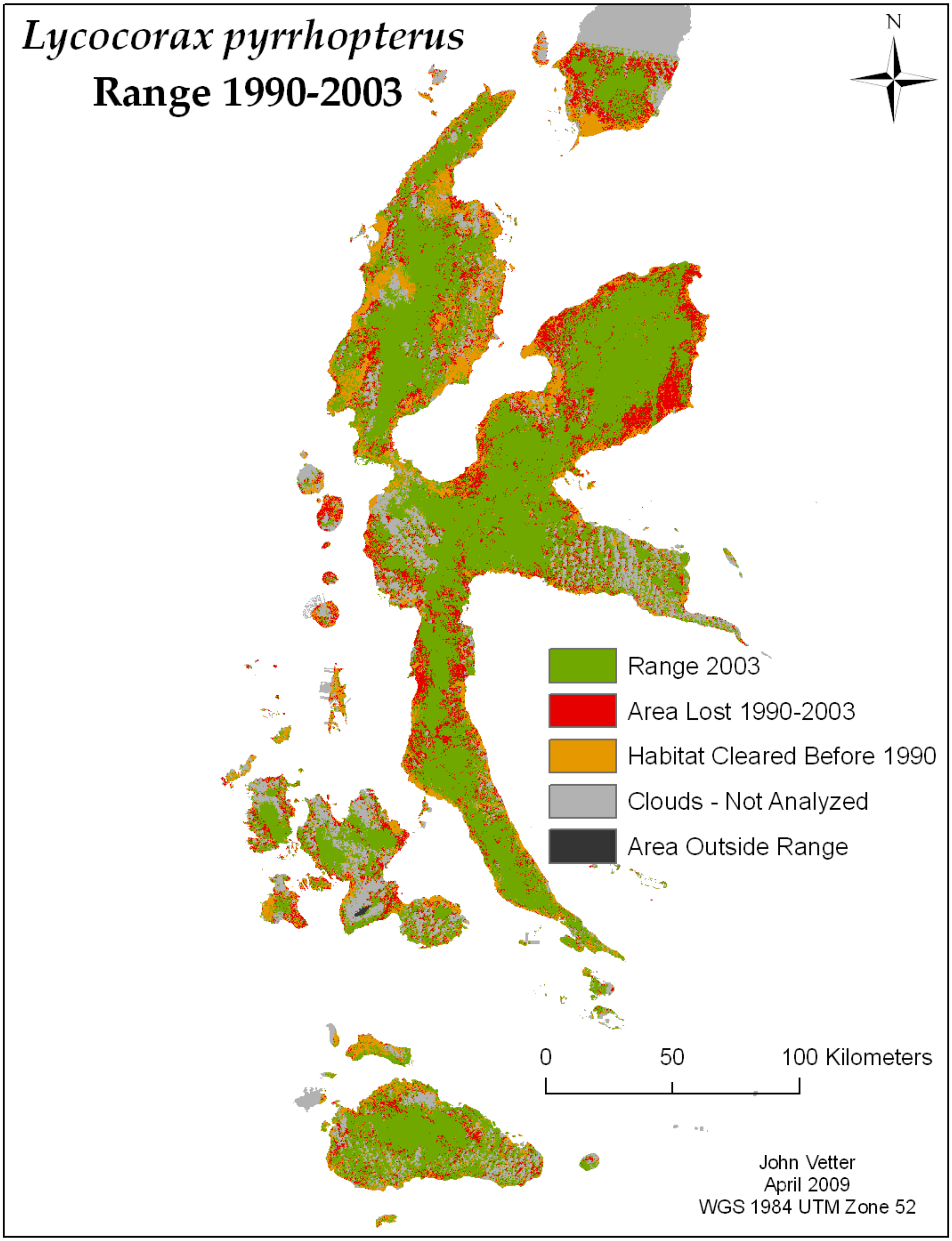

Figure E – Map of the range from 2003 (Green) and 1990 (Green plus Red) for the Paradise Crow (*Lycocorax pyrrhopterus*). Gray areas are clouds and orange areas were secondary growth or unforested in 1990. Black areas are outside the species range.

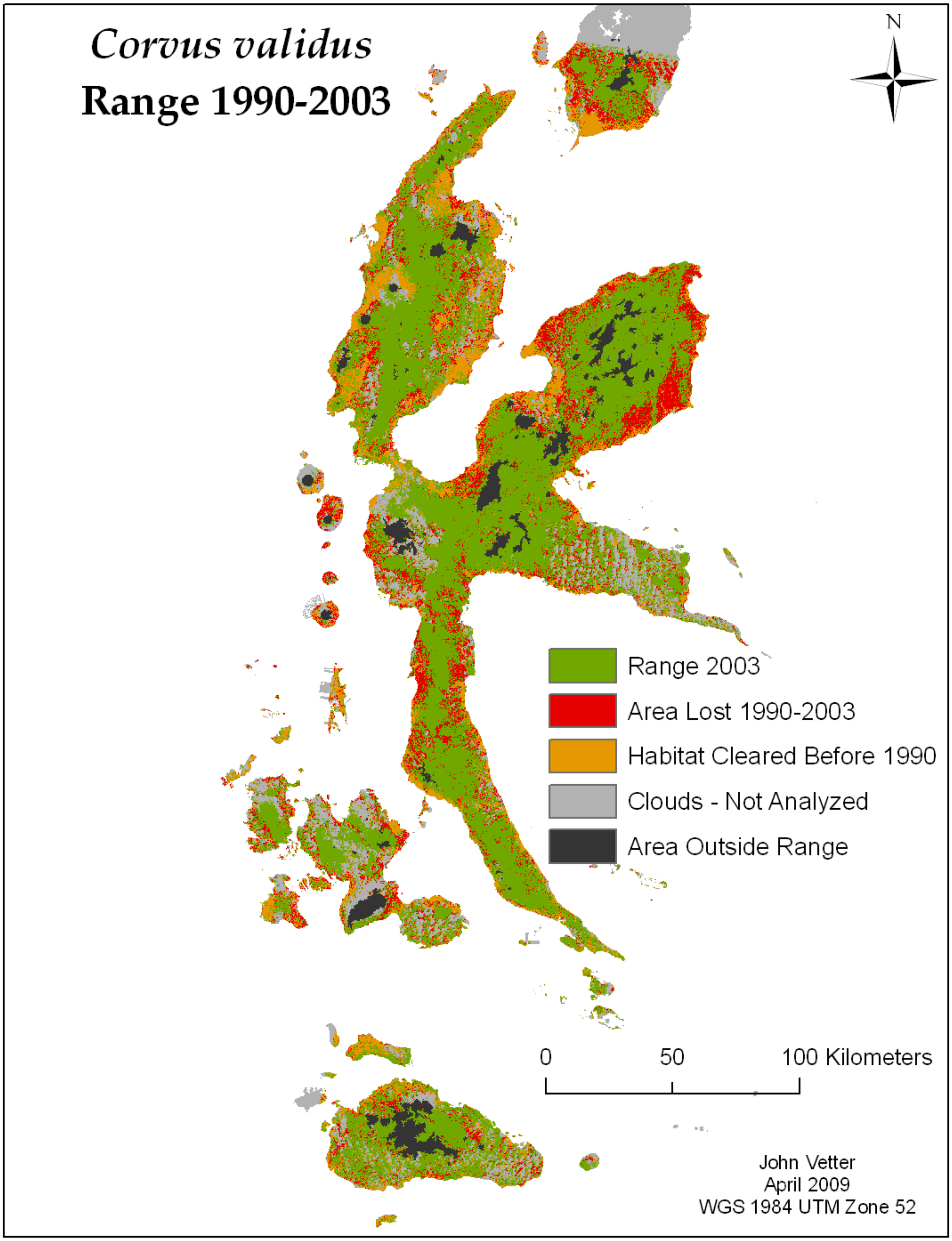

Figure F – Map of the range from 2003 (Green) and 1990 (Green plus Red) for the Long-billed Crow (*Corvus validus*). Gray areas are clouds and orange areas were secondary growth or unforested in 1990. Black areas are outside the species range.

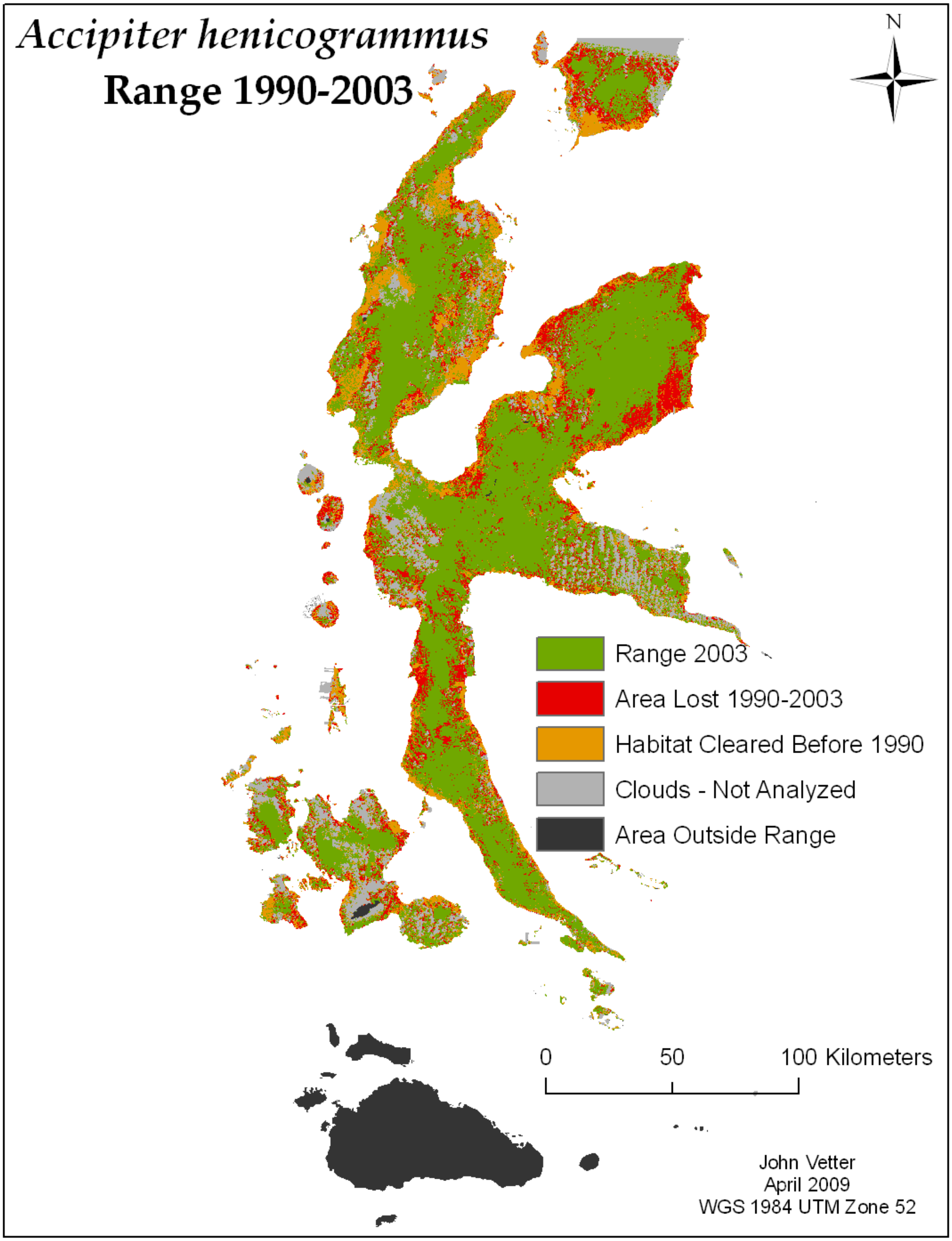

Figure G – Map of the range from 2003 (Green) and 1990 (Green plus Red) for the Moluccan Goshawk (*Accipiter henicogrammus*). Gray areas are clouds and orange areas were secondary growth or unforested in 1990. Black areas are outside the species range..

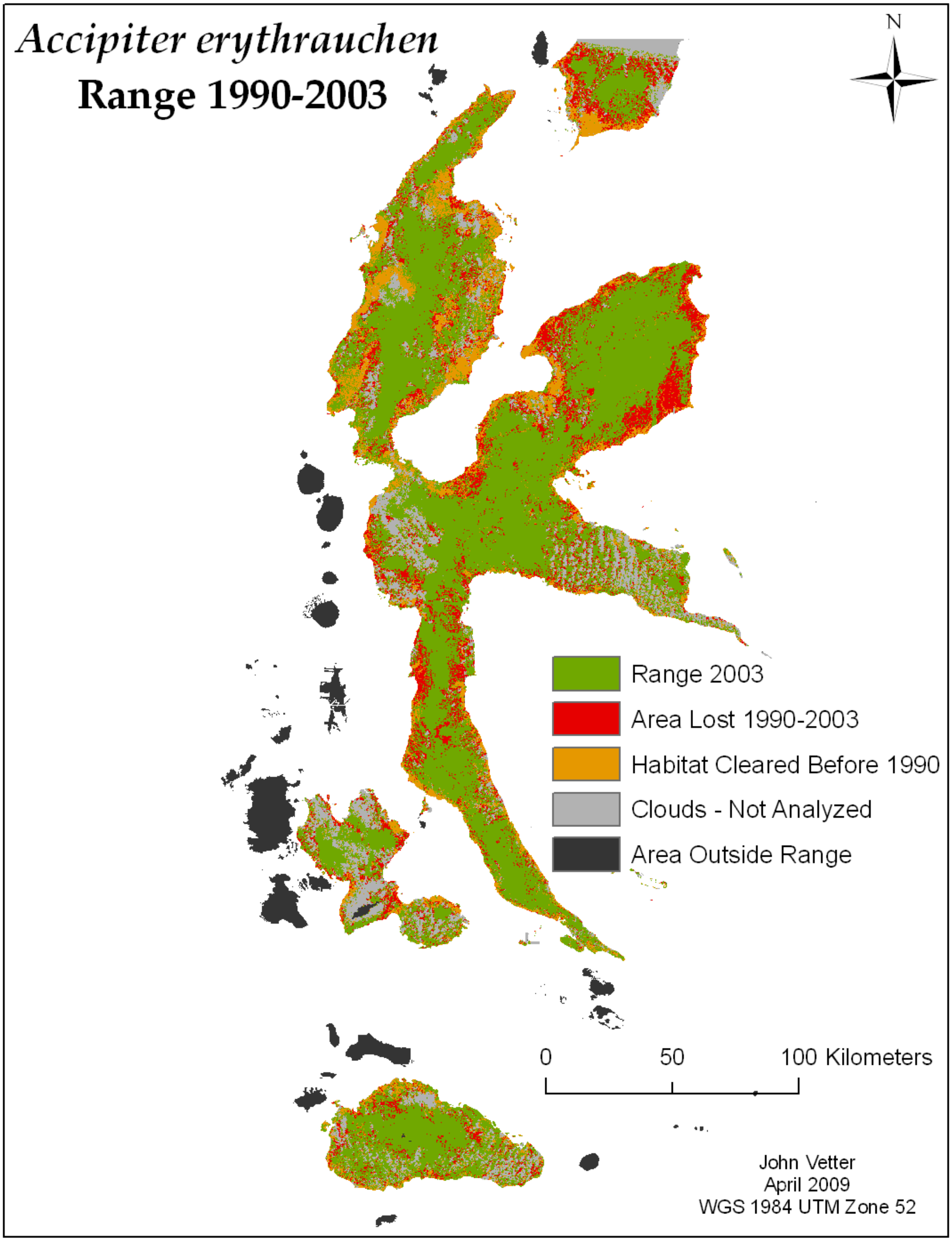

Figure H – Map of the range from 2003 (Green) and 1990 (Green plus Red) for the Rufous-necked Sparrowhawk (*Accipiter erythrauchen*). Gray areas are clouds and orange areas were secondary growth or unforested in 1990. Black areas are outside the species range.

