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Research Papers

When is an “Extinct” Species Really Extinct? Gauging the Search Efforts for Hawaiian Forest Birds and the Ivory-Billed Woodpecker

Quand une espèce "disparue" l'est-elle vraiment? Évaluation des efforts de recherche sur les oiseaux forestiers hawaïens et le Pic à bec ivoire

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ABSTRACT. Rare species, particularly those in inaccessible habitat, can go years without being observed. If we are to allocate conservation resources appropriately to conserving such species, it is important to be able to distinguish “rare” from “extinct.” Criteria for designating extinction, however, tend to be arbitrary or vaguely defined. This designation should not be made unless the search effort has been sufficient to yield a high degree of confidence that the species is in fact absent. We develop models to assess the probability of extinction and the search effort necessary to detect an individual in a small population. We apply these models to searches for nine potentially extinct Hawaiian forest birds and for the Ivory-billed Woodpecker (*Campephilus principalis*) in intensively searched areas in Arkansas. The Hawaiian forest bird survey was extensive, providing excellent information on population sizes and habitat associations of species encountered during the survey. Nonetheless, we conclude that the survey effort was not sufficient to conclude extinction ($p > 0.90$) for populations of 10 or fewer individuals for those species that were not encountered during surveys. In contrast, our analysis for Ivory-billed Woodpeckers suggests that, unless there were actually two or fewer birds present, the search effort was sufficient to conclude ($p > 0.95$) that Ivory–billed woodpeckers were not present in the intensively searched area. If one assumes distributions other than uniform, there is a greater chance that Ivory-billed Woodpeckers may persist in the intensively searched areas. Conclusions regarding occupancy of suitable habitat throughout the rest of the former range will require similarly intensive survey efforts. The degree of confidence in the absence of the Ivory-billed Woodpecker depended in part on our assumptions about the distribution of birds in the search area. For species with limited detection distance and small populations, a massive search effort may be required to conclude with confidence that a species is unlikely to be extant.

RÉSUMÉ. Les observations d’espèces rares peuvent être séparées par plusieurs années, particulièrement lorsque leur habitat est inaccessible. Si des ressources sont consacrées à la conservation de ces espèces, il est important de pouvoir établir des critères propres aux espèces « rares » et « disparues ». Par contre, les critères utilisés pour déterminer l’extinction tendent à être arbitraires et plutôt vagues. Cette désignation ne devrait jamais être appliquée, à moins que les efforts de recherche aient été suffisants pour affirmer avec confiance que l’espèce est effectivement absente. Nous avons développé des modèles afin d’estimer la probabilité d’extinction ainsi que l’effort nécessaire pour la détection d’un individu provenant d’une petite population. Nous avons appliqué ces modèles à neuf espèces d’oiseaux forestiers potentiellement disparus de Hawaï ainsi qu'au Pic à bec ivoire (*Campephilus principalis*) dans des sites de recherche intensive de l’Arkansas. L’inventaire des oiseaux forestiers d’Hawaï était extensif, ce qui nous a procuré de l’excellente information sur l’effectif des populations ainsi que l’association aux habitats des espèces rencontrées durant l’inventaire. Néanmoins, nous estimons que l’effort d’inventaire était insuffisant pour conclure à l’extinction ($p > 0.90$) chez les populations comprenant 10 individus ou moins parmi les espèces non détectées durant l’inventaire. À l’opposé, notre analyse pour le Pic à bec ivoire suggère qu'à moins que la population ne compte que deux individus ou moins, l’effort de recherche était suffisant ($p > 0.95$) pour conclure à l’absence de l'espèce dans le site de recherche intensive. Lorsqu’on suppose que la distribution de l’espèce n’est pas uniforme, la probabilité de persistance du Pic à bec ivoire est plus élevée dans les sites de recherche intensive. Les conclusions sur l’occupation de l’habitat favorable dans le reste de l’aire de répartition exigeront des efforts d’inventaire d’intensité comparable. Le degré de confiance quant à l’absence du Pic à bec ivoire dépendait en partie de nos suppositions par rapport à la

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distribution de l'espèce dans l'aire d'étude. Pour les espèces dont la distance de détection est limitée ainsi que pour les petites populations, un effort de recherche intensif peut être requis afin de conclure avec confiance que la présence de l'espèce est improbable.

Key Words: *Endangered Species Act; extinction; Hawaii; monitoring; survey effort*

INTRODUCTION

"Extinction is forever." True enough. For some species, the moment of extinction is known with certainty. The last three individuals of the Laysan Honeyeater (*Himatione sanguinea frathii*) perished in a dust storm in 1923 (Bailey 1956) and the last Passenger Pigeon (*Ectopistes migratorius*) died in the Cincinnati Zoological Garden in 1914 (Blockstein 2002). More often, however, species are declared "extinct" because recorded sightings became less frequent and then ceased altogether. But how can one be sure that a species is really extinct, instead of persisting undetected for years or decades? This problem is exacerbated if the species is cryptic or lives in dense or inaccessible habitat. Yet the decision about whether to declare a species extinct vs. "endangered" or "possibly extinct" is critical. In the United States, for example, legal protection of a species and its habitat ceases when the species is declared extinct. If the species is later discovered to be extant, the loss of critical habitat in the interim may hasten its eventual demise and preclude recovery efforts.

Rediscovery of "extinct" species occurs often enough to give one pause about making premature pronouncements. The Bermuda Petrel (*Petrodroma cahow*) was considered extinct by 1621, but a small breeding colony was discovered in 1951 (Murphy and Mowbray 1951). Gurney's Pitta (*Pitta gurneyi*) in Myanmar (Eames et al. 2005), a freshwater pearl mussel (*Margaritifera margaritifera*) in Portugal (Reis 2003), the Cherry-throated Tanager (*Nemosia rourei*) in Brazil (Bauer et al. 2000), Bulmer's fruit bat (*Aproteles bulmerae*) in Papua New Guinea (Flannery 1994), Wollemi pine (*Wollemia nobilis*) in Australia (Woodford 2002)—all were thought to be extinct for decades or known only from fossil remains until rediscovered in recent years. In fact, the phenomenon of prematurely declaring species extinct is common enough to have been christened "Romeo's error" (Collar 1998) and the "Lazarus effect" (Keith and Burgman 2004).

