Importance of Causal Analysis of Threats to Oceanic Avifaunas: Reply to Blackburn et al.

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We are pleased that Blackburn et al. (2008 [this issue]) have taken an interest in our causal modeling of threatened bird faunas on oceanic islands (Trevino et al. 2007). Our results indicated possible environmental influences on the number of threatened bird species from the physical and biotic characteristics of islands. Blackburn et al. discuss possible strengths and weaknesses of 2 methods of analyzing such influences: generalized-linear mixed modeling and causal modeling with structural equations and standardized partial-regression coefficients (these last used as measures of effect sizes). The former method excludes information because it does not incorporate the logical structure of causes, whereas the latter takes advantage of the fact that physical aspects of islands (island area and isolation from a mainland) might influence biotic factors (number of species in the avifauna, number of introduced mammalian predators, and time since human colonization of the islands) and that physical and biotic factors might influence the dependent variable (number of bird species under threat of extinction) (Fig. 1). Although physical factors are likely to influence biotic factors, we think the reverse is unlikely to be true. The method we used allowed us to test an a priori theoretical model that is a working hypothesis of causal mechanisms (Mitchell 1992) threatening birds on oceanic islands. This method can be used to refine and deepen understanding of the potential collaborative factors that may influence the extinction threat of ocean island avifaunas.

Blackburn et al. estimated a null expectation for the number of threatened species from the size of the avifauna. As we pointed out in our original article, "the larger the avifauna on an island, the greater the number of bird species that can potentially become threatened with extinction" (Trevino et al. 2007:129). Blackburn et al. estimate the correlation for this relationship for random data at about 0.74 and the regression weight at 0.60 (given random data), which is higher than the empirical correlation of 0.47 and regression weight 0.43. They insightfully point out that our path of 0.61 from number of extant avifauna to number of threatened avifauna is positive, as is the null hypothesis. Nevertheless, our path of 0.61 was a standardized, partial regression coefficient calculated after controlling for the effects of other variables and is not directly comparable to simple linear regression coefficients. These paths are interpreted as the proportional change in standard deviation of the dependent variable to a change of 1 SD in the independent (causal) variable (Li 1981). As we pointed out (Trevino et al. 2007), a path coefficient of 1.0 should occur if the islands exhibited a constant proportion of threatened species. We have also performed a similar estimation for the null expectation of the number of extinct species on oceanic islands (since European colonization; Karels et al. 2008), and found that the estimated path coefficient from size of the original avifauna to the number of species that had gone extinct ($p = 0.88$) was much higher than the empirical value ($p = 0.36$). Path coefficients lower than expected indicate heterogeneity among islands, such that both threats to current bird faunas and extinctions in the past influence some islands more than others (Karels et al. 2008). This interesting information may prove useful to future conservation efforts.

Some of the comments made by Blackburn et al. should be considered with care. First, the probability of threat of extinction is incorporated in our original path model as the relationship between the number of extant bird species on an island and the number of threatened bird species of the island. This is given a thorough explanation in Trevino et al. (2007) and Karels et al. (2008) and therefore will not be discussed further here. Second, the path coefficients in our analyses reflect the actual relationships that occur among the data variables, given their accuracy and consistency of measurement. Third,