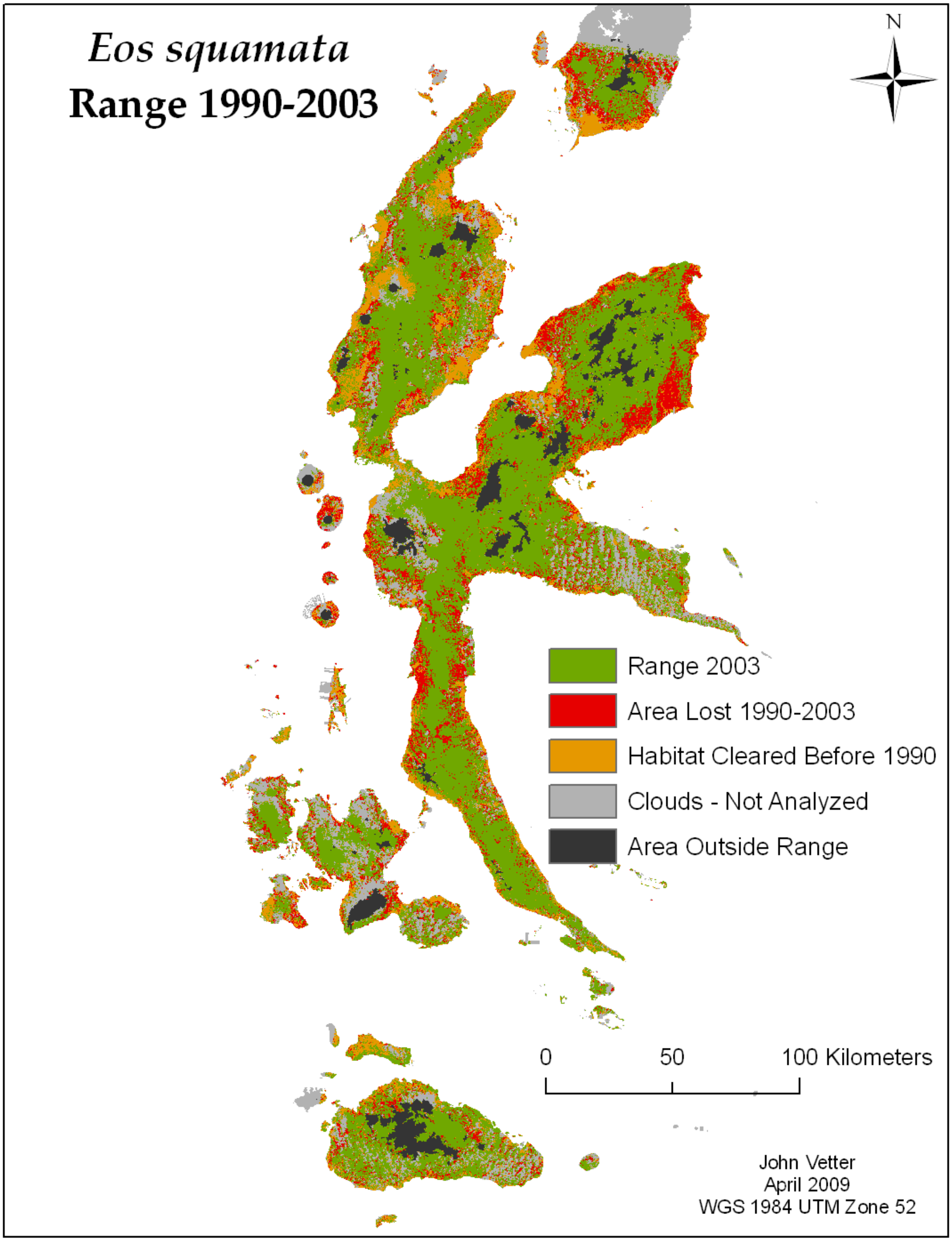

Figure I – Map of the range from 2003 (Green) and 1990 (Green plus Red) for the Violet-necked Lory (*Eos squamata*). Gray areas are clouds and orange areas were secondary growth or unforested in 1990. Black areas are outside the species range.

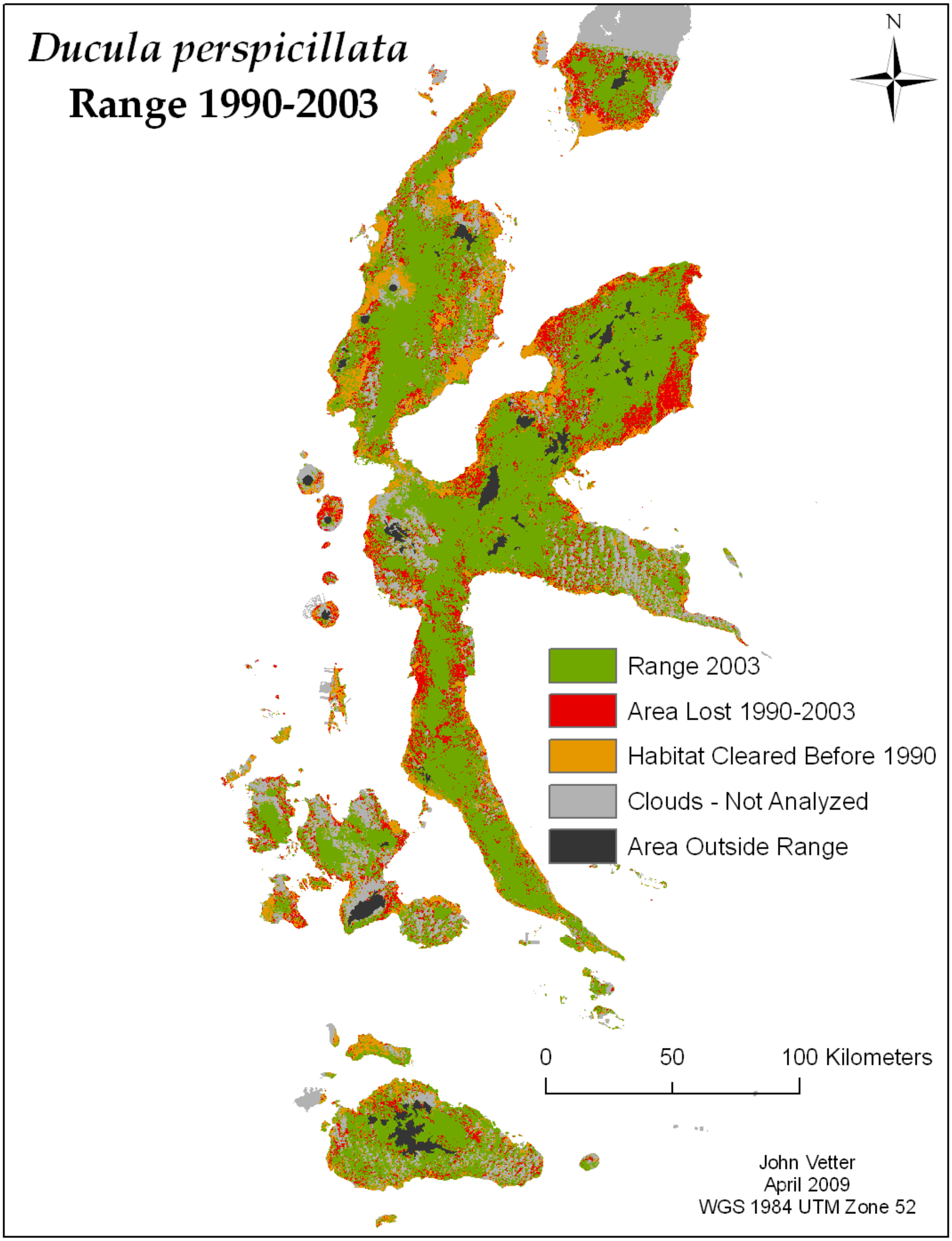

Figure J – Map of the range from 2003 (Green) and 1990 (Green plus Red) for the White-eyed Imperial-Pigeon (*Ducula perspicillata*). Gray areas are clouds and orange areas were secondary growth or unforested in 1990. Black areas are outside the species range.

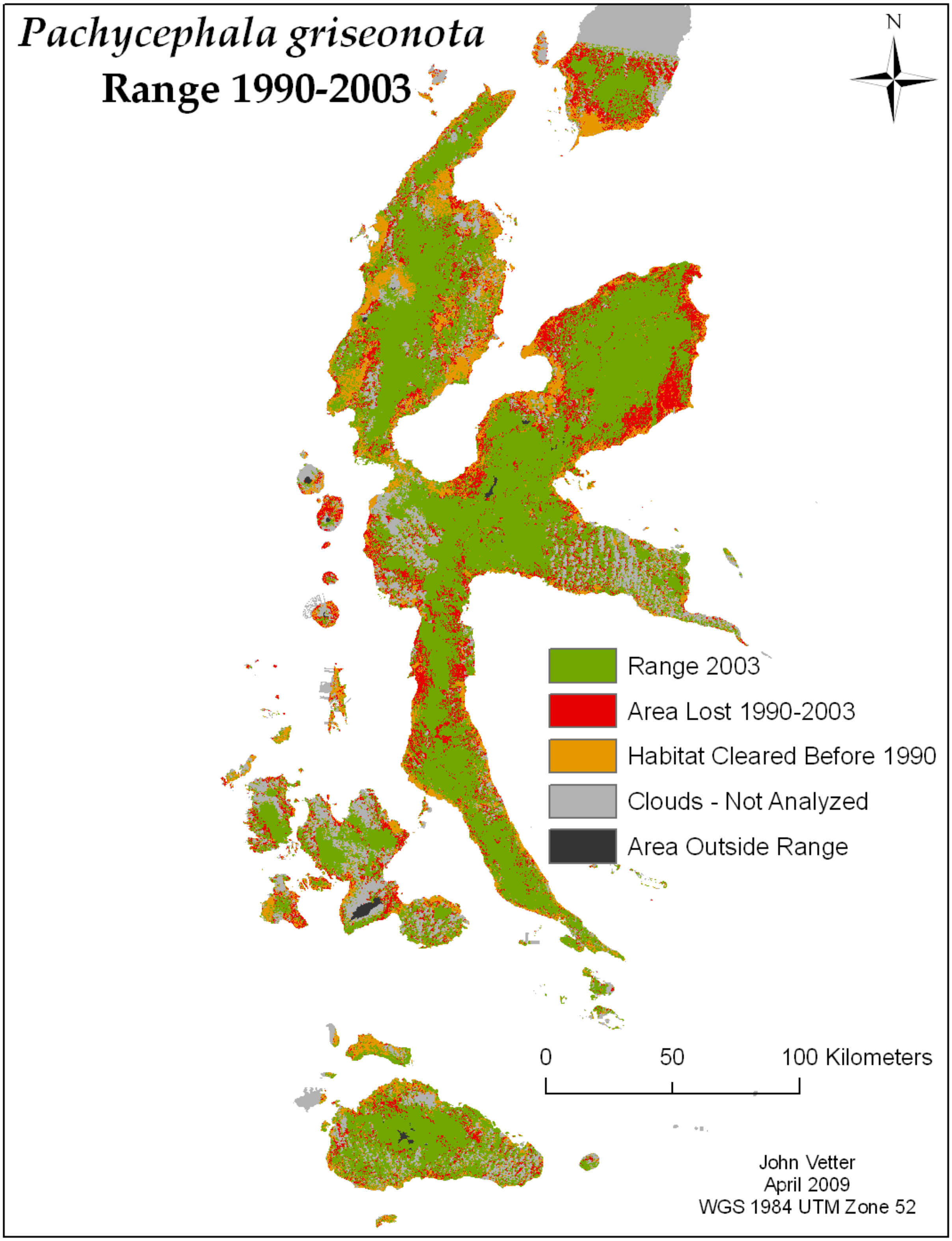

Figure K – Map of the range from 2003 (Green) and 1990 (Green plus Red) for the Drab Whistler (*Pachycephala griseonota*). Gray areas are clouds and orange areas were secondary growth or unforested in 1990. Black areas are outside the species range.

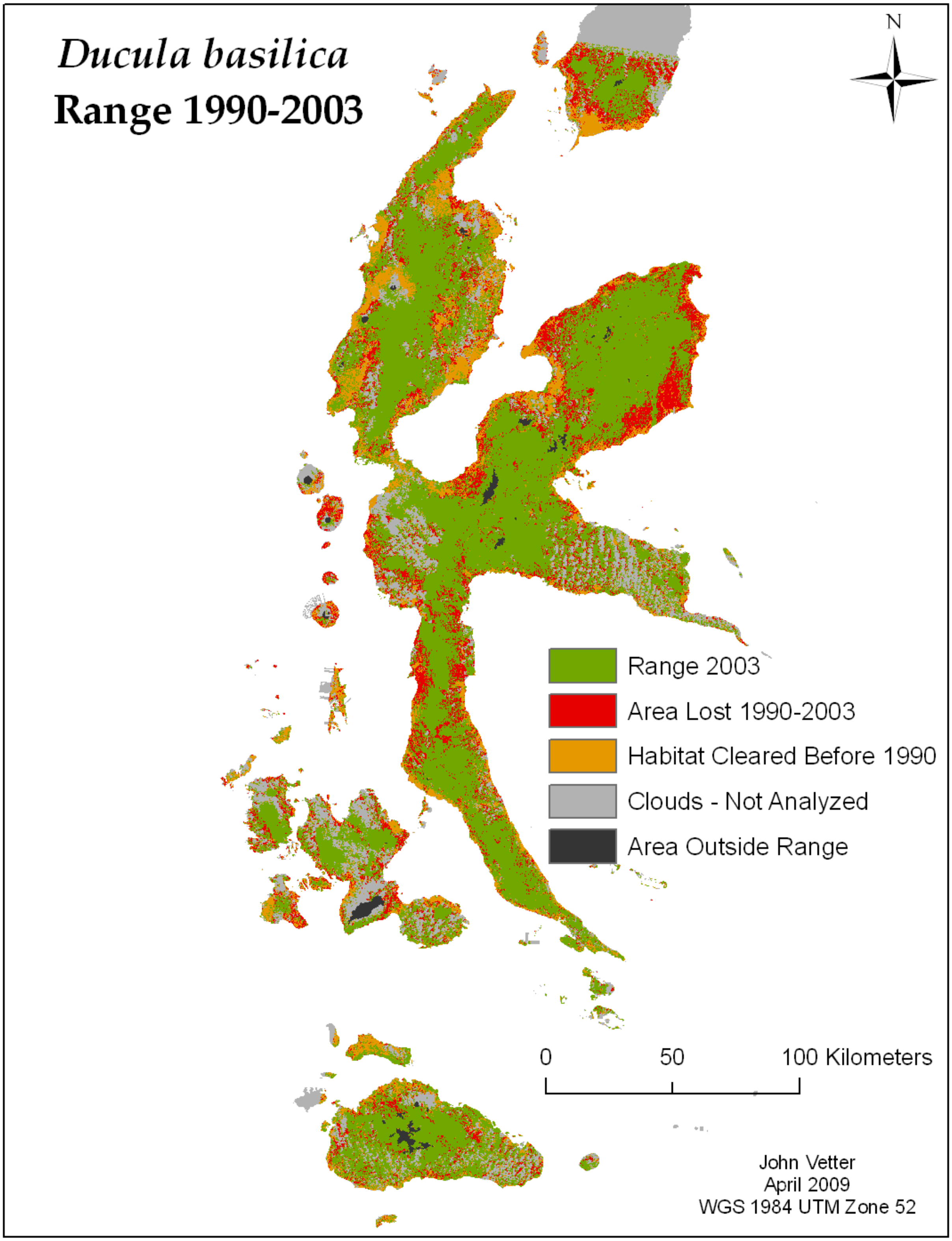

Figure L – Map of the range from 2003 (Green) and 1990 (Green plus Red) for the Cinnamon-bellied Imperial-pigeon (*Ducula basilica*). Gray areas are clouds and orange areas were secondary growth or unforested in 1990. Black areas are outside the species range.

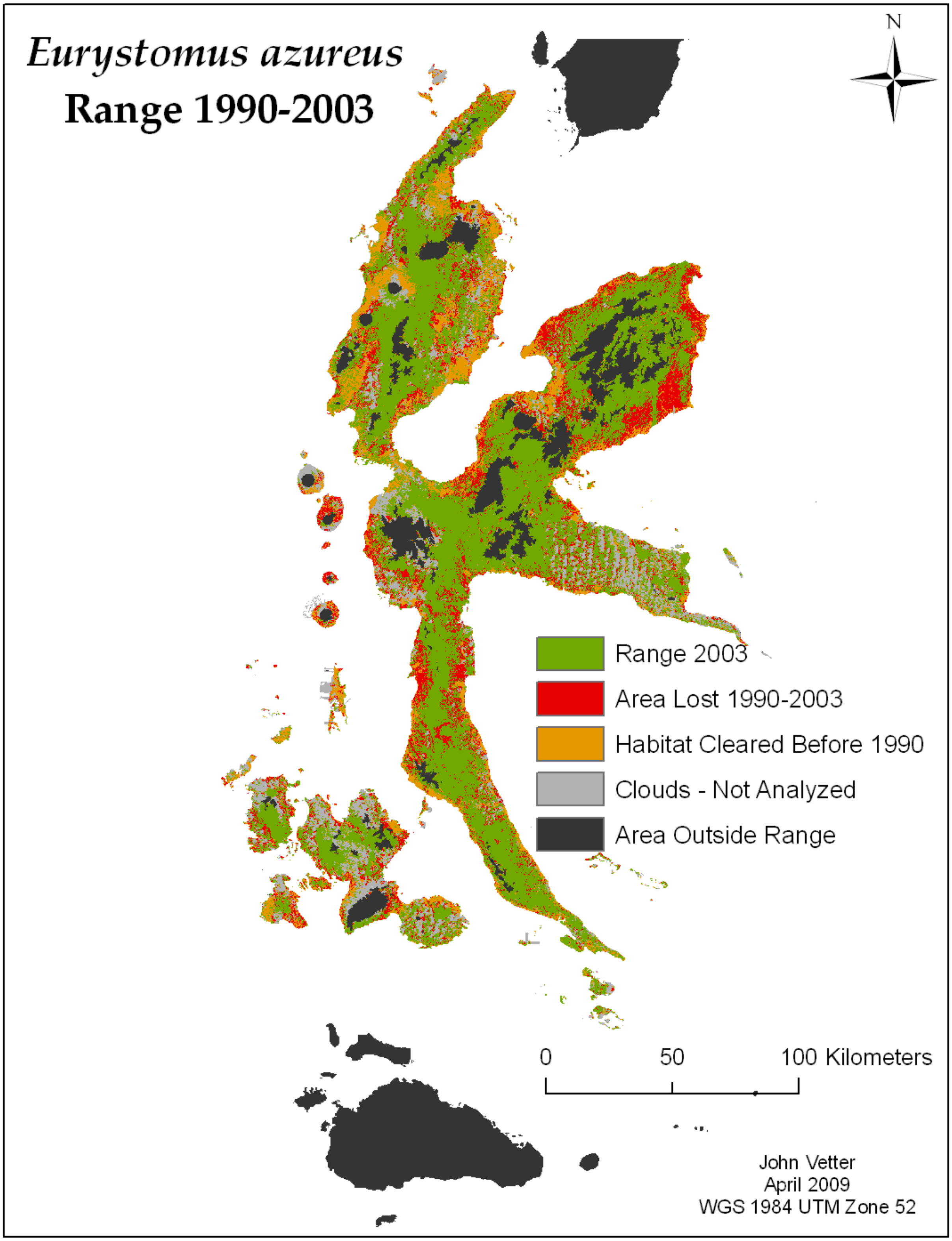

Figure M – Map of the range from 2003 (Green) and 1990 (Green plus Red) for the Purple Dollarbird (*Eurystomus azureus*). Gray areas are clouds and orange areas were secondary growth or unforested in 1990. Black areas are outside the species range.