The World Conservation Union defines a species as extinct if there is "no reasonable doubt that the last individual has died" (IUCN 2001). Determining the point of "no reasonable doubt," however, is tricky. Although the rediscovery of some presumably extinct species has happened serendipitously, more often it is associated with a focused search effort. When systematic searches occur, the effort required to find a rare species with low detectability can be substantial (Scott et al. 1986, Solow 1993, Reed 1996). For example, over a 6-week period in 2006, a team of scientists used sophisticated technology to search 3500 km of the Yangtze River in China in an attempt to find the Yangtze River dolphin (*Lipotes vexillifer*). Their failure led to the decision in August 2007 to declare the species officially extinct (Turvey et al. 2007). But, even though the search effort was intensive and one would think an animal the size of a dolphin would be hard to miss, there is uncertainty about whether the search effort was adequate to make such a terminal decision. In fact, a possible sighting (and filming) of a Yangtze River dolphin was reported later in August 2007 (http://news.bbc.co.uk/2/hi/science/nature/6969226.stm). The recently reported rediscovery (Fitzpatrick et al. 2005) of the Ivory-billed Woodpecker (*Campephilus principalis*) has captured the imagination of the American public and given new hope for its recovery (Walters and Crist 2005). The lack of indisputable evidence and alternative explanations of the original data, however, have raised doubts about the species' status (Jackson 2006, Sibley et al. 2006, Stokstad 2007). Rigorous quantitative estimates of the likelihood of persistence in a given area would help to clarify the situation.

This is the problem we address here. The probability of encountering individuals is determined by their abundance, conspicuousness, and home-range size. Other factors, such as habitat complexity, weather, and observer capabilities, also come into play (Ramsey and Scott 1981, Scott et al. 1986, Buckland et al. 2001). Collectively, these factors determine the likelihood that a species will be detected, given a certain search effort. So what we really want to know is what search effort is required to conclude with a high degree of certainty that a species is in fact extinct, or, conversely, given a certain search effort, what is the probability that individuals of a rare species should be recorded? We develop an approach to answer these questions and illustrate the approach using data from searches for potentially extinct Hawaiian forest birds and for the Ivory-billed Woodpecker in Arkansas.

METHODS

The question we ask is, what effort is required to realize certain values of the probability of extinction? If *N* is population size, we want to determine the probability that *N* is zero. With surveys, one may estimate the probabilities that populations of a given size are missed, i.e., conditional probabilities such as P(miss all | *N* = 5). To convert such probabilities to probabilities of extinction, we use a Bayesian argument. The population size is unknown. Suppose one can express, before sampling, a set of probabilities for the population size denoted by P(*N*=*k*), for *k* = 0, 1, 2,... A convenient form for these probabilities is the Poisson distribution (Appendix), where,

$$P(N = k) = \frac{e^{-m} m^{k}}{k!} \qquad (1)$$

The value of *m* is the mean of the distribution, and it determines all the probabilities exactly. Of particular interest is the prior probability that the population is extinct, which is P(*N*=0) = e^{-m}. We can specify the entire set of prior Poisson probabilities by specifying the prior probability of extinction. If P(*N*=0) = *Q*, then *m* = –ln(*Q*). If we assume a prior probability of extinction of 50% (inferred as Bayesian posterior probabilities from Scott et al. (1986: 54–55), that corresponds to *m* = –ln(1/2) = 0.6931.

Now, suppose that a survey is conducted that has total effective area of *E* in a species' range that has a total area of *A*. If the *N* members of the population each have probability *E*/*A* of detection and if they are detected independently over their range, then the probability that all are missed in the survey (*X*=0, where *X* equals the number of birds detected in a survey) is

$$P(X = 0 \mid N = k) = \left(1 - \frac{E}{A}\right)^{k} \qquad (2)$$

From this one may determine the effective area (*E*) that would need to be surveyed to detect at least one individual from several population sizes. It is calculated as:

$$E = A\left(1 - (1 - P)^{1/N}\right) \qquad (3)$$

Application of Bayes Theorem then produces a set of posterior probabilities for the population size. They are

$$P(N = k \mid X = 0) = \frac{e^{-m\left(1-\frac{E}{A}\right)}\left[m\left(1 - \frac{E}{A}\right)\right]^{k}}{k!} \qquad (4)$$

for *k* = 0, 1, 2, ... The resulting probability of extinction is

$$P(N = 0 \mid X = 0) = e^{-m\left(1-\frac{E}{A}\right)} \qquad (5)$$

To achieve a desired value, *V*, for the posterior probability of extinction, starting with a prior probability, *Q*, of extinction, requires a total effective area surveyed of

$$E = A\left(1 - \frac{\ln V}{\ln Q}\right) \qquad (6)$$

The area effectively surveyed from a line transect is $2Lw$, where w is the effective half-width or effective detection distance and L is the total transect length. In variable circular plot surveys, $E = n\pi r^2$, where r is the effective radius or effective detection distance and n is the total number of point counts.

APPLICATIONS

Ivory-billed Woodpecker

The decline of the Ivory-billed Woodpecker is widely attributed to loss of habitat, primarily large continuous forest with large mature trees and numerous snags. In addition, the opening up of these large tracts of land for logging is also thought to have increased collection and poaching of Ivory-billed Woodpecker (U.S. Fish and Wildlife Service 2006a, Snyder 2007).

Systematic surveys for Ivory-billed Woodpeckers using line transects and variable circular plots (VCPs) were concentrated in a 19 700-ha tract along White River (WR) and a 9500-ha tract at Bayou de View (BDV) in Arkansas, USA. This area was imbedded within a larger area of potential Ivory-billed Woodpecker habitat of 233 896 ha (Fig. 1) that was surveyed during the winter months of 2004–2005 and 2005–2006 (Fitzpatrick et al. 2005, Rohrbaugh et al. 2006). The survey was focused on areas with recent reported sightings of Ivory-billed Woodpeckers and nearby best available habitat—those areas thought to have the highest probability of detecting the species. Transects were placed systematically 50 m apart in these areas following Universal Transverse Mercator (UTM)-based transect lines. Stations on which variable circular counts were conducted were placed throughout the target area. Our calculations are based on those with a minimum of 60 m separation from the next nearest station. We used an effective detection distance of 25 m for linear transects and 50 m for VCPs. Variable circular plots have a larger effective detection distance because they are often situated at sites with a wider view than line transects and because a stationary observer is likely to see more than would an observer who is moving. These detection distances are similar to those known for Pileated Woodpeckers (*Dryocopus pileatus*), a large woodpecker that is common in the Arkansas study area (Fitzpatrick et al. 2005). The population size for the Ivory-billed Woodpecker is unknown but assumed to be small.