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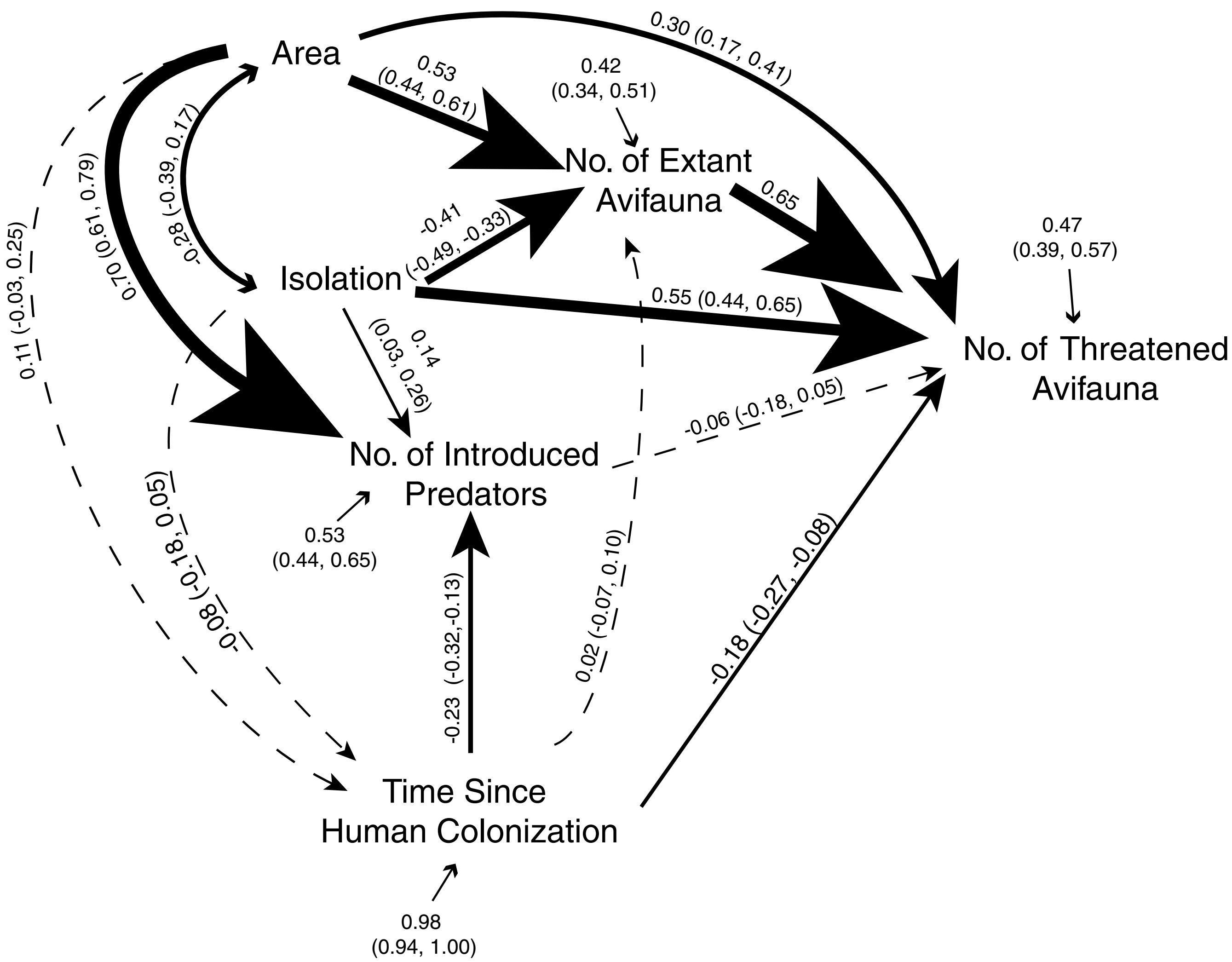

Figure 1. Correlation coefficients and causal relationships between physical aspects of oceanic islands (island area and isolation from a mainland), biological characteristics of islands (number of species in the avifauna, number of introduced predators, and time since humans colonized the islands), and the number of bird species currently under threat of extinction (the dependent variable). Area and isolation exhibit a correlation of 0.28 without affecting one another. Physical factors can influence biological variables but are unlikely to be substantially influenced by biotic factors; thus, one-way arrows represent hypotheses of causal relationships that are tested in the analyses. The path from number of extant avifauna to number of threatened avifauna, however, was fixed at a "null" standardized regression weight of 0.65 (unstandardized null regression weight of 0.60, see text). Solid arrows represent significant paths ($p < 0.05$*), with effect strength presented visually by the thickness and size of the arrows. Small single-headed arrows directed toward variables represent the proportion of unexplained variance not accounted for by the causal effects of the other variables. The 95% confidence limits for correlations, path coefficients, and unexplained variance are given inside parentheses, and* $n = 218$ *islands.*

