Bird Conservation International (1999) 9:351–372.

Status of the volcanically threatened Montserrat Oriole *Icterus oberi* and other forest birds in Montserrat, West Indies

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Summary

The Montserrat Oriole *Icterus oberi* is endemic to the Caribbean island of Montserrat where, prior to 1995, it was widely distributed across the island's three main interior mountain ranges: the Centre, Soufriere and South Soufriere Hills. In July 1995, a long-dormant volcano on Chances Peak in the Soufriere Hills began to erupt. Since then the forest habitat of the oriole on the Soufriere and South Soufriere Hills has been devastated by pyroclastic flows and surges, heavy ash eruptions and rock falls. The Montserrat Oriole populations that inhabited these two mountain ranges have probably been lost. In December 1997, a census of the remaining Centre Hills population was undertaken to assess its status in the face of the heavy ash fall that occurred earlier the same year. To do this, a systematic grid of 140 sample points was overlaid on an area of 1,437.5 ha encompassing the Centre Hills, and a 10-minute count of all bird species was undertaken at 137 of these points during an eight-day survey period. The distance from the point to each oriole detected was measured and records of all other species were allocated to one of five distance bands radiating out from the point. Distance sampling was used to model densities, and thus to estimate population sizes, of eight bird species in the study area. It was estimated that 4,000 (95% CIs 1,500–7,800) Montserrat Orioles remain in the Centre Hills and thus the world. Although the probability of pyroclastic flows and surges overrunning the Centre Hills is considered remote, it is recommended that the Montserrat Oriole be classified as Globally Threatened (Endangered) under the revised IUCN threat categories because of its loss of breeding habitat since 1995.

Introduction

In July 1995, a long-dormant volcano on Chances Peak in the Soufriere Hills at the southern end of the Caribbean island of Montserrat began to erupt (see Figure 1 for geographical locations). By November of the same year, a lava dome in the summit crater had begun to grow, signalling the start of an extended eruption typical of Caribbean andesite volcanoes (unpublished report, Montserrat Volcano Observatory 1997, Young 1997). Over the following two years, pyroclastic flows and heavy ash falls devastated much of the surroundings of the volcano including Plymouth, Montserrat's capital city. In 1997, the volcano entered a particularly active phase with regular eruptions sending ash plumes up to 10,000 m into the atmosphere with ash settling widely across the island, the extent of this dependent upon the wind direction prevailing at the time. All volcanic activity is closely monitored by the Montserrat Volcano Observatory (MVO) and the

https://doi.org/10.1017/S095927090000352X Published online by Cambridge University Press

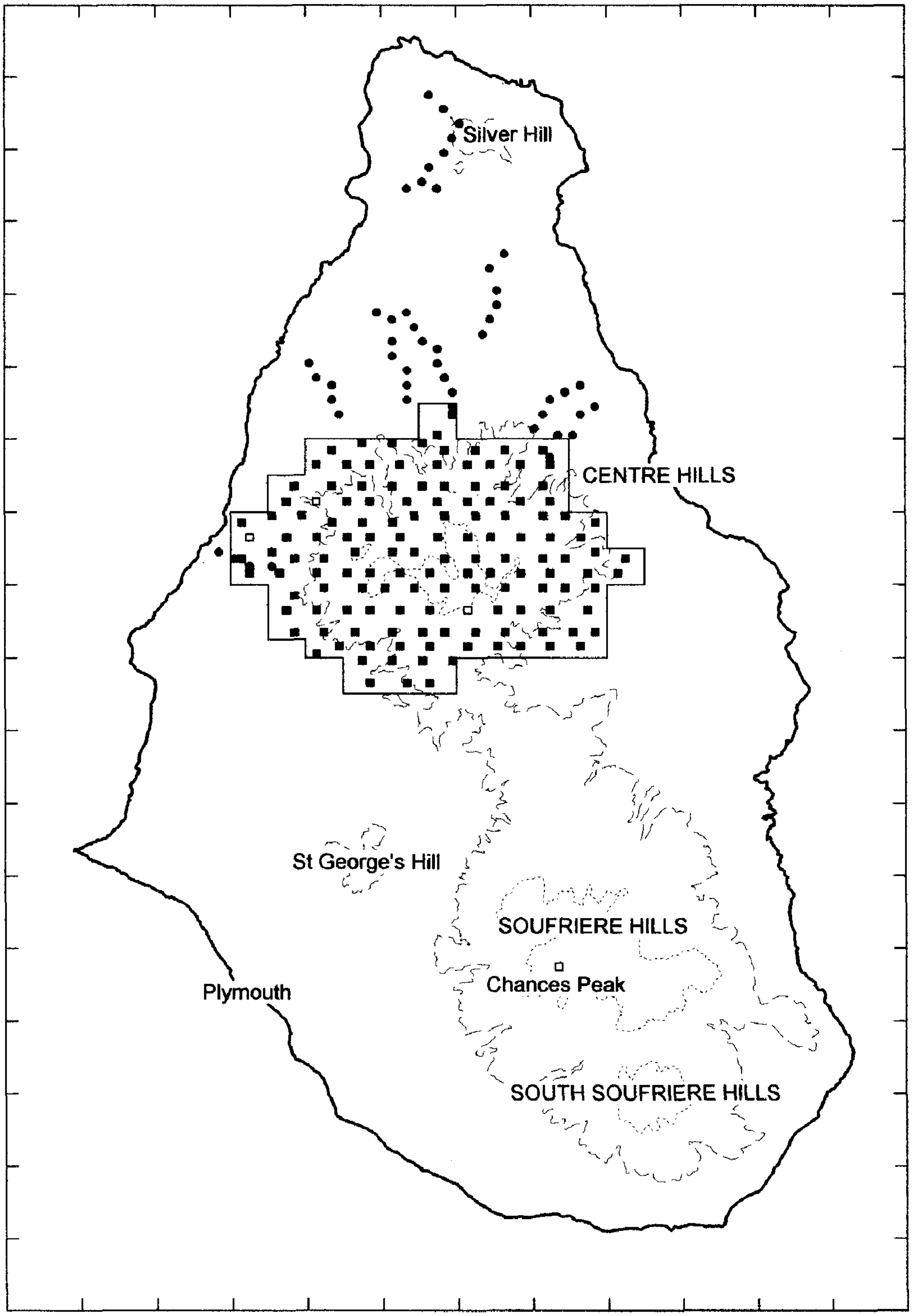

Figure 1. Map of Montserrat showing main mountain ranges. Dashed and dotted lines depict 1000′ (305 m) and 2000′ (610 m) contours respectively. The Centre Hills study area is outlined. The locations of the 140 points on the systematic sampling grid in the study area are denoted by small squares: filled for visited points, unfilled for points not visited. Filled circles denote the locations of fifty additional points sampled prior to the full census. The horizontal and vertical tick marks are 1-km eastings and northings of the British West Indies grid.

https://doi.org/10.1017/S095927090000352X Published online by Cambridge University Press

expectation is the Soufriere Hills volcano will continue to erupt for a few more years to come (unpublished report, MVO 1997).