Hawaiian Forest Birds

Many Hawaiian forest birds, particularly the honeycreepers (*Drepanidinae*), became extinct following first human contact (Banko et al. 2001). Other species may be extinct (Scott et al. 1986, Pratt 2005), but determining this with certainty is problematic. What we can do is conduct surveys that allow us to state the probability that at least one bird would have been detected from a population of stipulated size. The Hawaii Forest Bird Survey (HFBS) was a 6-year effort covering the forested areas of five principal islands in the Hawaiian Archipelago. The HFBS used VCPs (Reynolds et al. 1980) conducted at 9940 stations during 20 789 8-min count periods over 1401 km of transects (Fig. 2) (Scott et al. 1986) to document distribution and abundance of the endemic Hawaiian avifauna. Transects were placed 1.6 or 3.2 km apart located at right angles to elevational contours. Distances between stations were more than two times the anticipated effective detection distances of the most conspicuous species.

Several of the putatively extinct Hawaiian species occupied densely vegetated habitat in treacherous and inaccessible terrain when last recorded, making surveys and detection difficult. To analyze the likelihood that these species actually are extinct, we use information for a suite of Hawaiian forest birds surveyed by the HFBS (Fig. 2; Scott et al. 1986). We consider nine endemic species, two of which were on each of two islands (Table 1). Each of these species (or island populations) is thought to have become recently extinct (U.S. Fish and Wildlife Service 2006b) and had been proposed for removal from the Endangered Species List (Draft Ruling, U. S. Fish and Wildlife Service, Washington Office; pers. comm. from E. VanderWerf, U.S. Fish and Wildlife Service, 6 April 2006). Effective detection distances for most of these species are low (≤75 m), so a large number of survey stations is required to cover a species' historic range (Table 1).

Fig. 1. Map of the target search area for Ivory-billed Woodpeckers in Arkansas, USA, including the extent of search coverage for the Bayou de View and the White River sites in one or both years.

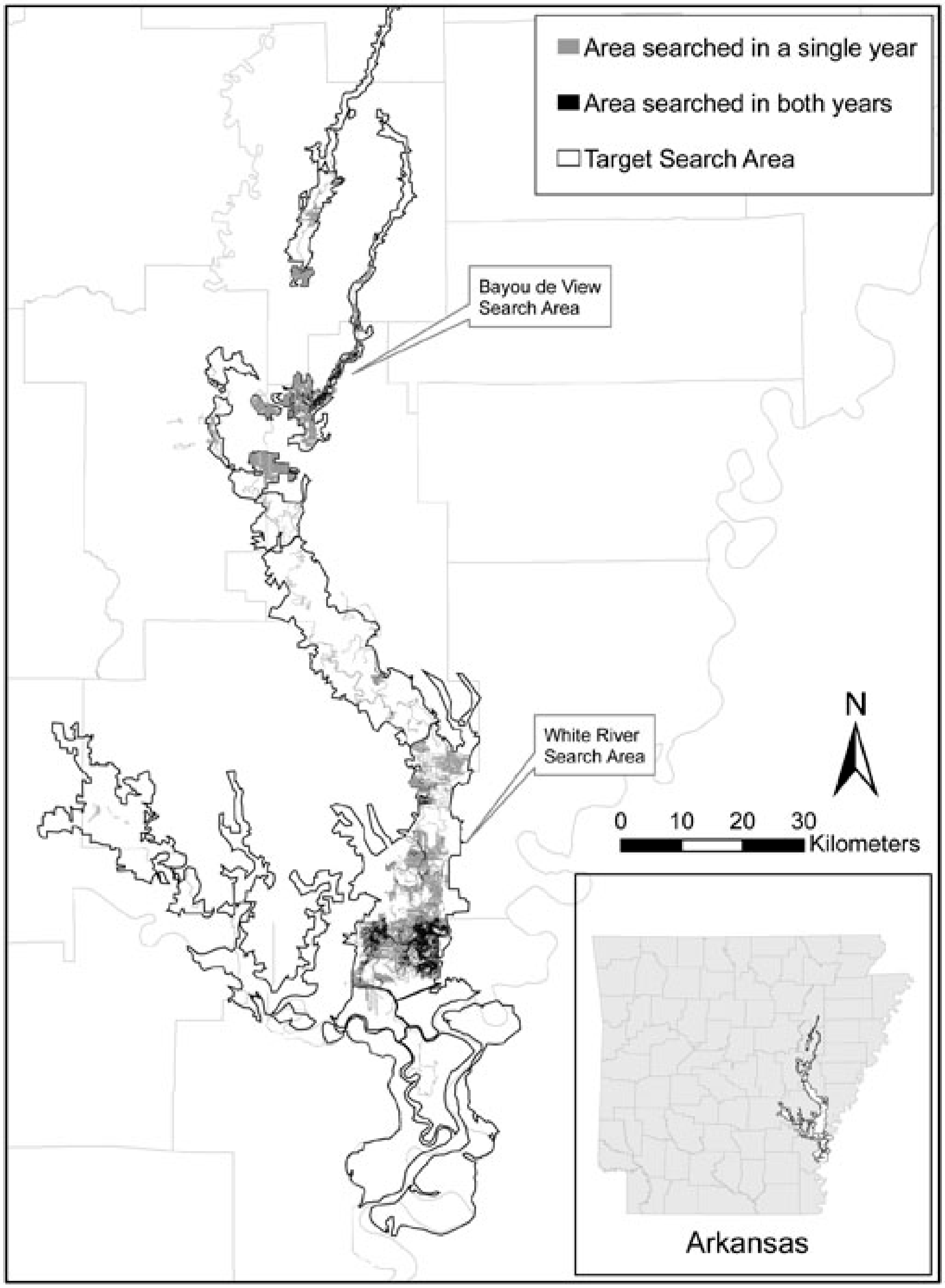


Fig. 2. Map showing the transect areas for the Hawaiian Forest Bird Surveys. From Scott et al. (1986).