the fact that the null expectation of the path leading from the size of an avifauna to the number of threatened bird species is not zero does not in any way invalidate the analysis, however helpful it may be to interpretation of the results. The null expectation provides an explanation for a strong relationship between the variables, in this case supporting the conclusions that we made in our original work (see above and Trevino et al. 2007). To investigate this further we first confirmed the coefficients and 95% confidence limits described by Blackburn et al., but we used the expanded data set analyzed in Trevino et al. (2007). The only exception was that we used PopTools (Hood 2000) to perform the randomization analysis. Once these results were verified, we used the structural-equation modeling program Amos 7.0 (Arbuckle 2006) to fix the path from avifauna size to threatened species to the null expectation of an unstandardized regression weight of 0.60 (see above and Fig. 1

in Blackburn et al.). We compared this model with the fixed null expectation (Fig. 1; $p = 0.65$) with our previous model in which the path was allowed unfettered estimation (Trevino et al. 2007) and tested the hypothesis of no relationship between number of extant avifauna and number of threatened avifauna other than the positive relationship expected by chance when the average probability of extinction is 0.085.

Fixing the path from extant avifauna to threatened avifauna produced a model that fit the more complete data set equally ($\chi^2 = 0.77$, df $= 1$, $p = 0.38$) and our original model (respectively; $\chi^2 = 0.85$, df $= 2$, $p = 0.66$, AIC (Akaike's information criterion) $= 38.8$; $\chi^2 = 0.08$, df $= 1$, $p = 0.77$, AIC $= 40.1$). There was virtually no difference in the other paths shown in Fig. 1 compared with our original model (Fig. 2 in Trevino et al. 2007). Therefore, as we stated before, the number of threatened avifauna depends on the number of extant avifauna. This analysis, however, allows us to clarify that the relationship is no different than that expected by chance. In effect, this is analogous to there being no biological or ecological relationship between these 2 variables. Because the remaining paths in our model take this relationship into account, neither our original analysis nor our conclusions need to be modified.

These results emphasize the importance of the biogeographical features of islands in determining the number of threatened species. The conclusion of Blackburn et al. that other paths are influenced by the null expectation is incautious. In path analysis the influence of each possible causal variable is estimated while other relationships are held statistically invariant. Thus, the actual relationship between size of the avifauna and numbers of threatened bird species on oceanic islands is held "constant" while other relationships are estimated, regardless of the relationship's statistical significance or any conclusion about it. Of course, the indirect paths that influence the number of threatened bird species through the influence of avifauna size, specifically, indirect influences of island area and isolation, need to be considered carefully. We think that it is reasonable to interpret these indirect influences. For example, our analysis in Fig. 1 and our original analysis provide a novel insight not evident from generalized-linear mixed modeling (as in Blackburn et al. 2004, 2008 [this issue]). On average, islands that are more isolated have smaller avifaunas, and due to the expected positive association of avifauna size and number of threatened bird species on islands, the indirect effect of island isolation on number of threatened bird species is negative (indirect path $= -0.27$). Thus, the strong direct influence of island isolation is somewhat mitigated by the indirect influence that isolation has through the size of the avifauna.

This logic leads to a further advantage of using path analysis rather than examination of the probability of threat to bird species on islands. Asking what factors threaten oceanic birds is a complex question, and path analysis (or structural-equation modeling) is a scientific tool that allows one to examine such complex systems. According to Grace (2006), advancement in ecological science will be limited if ecologists continue to focus on univariate or one-dimensional theories that do not take into account the simultaneous influences and responses that exist in complex systems. Given that an average of about 8.5% of bird species are threatened on oceanic islands, we think it is fundamentally important to know that larger isolated islands tend to have more species at risk, whether this is expected at random or not. On average, fewer species are threatened on small islands than on larger islands. Although conservation plans should focus on all available information, conservation resources spent on larger islands should affect more species, on average and with other things being equal. This rationale is fundamental and central to our analyses and conclusions, both here and in Trevino et al. (2007) and Karels et al. (2008).

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