While the continuing volcanic activity has had a devastating effect on the lives of Montserrat's human population, little is known about its effects on the island's wildlife. Of greatest concern are the threats to the island's endemic fauna, most notably the Montserrat Oriole *Icterus oberi*, the Galliwasp *Diploglossus montiserratii*, and an anolid lizard, *Anolis lividus*. Little is known about the Galliwasp (Schwartz and Thomas 1975, Schwartz *et al.* 1978), which is known only from the type specimen. The anolid lizard is, by contrast, well studied and widespread throughout the island; it is unlikely to be much threatened by the volcanic activity. However, the same is not true for the Montserrat Oriole, whose most important population was located in the Soufriere and South Soufriere Hills prior to the volcanic activity (Arendt and Arendt 1984, Arendt 1990). The island is also home to two endemic subspecies, the Black Snake *Alsophis antillensis manselli* and a ground lizard *Ameiva pluvianotata pluvianotata*, and to one of two populations of the Mountain Chicken *Leptodactylus fallax*, a frog that is also found on Dominica.

In October 1997, the Montserrat Ministry of Agriculture, Trade and the Environment (MATE) invited representatives from the Jersey Wildlife Preservation Trust (JWPT) and the Royal Society for the Protection of Birds (RSPB) to the island to assess the impacts of the volcanic activity on the island's wildlife. One of the main recommendations arising from this visit was that the status of the Montserrat Oriole population should be assessed as a matter of urgency. This paper reports the results of the subsequent status assessment which was undertaken as a partnership between MATE, RSPB, JWPT, WWF and the International Institute for Tropical Forestry (IITF), with additional support from the American Bird Conservancy.

The status of the Montserrat Oriole prior to 1995

Arendt and Arendt (1984) estimated that about 1,000–1,200 Montserrat Orioles were present on the island in 1984. This figure was based on estimates of oriole nesting densities obtained from a combination of mist netting (see Terborgh and Faaborg 1973) and variable-width line transects (Emlen 1971, 1977) at eight chosen sites widely scattered around the island. These census data were supplemented by "walking censuses" conducted in every major habitat throughout the island, and by information on territory size from their own observations of breeding Montserrat Orioles and from the literature on Northern Orioles *Icterus galbula* (Pleasants 1981). Overall population size was estimated by multiplying the estimated densities by the area of suitable habitat (forest and woodland). This was measured from a 1:25,000 land use map, itself based on interpretation of 1982 aerial photographs, and was estimated at 3,000 ha. Estimates as high as 12,000 breeding pairs (24,000 individuals) were entertained in the 1984 analyses, but were discarded owing to the violation of various assumptions contained in the analytic procedures. From a conservation and management viewpoint, it was thought best to be too conservative, rather than too liberal. Arendt and Arendt (1984) did not provide confidence intervals around their population estimate and stressed that it was a best guess in the absence of a more comprehensive census method.

Arendt (1990) and Evans (1990, unpubl. data) both suggested that Hurricane Hugo, which destroyed much of Montserrat's forests in September 1989, had little effect on the oriole's subsequent breeding population. Although Arendt (1990) made no attempt to estimate the size of the island's population in 1990, he observed 112 individual orioles during 90 fixed-radius point counts and suggested that the total population was still at least in the hundreds. Evans (1990, unpubl. data) suggested that Arendt and Arendt's 1984 estimate was too low, but did not provide an alternative.

While there remains some uncertainty about the population status of the Montserrat Oriole prior to volcanic activity, its distribution was well known. Arendt and Arendt (1984) showed that there were three main strongholds, each associated with one of the island's three main interior mountain ranges; these were, from north to south, the Centre, Soufriere and South Soufriere Hills (Figure 1). These ranges between them encompassed all the major forest types (dry, moist, wet and dwarf at increasing elevations, respectively) inhabited by orioles. Although orioles have been recorded at lower elevations in the more xerophytic scrub and even as close as 23 m from the sea, such records are rare. Arendt and Arendt's (1984) results showed that the densities of orioles in the Soufriere and South Soufriere Hills were greater than those of the Centre Hills, though birds redistributed following Hurricane Hugo (Arendt 1990, see below).

Habitat loss as a consequence of volcanic activity on Montserrat

The forest habitat surrounding the Soufriere Hills has been entirely destroyed by pyroclastic flows, and its population of orioles – previously the largest – must be considered lost. Until late December 1997, the forests of the South Soufriere Hills had been partially protected from pyroclastic flows by a high level ridge (the "Galway Wall") and there was hope that the "bamboo forest" of the South Soufriere Hills might still harbor orioles. On 26 December 1997, this wall was breached by pyroclastic flows and surges spreading southward from the volcano, almost to the summit of the South Soufriere Hills (unpublished report by E. S. Calder, S. R. Young, R. S. J. Sparks, J. Barclay, B. Voight, R. A. Herd, R. Luckett, G. E. Norton, L. Pollard, L. Ritchie and R. E. A. Robertson 1998). Though there is a small chance that some orioles may still occur in this region, their fate will remain unknown for some time, as the area remains isolated, deep within a government-imposed exclusion zone extending across much of the southern two-thirds of the island. The orioles in the Centre Hills thus form the only known extant population. Given the reasonably high elevation of much of the Centre Hills and the topography of the land between it and the Soufriere Hills volcano, it is unlikely that this area will be overrun by pyroclastic flows. It is, however, frequently subjected to ash falls, heavily so in autumn 1997. Here we report on a comprehensive survey of the remaining population of the Montserrat Oriole, now limited to the Centre Hills.

Study area and methods

Timing and species coverage

The census of the Centre Hills was undertaken during 3–10 December 1997. Fieldwork was carried out by the authors and up to seven of MATE's forestry

https://doi.org/10.1017/S095927090000352X Published online by Cambridge University Press

staff, generally working in teams of three or four. The survey was undertaken in the non-breeding season. Although it would have been ideal to survey during the breeding season, fears for the survival of the species in the face of continued heavy ashing from the volcano in autumn 1997 required that the census be undertaken earlier.

Although the Montserrat Oriole is the only single-island endemic species of bird on the island, a four-island endemic, the Forest Thrush *Cichlherminia lherminieri* also occurs. Therefore, all species of birds encountered within the Centre Hills were included in the survey as monitoring of these species may provide additional information on the state of health of the island's avifauna in general.

The Centre Hills study area

The survey area comprised 1,437.5 ha (Figure 1). The precise boundary within which the survey was undertaken was determined from mapped information contained within Arendt and Arendt (1984) and from the local knowledge of MATE's forestry staff. This boundary encompassed nearly all major forest types (moist, wet and dwarf) within the Centre Hills and even extended into dry forest at lower elevations. It is possible that a very small amount of suitable oriole habitat existed outside the southern edge of the survey area, though still within the Centre Hills. However, the extent of this area was very small compared with that included within the survey area (*c.* 5% of surveyed area). It was omitted because it was too far into the exclusion zone and thus considered unsafe for fieldwork.

Sampling design

A systematic grid of 140 sample points was overlaid on a 1:25,000 map of the study area (Figure 1). The number of points to be covered was based upon the number of days available for the work, and the number of points it was estimated could be covered each day. A few hundred metres separated each point. Although the grid was systematic, sample points fell at random with respect to habitat, sometimes falling in steep-sided ravines (known locally as "ghauts"), sometimes on ridges and sometimes in between.

