The Condor 115(2):442–447

MORE MISLEADING TREND ANALYSIS OF HAWAIIAN FOREST BIRDS

Leonard A. Freed[1,3] and Rebecca L. Cann[2]

[1]*Department of Biology, University of Hawaii at Manoa, Honolulu, HI 96822*
[2]*Department of Cell and Molecular Biology, University of Hawaii at Manoa, Honolulu, HI 96822*

Abstract. Accurate analysis of trends in densities estimated from survey data depends on selection of a model that fits the data. When such analysis uses data recorded at different times in the same area but from different transects, then the target species' density and spatial heterogeneity become an issue. It is possible, even in the absence of environmental change, that one set of transects may underestimate or overestimate the density entirely on the basis of location. The resulting risk is that the density estimated earlier may falsely indicate a decline or an increase when compared to the densities estimated later. We investigate this problem for trend analysis of two species of endangered Hawaiian birds at Hakalau Forest National Wildlife Refuge, island of Hawaii. Assertions based on Bayesian regression, and accepted by the U.S. Fish and Wildlife Service, purportedly indicate increases in the density of the endangered Hawaii Akepa (*Loxops coccineus coccineus*) from 1977 to 2007 and of the endangered Hawaii Creeper (*Oreomystis mana*) from 1987 to 2007. Here we show, at four study sites spanning the south–north axis of the refuge, that capture rates per mist-net hour of both species declined significantly and the 1977 transects used underestimated density because of location. We submit that the main reason for the differences between our piecewise regression and Bayesian regression is the inappropriate use of Bayesian regression. Analysis by the appropriate model indicates that since 2000 all Hawaiian birds at Hakalau Forest National Wildlife Refuge have been declining.

Key words: *trend analysis, heterogeneous density, residual analysis, endangered species, Hawaii Akepa, Hawaii Creeper.*

Más Análisis de Tendencia Engañosos de las Aves de Bosque de Hawái

Resumen. El análisis exacto de las tendencias en la densidad estimadas a partir de datos de inventario depende de la selección de un modelo que se ajuste a los datos. Cuando un análisis de este tipo usa datos registrados en diferentes momentos en la misma área pero en diferentes transectas, entonces la densidad de la especie elegida y la heterogeneidad espacial se convierten en una cuestión. Es posible, incluso en ausencia de cambios ambientales, que un grupo de transectas pueda subestimar o sobreestimar la densidad basadas por completo en la ubicación. El riesgo resultante es que la densidad estimada primero puede indicar falsamente una disminución o un aumento cuando se compara con las densidades estimadas posteriormente. Investigamos este problema para los análisis de tendencia de dos especies de aves en peligro de la isla de Hawái, en el Refugio Nacional de Vida Silvestre del Bosque de Hakalau. Las afirmaciones basadas en regresiones bayesianas, y aceptadas por el Servicio de Vida Silvestre y Pesca de EEUU, supuestamente indican aumentos en la densidad de las especies en peligro *Loxops coccineus coccineus* desde 1977 hasta 2007 y *Oreomystis mana* desde 1987 hasta 2007. Aquí mostramos que en cuatro sitios de estudio que abarcan el eje sur-norte del refugio, las tasas de captura por hora de red de niebla de ambas especies disminuyeron significativamente y que la transecta usada en 1977 subestimó la densidad debido a su ubicación. Presentamos que la razón principal de las diferencias entre nuestra regresión por tramos y la regresión bayesiana es el uso inapropiado de la regresión bayesiana. El análisis dado por el modelo apropiado indica que desde el 2000 todas las aves hawaianas en el Refugio Nacional de Vida Silvestre del Bosque de Hakalau han estado disminuyendo.

INTRODUCTION

Trend analysis is an important component of conservation biology (Ralph and Scott 1981, Goldsmith 1991), and must be conducted with great care (Dixon et al. 1998, Edwards 1998, Thomas and Martin 1996, Bart et al. 2003, Sauer et al. 2004). This is especially true for endangered species, where an error in either direction can have significant consequences. If the error asserts that a species is declining when in fact it is not, then managerial resources may be wasted on a problem that does not exist. Other more immediate problems may be ignored because of misplaced funding and effort. The alternative error asserts that endangered species are stable or increasing when in fact they are declining. This error is more serious because it may lead to further declines and extinction while the agency responsible for management is misled.