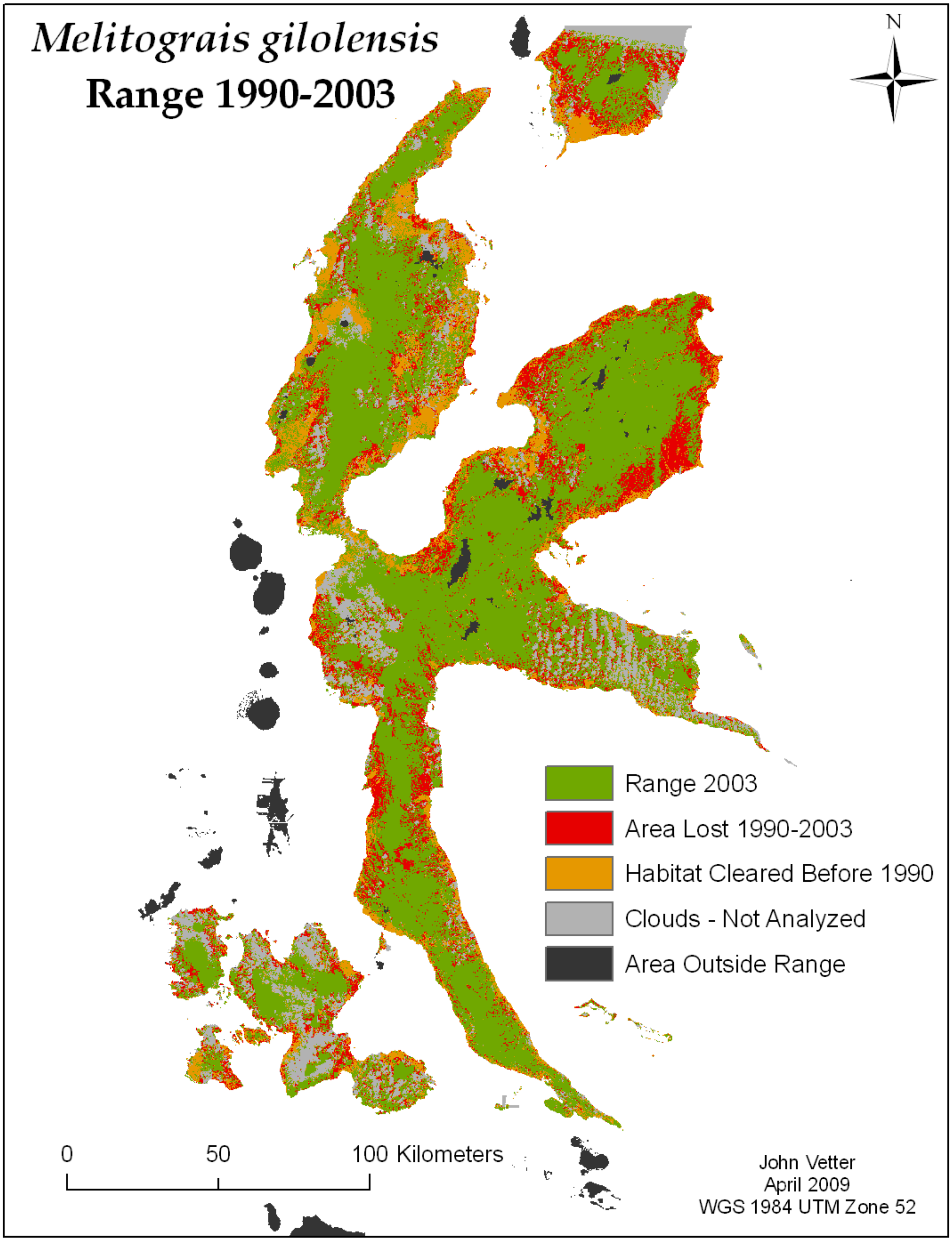

Figure N – Map of the range from 2003 (Green) and 1990 (Green plus Red) for the White-streaked Friarbird (*Melitograis gilolensis*). Gray areas are clouds and orange areas were secondary growth or unforested in 1990. Black areas are outside the species range.

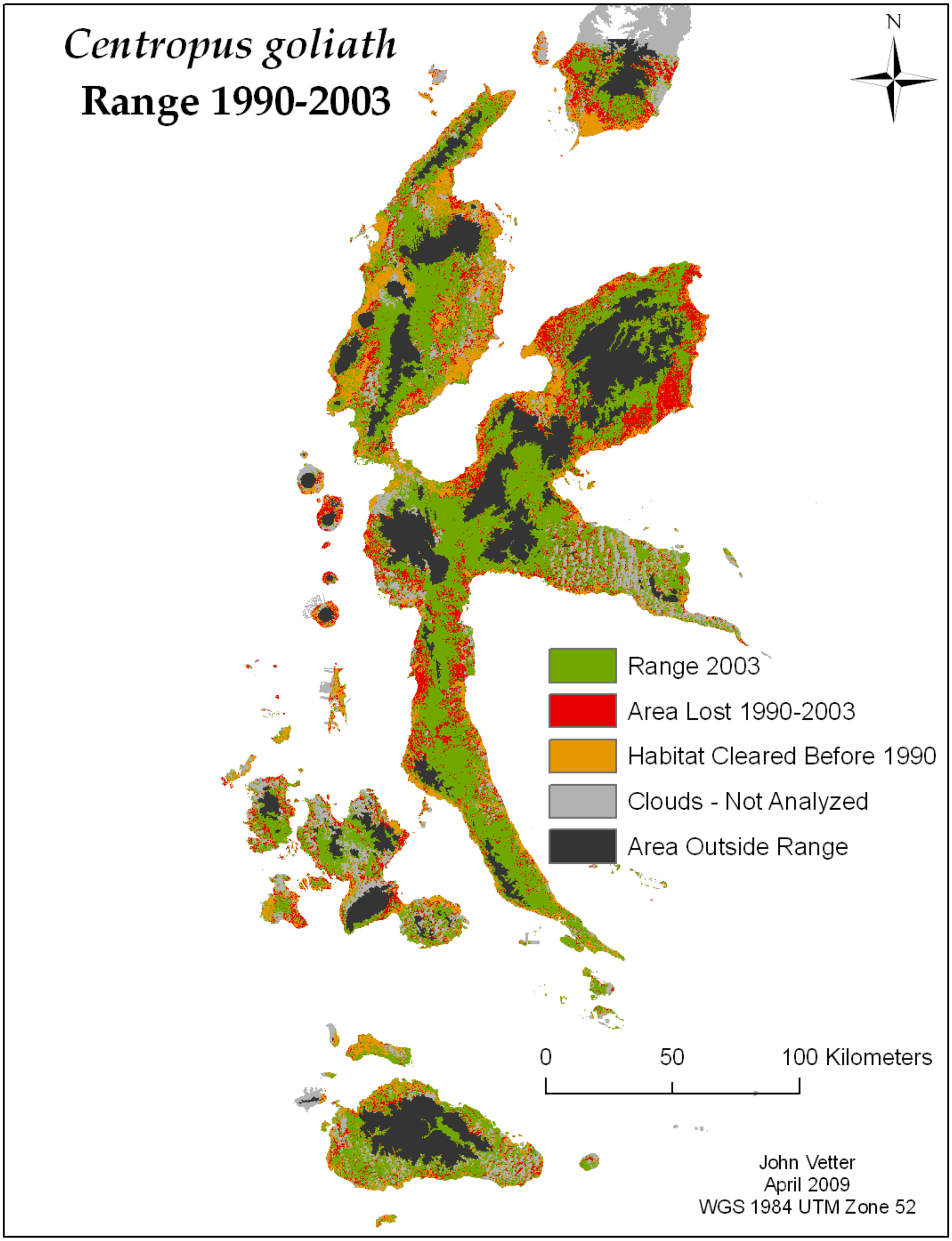

Figure O – Map of the range from 2003 (Green) and 1990 (Green plus Red) for the Goliath Coucal (*Centropus goliath*). Gray areas are clouds and orange areas were secondary growth or unforested in 1990. Black areas are outside the species range.

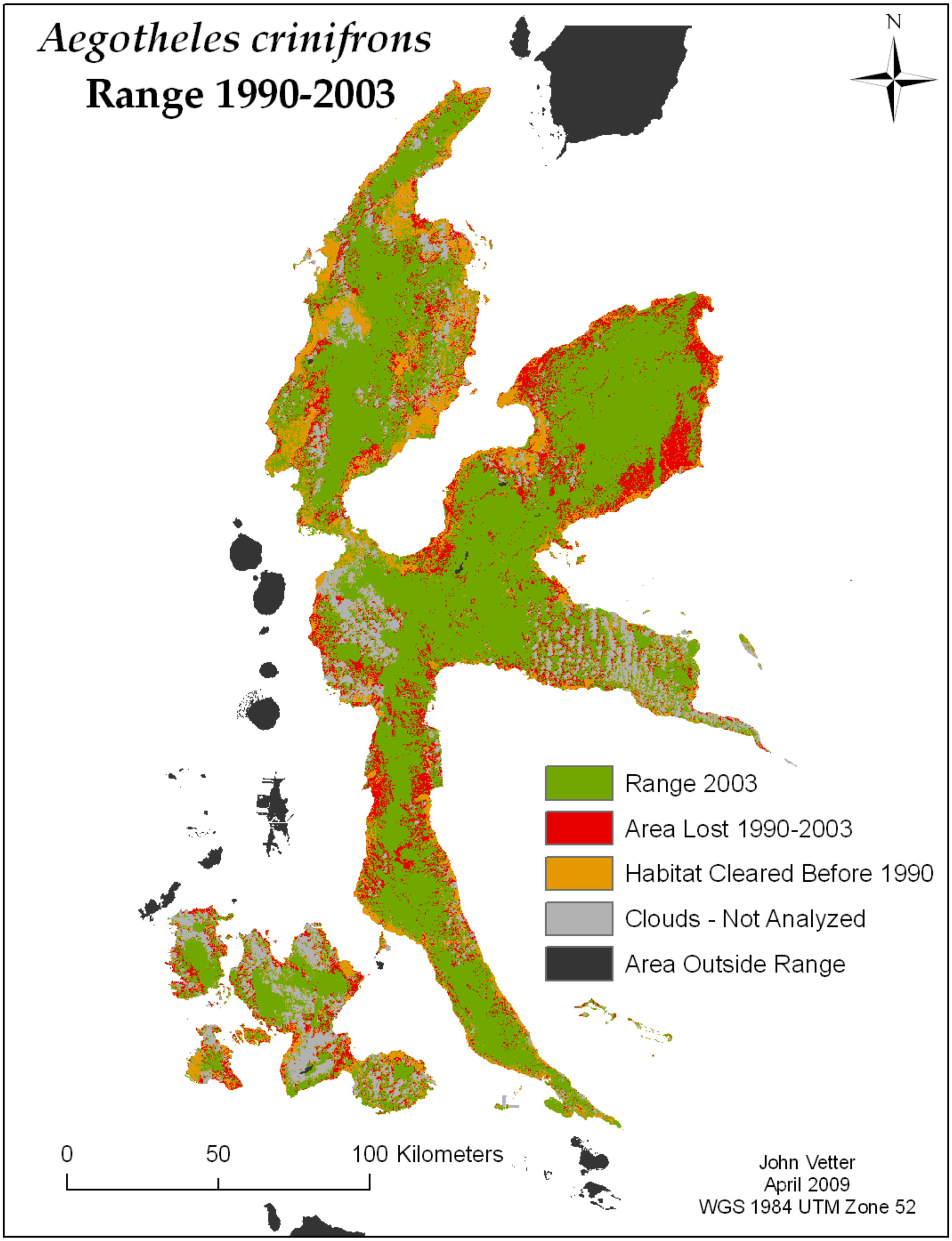

Figure P – Map of the range from 2003 (Green) and 1990 (Green plus Red) for the Long-whiskered Owlet-nightjar (*Aegotheles crinifrons*). Gray areas are clouds and orange areas were secondary growth or unforested in 1990. Black areas are outside the species range.

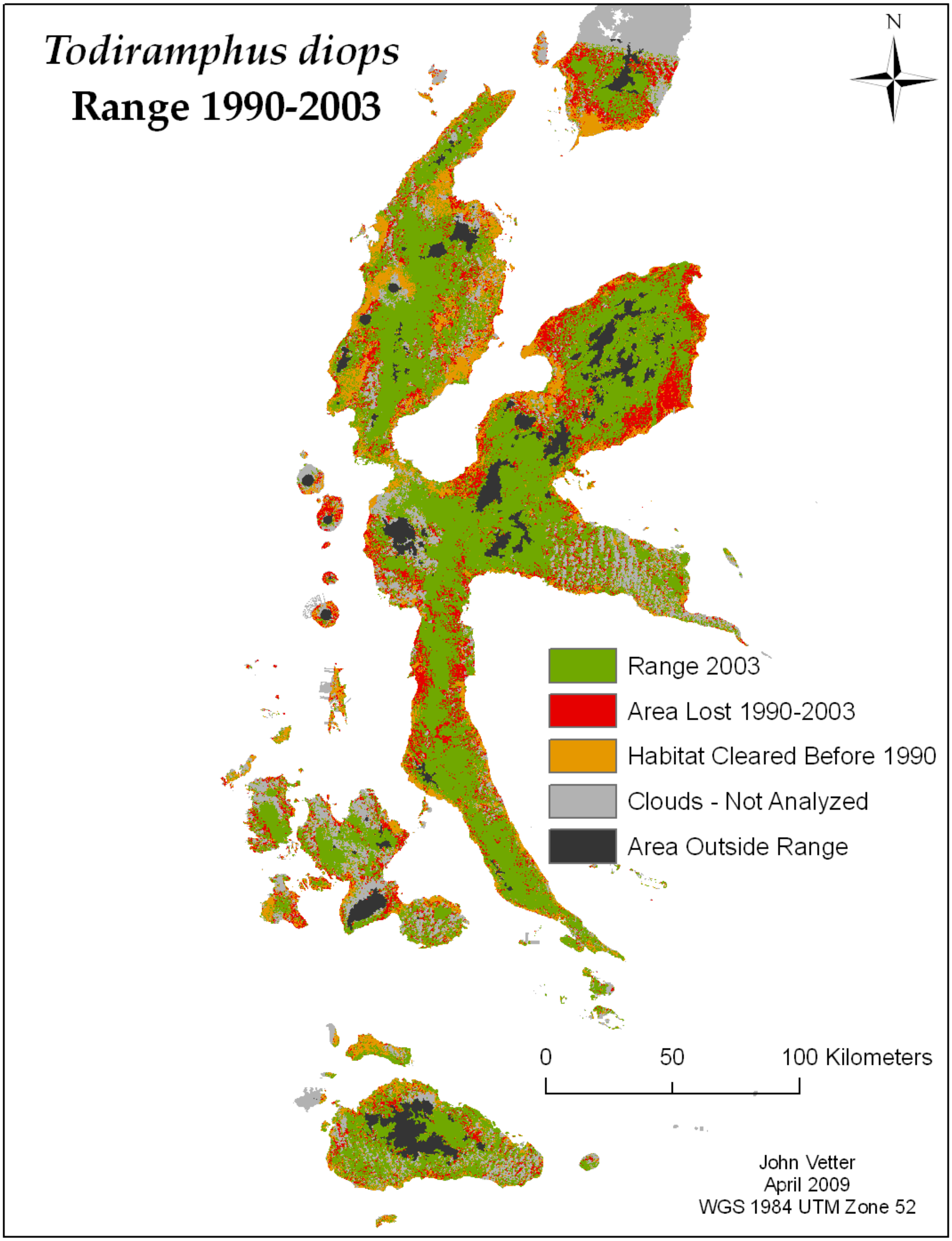

Figure Q – Map of the range from 2003 (Green) and 1990 (Green plus Red) for the Blue-and-white Kingfisher (*Todiramphus diops*). Gray areas are clouds and orange areas were secondary growth or unforested in 1990. Black areas are outside the species range.