Field methods

Each point was to be visited once during the survey period, though in practice three were missed (see Results). Gaining access to the points was physically demanding, sometimes dangerous and frequently required paths to be cut through the vegetation with machetes. Given the terrain and the scale of the map, the precise location of each point was not always easy to determine on the ground. Despite this, every attempt was made to get as close as was practically possible to the location of each mapped point, often relying on a compass and a "hip-chain" distance-measuring device. Although a global positioning system (GPS) was available, it did not function properly.

Once at a point, each team of observers waited for two minutes before undertaking a 10-minute count of all individuals of all species heard and/or seen. The radial distance from the point to the location at which each oriole was first detected was measured, either with a tape measure or by pacing if the number of paces per metre for the observer was known (usually *c.* 1.15 paces/m). For all other species, each record was allocated to one of five distance bands radiating out from the point: 0–5 m, 5–10 m, 10–20 m, 20–40 m and greater than 40 m. For analytical purposes, the outer limit of the most distant band was taken as 80 m; it is unlikely that any birds were recorded at greater distances than this.

Whenever individuals of species other than orioles were clustered together, the distance band within which the cluster fell was recorded, rather than that of each individual bird. The reason for this was that distance measurements were central to the subsequent analyses and distances to individual birds within a cluster could not be considered statistically independent of one another. In practice, most records were of individuals rather than clusters (see Results). The number of birds in each cluster was also recorded. For orioles, although it was sometimes clear that birds were clustered together (e.g. as a pair), on other occasions it was much less clear. To overcome any subjectivity, an arbitrary decision rule was used to discriminate between individuals and clusters: orioles first recorded within 15 m of one another were considered to be part of the same cluster, if they were further apart than this they were treated as separate individuals. The distance to each cluster was calculated as the mean distance to each individual in the cluster. A separate set of analyses, which treated each individual oriole as an independent data point, was run but is not presented here as the results were extremely similar to those which used clusters.

At the end of each 10-minute count, three minutes of a continuous tape of Montserrat Oriole vocalizations was played at maximum volume (*c.* 90–100 dBs) on a portable tape-recorder. The vocalizations were taken from a recording of a young male oriole, originally recorded at Galway's Soufriere in the Soufriere Hills in May 1992. Numbers of orioles, and distances to each, were recorded using the methods outlined for the 10-minute silent period. The data for the two periods were kept separate.

Additional observations

Prior to the Centre Hills census, from 26 November to 1 December 1997, fifty additional points were sampled in the remaining forested ravines in the northern half of the island, mostly outside of the main study area. The method used at these points (*sensu* Hutto *et al.* 1986) was similar, but with the following exceptions: counting stations were placed along a transect at 100-m intervals rather than allocated on a systematic grid, birds were categorized into two distance bands, up to and beyond 25 m, and no tape playback was used.

Orioles were sometimes recorded while walking through the Centre Hills, mostly when moving between counting stations. Wherever possible, the approximate grid reference of each oriole or cluster of orioles was recorded, as was the number of individuals present and their sex.

Density and population estimation

Densities, and thus population sizes, of all species for which sufficient information was obtained were estimated using distance sampling. Buckland *et al.* (1993)

provide a comprehensive explanation of this method. In brief, to determine the density of a given species in the study area, it was necessary to estimate the number of birds that were present around each point, but which were not detected. This was calculated from the way in which the number of birds detected declined with distance, assuming that if birds were randomly distributed across the forest then there would have been similar numbers in equal-area distance bands at different distances from the observer. On the assumption that all birds present at the point were recorded, it was possible to model the way detectability (or detection probability: the proportion of birds actually present that were detected) declined with distance. Once this was determined, the number of birds missed could be estimated and added to those counted to calculate the total numbers present.

To determine the precise manner in which detection probability varies with distance (the "detection function"), Buckland *et al.* (1993) suggested fitting several separate *a priori* models – uniform, half-normal and hazard-rate – to determine which fits the distance data best. Detection probability declines steeply with distance in the hazard-rate model, and increasingly less so for the half-normal and uniform models (see Buckland *et al.* 1993, p. 47). Within each model it is possible to use cosine, simple and hermite polynomial series expansions to adjust the key function to improve the fit of the model to the data. We have followed Buckland *et al.*'s suggestions and have used four separate combinations of key functions and expansions: a uniform key function with both cosine and polynomial adjustments, a half-normal key with hermite adjustments and a hazard-rate key with cosine adjustments.

For each of these four separate models, several submodels were tested, each with an increasing number of adjustment parameters. Within each model, the submodel that fit the data best was determined using Akaike's Information Criterion (AIC; this statistic identifies a model that fits the data well, but with as few parameters as possible). The best overall model was then selected in the same manner. Although AIC allowed a comparison among models to determine which fit the data best, it did not allow a statistical assessment of how well it fit. This was done with a χ^2 Goodness of Fit (GoF) test, which compared the number of clusters recorded in each distance band with the number predicted by the model.

Density and population estimation was undertaken using DISTANCE software (Laake *et al.* 1993). For each species, separately, this fit the chosen models to the data, selected the best one and estimated mean densities and population sizes in the study area based on this model. 95% CIs were calculated by bootstrapping (1,000 iterations).

Results

Numbers of each species recorded

Of the 140 points, 137 were visited, and at these 733 clusters encompassing 770 individual birds of 27 different species were recorded during the 10-minute silent periods. The four-letter codes of each of these species are listed in Table 1, as are the number of clusters and individuals of each species in each distance band.

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Table 1. Number of clusters and individual birds recorded in each distance band. Number of individual birds is given only if it was different to the number of clusters. See Appendix for explanation of species codes.

Species code	No. of clusters (birds in parentheses) in each distance band (m)						Total no. of clusters (birds)
	0–5	5–10	10–20	20–40	40–80	Unknown	
ACHU[a]	36	13	2	2	0	0	53
AMKE	1	0	1	1	0	0	3
ANEU	0	0	1	0	0	0	1
BANA[a]	51	62 (66)	43 (48)	20 (21)	5	5	186 (196)
BFGR	1	1	2 (3)	0	0	0	4 (5)
BWVI	0	0	1	0	0	0	1
CAEL[a]	9 (10)	23	24 (25)	16	5	0	77 (79)
CMWA	1	0	0	0	0	0	1
FOTH[a]	1	8	15	10	1	0	35
GNBH	0	1	0	1	0	0	2
GRAK	0	0	1	0	0	0	1
GTCA	1	0	2	0	0	0	3
HOWA	0	0	0	0	0	1	1
LESB	3	6 (8)	1	0	0	0	10 (12)
LOWA	1	0	0	1	0	0	2
MACU	0	0	1	0	0	0	1
MTOR[a]	2 (4)	8 (10)	6 (10)	6 (8)	7 (8)	0	29 (40)
NOPA	0	0	1	0	0	0	1
PETH[a]	18 (19)	54 (56)	83 (89)	54	13	2 (3)	224 (234)
PTCA	4	6	0	2	0	0	12
SBAN	0	0	0	0	1	0	1
SBTH[a]	4	13	15	7	4	0	43
SNPI	2 (3)	2	3	0	1	0	8 (9)
TREM[a]	7	7	4	10	2	1	31
UNID	0	0	0	0	0	1	1
YTVI	0	0	1	0	0	0	1
ZEND	0	0	1	0	0	0	1
Totals	142(147)	204(214)	208(225)	130(133)	39(40)	10(11)	733(770)

[a]Species with 20 or more records in total.