Manuscript received 5 October 2011; accepted 14 September 2012.
[3]E-mail: lfreed@hawaii.edu

The Condor, Vol. 115, Number 2, pages 442–447. ISSN 0010-5422, electronic ISSN 1938-5422. DOI: 10.1525/cond.2013.110165

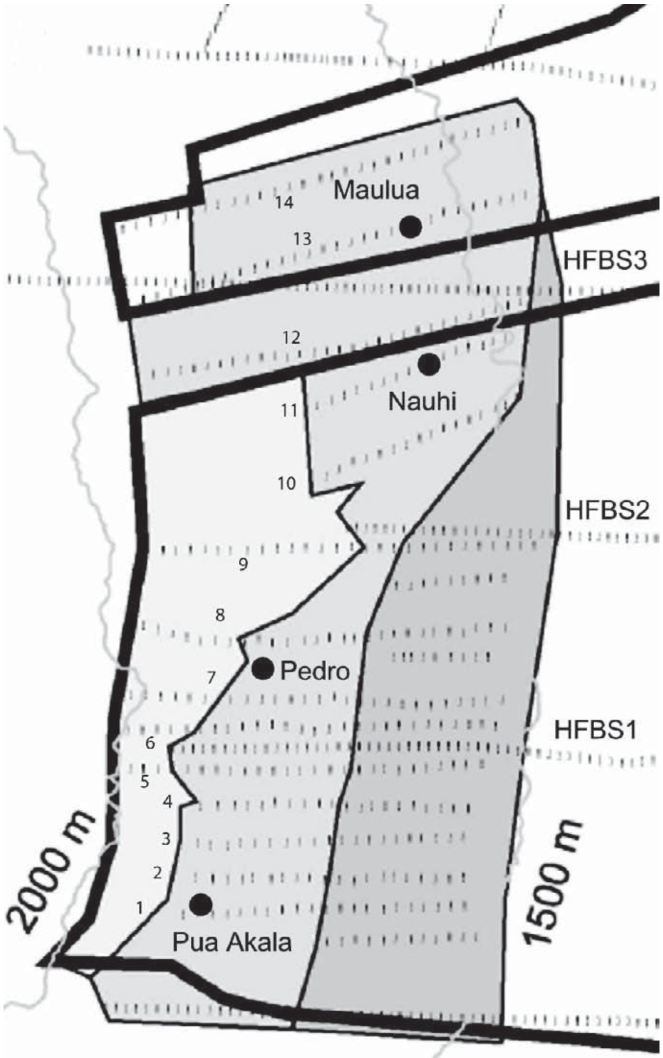

FIGURE 1. Surveyed portion of Hakalau Forest National Wildlife Refuge. The refuge is outlined by thick black lines (north at top). Only the medium gray area of open forest was considered by Camp et al. (2009b); the lighter gray area to the left is the restoration area and the darker grey area to the east is the area of closed forest. Labeled dark circles, study sites where birds were banded for our study. The three Hawaii Forest Bird Survey transects that provided the estimates of density for 1977 are indicated by HFBS1 through 3. The other numbered transects are those used from 1987 to 2007.

An example of the latter problem with trend analysis can be illustrated with Hawaiian forest birds. These birds are exposed to introduced predators (Lindsey et al. 2009), competitors (Freed and Cann 2012a), and parasites (Freed et al. 2005, 2008a). Camp et al. (2010) estimated densities from 21 years of survey data, and performed Bayesian regression to determine trend. They asserted that all native bird species were stable or increasing in the major 3373-ha area of open forest of Hakalau Forest National Wildlife Refuge (Fig. 1). However, they did not analyze the residuals from their regression, essential to determining whether the data meet the assumptions of the model employed. Residuals should be analyzed in every regression analysis, even for additive models (Fewster et al. 2000) and diverse Bayesian analyses (Ntzoufras 2009).

Standard statistical practice indicates that the model must fit the data to be acceptable and must be modified or rejected if there is lack of fit or other assumptions are not met (Belsley et al. 1980, Cook and Weisberg 1982, Crawley 2002). We analyzed the residuals from single-slope regression and found that those for five sets of years differed significantly (Freed and Cann 2010). When the density values bend within the series, indicating an initial increase followed by a decrease, which is the case with Hawaiian forest birds at Hakalau (Freed and Cann 2010), no single-slope regression model, including the Bayesian regression used by Camp et al. (2010), will fit the data. The first nine points of the series, making up most of the increase, were low values with high coefficients of variation, exactly the opposite pattern of the rest of the series (Freed and Cann 2010).