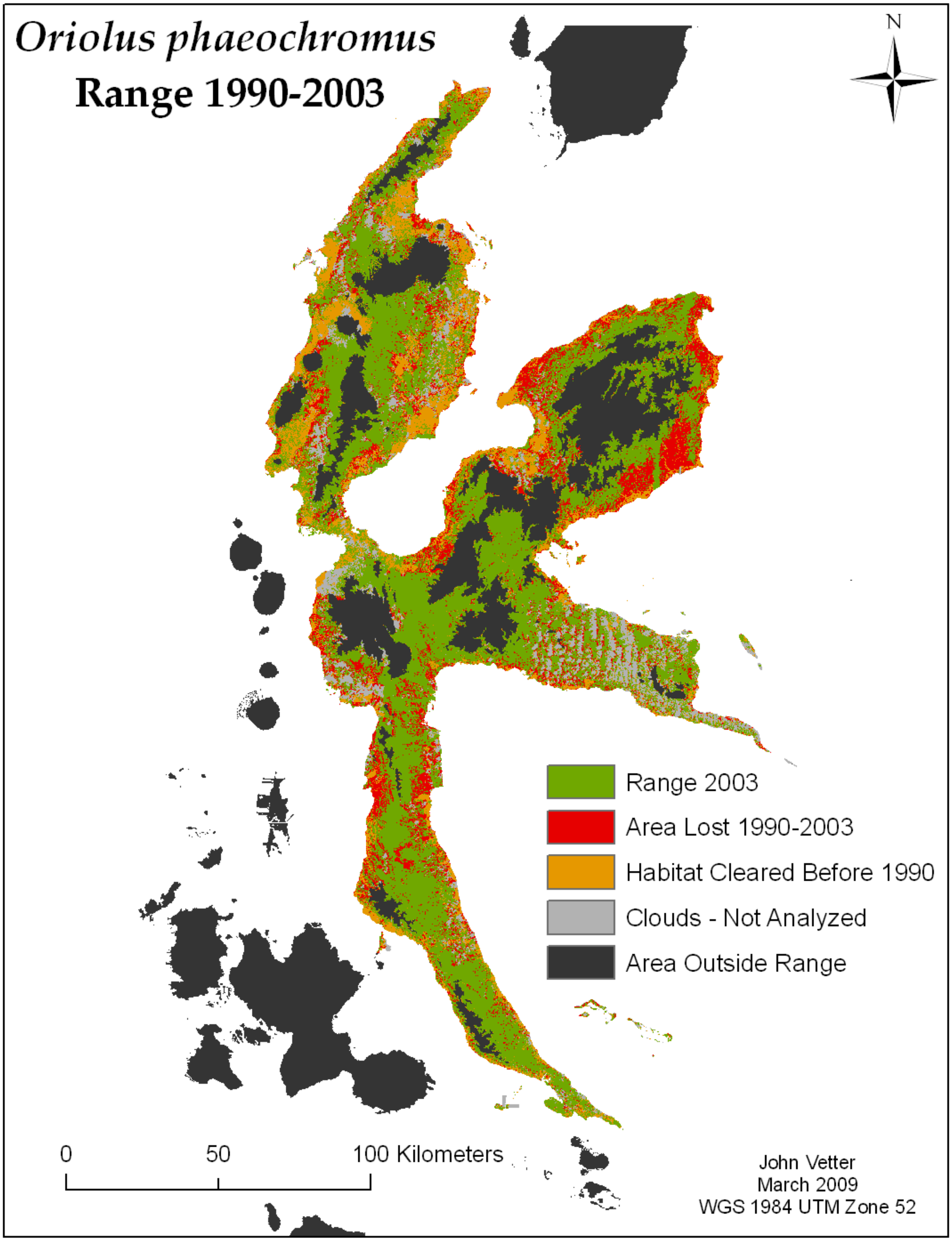

Figure R – Map of the range from 2003 (Green) and 1990 (Green plus Red) for the Dusky-brown Oriole (*Oriolus phaeochromus*). Gray areas are clouds and orange areas were secondary growth or unforested in 1990. Black areas are outside the species range.

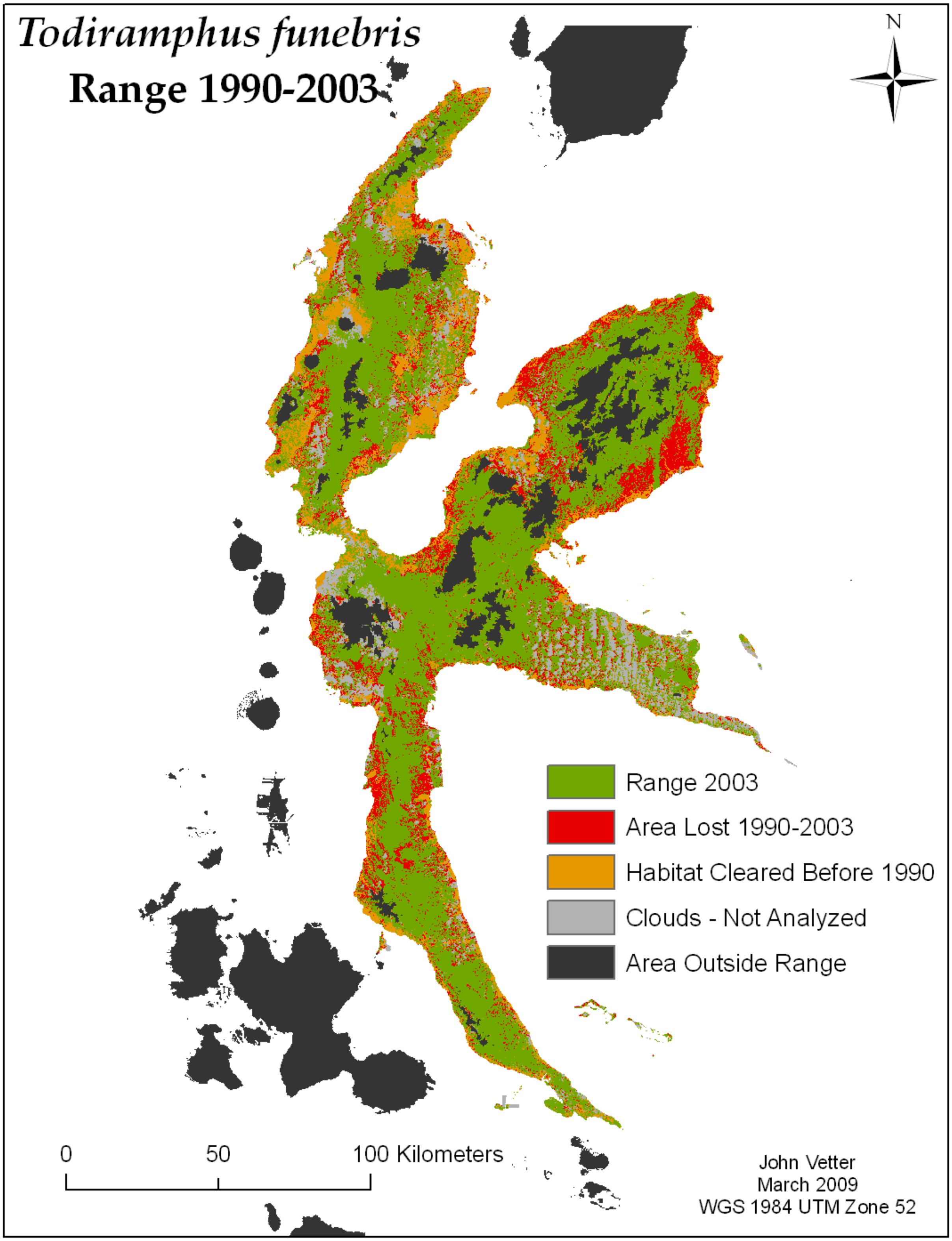

Figure S – Map of the range from 2003 (Green) and 1990 (Green plus Red) for the Sombre Kingfisher (*Todiramphus funebris*). Gray areas are clouds and orange areas were secondary growth or unforested in 1990. Black areas are outside the species range.

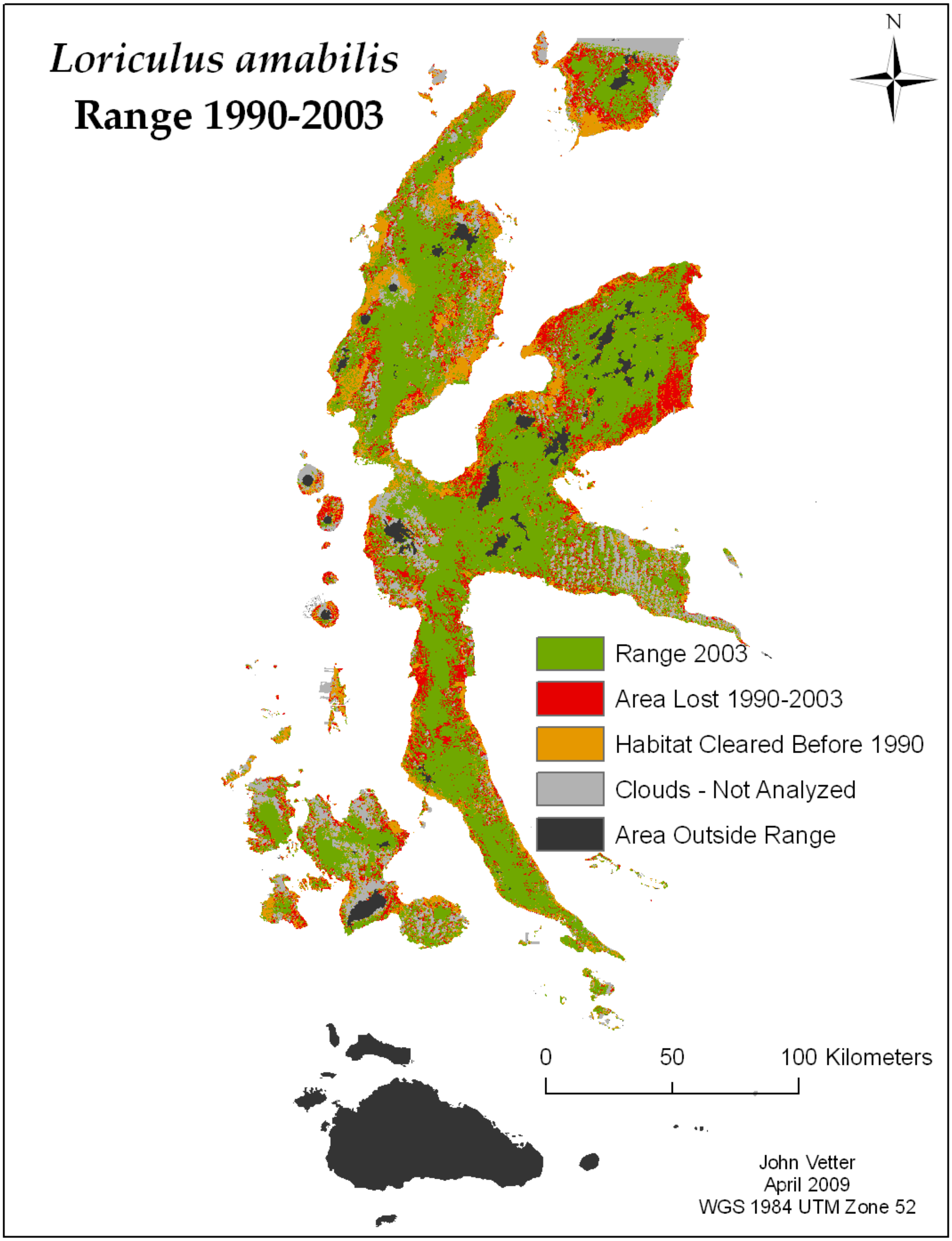

Figure T – Map of the range from 2003 (Green) and 1990 (Green plus Red) for the Moluccan Hanging-parrot (*Loriculus amabilis*). Gray areas are clouds and orange areas were secondary growth or unforested in 1990. Black areas are outside the species range.

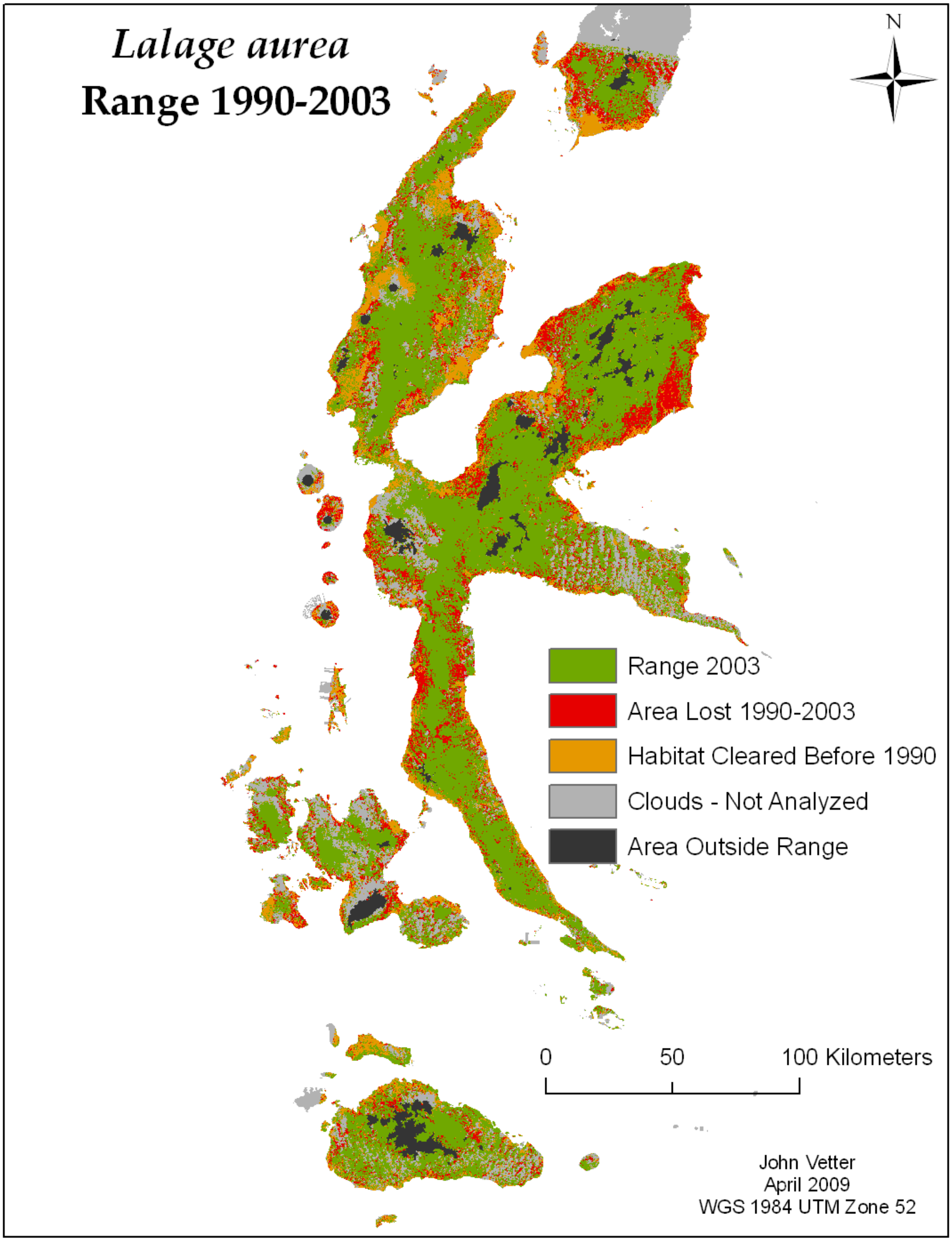

Figure U – Map of the range from 2003 (Green) and 1990 (Green plus Red) for the Rufous-bellied Triller (*Lalage aurea*). Gray areas are clouds and orange areas were secondary growth or unforested in 1990. Black areas are outside the species range.