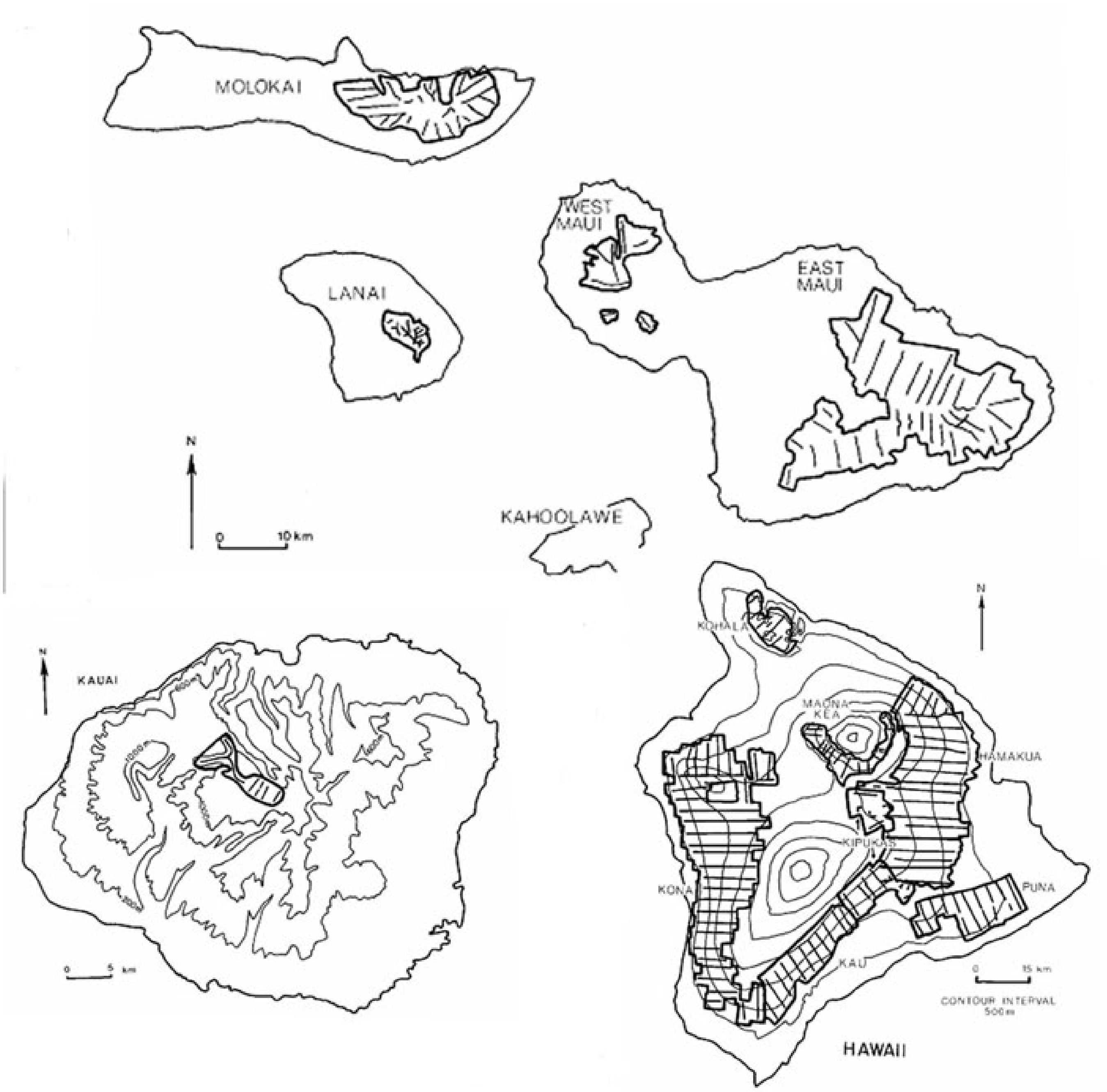


Table 1. Search effort required to make statement of probability of absence (extinction) for eight species of Hawaiian forest birds. All have been suggested for delisting by the U.S. Fish and Wildlife Service and were reported as presumed extinct in a 2003–2004 report to Congress (U.S. Fish and Wildlife Service 2006b).

						Number of point counts required for three levels of confidence in absence		
Species	Island	Range (km^2)	Effective detection distance (m)	Effective area surveyed / station (ha)	Number of point counts done	0.90	0.95	0.99
Lesser ’Akialoa *Hemignathus ellisianus obscurus*	Hawaii	1045	32	0.32	2319	275 462	300 800	320 128
Moloka’i Creeper *Paroreomyza flammea*	Molokai	573	28	0.25	131	197 280	215 427	229 270
Kamao *Myadestes myadestinus*	Kauai	25	60	1.13	140	1875	2047	2179
Oloma’o *M. lanaiensis*	Molokai	16	23	0.17	120	8165	8916	9488
Kaua’i O’o *Moho braccatus*	Kauai	25	66	1.37	140	1550	1692	1801
Greater ’Akialoa *Hemignathus ellisianus procerus*	Kauai	25	32	0.32	140	6590	7197	7659
O’u *Psittirostra psittacea*	Hawaii	145	66	1.37	357	8986	9812	10 443
Nukupu’u *Hemignathus lucidus*	Kauai	25	66	1.37	140	1550	1692	1801
	Kauai	25	39	0.48	140	4437	4845	5157
Maui Akepa *Loxops coccineus*	Maui	7	39	0.48	35	1243	1357	1444
	Maui	23	34	0.36	84	5371	5865	6242

RESULTS

Ivory-billed Woodpecker

Assuming an effective detection distance for visual detections of 25 m for line-transect surveys and 50 m for VCPs, 48%–54% of BDV and 44%–59% of WR were effectively searched in the 2 years (Table 2). The probabilities of visually detecting a single remaining individual were approximately 0.5 for each year of survey, increasing to a probability of roughly 0.75 of detecting a single individual in at least one of the two survey years (Table 3). At least one individual from a population of two or more individuals should have had a roughly 95% or greater chance of being detected over the 2 years (Table 3).