We used the same density estimates but performed a piecewise regression, using year 2000 as a breakpoint (Freed and Cann 2010). A piecewise regression estimates two slopes, one from the beginning of the series to the breakpoint, the second from the breakpoint to the end of the series. We chose year 2000 as the breakpoint because that was the year that the introduced Japanese White-eye (*Zosterops japonicus*), a known competitor of many Hawaiian birds (Mountainspring and Scott 1985), increased in density on our study site and in the open forest (Freed et al. 2008b, Freed and Cann 2012a). That was also the year when the growth of juveniles of seven of eight native species measured was stunted (Freed and Cann 2009) and when young birds and adults of all species had difficulty replacing their feathers during the postjuvenile and annual molt (Freed and Cann 2012b). These problems persisted through 2006, when our research was permanently ended. Piecewise regression indicated that all species were declining after 2000. We also tested the residuals from the piecewise regression in the same way we tested them from single-slope regression. The piecewise regression had adequate fit (Freed and Cann 2010), reflected the demographic problems of birds on our study sites (Freed et al. 2008b, Freed and Cann 2009, 2012b), and extended these problems to the larger area of the refuge from which the estimates of density were obtained.

Trend analysis can also be complicated by the comparison of discontinuous data sets that (a) are not collected at precisely the same location over time and (b) are not collected by the same methods. If birds' density in a survey area is spatially heterogeneous, then subtle differences in the survey locations between the initial survey period and a more recent survey period may contribute to the perception of population increases or declines that never occurred. The problem would be exacerbated if the non-overlapping survey areas differ greatly in abundance. Spatial heterogeneity can be generated by differences in habitat that lead to variation in carrying capacity or by differences in biotic factors that keep some portion of the area below carrying capacity.

In their analysis of trends of bird densities at Hakalau, Camp et al. (2009a) included estimates of density in 1977 from three transects at Hakalau generated by the Hawaii Forest Bird Survey (HFBS) of 1977 (Scott et al. 1986). These estimates were considered along with annual estimates from transects surveyed from 1987 to 2007. Camp et al. (2009a) were careful to just use the HFBS transects that were contained in the open forest area that also contained their recently surveyed transects (Fig. 1). They did not include the 1977 data in the trend analysis, but asserted for the endangered Hawaii Akepa (*Loxops coccineus coccineus*) that the bird had increased in density over the last three decades, because the density in 1977 was the lowest estimated. However, the HFBS documented a decrease in densities of the Akepa and the endangered Hawaii Creeper (*Oreomystis mana*) from the southern to the northern end of the refuge (Scott et al. 1986). It is possible that the three transects from 1977 do not fully represent the 14 transects used from 1987 to 2007. The purpose of this paper is to determine (1) if, from rates of capture in mist nets, the gradient of density across the refuge still exists, (2) if use of the 1977 estimates incorporates the spatial heterogeneity evenly, and (3) if use of these estimates improves the fit of the single-slope model. Even though Camp et al. (2009a) asserted that the creeper increased only from 1987 to 2007, we deal with the objectives above for that species to show the generality of the gradient of density and the lack of fit of a single-slope model.

METHODS

First, we determine whether the Hawaii Akepa and Hawaii Creeper continue to decline in density along a south-to-north gradient as represented by four study areas: Pua Akala, Pedro, Nauhi, and Maulua (Fig. 1). For each of these sites we summarized the rates of capture of adult birds per hour of aerial mist net operated (Table 1). These nets were operated 10 to 20 m above the ground. The long-term Pua Akala site was matched with Pedro from 1995 to 1996 (Hart 2001), with Nauhi during 2005, and with Maulua from 1992 to 1995. We analyzed the capture rates with a linear model with two species and a linear contrast of spatial trend of the four study sites from south to north (which uses only 1 degree of freedom), along with the interaction of species.

Second, we determined whether data from the three transects that were used from the 1977 survey fall within the range in density of the transects used from 1987 to 2007. Hart (2001) studied the Hawaii Akepa at Pua Akala and Pedro from 1994 to 1997 and established by mist-netting and circular-count analysis that the Akepa was 3 times as

TABLE 1. Hours of mist-net operation during the years when captures of the Hawaii Akepa and Hawaii Creeper per study site were compared.