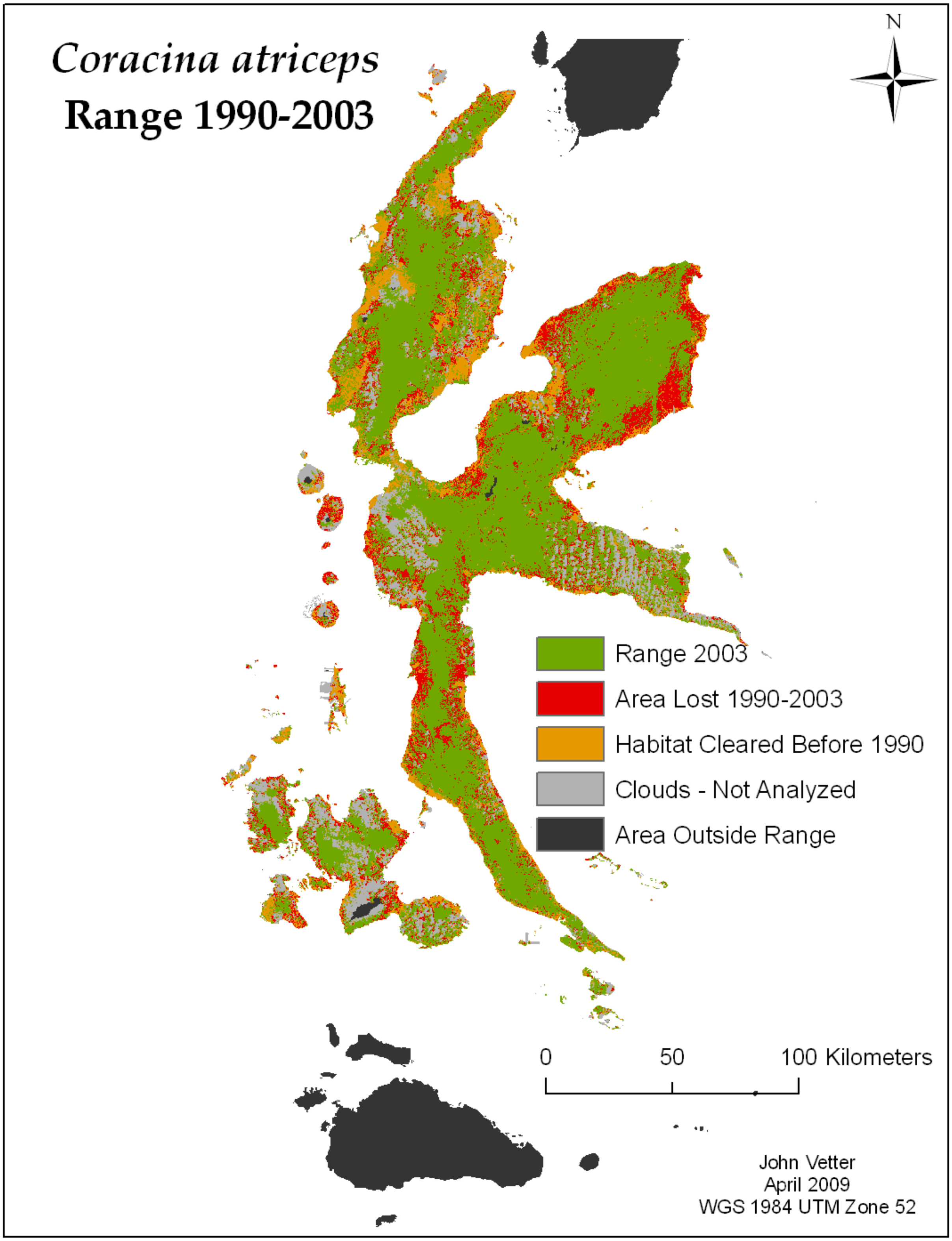

Figure V – Map of the range from 2003 (Green) and 1990 (Green plus Red) for the Moluccan Cuckooshrike (*Coracina atriceps*). Gray areas are clouds and orange areas were secondary growth or unforested in 1990. Black areas are outside the species range.

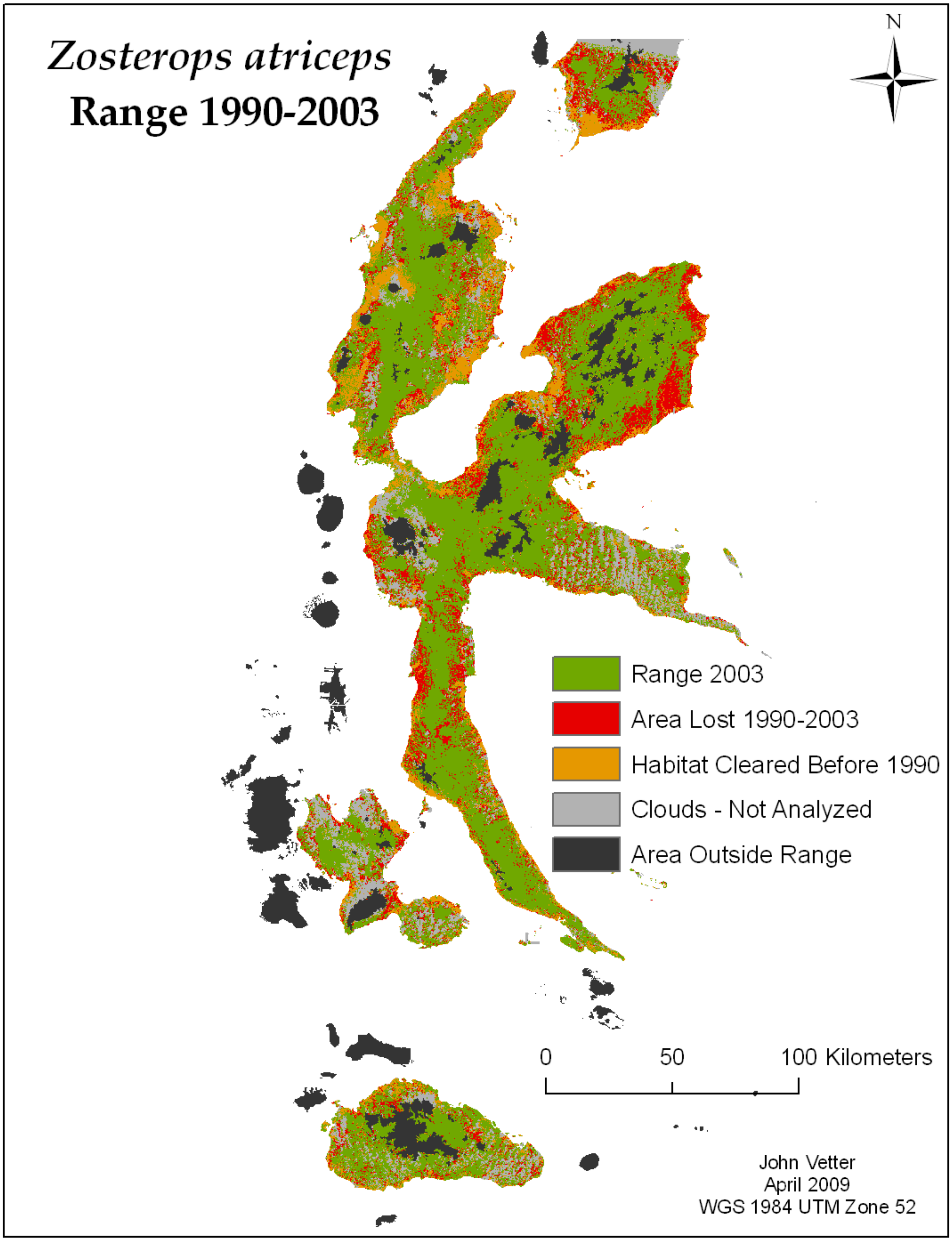

Figure W – Map of the range from 2003 (Green) and 1990 (Green plus Red) for the Creamy-throated White-eye (*Zosterops atriceps*). Gray areas are clouds and orange areas were secondary growth or unforested in 1990. Black areas are outside the species range.

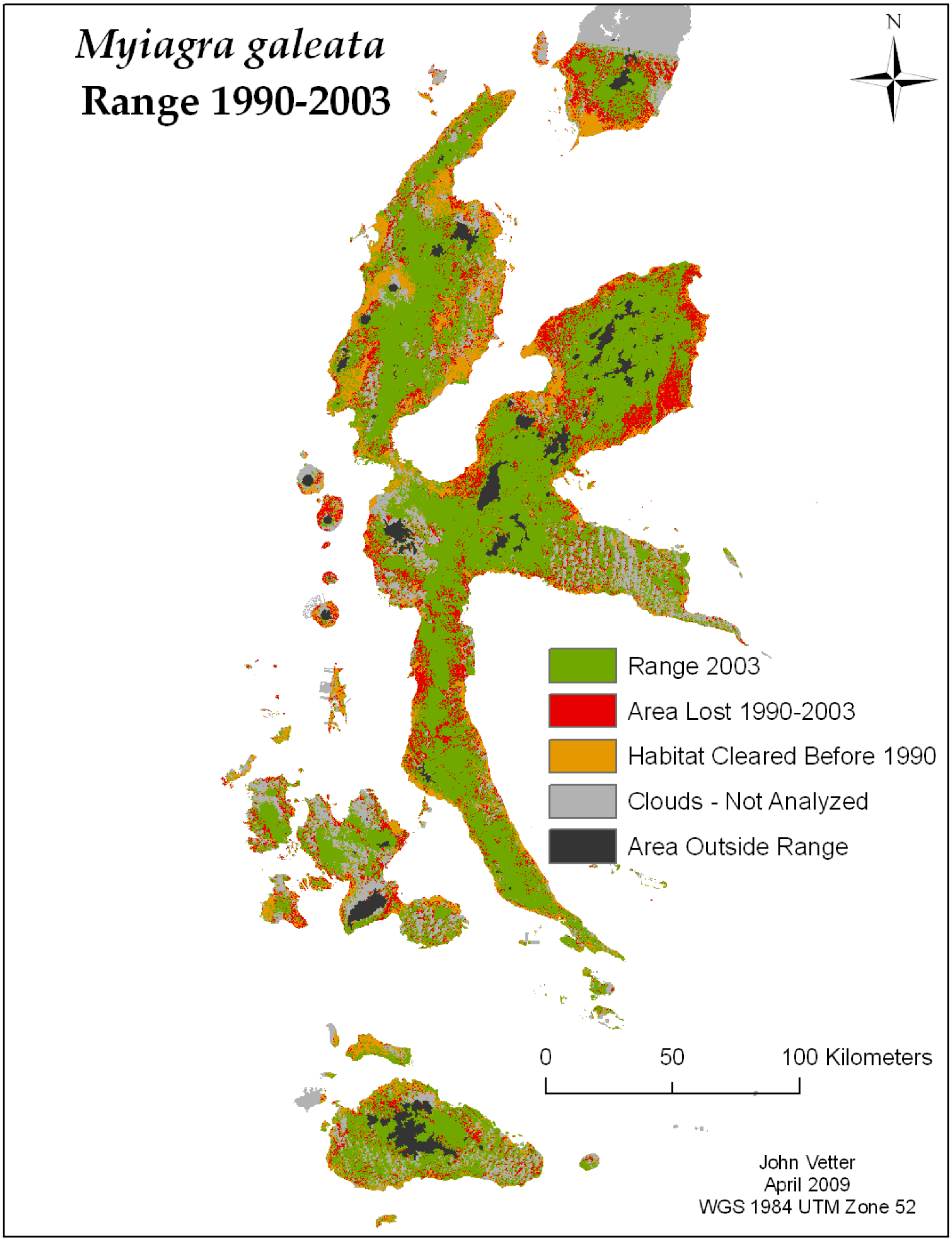

Figure X – Map of the range from 2003 (Green) and 1990 (Green plus Red) for the Dark-grey Flycatcher (*Myiagra galeata*). Gray areas are clouds and orange areas were secondary growth or unforested in 1990. Black areas are outside the species range.

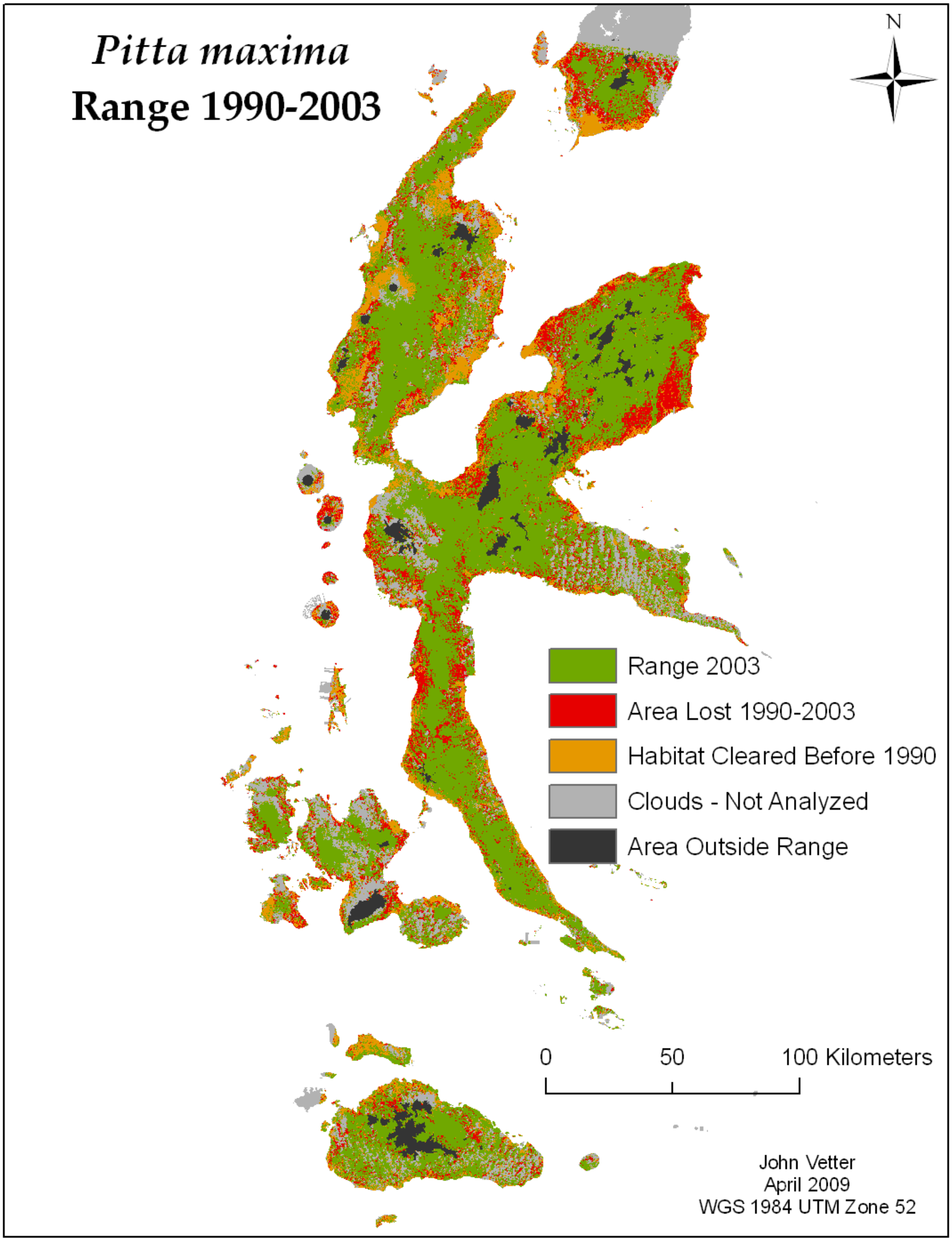

Figure Y Map of the range from 2003 (Green) and 1990 (Green plus Red) for the Ivory-breasted Pitta (*Pitta maxima*). Gray areas are clouds and orange areas were secondary growth or unforested in 1990. Black areas are outside the species range.