The exact distance measures for orioles have been retrospectively categorized into the same bands used for other species for ease of comparison. The vernacular and scientific names of all species along with their codes are given in the Appendix. The manner in which the number of clusters (and individual birds) recorded declined with distance is clear from Table 1; across all species more than three times as many clusters and individual birds were seen within 20 m (554 clusters, 586 individuals) as between 20 and 80 m (169 clusters, 184 individuals). This effect becomes even more apparent if the area encompassed by each distance band is taken into account: 0–20 m covers 1,257 m^2 while 20–80 m covers 18,852 m^2. It is also clear that there was great variation among species in the effect of distance on the numbers detected. Antillean Crested Hummingbirds, for example, were rarely recorded beyond 10 m, while Montserrat Orioles and Gray Tremblers were frequently recorded beyond this distance (Table 1). This interspecific difference in detection probability was due, at least in part, to differences in body size. Using weight as a measure of body size, a greater proportion of clusters was recorded within 10 m than beyond for lighter

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Table 2. The influence of tape playback. Number of Montserrat Oriole clusters (individual orioles in parentheses, if different) in each distance band during two separate periods: 10 minutes of silence then 3 minutes of tape playback

Period	No. of clusters (birds) in each distance band (m)						Total no. of clusters (birds)
	0–5	5–10	10–20	20–40	40–80	Unknown	
Silent	2 (4)	8 (10)	6 (10)	6 (8)	7 (8)	0	29 (40)
Tape	10 (19)	8 (12)	7 (13)	7	2	3	37 (56)

species than for heavier species. (Rank correlation of proportion of clusters recorded within 10 m against body weight across all species with 10 or more clusters, $rs = -0.77$, $n = 10$, $P < 0.01$. Proportions of clusters taken from Table 1, body weights from unpublished data.) Differences in vocalizations between species may also account for part of this interspecific variation.

Forty percent more orioles were recorded during the three minutes of tape playback than during the 10-minute silent period (Table 2). However, orioles were also recorded closer during the playback, strongly suggesting that the tape lured birds towards the observer (chi-squared 2x2 contingency comparing the number of individual orioles recorded up to 5 m from the observer with the number beyond, during the silent and tape periods, $\chi^2 = 6.9$, $df = 1$, $P < 0.01$; the same analyses for oriole clusters fell just short of significance, $\chi^2 = 3.8$, $df = 1$, $P = 0.06$). Because one of the assumptions of distance sampling is that observers should not influence the location of birds (see Discussion), the data from the tape period were not used in density or population estimation.

Model fitting

Models to determine the manner in which detection probability varied with distance were run for all eight species with more than 20 records (Table 1). For each species, detection probability declined markedly with distance. This was particularly so for seven species (including the Montserrat Oriole) for which the hazard-rate model with no adjustments fit the data best (Table 3). The data for the remaining species (Forest Thrush) were best fit to a half-normal model, again with no adjustments. Given the density of the vegetation in many areas of the Centre Hills, it is perhaps not surprising that detection probabilities declined so steeply with distance.

Detection functions are illustrated for the Montserrat Oriole and three other selected species (Pearly-eyed Thrasher, Bananaquit and Forest Thrush) in Figure 2. For the Montserrat Oriole (Figure 2a), the hazard-rate model predicted that nearly all oriole clusters (*c.* 97%) within 8.75 m were located, while just under half (*c.* 43%) between 8.75 m and 17.5 m were. The detection probabilities for the Pearly-eyed Thrasher were similar (Figure 2b), with all clusters up to 10 m, and about 40% between 10 m and 20 m, detected. For Bananaquits, detection probability declined more steeply (Figure 2c), with all clusters within 5 m, but only about 40% between 5 m and 10 m, detected. Interestingly, for the Forest Thrush, detection probability was lower at 0–5 m compared with 5–10 m (Figure 2d). The most likely reason for this was that Forest Thrushes moved away from the obser-

Table 3. Model selection for all species. Models have been fit to grouped (five bands) distance data, except for Montserrat Oriole (MTOR) for which they were fit to measured distance data. The Goodness-of-Fit (GoF) statistic is given for the best model for each species

Species code	No. points	No. clusters	Model (key+adjust)	No. parametres		AIC	χ^2 GoF	*df*	*P*
				Key	adjust				
ACHU	137	53	Uniform + cosine	0	4	272.86			
			Uniform + polynomial	0	4	370.66			
			Half-normal + hermite	1	0	127.71			
			Hazard-rate + cosine	2	0	96.81[a]	2.18	2	0.34
BANA	135	181	Uniform + cosine	0	4	690.39			
			Uniform + polynomial	0	3	940.01			
			Half-normal + hermite	1	0	604.64			
			Hazard-rate + cosine	2	0	515.42[a]	1.67	2	0.43
CAEL	137	77	Uniform + cosine	0	4	255.09			
			Uniform + polynomial	0	4	326.28			
			Half-normal + hermite	1	0	252.57			
			Hazard-rate + cosine	2	0	232.57[a]	0.78	2	0.68
FOTH	137	34	Uniform + cosine	0	4	96.53			
			Uniform + polynomial	0	3	122.53			
			Half-normal + hermite	1	0	90.24[a]	261	3	0.46
			Hazard-rate + cosine	2	0	91.45			
MTOR	137	29	Uniform + cosine	0	4	240.86			
			Uniform + polynomial	0	4	245.30			
			Half-normal + hermite	1	0	246.73			
			Hazard-rate + cosine	2	0	236.63[a]	3.50	5	0.62
PETH	135	220	Uniform + cosine	0	4	658.03			
			Uniform + polynomial	0	3	828.60			
			Half-normal + hermite	1	0	661.80			
			Hazard-rate + cosine	2	0	634.80[a]	2.71	2	0.26
SBTH	137	43	Uniform + cosine	0	4	145.22			
			Uniform + polynomial	0	4	176.31			
			Half-normal + hermite	1	0	145.39			
			Hazard-rate + cosine	2	0	130.43[a]	0.32	2	0.85
TREM	136	30	Uniform + cosine	0	4	115.55			
			Uniform + polynomial	0	4	132.36			
			Half-normal + hermite	1	0	110.83			
			Hazard-rate + cosine	2	0	99.53[a]	6.24	2	0.04

[a]Denotes the best model (smallest value of Akaike's Information Criterion, AIC). Note that it is not possible to use AIC to compare between the models for different species. The closer the GoF *P*-value is to 1, the better the fit of the model to the data.