		Hours	
Year(s) of comparison	Study sites compared	Site 1	Site 2
1992–1995	Pua Akala and Maulua	3192	800
1995–1996	Pua Akala and Pedro	854	2554
2005	Pua Akala and Nauhi	3079	1237

abundant at Pua Akala, over a distance of approximately 4 km. This difference has persisted since the HFBS in 1977 (Hart 2001) and supports the assumption of no change in density since 1977. The linear trend in capture rates from south to north (presented below) thus justifies interpolating the capture rates between study sites for both the HFBS transects and the recent transects. We modeled the capture rate of a given transect by taking a linear combination of the capture rates at the two study sites weighted by the proportional distance of the transect to each of them. For example, the HFBS1 transect is located 74% of the distance between the Pua Akala and Pedro study sites (Fig. 1), so its estimated capture rate would be 0.26 that of Pua Akala and 0.74 that of Pedro. Then we compared the capture rates of recent transects 1–4 that fall outside to the south of the first HFBS1 transect. We combined the fifth recent transect with the first HFBS transect so that the variance of both sets of transects could be estimated. Then we performed an analysis of variance with species, transect type (1–4, 5–HFBS1), and the interaction, with species entered into the model first. For the HFBS2 transect, we used its mean in the same type of test with transects 6 through 11, which span the recent transects between HFBS1 and HFBS3. One transect set combined recent transects 6–8 and 10–11. The second combined recent transect 9 and HFBS2. HFBS3 only has two transects (13 and 14) that fall outside to the north, obviating statistical analysis. However, this was an area where these endangered birds were at vanishingly low densities (Scott et al. 1986), which we confirmed by rates of capture in mist nets.

Third, we performed a residual analysis on the survey data (from Camp et al. 2009b) that included density estimates from 1977 and 1987 to 2007. This determined whether the inclusion of the 1977 data results in adequate fit of a single-slope model, justifying the assertion that endangered species are stable or increasing on the refuge, an assertion made consistently by Camp et al. (2009a,b, 2010). We calculated the residuals for each species from years split into three relatively equal groups 1–8 (1977, 1987–1993), 9–15 (1994–2000), and 16–22 (2001–2007), then analyzed the variance of the residuals, using species and year set as factors. If residuals fit the model, there should be no year-set effect, just a horizontal band with mean 0. A significant effect would indicate that residuals in one set are larger than those in another set, formally indicating lack of fit of the model.

RESULTS

Both the Hawaii Akepa and Hawaii Creeper have a significant spatial trend of lower capture rates from Pua Akala to Maulua (Fig. 2, Table 2). The significant interaction indicates that the shape of the species' decline differs.

Analysis of variance revealed that the Akepa and creeper varied in capture rates along recent transects 1–5 and HFBS1 (species, $P < 0.0001$), but capture rates were higher in recent transects 1–4 than in recent transect 5 and HFBS1 (transects, $P = 0.002$). The interaction was not significant ($P = 0.22$). The differences in capture rates between transect sets were 0.0207 vs. 0.0155 for the Akepa and 0.0103 vs. 0.0074 for the creeper. Thus the southernmost HFBS transect underestimates density at the southern end of the refuge. The second HFBS transect, with recent transect 9, was surrounded by recent transects 6–8 and 10–11 and had no difference in capture rates between the species ($P = 0.10$), the transect sets (0.71), or the interaction ($P = 0.77$). Thus the second transect correctly estimated the surrounding densities. No Akepa were captured at the Maulua site near HFBS3 and only one creeper was captured. The underestimation of density is limited to HFBS1, but this makes the low estimate of density from the three HFBS transects an artifact of the spatial heterogeneity of density.

Residuals of the single-slope trend analysis that included year 1977 did not vary by species but did by year sets (Fig. 3, Table 3). For both species, the years 9–15 had positive residuals while the preceding and following year sets had negative residuals. This indicates that the lack of fit of the model including year 1977 was significant for both species.