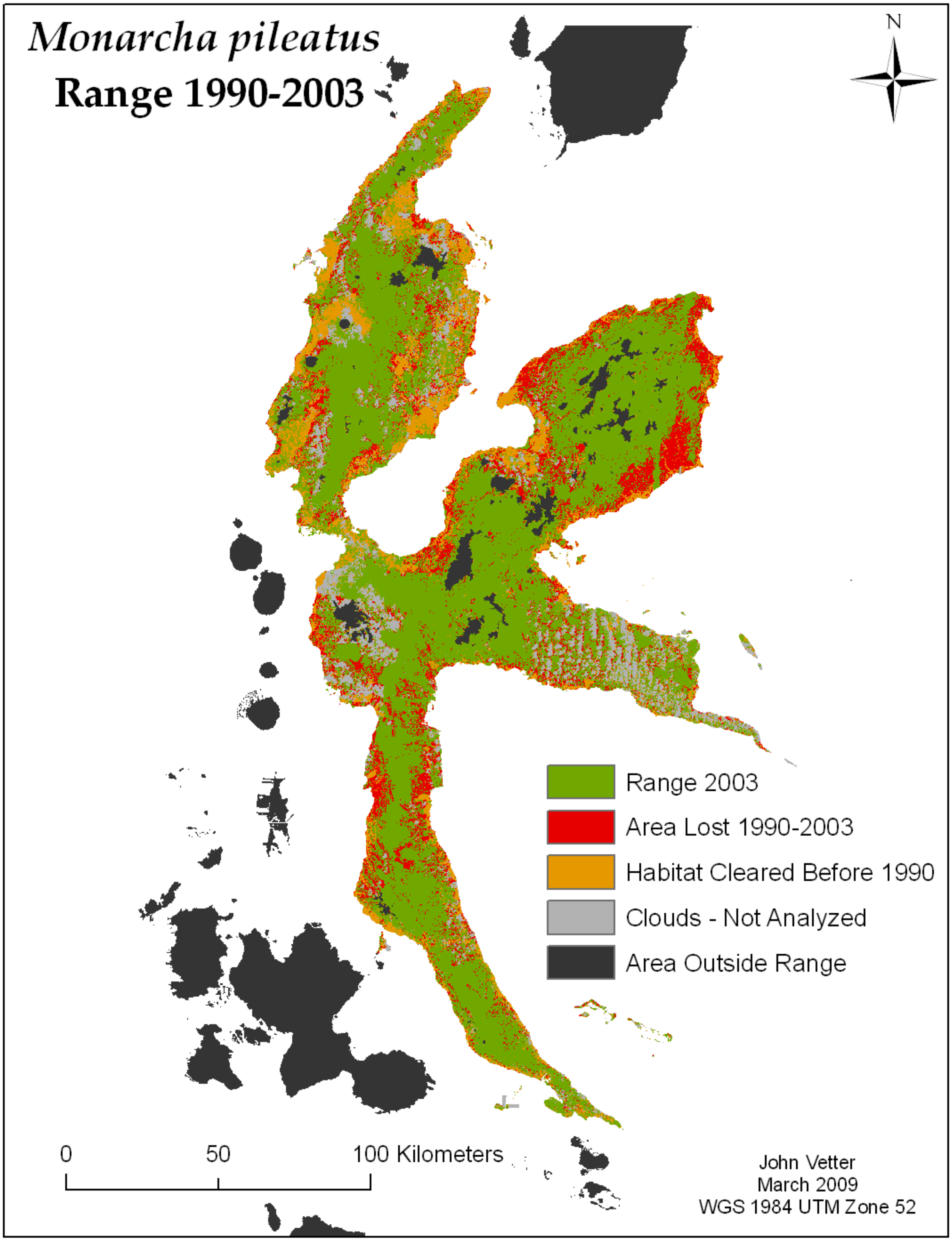

Figure Z – Map of the range from 2003 (Green) and 1990 (Green plus Red) for the White-naped Monarch (*Monarcha pileatus*). Gray areas are clouds and orange areas were secondary growth or unforested in 1990. Black areas are outside the species range.

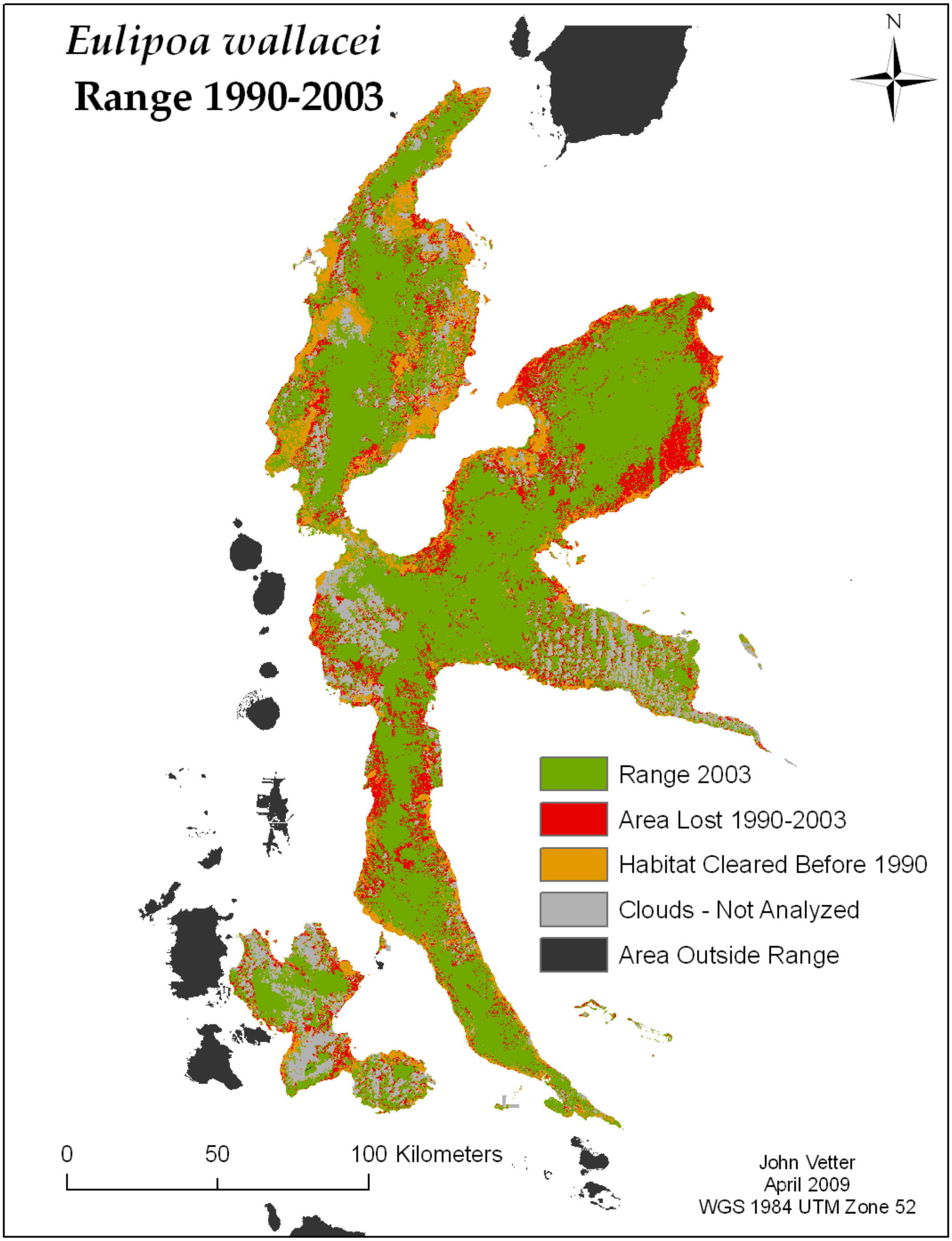

Figure AA – Map of the range from 2003 (Green) and 1990 (Green plus Red) for the Moluccan Megapode (*Eulipoa wallacei*). Gray areas are clouds and orange areas were secondary growth or unforested in 1990. Black areas are outside the species range.

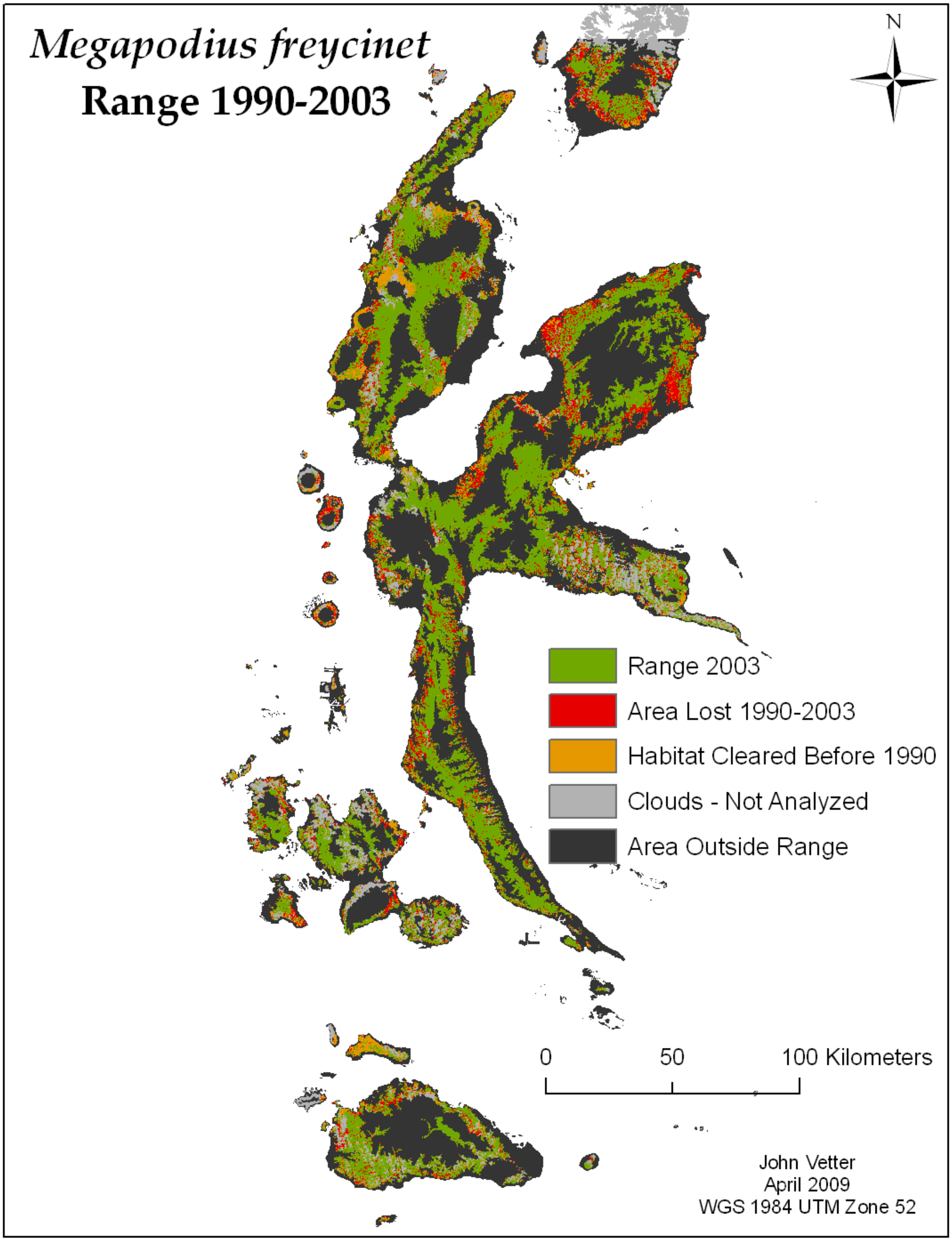

Figure BB – Map of the range from 2003 (Green) and 1990 (Green plus Red) for the Dusky Megapode (*Megapodius freycinet*). Gray areas are clouds and orange areas were secondary growth or unforested in 1990. Black areas are outside the species range.

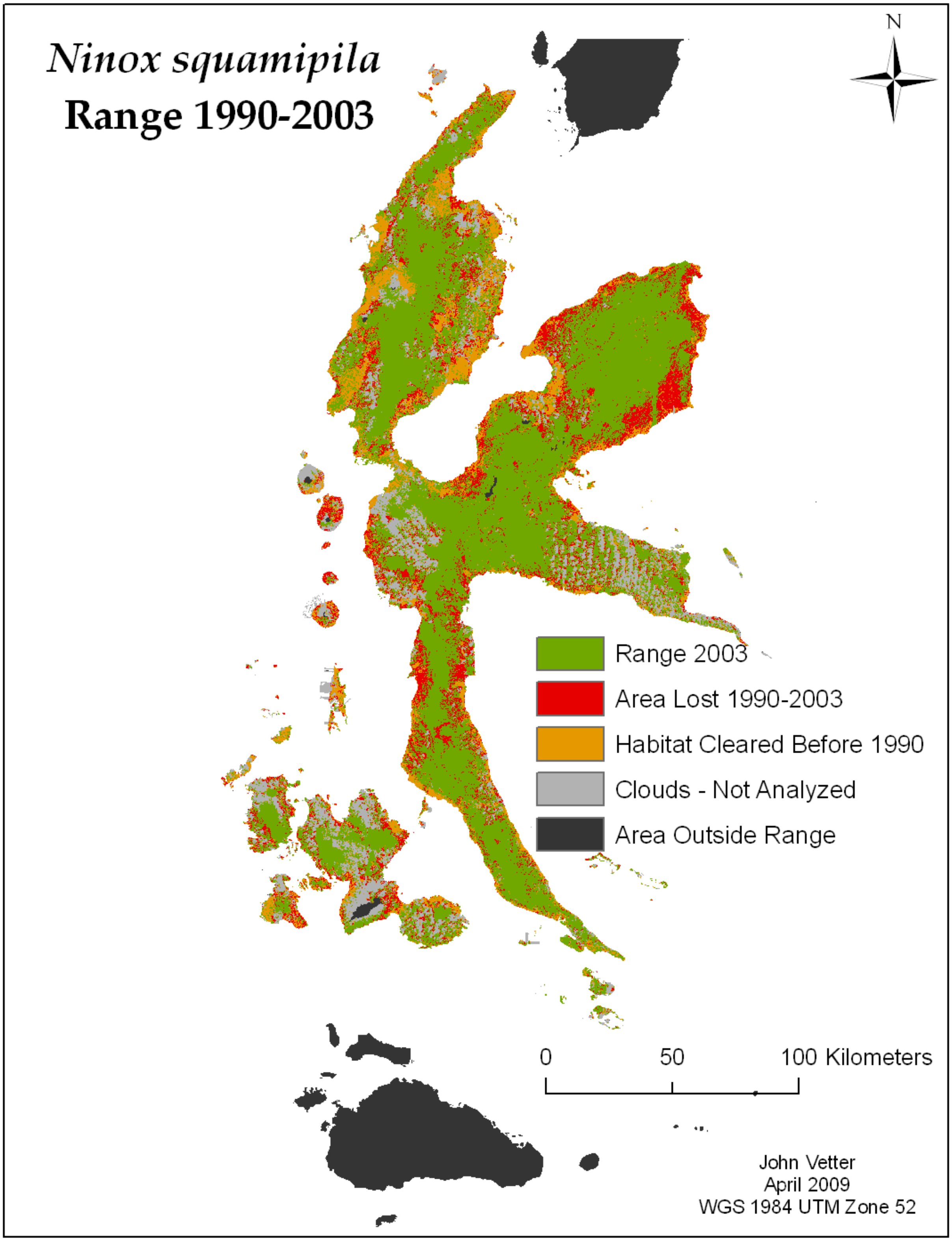

Figure CC – Map of the range from 2003 (Green) and 1990 (Green plus Red) for the Moluccan Hawk-owl (*Ninox squamipila*). Gray areas are clouds and orange areas were secondary growth or unforested in 1990. Black areas are outside the species range.

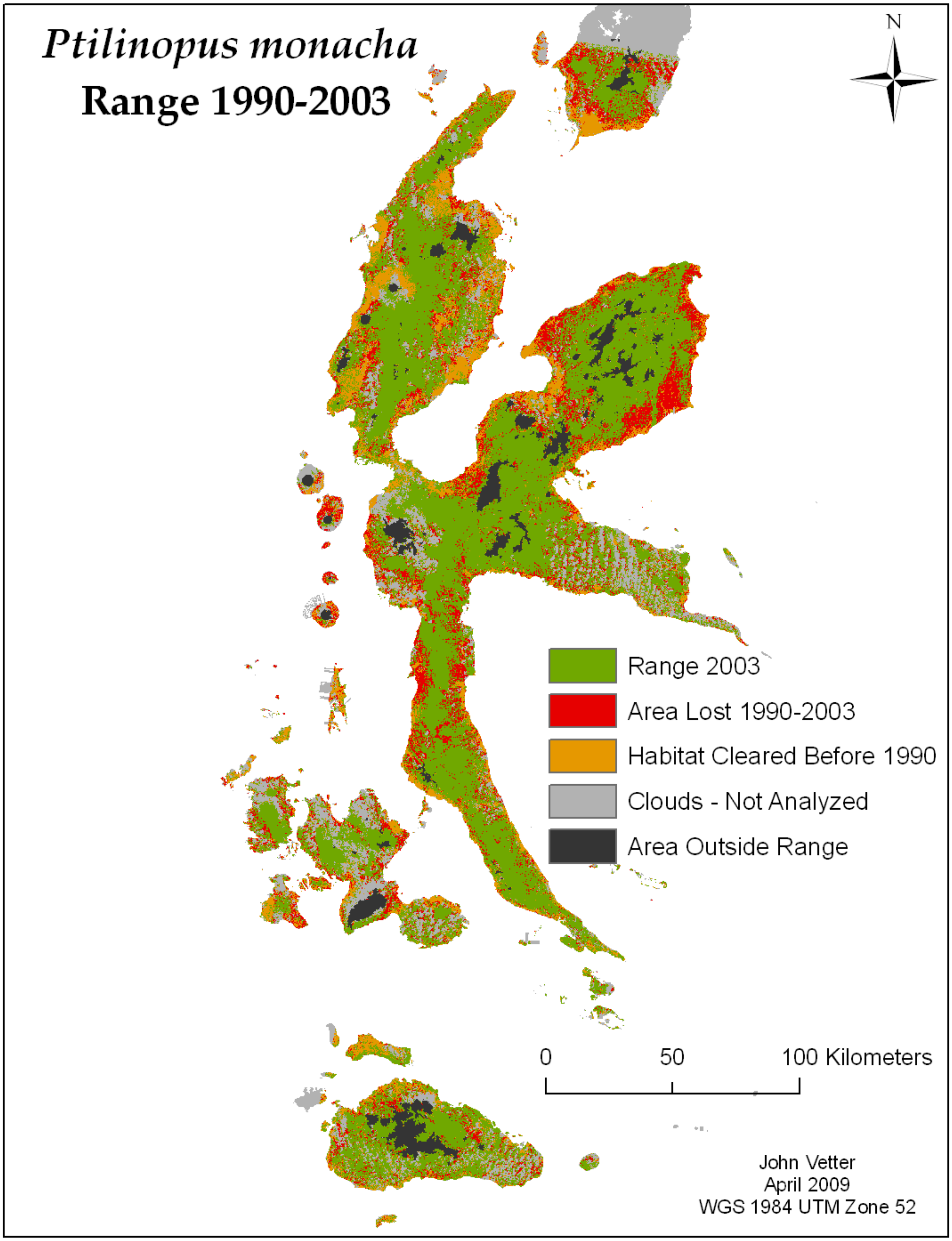

Figure DD – Map of the range from 2003 (Green) and 1990 (Green plus Red) for the Blue-capped Fruit-dove (*Ptilinopus monacha*). Gray areas are clouds and orange areas were secondary growth or unforested in 1990. Black areas are outside the species range.