Of the overall 233–896-ha Arkansas study area (Figs. 1 and 3), 29 200 ha were intensively searched through 2006. Given the detection probabilities we used, this survey effort yielded roughly a 93% chance of detecting at least one individual from a population of 20 birds, a 74% chance from a population of 10, and only a 49% chance if five individuals were actually present in the study area

Table 2. Effective areas surveyed (EAS) for Ivory-billed Woodpeckers by visual means during 2 years for tracts along White River (WR) and Bayou de View (BDV), Arkansas (Fig. 2), assuming effective detection distances of 25 m for line transect (LT) surveys and 50 m for variable circular plot (VCP) surveys.

		2004–2005			2005–2006		
Survey Site	Area (ha)	LT (km)	VCP (#)	EAS (ha)	LT (km)	VCP (#)	EAS (ha)
BDV	9500	900	300	4592	1000	613	5168
WR	19 700	2 280	518	11 559	1660	1552	8725

as a whole (Fig. 3). The chance of detecting a population consisting of a single bird is only 12%. Thus, given this search effort, if more than a very few Ivory-billed Woodpeckers were present in the search area during the surveys, their presence should have been detected.

We also calculated Bayes' posterior probabilities of extinction for the Ivory-billed Woodpecker in those areas that were intensively surveyed, assuming that there were no valid detections. Beginning with prior probabilities of extinction of 50% in both BDV and WR, the surveys result in posterior probabilities of 70% in BDV and 75% in WR. Considering the large search effort, one might anticipate that not detecting any birds would lead to higher posterior probabilities of extinction than these. That there remains considerable doubt of extinction results from the moderate probabilities of missing populations consisting of only one or two individuals.

How do home-range size and the assumed distribution affect our estimates of the likelihood of detecting Ivory-billed Woodpeckers? Suppose that a single Ivory-billed Woodpecker occupies a home range of area H, that it can be at any position within the home range at the survey time, and that it does not venture outside its home range. In a target region with area A, the probability that any given individual will be missed by a survey that effectively covers the fraction p of the total area is $(1 - fp)$, where $f = H/A$. Therefore, it follows that the probability that all individuals of a population of size N will be missed is $P(n = 0 \mid N) = (1 - fp)^N$. Figure 4 shows the posterior probabilities of extinction given that there were no valid visual detections in either winter. It assumes a geometric prior distribution with prior probability of extinction of 0.5. The results are graphed against a range of home-range sizes. With very large home-range sizes, home ranges will naturally overlap. When the size of the home range exceeds the area of the target region, one arrives at the "uniform distribution" situation. The effectiveness of a survey is measured by the difference between the posterior probability of extinction and the prior probability of extinction. As the graph indicates, the home range must be large for the survey to have been moderately effective. The surveys as conducted would produce posterior probabilities of extinction exceeding 80% only if the home range of an individual Ivory-billed Woodpecker exceeds 5000 ha.

Home-range size is unknown for Ivory-billed Woodpeckers. During his studies, Tanner (1942) followed birds and found that, during the nesting season, individuals often traveled >2.0 km from the nest, with one record of a bird traveling 4.0 km from its nest in the course of daily activities. Based on anecdotal information, winter ranges (when current Ivory-billed Woodpecker surveys are done) were much larger than nesting-season ranges (Tanner 1942). From this, if winter home ranges are equivalent to a circle with a 4.0 km radius, home range size would be 50 km^2 (5000 ha), which would produce posterior probabilities of extinction slightly under 80% in both BDV and WR. From this analysis, we conclude that much greater search efforts will be required to obtain a level of 90% or greater for posterior probabilities of extinction.

Table 3. Probabilities of sighting at least one Ivory-billed Woodpecker for populations of different sizes, given areas surveyed in 2004–2005 and 2005–2006 in an estimated 19 700-ha tract along White River (WR) and a 9500-ha tract at Bayou de View (BDV). Also included are joint probabilities of detection in at least 1 year, assuming independent probabilities between years.

		Population Size				
Survey Area		1	2	5	10	20
BDV	2004–2005	0.483	0.733	0.963	0.999	1.000
	2005–2006	0.544	0.792	0.980	1.000	1.000
	combined	0.764	0.944	0.999	1.000	1.000
WR	2004–2005	0.587	0.829	0.988	1.000	1.000
	2005–2006	0.443	0.690	0.946	0.997	1.000
	combined	0.770	0.947	0.999	1.000	1.000

Hawaiian Forest Birds

Based on our calculations from the HFBS data, none of the endangered Hawaiian forest birds we assessed was surveyed sufficiently to yield a greater than 90% probability of detecting at least one bird from a population of 10 or more individuals. In most cases, we conclude that the HFBS survey effort was 1–2 orders of magnitude less than that required to assert extinction with a high degree of certainty.