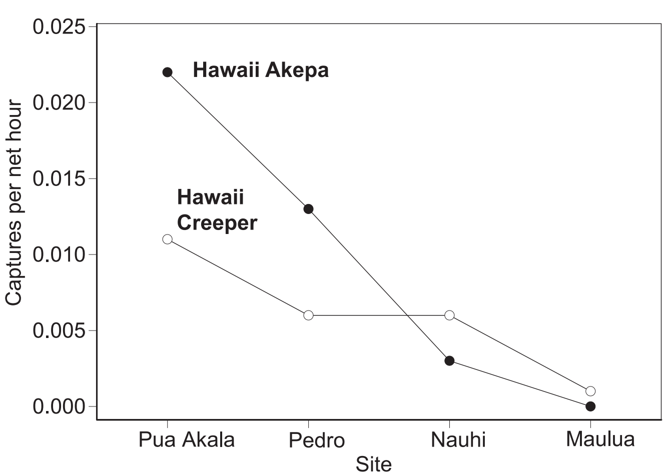

FIGURE 2. Standardized rates of capture of the Hawaii Akepa and Hawaii Creeper (individual adult birds per aerial mist-net hour) at four study sites that span the refuge from south to north. Hours of mist-net operation are in Table 1, the analysis of variance of capture rates in Table 2.

TABLE 2. Analysis of variance table for documenting the heterogeneity of rates of capture of the Hawaii Akepa and Hawaii Creeper in Hakalau Forest National Wildlife Refuge.

Effect	Degrees of freedom	Sum of squares	Mean square	*F*-value	*P*-value
Species	1	0.00002	0.00002	5.70	0.075
Sites (trend)	1	0.00028	0.00028	65.33	0.001
Species × sites (trend)	1	0.00005	0.00005	12.30	0.025
Residuals	4	0.00002	0.000004		

DISCUSSION

We have formally documented spatial heterogeneity in rates of capture of these two endangered birds on the refuge, heterogeneity that matches the gradient in density from the Hawaii Forest Bird Survey (Scott et al. 1986). Hart (2001) showed that the ratio of 3 to 1 between Pua Akala and Pedro in captures of the Hawaii Akepa matched the difference between the sites in his survey data. Woodworth et al. (2001) also banded at the Pua Akala, Nauhi, and Maulua sites but did not use aerial mist nets, and acknowledged that they missed many individuals of these canopy species. Use of transects from the HFBS underestimated density because the southernmost transect missed the highest density of the endangered species in the southern portion of the refuge. However, this was of lesser consequence because the model that was applied to the data, including the density estimates from 1977, still had significant lack of fit, as did the residuals from just 1987 to 2007 for both species (Freed and Cann 2010).

There was a fourth HFBS transect just outside the southern boundary of the refuge (Fig. 1). Camp et al. (2009a) did not incorporate the data from this transect because it falls outside

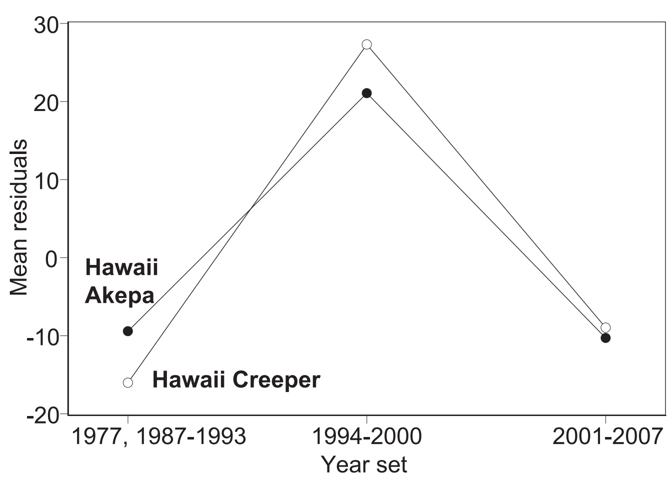

FIGURE 3. Mean residual values for sequential sets of years for the Hawaii Akepa and Hawaii Creeper in units of birds km^{-2}.

TABLE 3. Analysis of variance table of residuals from trend analysis over three year sets.

Effect	Degrees of freedom	Sum of squares	Mean square	*F*-value	*P*-value
Species	1	0.15	0.15	0.01	0.94
Year set	2	1677.13	838.56	40.10	0.02
Residuals	2	41.83	20.91		

of the area sampled by the recent transects. Our capture-rate data suggest that if that transect had been used, the four HFBS transects would have sampled the entire spatial heterogeneity in density more evenly. As a result, instead of the density of the Hawaii Akepa in 1977 being lowest, it would have been more similar to that estimated 1987–2007, nullifying the claim by Camp et al. (2009a) that the bird has increased over the last 3 decades. The assertion that these two species of endangered birds are stable or increasing in the refuge (Camp et al. 2009a,b, Camp et al. 2010) is simply not true (Freed and Cann 2010, 2012a) because it is based a model that does not fit the data. Bayesian regression is not a valid reason for not analyzing residuals (Ntzoufras 2009).