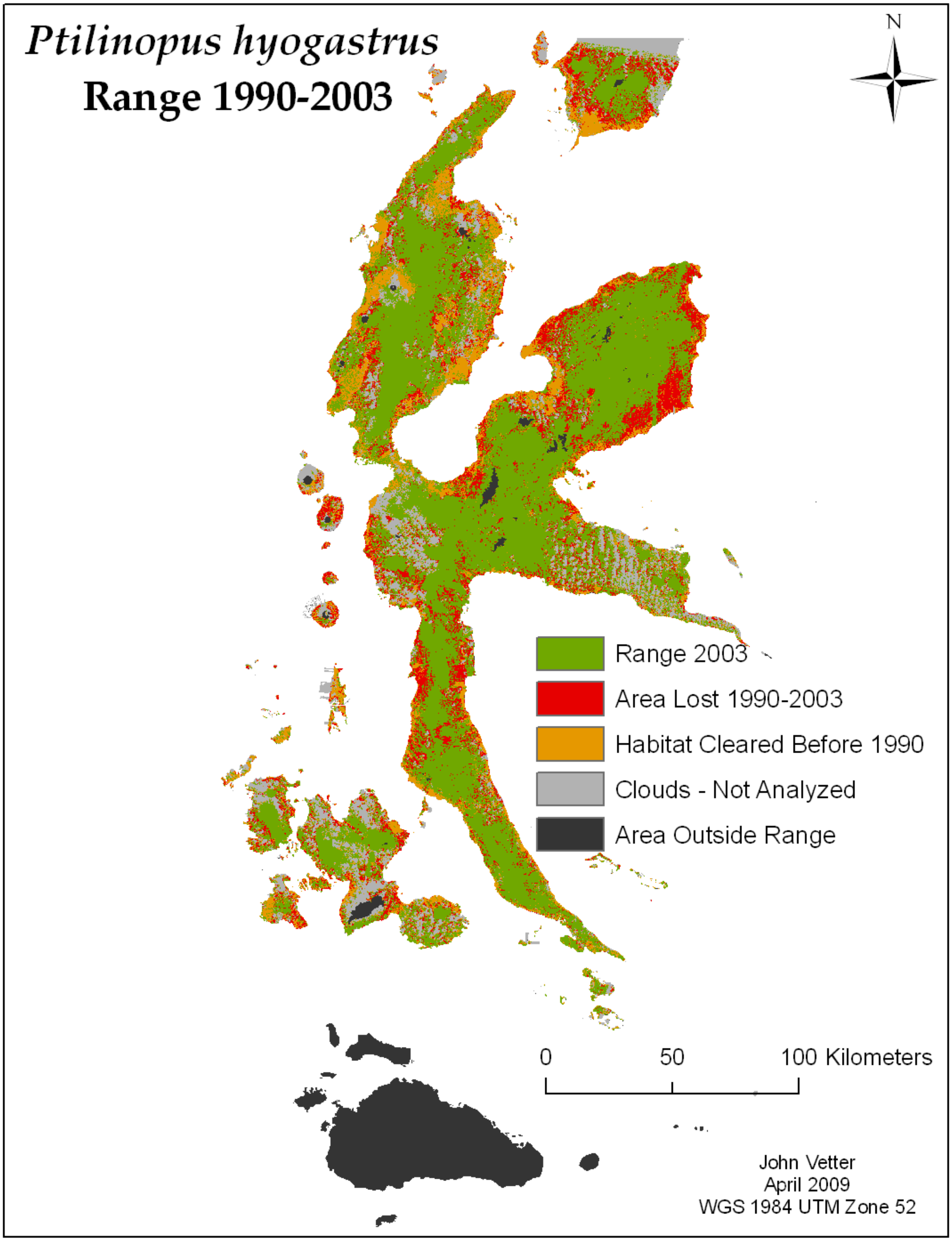

Figure EE – Map of the range from 2003 (Green) and 1990 (Green plus Red) for the Grey-headed Fruit-dove (*Ptilinopus hyogastrus*). Gray areas are clouds and orange areas were secondary growth or unforested in 1990. Black areas are outside the species range.

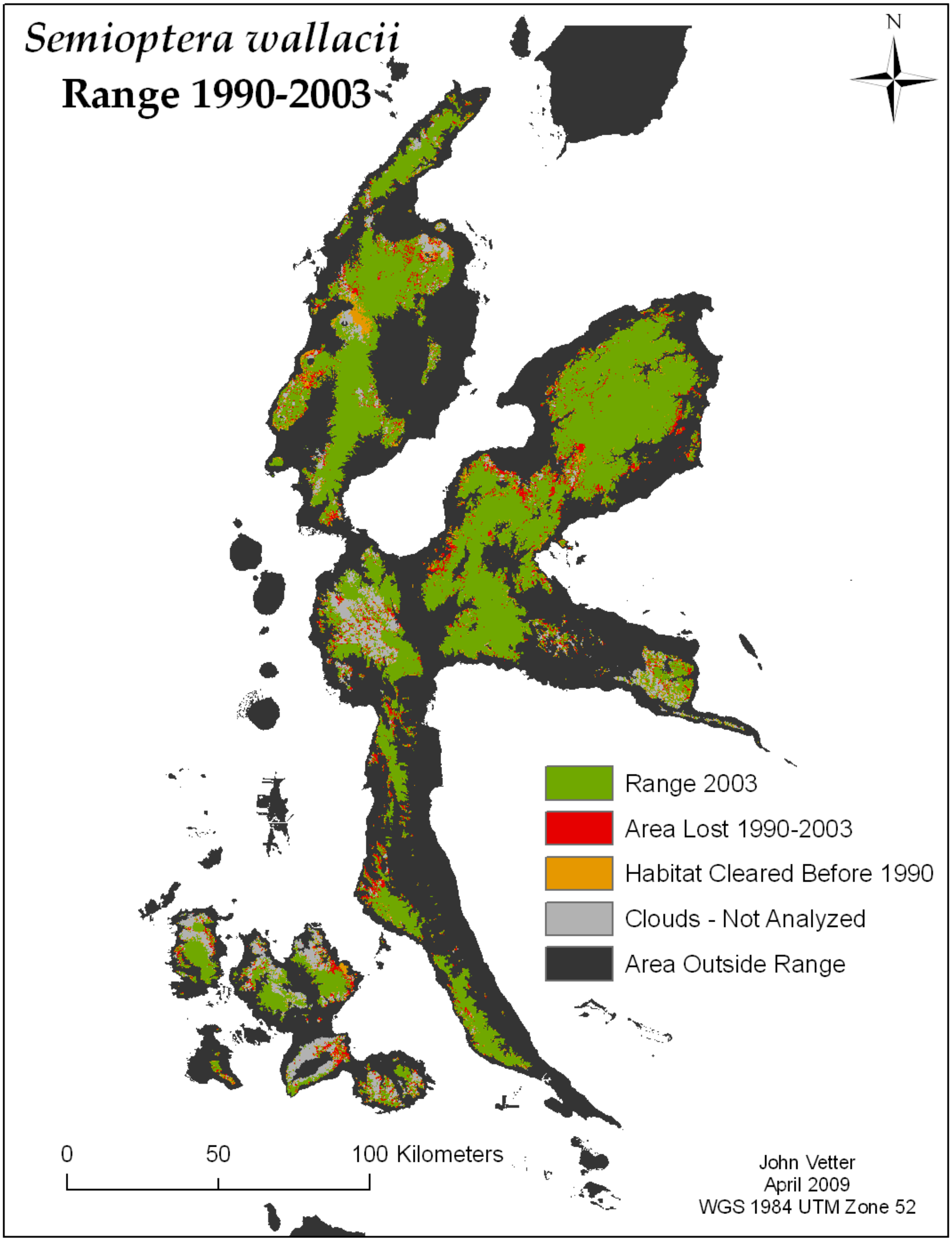

Figure FF – Map of the range from 2003 (Green) and 1990 (Green plus Red) for the Wallace's Standardwing (*Semioptera wallacii*). Gray areas are clouds and orange areas were secondary growth or unforested in 1990. Black areas are outside the species range.

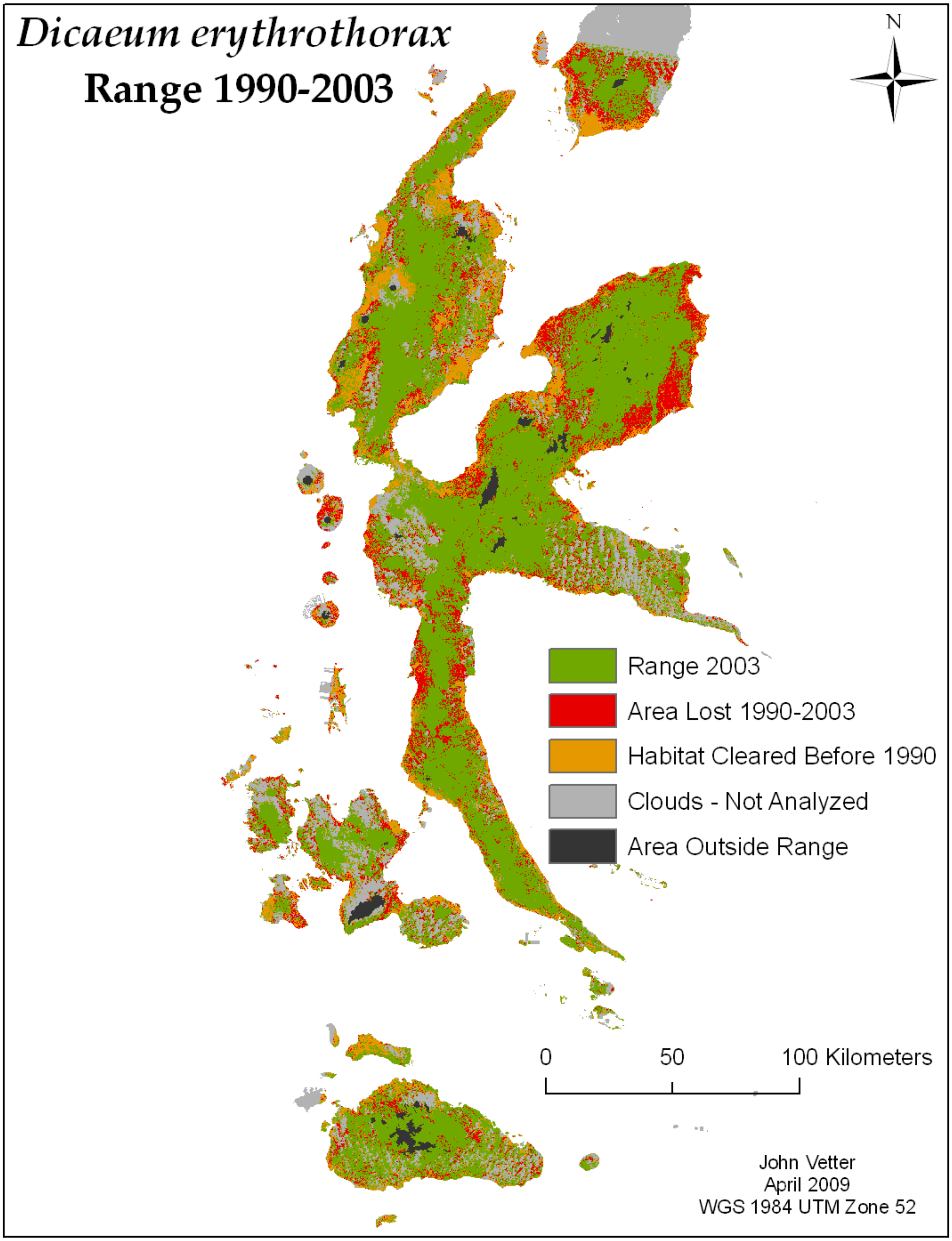

Figure GG – Map of the range from 2003 (Green) and 1990 (Green plus Red) for the Flame-breasted Flowerpecker (*Dicaeum erythrothorax*). Gray areas are clouds and orange areas were secondary growth or unforested in 1990. Black areas are outside the species range.

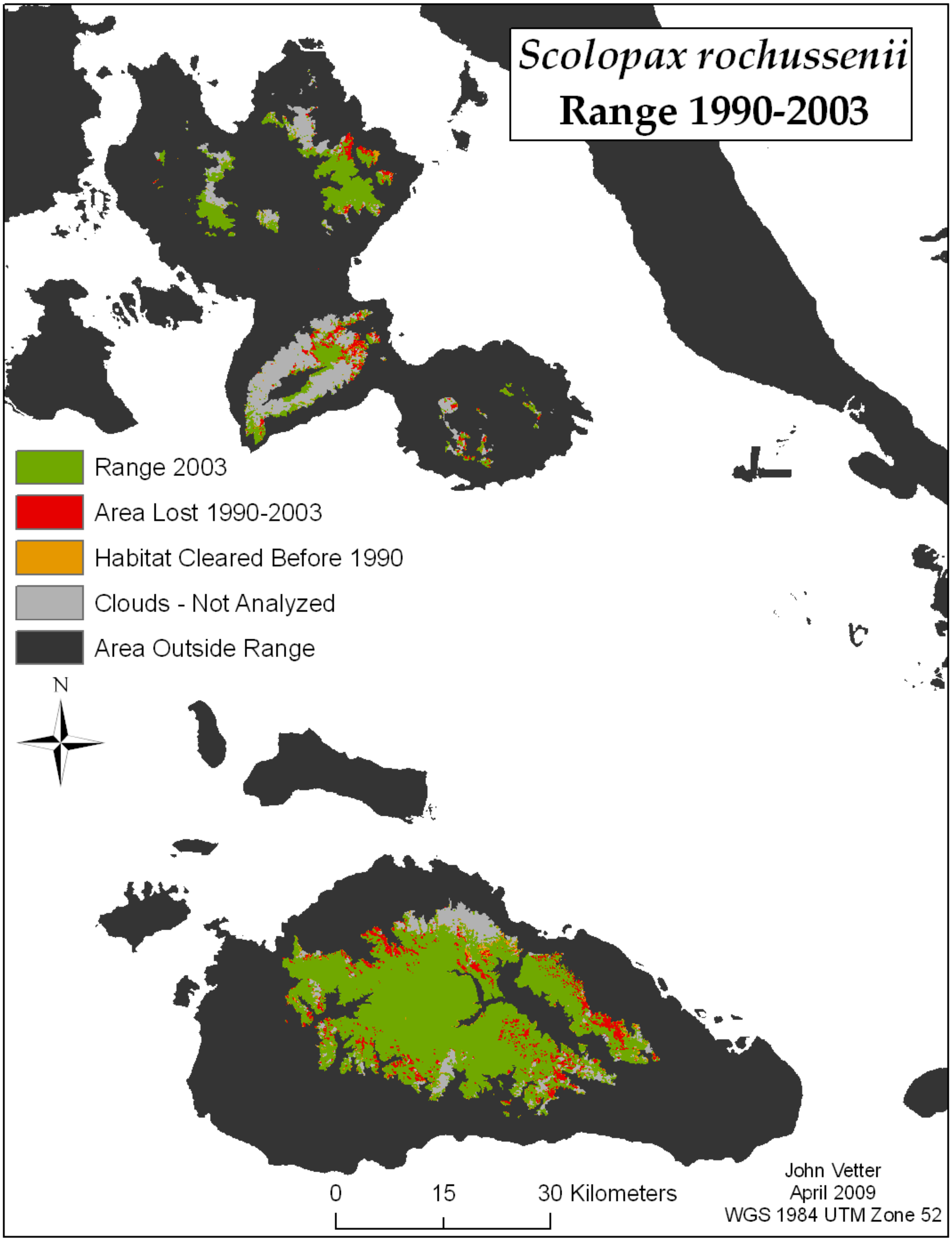

Figure HH – Map of the range from 2003 (Green) and 1990 (Green plus Red) for the Moluccan Woodcock (*Scolopax rochussenii*). Gray areas are clouds and orange areas were secondary growth or unforested in 1990. Black areas are outside the species range.