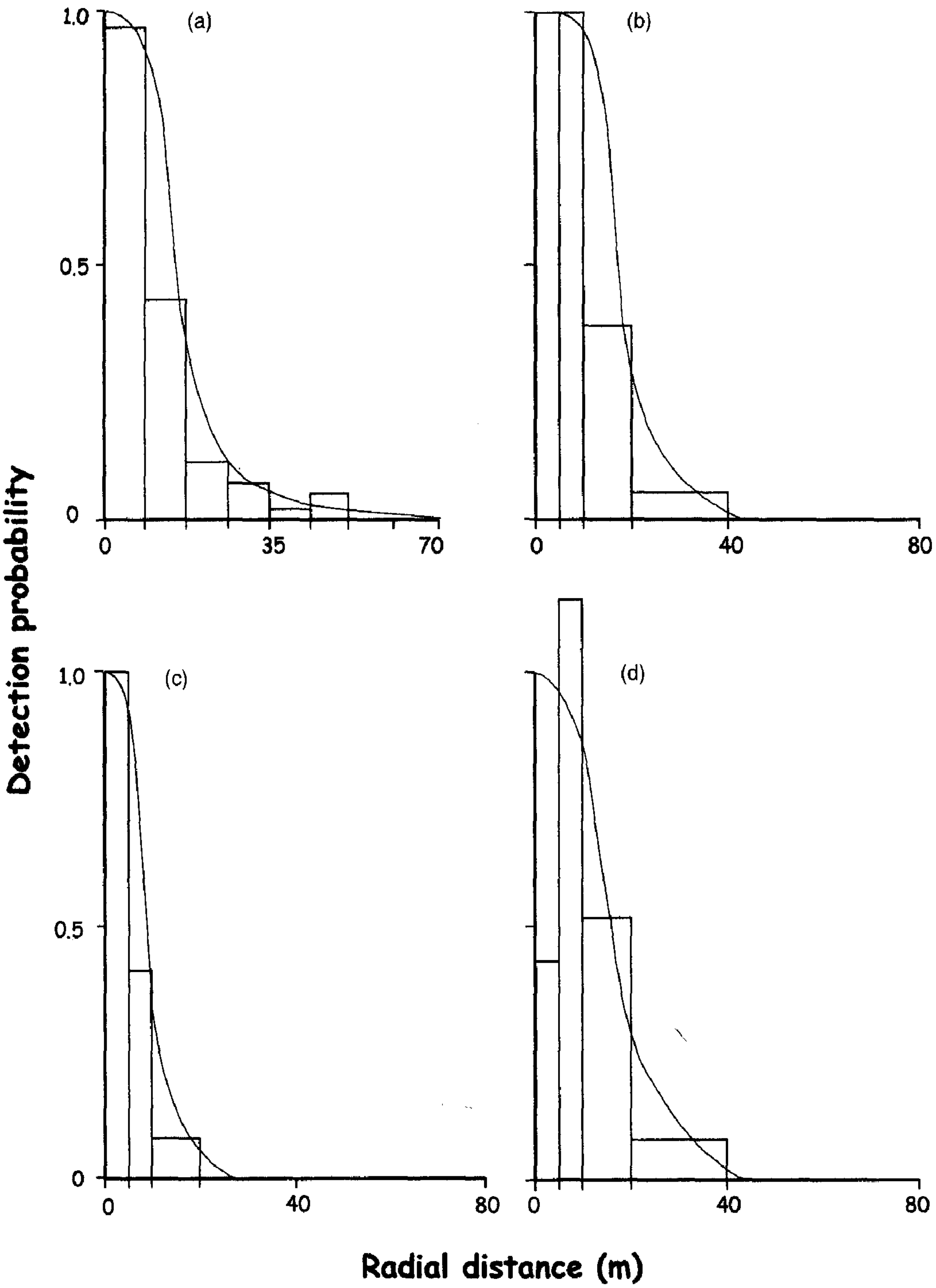

Figure 2. Detection functions for (a) Montserrat Oriole, (b) Pearly-eyed Thrasher, (c) Bananaquit and (d) Forest Thrush. The solid line is the detection function that represents the probability that a cluster of birds present at a given distance will be detected. These functions were estimated from a hazard-rate model for (a)–(c) and from a half-normal model for (d).

Table 4. Estimated densities and population sizes of each species within the Centre Hills study area

Species	Mean density (birds/ha)	95% CIs of density[a]	Mean population size (birds)[b]	95% CIs of population size[a,b]
ACHU	47.4	27.7–132.7	68,000	40,000-190,000
BANA	48.5	34.4–65.3	70,000	49,000–94,000
CAEL	8.6	5.0–14.0	12,500	7,100–20,000
FOTH	2.2	1.0–3.8	3,100	1,400–5,400
MTOR	2.8	1.1–5.4	4,000	1,500–7,800
PETH	17.5	13.1–23.1	25,000	19,000–33,000
SBTH	4.3	2.4–7.5	6,200	3,400–11,000
TREM	7.9	–	11,500	–

[a]95% CIs calculated by bootstrapping with 1000 iterations.

[b]Estimates of population size rounded as follows: 1000 to <10,000 to nearest 100; 10,000 to <20,000 to nearest 500; >20,000 to <100,000 to nearest 1,000; >100,000 to nearest 10,000.

–No attempt made to bootstrap CIs because of poorly fitting model (see Table 3); estimates for Gray Trembler should be considered suspect.

ver, thus breaking one of the assumptions of the distance sampling method (see Discussion) and casting doubt on the robustness of the Forest Thrush model.

With the exception of the Gray Trembler, the observed data for each species fit its best model extremely well (Table 3). For example, the hazard-rate model for the Montserrat Oriole predicted that 5.7, 7.8, 4.9, 3.4 and 7.3 oriole clusters would be counted in increasing distance bands away from the observer; the observed values were 6, 8, 3, 4 and 8. The reason why the trembler model did not fit the data well is apparent from Table 1: large numbers of tremblers were recorded between 20 and 40 m, though the cause remains unclear.

Density and population estimation

Estimated densities and population sizes for each species are shown in Table 4. Although densities varied greatly among species (from *c.* two Forest Thrushes per hectare to nearly 50 Bananaquits per hectare), they were generally high. Because the trembler model fit the data poorly, and because Forest Thrush behaviour may have been influenced by the presence of observers, the estimates for these species should be taken as only indicative. Confidence intervals were generally wide; these could have been improved with a greater sampling intensity.

There were an estimated 2.8 Montserrat Orioles per hectare, and thus an estimated total of 4,000 (95% CIs 1,500–7,800) individual orioles within the Centre Hills study area.

The distribution and sex ratio of Montserrat Orioles

In total, 120 individual Montserrat Orioles were observed (Table 5). Forty of these were recorded during the 10-minute silent periods, an additional 30 were lured to the counting stations with the tape playback and the remaining 50 were recorded while traversing the Centre Hills. Among these, 102 were sexed and although there was a slight tendency for more females (56) than males (46) to be recorded, this was not significantly different from a 50:50 sex ratio ($\chi^2 = 0.32$, $df = 1$, $P > 0.05$). While at each counting station, a significantly higher proportion of

Table 5. The total numbers and sex of Montserrat Orioles recorded. Ten minutes of silence at each counting station ("Silent" period) were followed by three minutes of tape playback. Note that birds recorded during the silent period were often re-recorded during the tape playback; the combined row removes these duplicates. Other, birds recorded while moving between points and during a trial of methods

Period	Male	Female	Unknown	Total
Silent	8	10	22	40
Tape	23	26	7	56
Silent + tape combined	28	30	12	70
Other	18	26	6	50
Total records	46	56	18	120

birds was sexed during the tape playback than during the silent period (87.5% *cf* 45%; $\chi^2 = 18.0$, $df = 1$, $P < 0.001$). This was probably because birds approached more closely during the tape playback period (Table 2) and could thus be sexed by plumage characteristics.