The piecewise regression, which fits the data, implies that the data from 2000 to 2007 reflect conditions on the refuge. Since 2000, in the refuge's open forest, tens of thousands of native birds have perished, amounting to an estimated loss of one-third of its birds (Freed and Cann 2012a). In the area of closed forest, the refuge only lost 10% of its birds (Freed and Cann 2012a). The mechanisms for the declines are at least partially known. The Japanese White-eye is the only bird that is increasing in the refuge, first in the restoration area, then in the open forest beginning in 2000, and eventually in the closed forest (all areas shown in Fig. 1) (Freed and Cann 2012a). The white-eye overlaps in multiple foraging substrates with each native species in what is a simple forest dominated (90%) by one tree species (Freed et al. 2008a). With the increase in the white-eye, growth of juvenile native birds was stunted, as attested by their lower mass, shorter bills, and shorter tarsi (Freed and Cann 2009). Both young and adults of all species took longer to complete molt, and molt of adults' primaries was asymmetric (Freed and Cann 2012b). The changes in growth and molt are associated with severe food limitation.

The declines from these changes in condition and their demographic consequences were captured in the piecewise regression (Freed and Cann 2010) and in functional data analysis of changes in mean density between 1999–2001 and 2006–2007 (Freed and Cann 2012a). In the Hawaii Akepa, survival of juveniles declined significantly from lower mass, as did that of second-year birds from shorter bills (Freed and Cann 2009). It followed that there was lower recruitment and the recruits did not survive as well. Only 36% of adult birds survived from 2005 to 2006. In addition, its seasonal variation in sex-allocation adaptation has been dismantled to the point that the sex ratio of young birds has changed from 57% to 13% females (Freed et al. 2009). This chronic low replacement of females was evident in the more male-biased adult sex ratio at all of our study sites at Pua Akala between 1900 and 1650 m in elevation. The change in sex ratio also implies that density estimates from current surveys are probably inflated because detections in March now include more males protecting their mates against other males seeking a mate. The change in molt of the Hawaii Creeper was the greatest of any native bird, including females in which molt and breeding overlapped, something they had previously avoided (Freed and Cann 2012b). Survival of adult Hawaii Creepers at our open-forest study sites decreased from 2002 to 2004 (Freed and Cann 2012b). Both the Akepa and creeper had essentially disappeared from our 1770-m site at Pua Akala in 2008 (Freed et al. 2008b).

A common assumption in data analysis is that using all of the data is better than using just most of it. This is true, but only if the data are relevant to the question asked or the hypothesis being tested. Selection of the model and data should flow from this, and analysis of residuals should determine if the model fits the data. Using the density from 1977 did not improve the fit of the Camp et al. (2009a) model. If there is an environmental change, then data only at and after the change should be used. The spillover of the white-eye from the adjacent area of the refuge being reforested represents a substantial environmental change. The challenge for management is to determine whether the declines of all native species after 2000 can be reversed. Piecewise regression, as the appropriate tool to identify the magnitude of a dynamic environmental change, is also appropriate to identify the success of management. The breakpoint would be when management begins. Ideally, the negative slopes from 2000 to 2007 should, with appropriate management, be replaced by positive slopes.

This example with Hawaiian forest birds should be a strong cautionary warning to anyone analyzing trends in survey data and to all regulatory agencies that depend on such analyses. Heterogeneity of densities needs to be considered because of the strong effect on estimates of population trajectories generated over long periods. If survey data from several periods are to be used, it is necessary to ensure that the data from the two periods are comparable in that they accurately reflect the spatial heterogeneity of densities in the landscape. Even more generally, researchers, reviewers, editors, and regulatory agencies need to focus closer attention on the questions being addressed, on the model and data being used to address the questions, and how well the model fits the data. An inappropriate model can miss a significant environmental change, as we have shown.

ACKNOWLEDGMENTS

We appreciate financial support from the John D. and Catherine T. Foundation (World Environment and Resources Program, 8900287) and the National Center for Environmental Research (Science to Achieve Results, Environmental Protection Agency, R82-9093). T. Smith discussed the issues with us, and we received sound advice from two anonymous peer reviewers.

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