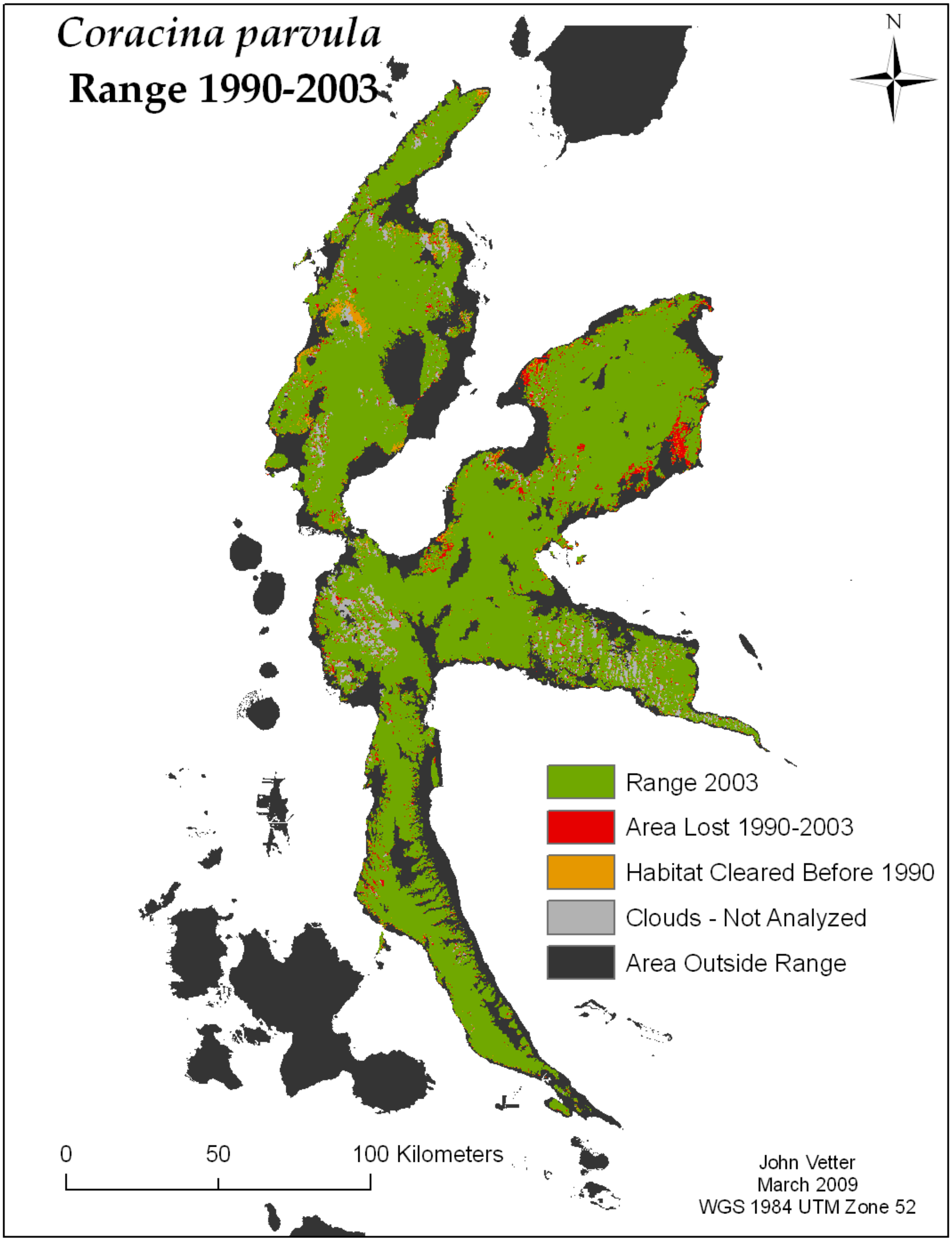

Figure II – Map of the range from 2003 (Green) and 1990 (Green plus Red) for the Halmahera Cuckooshrike (*Coracina parvula*). Gray areas are clouds and orange areas were secondary growth or unforested in 1990. Black areas are outside the species range.

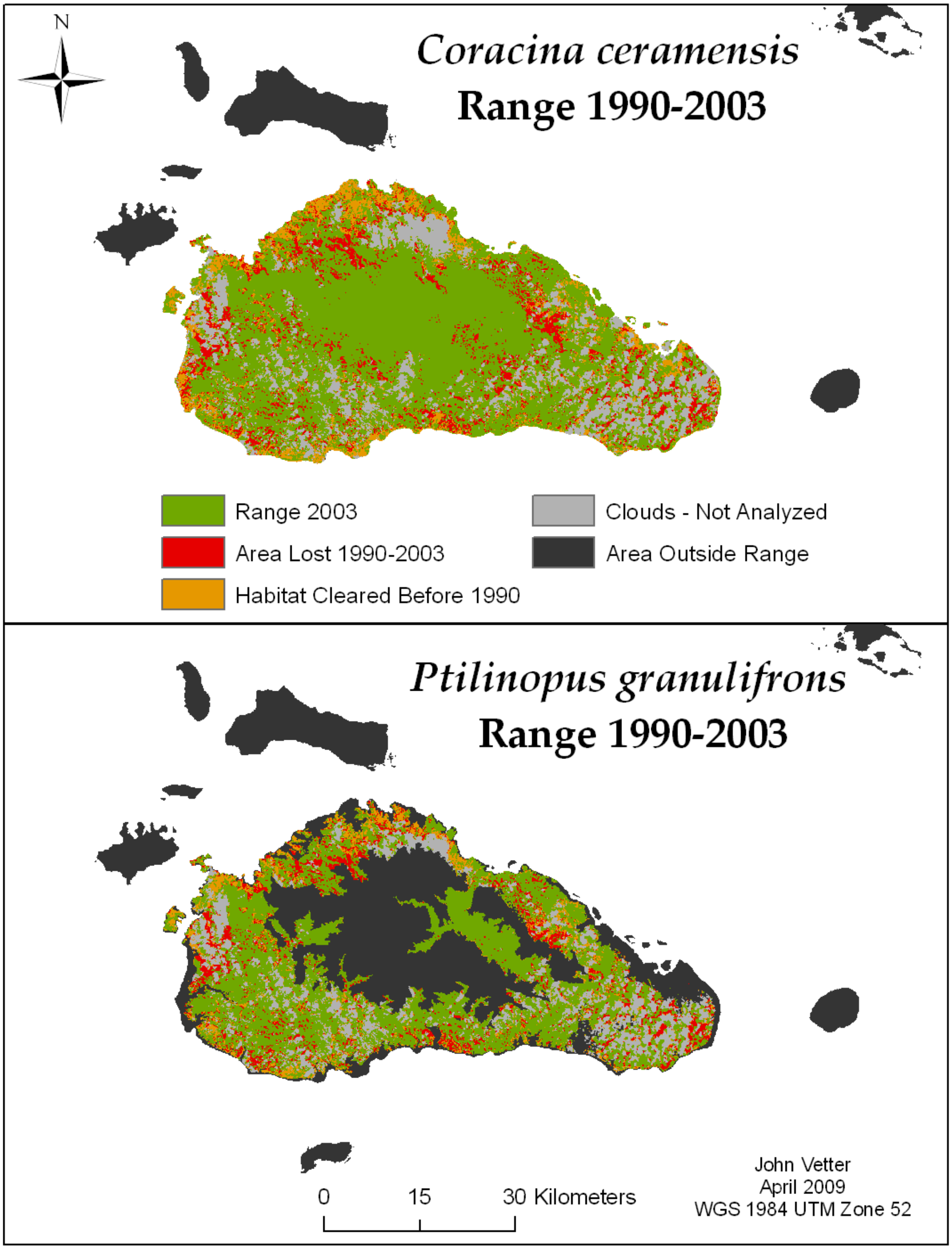

Figure JJ – Map of the range from 2003 (Green) and 1990 (Green plus Red) for the Pale Cicadabird (*Coracina ceramensis*) (top) and Carunculated Fruit-dove (*Ptilinopus granulifrons*) (bottom). Gray areas are clouds and orange areas were secondary growth or unforested in 1990. Black areas are outside the species range.

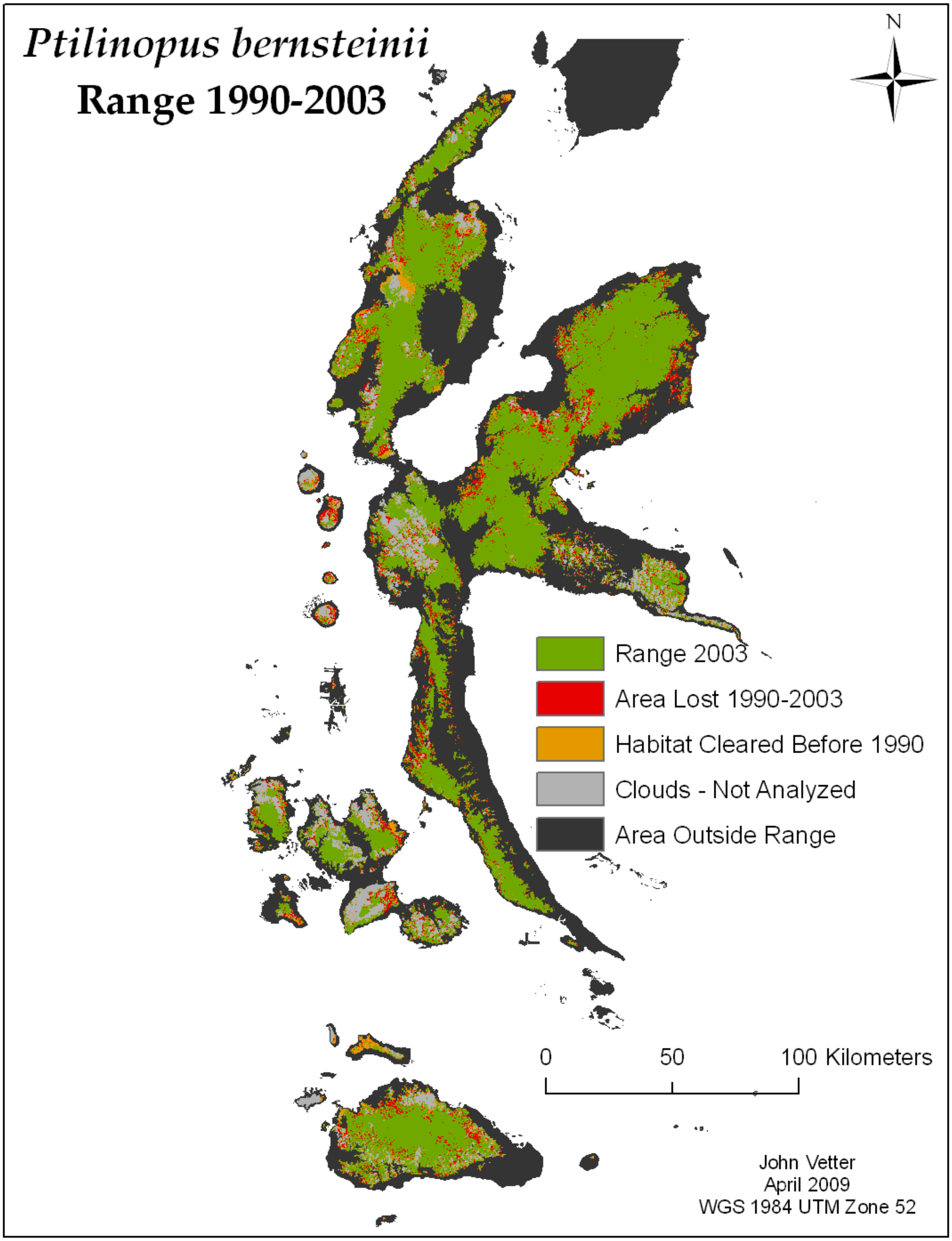

Figure KK – Map of the range from 2003 (Green) and 1990 (Green plus Red) for the Scarlet-breasted Fruit-dove (*Ptilinopus bernsteinii*). Gray areas are clouds and orange areas were secondary growth or unforested in 1990. Black areas are outside the species range.

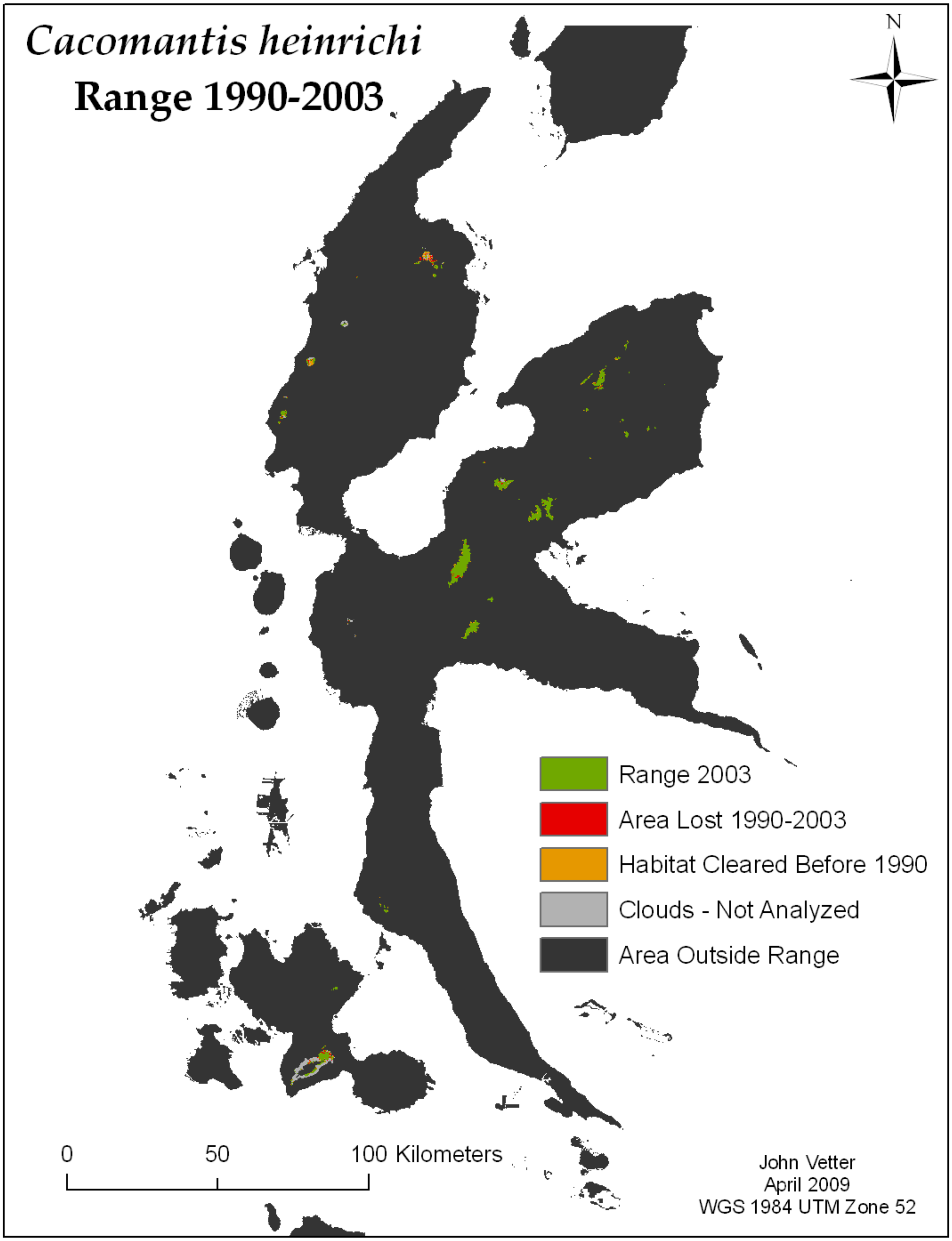

Figure LL – Map of the range from 2003 (Green) and 1990 (Green plus Red) for the Moluccan Cuckoo (*Cacomantis heinrichii*). Gray areas are clouds and orange areas were secondary growth or unforested in 1990. Black areas are outside the species range.