Montserrat Orioles were recorded at 59 sites for which an approximate grid reference was known; 44 of these were points on the systematic grid, and 15 were sites found while moving between points. No orioles were recorded at the additional 50 counting stations outside of the Centre Hills; this supports the assumption that the remaining orioles were restricted to the Centre Hills.

A summary of the distribution of the sites at which orioles were recorded is given in Figure 3. Assuming that Montserrat Orioles no longer survive in the Soufriere and South Soufriere Hills, Figure 3 implies that the remaining global distribution of the Montserrat Oriole is very limited: 46 of the 59 sites (78%) were located in an area of 8 km^2.

Discussion

Assumptions of distance sampling

For our density and population estimates to be reliable, all the assumptions of the distance sampling method must have been met; there are several of these (Buckland *et al.* 1993). First, all birds at the counting station (i.e. where the observer was standing and vertically above that point) must be counted. We think it is highly unlikely that any birds present at the counting station were missed – particularly so for Montserrat Orioles that feed reasonably close to the ground and are very visible and audible when close. The relatively long duration (10 minutes) of counts increased the chances of detecting all birds present.

Second, all birds must be detected at their initial location. Ideally, the count should be a snapshot of birds present around the point and if birds move into, or out of, the plot during the counting period then densities are likely to be over- or underestimated, respectively. The duration of the counts is thus a compromise between keeping it long enough to ensure that all birds at the point are detected, but not so long that there are substantial movements of birds through the plot. Buckland *et al.* (1993) recommend count durations of 5–10 minutes for songbirds, which we adopted. Despite this, we feel that the density (and thus population

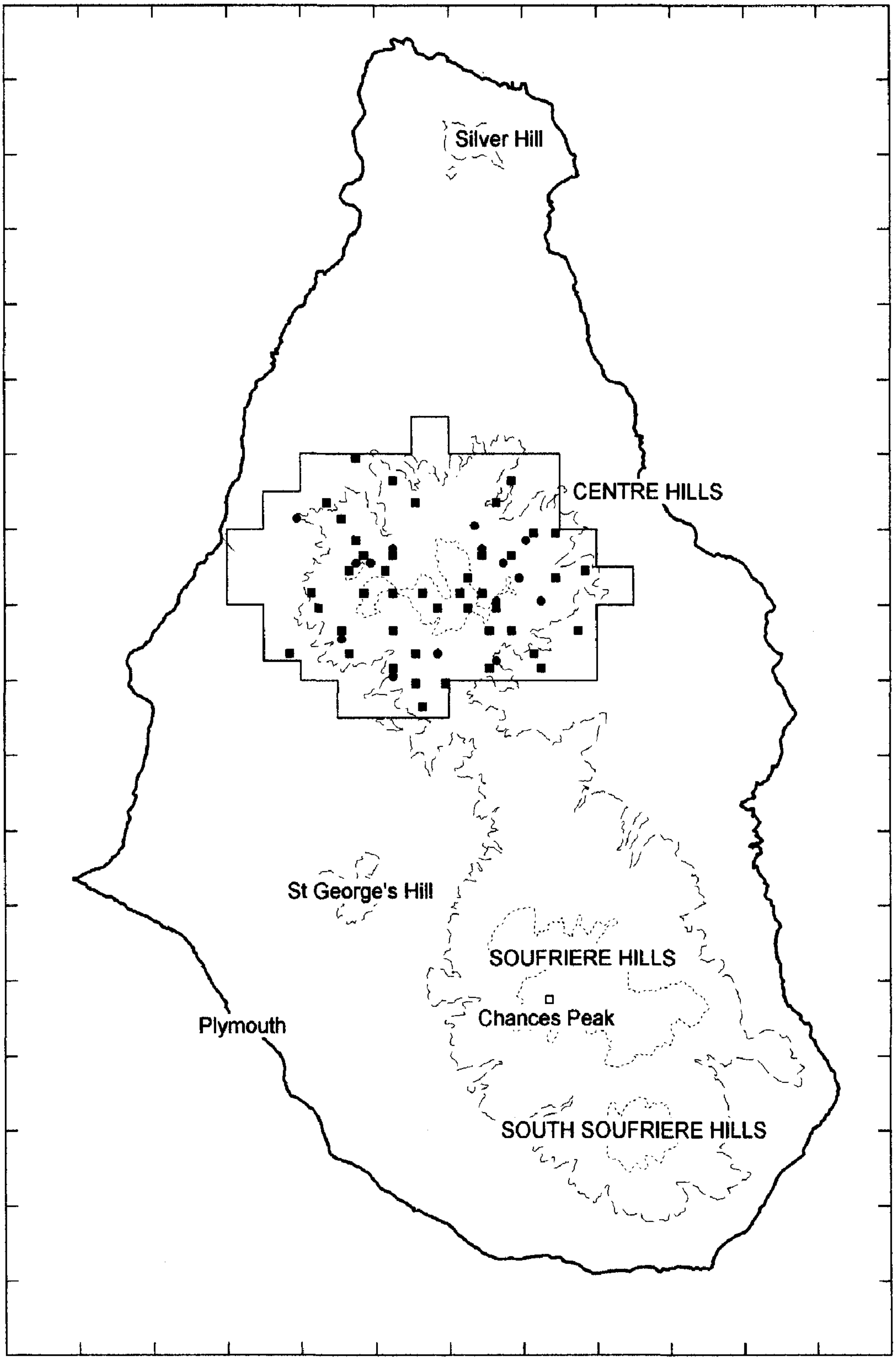

Figure 3. Locations at which Montserrat Orioles were recorded. Square symbols are points on the systematic grid at which orioles were recorded; round symbols are oriole locations off the systematic grid (mostly noted while moving between points). Other details as for Figure 1.

size) of Antillean Crested Hummingbirds is likely to be an overestimate because of the rapid speeds at which they move, and because they are virtually undetectable beyond 10 m. The extent to which other species moved into or out of the plot during the count is unknown, and although it is possible that our density estimates might be high, we do not think this represents a major bias. In principle, one way of attempting to overcome this bias is to use line transects rather than point counts (Buckland *et al.* 1993), particularly where the speed of movement of the species under investigation is appreciably less than that of the observer (Hiby 1986). Prior to our fieldwork, a brief trial of the line transect method was undertaken. Unfortunately, the vegetation was so dense that trails often had to be cut with machetes and the terrain often so difficult that observers had to watch where they were putting their feet when traversing the Centre Hills. Under such conditions it was not practical to record birds while moving.

Third, birds must not move in response to the observer. There is evidence from the detection probabilities that Forest Thrushes moved away from the observer, thus probably underestimating densities for this species; however, sample sizes were low and it is hard to be definitive. Apart from this species, there is no evidence from the distance data that birds attempted to flee the observers. Montserrat Orioles were lured towards the point by the tape playback and for this reason these data were not used in density or population estimation. However, we know that orioles were lured by the tape playback only because of the comparison with the silent period, and we cannot rule out the possibility that orioles and other species moved towards the observers out of inquisitiveness during the silent period itself. There was, however, no suggestion of this from the distance data.