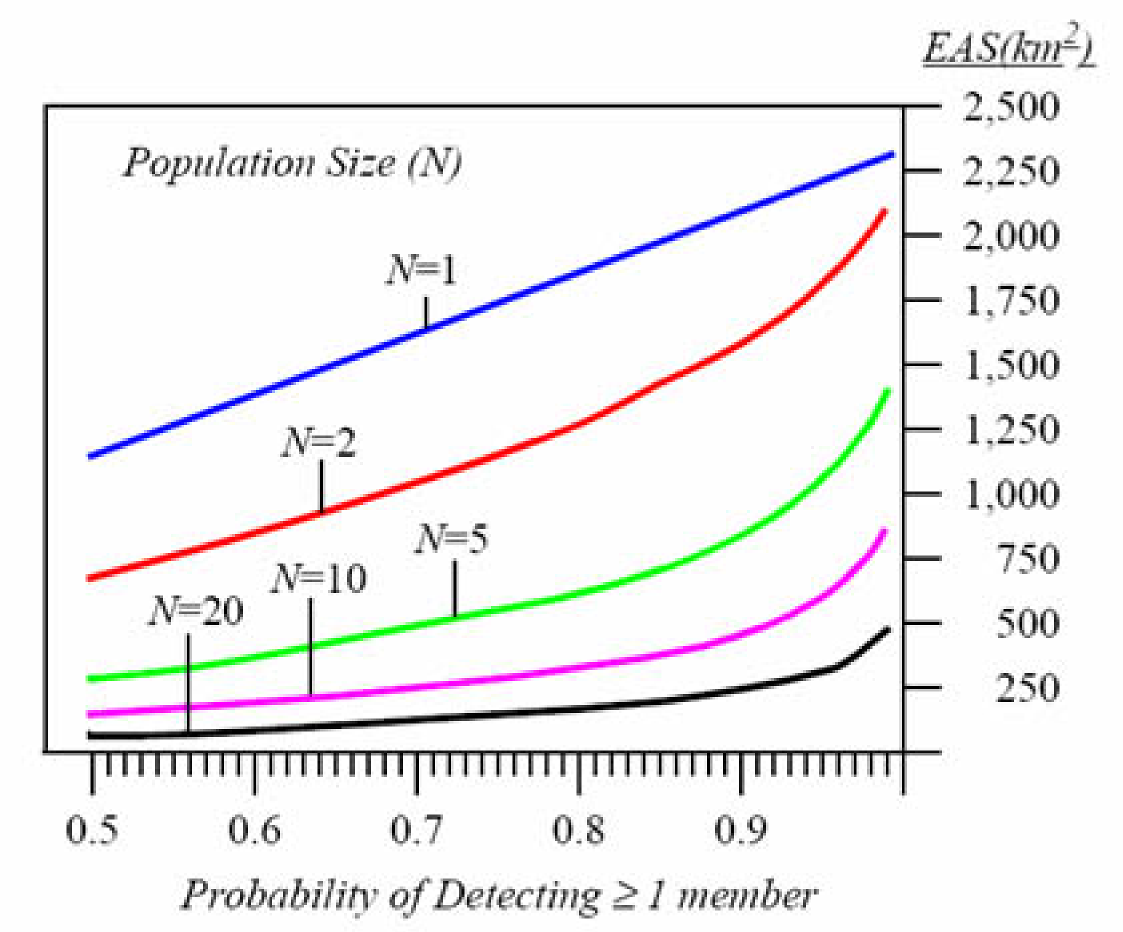
Choice of Prior

The choice of prior distribution and prior probability of extinction will influence the sampling effort required to produce a desired level of certainty of extinction. To illustrate the range of effects of such choices, consider the Oloma'o (scientific names of species are given in Table 1) of Molokai, Hawaii. Its range is $A = 1600$ ha. With its effective detection distance of 23 m (Scott et al. 1986), the effective area covered by a single station count is $f = 0.166$ ha. Again, let Q be the prior probability of extinction and V be the desired posterior probability of extinction following a survey of n stations that result in no detections. The Poisson prior distribution loads most of its probabilities of $N > 0$ on very low population sizes, where the probabilities of missing them are high. With a Poisson prior distribution, the required number of stations (n) is:

$$n \geq \left(\frac{A}{f}\right)\left(1 - \frac{\ln V}{\ln Q}\right) \tag{7}$$

We might also consider the prior probability of extinction as a Geometric probability distribution, where $P(N = k) = (1\text{-}p)\ p^k$, for $k = 0, 1, 2, \ldots$ (Appendix). The Geometric distribution spreads its probabilities of $N > 0$ over a wider range of population sizes than does the Poisson distribution. It is less likely that these larger populations would be missed by the survey effort. The posterior probabilities of extinction (given that there were no confirmed detections) are, therefore, somewhat higher for the Geometric prior distribution. With a Geometric prior distribution, the required number of stations (n) is:

Fig. 3. The area that must be effectively surveyed (EAS) relative to the probability of detection of at least one member of a randomly distributed population of Ivory-billed Woodpeckers across a 233 896-ha study area for actual populations of different sizes.



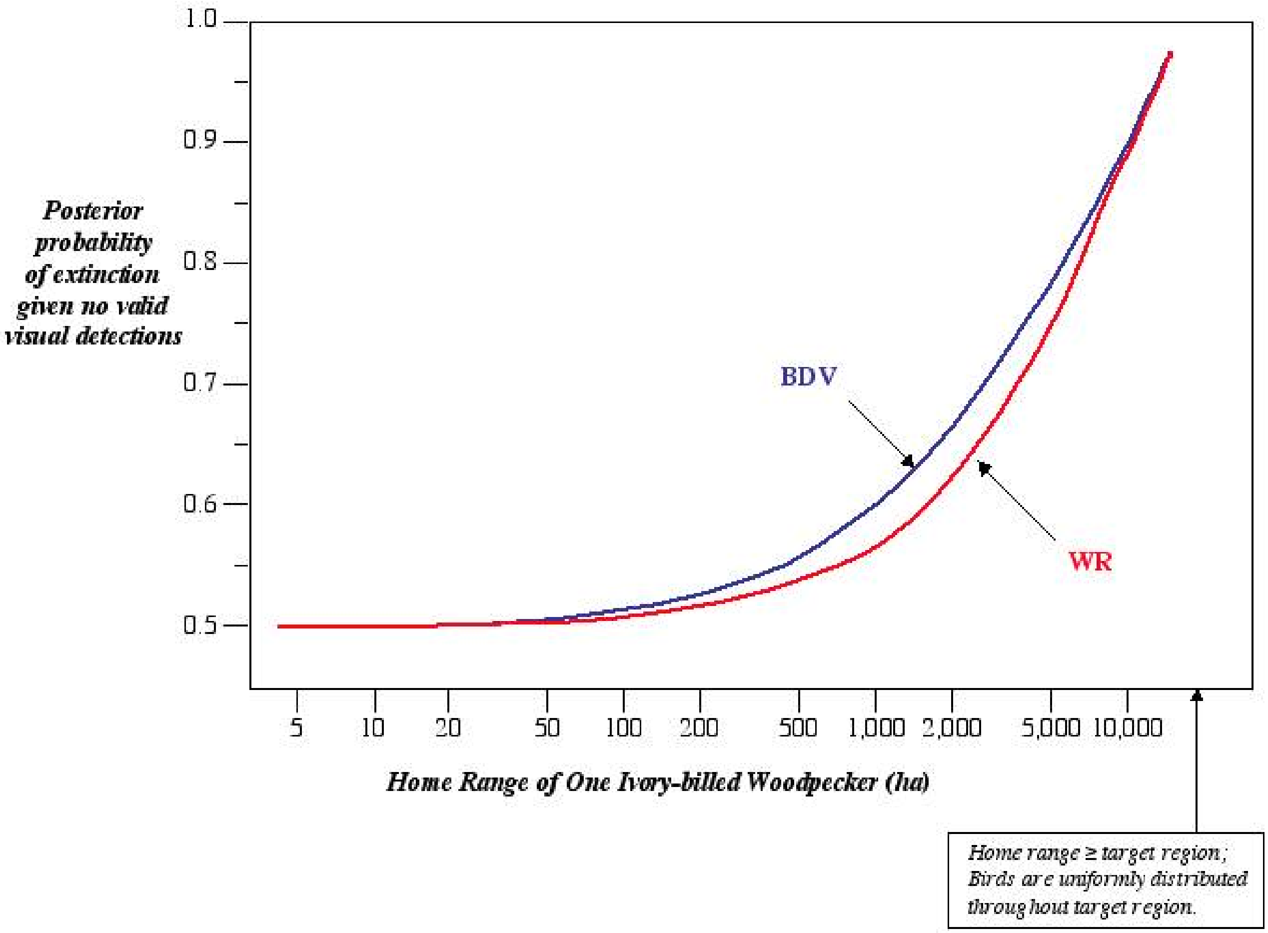
$$n \geq \left(\frac{A}{f}\right)\left(1-\frac{1-V}{1-Q}\right) \qquad (8)$$