Fourth, all measurements must be exact, or all birds must be correctly assigned to a distance band. Distances to Montserrat Orioles were as exact as possible; they were either determined with a tape measure or paced wherever a more exact measure was impossible. We feel confident that paced distances were reasonably precise because all observers estimated the number of paces they took per 100 m prior to undertaking the fieldwork; from these estimates it was possible to determine distances. For other species, precise distances were not measured; rather, they were allocated to distance bands by estimation. Despite this we are reasonably confident that birds were correctly allocated to a distance band, and we attempted to ensure precision by training all observers in distance estimation prior to fieldwork.

Finally, all counting stations must be located at random with respect to the distribution of birds. Because all counting stations were located on a systematic grid, this assumption was met.

Montserrat Oriole population size

Arendt and Arendt (1984) conservatively estimated that about 1,000–1,200 Montserrat Orioles were present on the island in 1984. Evans (1990, unpubl. data) suggested that this estimate was too low, but did not provide an alternative. If we make the reasonable assumption that the Soufriere and South Soufriere Hills populations have been destroyed, we are faced with an apparent conundrum. Half to two-thirds of the Montserrat Oriole's population has been destroyed, but

Table 6. Comparison of post-hurricane (March 1990) and post-volcanic (December 1997) disturbance point count results in the Centre and Soufriere Hills, Montserrat. Playback was used in both years. All comparisons are of 1997 Centre Hills data with 1990 data. Because of the problem of non-independence of orioles at individual counting stations, all comparisons are of the proportion of counting stations at which orioles were recorded. All tests are z-test of proportions, with Yates correction applied

Mountain range	Year	Total no. points	No. orioles observed	No. orioles per point	Points with orioles		Comparison of 1990 and 1997	
					No.	%	z	P
Centre Hills	1990	30	40	1.33	18	60	3.46	<0.001
Soufriere Hills	1990	30	62	2.06	20	67	4.23	<0.001
Centre and Soufriere Hills combined	1990	60	102	1.70	38	63	4.93	<0.001
Centre Hills	1997	137	56	0.41	36	26	–	–

the estimate of its population size has increased (to 4,000 individuals, 95% CIs 1,500–7,800). This conundrum can only be explained if the 1984 estimate was too low, the 1997 estimate too high, or both.

Methods of estimating abundances of biological populations have developed very rapidly over the past decade, and distance sampling was in its infancy when Arendt and Arendt undertook their initial status assessment. We are confident that the method presented here is much more robust than that used for the 1984 assessment, which relied on a variety of techniques, none designed to estimate absolute densities.

An examination of the data collected by Arendt (1990) shows that the population in 1990 following Hurricane Hugo was substantially larger than that suggested by both the 1984 and 1997 estimates. In 1990, Arendt observed 102 individual orioles during 60 fixed-radius point counts in the Soufriere and Centre Hills; 40 of these orioles were recorded in 30 counts in the Centre Hills (Table 6). An additional 82 orioles were observed in lowland areas and along transects in between counting stations. Arendt recorded orioles in two distance bands, up to 25 m and beyond. In principle, it would be possible to apply a half-normal binomial model (Ramsey and Scott 1979, Bibby *et al.* 1985, Buckland 1987) to estimate oriole densities in 1990, and to compare them with those in 1997. We have not done this here for two reasons. First, Arendt (1990) used tape playback to elicit responses from orioles at all counting stations. Second, not all counting stations were located at random within the three mountain ranges, but rather at locations chosen because they held large concentrations of orioles in 1984 and presumably would in 1990. Both introduce biases likely to overestimate density (but see Parker 1991 and Graves 1996).

Although it is not sensible to attempt to estimate densities in 1990, it is possible to compare the numbers of orioles recorded using playback in both 1990 and 1997. The mean number of orioles recorded per counting station using tape playback in 1990 was substantially higher than that recorded in 1997 (Table 6). However, there were several differences between the 1990 and 1997 counts. First, in 1990 the tape playback was of vocalizations of congeneric species recorded prior to fieldwork, although later enhanced with Montserrat Oriole vocalizations once recorded in the field. Second, the counts were undertaken in March when birds might have been more responsive to tapes. Finally, as outlined above, not all of the counting stations were placed at random. While many points were placed randomly along 1-km transect routes, others were placed in the post-disturbance refugia (protected ravines) used by displaced orioles and other species. Because of this, it is not sensible to suggest that densities in the Centre Hills declined markedly between 1990 and 1997; rather the 1990 census results revealed "super concentrations" of orioles. Orioles were packed into the refugia and regenerating forest belt between 400 and 600 m elevation in the Centre and Soufriere Hills. Although point-count and walking censuses were conducted from 100 to 900 m elevations, significantly more orioles were observed between *c.* 400 and 600 m elevation (Arendt 1990).

The use of protected ravines by the Montserrat Oriole following hurricane damage is the first quantified documentation of this behaviour in the Caribbean (see Wiley and Wunderle 1993 for a review). However, it has been known for some time that insular birds in the Pacific Ocean (e.g. Hawaiian islands) take cover and survive for extended periods in protected valleys during and after major storms, including hurricanes (Conant *et al.* 1998).

In 1990 an oriole pair was recorded at every counting station in the ravines of the Soufriere Hills and orioles were encountered every 20–25 m in between counting stations (Arendt 1990, James Daley, pers. obs.). Such densities suggest that before the onset of volcanic activity, the island would have supported an oriole population in the thousands.

Because fieldwork in 1997 was undertaken after the breeding season, the estimate of 4,000 individuals will undoubtedly include birds fledged in 1997. Insufficient information on post-fledging survival of Montserrat Orioles exists to enable us to convert this post-breeding population estimate into one of the number of breeding pairs with any precision. However, it is likely that there were *c.* 1,000 breeding pairs of orioles in 1997.

It is possible that the population of orioles in the Centre Hills has been swollen by immigration of birds that formerly inhabited the Soufriere and South Soufriere Hills. Unfortunately, very few orioles have ever been banded on Montserrat; thus there are no data on oriole dispersal on the island. However, as pyroclastic flows travel at velocities in excess of 100 kph and at temperatures up to 800 °C (unpublished report, MVO 1997), it is highly unlikely that birds within the vicinity would be able to escape instant death.

The conservation status of the Montserrat Oriole

Before the start of volcanic activity, BirdLife International (Collar *et al.* 1994) did not consider the Montserrat Oriole to be globally threatened under the revised International Union for Conservation of Nature (IUCN) threat categories (IUCN 1996); rather, they considered it "near-threatened". Given the likelihood that more than half of the oriole's habitat has been destroyed since 1995, we suggest that the Montserrat Oriole be reclassified as globally threatened.

It is unlikely that the oriole would qualify as Critically Endangered under the revised criteria as it does not pass any of the relevant thresholds for this threat category. The oriole's past area of occupancy – the best measure available given the uncertainty of population estimates – has not been reduced, and is not likely to be reduced in the future, by 80% or more due to volcanic activity (criterion A, IUCN 1996) because the Centre Hills population seems reasonably secure. It could not qualify under criteria B–D either as its remaining known area of occupancy is not 10 km^2 or less (it is *c.* 15 km^2) and its population does not number fewer than 250 mature individuals.