The sampling effort under the different assumptions of prior distributions (Table 4) was less than 10% greater for the Poisson prior distribution. Yet the message is the same: it requires very intensive efforts to conclude with a high degree of certainty that the species is extinct.

DISCUSSION

Using a combination of biological data and statistical calculations, we show, on the basis of the Hawaiian Forest Bird Survey in the 1980s, it would be premature to declare that the Hawaiian forest birds we evaluated are in fact extinct. More recent intensive survey efforts, however, suggest that the Greater ’Akialoa and Molokai Creeper, two species that were not detected during the HFBS, and three species that were detected, the O’u on Kauai, Kauai O’o, and Kama’o, have high likelihoods ($p > 0.95$) of being extinct (Reynolds and Snetsinger 2001). Reynolds and Snetsinger’s analysis used data from

Fig. 4. The relationship between home-range size and posterior probability of extinction given no valid visual detections and the search efforts at White River (WR) and Bayou de View (BDV). We assume a geometric prior distribution with prior probability of extinction being 0.5. The arrow indicates a home range as large as the surveyed area; this gives the same results as having birds uniformly distributed throughout the region.



Home range ≥ target region;
Birds are uniformly distributed
throughout target region.

targeted searches in 1994–1996. These searches differed from the HFBS in survey methods (they defined a single visit as 10–20 h of auditory and visual searching, whereas the HFBS single survey was an 8-min point count), in what was calculated (they determined the probability of detecting at least one individual from a population of 10 across the species range, whereas we determined the probability that *N*=0), and in detection distances (they assumed greater detection distances for the Kaua'i O'o [150 m using song playback] and Greater 'Akioloa [39 m]). Regardless, this is an example of the intensive search effort required to have a statistically strong certainty of the likelihood of extinction.

The search effort required to have a high degree of certainty that a species occurs (or does not occur) in an area becomes extremely large for populations of 10 or fewer individuals. Our analysis of the search

Table 4. Sampling effort (number of variable circular plot (VCP) stations) required for three levels of statistical confidence of extinction (i.e., desired posterior probabilities) (V) across a range of prior probabilities of extinction (Q) for two prior probability distributions.

Poisson prior										
Q =		0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
V =	0.90:	9,188	8,998	8,786	8,522	8,165	7,643	6,785	5,083	–
	0.95:	9,414	9,322	9,218	9,090	8,916	8,662	8,244	7,416	4,942
	0.99:	9,587	9,568	9,548	9,523	9,489	9,439	9,357	9,195	8,710
Geometric prior										
Q =		0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
V =	0.90:	8,559	8,425	8,253	8,024	7,703	7,222	6,419	4,815	–
	0.95:	9,094	9,027	8,941	8,826	8,666	8,425	8,024	7,222	4,815
	0.99:	9,522	9,508	9,491	9,468	9,436	9,388	9,308	9,147	8,666

effort for Ivory-billed Woodpeckers in the White River and Bayou de View, assuming a uniform distribution of birds if they are present, suggest that if birds were present the actual number of individuals was very low ($N \leq 2$). With this assumption it is unlikely that birds were still present in the intensively searched area but not seen during surveys. However, below, we present distributions other than the uniform, which suggest higher probabilities that the Ivory-billed Woodpeckers may still persist in White River and Bayou de View.

Based on historical information, Ivory-billed Woodpeckers could be heard over much greater distances than they could be seen (Tanner 1942). If the greater auditory detection distances are used in our analysis, the survey effort in intensively searched regions of Arkansas would have virtually guaranteed detection if even a single bird was present. In fact, there are auditory records during these surveys that may be Ivory-billed Woodpeckers (Charif et al. 2005) (see also http://www.birds.cornell.edu/ivory, accessed 2007; but see Jones et al. 2007). The auditory records, if they are of Ivory-billed Woodpeckers, are consistent with the presence of a few individuals in the area.

The Ivory-billed Woodpecker surveys we considered included only ~12% of the forested habitat in the overall search area in Arkansas, so our analysis does not enable us to assess the likelihood that Ivory-billed Woodpeckers are extinct in the wider search area, much less across the currently presumably suitable habitat within the species' historic range. Based on a statistical assessment using time series of historic sightings, Roberts (2006) argued that a declaration of extinction is premature for this species. There are large forested areas of the historic range of the Ivory-billed Woodpecker, such as the Apalachicola and Chipola Rivers in Florida (ca. 73 000 ha) and the Atchafalaya Swamp in Louisiana (ca. 536 000 ha) that include possible habitat. The effort required to extend the search for Ivory-billed Woodpeckers to the large tracts of potential habitat will require hundreds of thousands of count periods or thousands of kilometers of transects. That process has already begun in other portions of the species' historic range in an attempt to locate birds and suitable habitat (Hill et al. 2006, Rohrbaugh et al. 2007) (see also http://www.fws.gov/ivorybill/ and http://www.birds.cornell.edu/ivory/latest/0708summary/document_view, accessed 2007). Since 2007, a tool for broadcasting imitations of double-knock drums of Ivory-billed Woodpeckers is being widely used in surveys. Ivory-billed Woodpeckers would likely respond to these imitations in a way that improves their detectability at distances larger than the effective detection distances we used for our calculations based on visual encounters. Area effectively searched would be higher, and the overall search effort required for absence inferences lower, with use of this tool.