The Montserrat Oriole does, however, now qualify as Endangered on the basis of population reduction (criterion A) measured as a decline in area of occupancy. Volcanic activity led to the complete destruction of at least half of its former forest habitat in the Soufriere and South Soufriere Hills over a three-year period. Although the oriole may also qualify on criteria B and C, as its area of occupancy is much less than 500 km^2 and there are probably fewer than 2,500 mature individuals in the population, respectively, it probably does not fulfil the additional subcriteria needed for qualification. Thus, for example, the remaining population(s) are not severely fragmented, do not exist at less than five locations (though it could be argued that they occur at only one), may not necessarily decline in the future and are not obviously prone to extreme fluctuations.

The future of the Montserrat Oriole

On the reasonable assumption that the Soufriere and South Soufriere Hills populations have been destroyed, only 4,000 (95% CIs 1,500–7,800) Montserrat Orioles remained in the world in December 1997. Nearly 80% of these were located in an area of 8 km^2 in the Centre Hills of Montserrat, at a distance of about 5 km from an active volcano. The future prognosis for the oriole depends upon the extent to which the Centre Hills will be affected by volcanic activity in southern Montserrat. The MVO considers that there is a 1 in 800 chance over a six-month period that a high velocity pyroclastic surge produced by a volcanic explosion ten times larger than that currently witnessed could reach 3.5–4.5 km toward the Centre Hills, but even then it would not surmount them. An explosion 30 times greater than that already witnessed would produce a pyroclastic surge that could overrun the Centre Hills, but the probability of this is projected at 1 in 3,000 over a six-month period (unpublished report, MVO 1997; see also Wadge and Isaacs 1988). The threat to the oriole population in the Centre Hills is thus remote. However, increased volcanic activity may lead to continuing ash falls in the Centre Hills. Although the size of the current population was larger than anticipated, heavy ashfall could cause health problems for the remaining birds and could lead to reproductive failure during the breeding season. In addition to destroying most birds present in an area of 600 km^2 (Anderson and McMahon 1985, Manuwal *et al.* 1987), ash fall from the Mount St Helens eruption in May 1980 led to nest abandonment by Northern Orioles (Butcher 1980), and reduced breeding success of Ring-billed Gulls *Larus delawarensis*, and California Gulls *Larus californicus* (Hayward *et al.* 1982). A separate MATE/RSPB/American Bird Conservancy study investigated the breeding productivity of the oriole in 1998; the results of this study will be published once available.

A monitoring programme for the Montserrat Oriole, based largely on visits to a sample of the counting stations outlined here, has been instigated and will allow an assessment of the status of the oriole and other forest birds on the island every three months. Should this monitoring show that the oriole population has fallen to critically low levels, arrangements will be made to establish a captive population(s) of orioles; the logistics necessary to execute such a programme have been investigated by JWPT.

The Centre Hills currently receives *de facto* forest protection status from the Montserrat government because of its biological richness and its provision of many environmental and economic services – most importantly as a water catchment. The entire area is earmarked to receive a more formal protection status, although only those areas owned by the government will be given the highest level of protection as a Forest Reserve. Areas in private ownership will be declared as Protected Forest by agreement between the landowner and the government. Funds permitting, the Montserrat government would acquire the entire area. It is hoped that the declaration of these protected area statuses will be sufficient to safeguard the oriole's habitat. Fortunately much of the terrain of the Centre Hills is unsuitable for agriculture or development.

The status of Montserrat's other forest birds

Although the single-island endemic Montserrat Oriole was clearly the species most threatened by volcanic activity, a crude assessment of the impact of the volcano on the status of Montserrat's other forest birds can be made. Of the species listed in Table 4, five (Bananaquit, Antillean Crested Hummingbird, Caribbean Elaenia, and the two species of thrasher) are widely distributed across the West Indies (American Ornithologists' Union 1983, Raffaele *et al.* 1998). It is thus unlikely that the global populations of these five species have been affected by volcanic activity on Montserrat. The Trembler, by contrast, is restricted to 10 islands in the Lesser Antilles, while the Forest Thrush is a four-island endemic, uncommon in Guadeloupe and Dominica, rare on St Lucia and now threatened by volcanic activity on Montserrat. Although estimates of these two species' populations sizes on Montserrat (Table 4) and elsewhere are uncertain, it is likely that the Forest Thrush has lost a large part, and the Trembler a small part, of its global range to volcanic activity on Montserrat.

Acknowledgements

We thank Debbie Pain, Ken Smith, Mark Avery, Ellen Kelly, Dieter Hoffman, Phil Atkinson and Alistair Gammell (RSPB), Dr Ariel Lugo (IITF), John Hartley and Andrew Owen (JWPT), Colin Clubbe (Royal Botanic Gardens, Kew) and Stuart Chapman (WWF) for their help and guidance in this work. We also acknowledge the generous support of the American Bird Conservancy. Without the help of MATE's forest rangers in the field it would have been difficult to complete the census. They helped guide us to the counting stations, cut and marked trails, counted birds and (with but a few exceptions) always ensured we got neither lost nor into danger. For this we are indebted to: Philemon "Pie" Murrain, James "Scriber" Daley, John "Gamby" Martin, Lloyd Martin, Lloyd Aymer and Trevor Aymer. Angela Arendt not only helped in the field, but also ensured we kept body and soul together. Finally, we thank the people of Montserrat for their warmth and sincerity that made our (WJA and DWG) visit so enjoyable and for their astonishing resilience in the face of enormous adversity.

Appendix. Four-letter codes[a], vernacular and scientific names of species recorded.

Species code	Vernacular name	Scientific name
ACHU	Antillean Crested Hummingbird	*Orthorhynchus cristatus*
AMKE	American Kestrel	*Falco sparverius*
ANEU	Antillean Euphonia	*Euphonia musica*
BANA	Bananaquit	*Coereba flaveola*
BFGR	Black-faced Grassquit	*Tiaris bicolor*
BWVI	Black-whiskered Vireo	*Vireo altiloquus*
CAEL	Caribbean Elaenia	*Elaenia martinica*
CMWA	Cape May Warbler	*Dendroica tigrina*
FOTH	Forest Thrush	*Cichlherminia lherminieri*
GNBH	Green Heron	*Butorides striatus*
GRAK	Gray Kingbird	*Tyrannus dominicensis*
GTCA	Green-throated Carib	*Eulampis holosericeus*
HOWA	Hooded Warbler	*Wilsonia citrina*
LESB	Lesser Antillean Bullfinch	*Loxigilla noctis*
LOWA	Louisiana Warbler	*Seiurus motacilla*
MACU	Mangrove Cuckoo	*Coccyzus minor*
MTOR	Montserrat Oriole	*Icterus oberi*
NOPA	Northern Parula	*Parula americana*
PETH	Pearly-eyed Thrasher	*Margarops fuscatus*
PTCA	Purple-throated Carib	*Eulampis jugularis*
SBAN	Smooth-billed Ani	*Crotophaga ani*
SBTH	Scaly-breasted Thrasher	*Margarops fuscus*
SNPI	Scaly-naped Pigeon	*Columba squamosa*
TREM	Gray Trembler	*Cinclocerthia gutturalis*
UNID	Unidentified warbler	–
YTVI	Yellow-throated Vireo	*Vireo flavifrons*
ZEND	Zenaida Dove	*Zenaida aurita*

[a]Four-letter code used by USGS Biological Resources Division's Bird Banding Laboratory at the Patuxent Wildlife Research Center in Washington, DC.

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