Model Assumptions

All modeling analyses make assumptions, of course, and ours is no exception. In this analysis, we assumed that each bird in the population would be detected with a probability equal to the fraction of the target area that is effectively surveyed. That would be the case, for example, if the birds were uniformly distributed; this assumption is also a reasonable default if we are ignorant of a more complex spatial distribution. If the birds are spatially distributed in ways other than uniformly, survey efforts are likely to be even less effective. This can be illustrated simply. Suppose that the proportion of the target area effectively surveyed is p, but that the population occupies only a fraction (f) of the target region. In that case, the chance that an individual will be detected in the survey is fp. As an example, consider the case where no Ivory-billed Woodpeckers were confirmed in the 2 years of survey effort. Starting with a 50% prior probability of extinction and a geometric prior distribution, the posterior probability of extinction declines steadily with f from 88% when f=1 to 55% when f=0.1. So, if a remaining population is confined to a small sub-region of the area targeted by the surveys, an even greater search effort than the enormous effort already taken would be needed to achieve substantial gains in the certainty that the Ivory-billed Woodpecker is extinct in the target region when no birds are detected. Known differences in distribution can be handled by stratification of effort at the design stage and by covariate analysis at the analysis stage. Standard survey methods allow for clustering by counting the clusters rather than the individuals, so even if Ivory-billed Woodpeckers travel in pairs it does not invalidate the methods and results we present.

We also assumed a constant detection distance. Detectability may vary by habitat, by time of day, by observer, and by other factors. Methods exist for incorporating such variations into the analysis (Ramsey et al. 1987, Beavers and Ramsey 1998), but they depend on having actual detections of the species in a variety of conditions to calibrate the detectability functions. Lacking actual detections, we relied on knowledge of the species' biology and that of similar species to set an arbitrary detection distance. Finally, we made assumptions about Ivory-billed Woodpecker behaviors. For example, we assumed that birds are neither attracted to nor repelled by observers. If this assumption were violated, detection distances would be different—increased if birds avoid surveyors (Tanner 1942) and reduced if birds are attracted to observers—yielding different detection likelihoods.

Implications

Determining whether or not a species is extinct is a problem with both biological and economic consequences. It is not possible to prove with absolute certainty the absence of a species—statements about extinction (or about the successful eradication of introduced or invasive species [Morrison et al. 2007]) are probabilistic. Achieving a lack of reasonable doubt requires sufficient survey efforts, coupled with realistic probability calculations. As we have shown, assumptions about the distribution of a species' influence answers to how much search effort is required for a specified level of confidence in the absence of a species. Thus, if little information is available, we suggest assuming distributions that are consistent with biological evidence and modeling outcomes under varying assumptions of distribution. We suggest that statements about extinction should be accompanied by a statement of probability or uncertainty and sufficient information about how that conclusion was determined. Declaring a species as extinct or delisting a species where legal protection exists is a poor idea unless statistically sufficient survey efforts have been made.

What should one consider when establishing sampling protocols for species that are vanishingly rare so that precious conservation resources are efficiently spent? We suggest that the first step involves searching in those areas where there is the greatest chance of encountering the species of interest. This determination can be based on historical records, recent sightings, and/or best remaining available habitat. Next, it is important that highly skilled observers be chosen, screening potential observers for hearing, vision, experience, and physical ability to do the job. Those selected can then be trained in the methods and identification issues. Once a search area has been selected, the sampling method needs to be determined. Line transects are appropriate when it is possible to survey while moving, whereas point counts are appropriate when the observer must traverse difficult terrain. It is important that sampling points and/or transects be located in a way that gives all parts of the target region some quantifiable chance of being selected. The time of year and day, weather conditions, etc. should be chosen to increase chances that species of interest will be detected (Ralph and Scott 1981, Buckland et al. 2001). The Ivory-billed Woodpecker surveys have been conducted during the winter and early spring when birds are expected to drum and call more frequently and when deciduous trees lacked leaves, increasing chances of seeing a bird at a distance in heavily forested areas. The HFBS was conducted in areas of remaining habitat when birds were highly vocal and favorable weather was likely.

Questions will always arise as to how resource managers should allocate limited funds among endangered species and habitat protection, and how the costs of protection should be balanced against the likelihood that a species is still extant and, if so, can be managed to recovery (Scott et al. 2005). What level of certainty should be sufficient to declare a species extinct and shift resources elsewhere, vs. mounting what may be a massive surveying effort to improve our confidence in that declaration? Ultimately, these are societal, not scientific, decisions. We argue that, if one wants to protect against the error of declaring an extant species as extinct, the threshold for “reasonable doubt” should be set high, perhaps higher than the commonly used 95% level.

Decisions about allocating resources to threatened or endangered species are difficult because the consequences of habitat protection cannot always be anticipated and some payoffs may be a long time in coming. Others have suggested that a structured decision-making process would allow managers to determine if resources would be better spent searching for the species than in managing the habitat (Chades et al. 2008). The search for the Ivory-billed Woodpecker has sparked conservation efforts and searches throughout the southeastern United States. Indeed, we would not be discussing Ivory-billed Woodpecker conservation and resource allocation if the area in Arkansas where Ivory-billed Woodpeckers were reported in 2004 and early 2005 had not been set aside over several decades as a refuge for other species by the U.S. Fish and Wildlife Service (Butch 2003) and The Nature Conservancy.

Responses to this article can be read online at:
http://www.ace-eco.org/vol3/iss2/art3/responses/

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Appendix 1. Appendix

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