

11. Girdler, F., Gascoigne, K.E., Eysers, P.A., Hartmuth, S., Crafter, C., Foote, K.M., Keen, N.J., and Taylor, S.S. (2006). Validating Aurora B as an anti-cancer drug target. *J. Cell Sci.* **119**, 3664–3675.
12. Hauf, S., Cole, R.W., LaTerra, S., Zimmer, C., Schnapp, G., Walter, R., Heckel, A., van Meel, J., Rieder, C.L., and Peters, J.-M. (2003). The small molecule Hesperadin reveals a role for Aurora B in correcting kinetochore-microtubule attachment and in maintaining the spindle assembly checkpoint. *J. Cell Biol.* **161**, 281–294.
13. Fujiwara, T., Bandi, M., Nitta, M., Ivanova, E.V., Bronson, R.T., and Pellman, D. (2005). Cytokinesis failure generating tetraploids promotes tumorigenesis in p53-null cells. *Nature* **437**, 1043–1047.
14. McInnes, C., Mazumdar, A., Mezna, M., Meades, C., Midgley, C., Scaerou, F., Carpenter, L., Mackenzie, M., Taylor, P., Walkinshaw, M., *et al.* (2006). Inhibitors of Polo-like kinase reveal roles in spindle-pole maintenance. *Nat. Chem. Biol.* **2**, 608–617.
15. Peters, U., Cherian, J., Kim, J.H., Kwok, B.H., and Kapoor, T.M. (2006). Probing cell-division phenotype space and Polo-like kinase function using small molecules. *Nat. Chem. Biol.* **2**, 618–626.
16. Musacchio, A., and Hardwick, K.G. (2002). The spindle checkpoint: structural insights into dynamic signalling. *Nat. Rev. Mol. Cell Biol.* **3**, 731–741.
17. Hansen, D.V., Loktev, A.V., Ban, K.H., and Jackson, P.K. (2004). Plk1 regulates activation of the anaphase promoting complex by phosphorylating and triggering SCFbetaTrCP-dependent destruction of the APC inhibitor Emi1. *Mol. Biol. Cell* **15**, 5623–5634.
18. Moshe, Y., Boulaire, J., Pagano, M., and Hershko, A. (2004). Role of Polo-like kinase in the degradation of early mitotic inhibitor 1, a regulator of the anaphase promoting complex/cyclosome. *Proc. Natl. Acad. Sci. USA* **101**, 7937–7942.
19. den Elzen, N., and Pines, J. (2001). Cyclin A is destroyed in prometaphase and can delay chromosome alignment and anaphase. *J. Cell Biol.* **153**, 121–136.
20. Demetri, G.D., van Oosterom, A.T., Garrett, C.R., Blackstein, M.E., Shah, M.H., Verweij, J., McArthur, G., Judson, I.R., Heinrich, M.C., Morgan, J.A., *et al.* (2006). Efficacy and safety of sunitinib in patients with advanced gastrointestinal stromal tumour after failure of imatinib: a randomised controlled trial. *Lancet* **368**, 1329–1338.

¹Congenia S.r.l., Genextra Group, Via Adamello 16, I-20139 Milan, Italy.
²Department of Experimental Oncology, European Institute of Oncology, Via Ripamonti 435, 20141 Milan, Italy; and Research Unit of the Italian Institute of Technology (IIT) Foundation at the IFOM-IEO Campus, Via Adamello 16, I-20139 Milan, Italy.
E-mail: simon.plyte@congenia.it, andrea.musacchio@ifom-ieo-campus.it

DOI: 10.1016/j.cub.2007.02.018

Conservation Ecology: Area Trumps Mobility in Fragment Bird Extinctions

Tropical forest understory birds are highly sensitive to habitat fragmentation. Recent results from a monumental Amazonian fragmentation experiment show that habitat needs of these specialized birds make mobility a liability, leading to their extinctions from forest fragments.

Cagan H. Sekercioglu

Tropical forests are disappearing at a rapid rate while the remnants face an increasing number of threats [1]. Although a growing number of studies [2–6] have addressed the effects of forest fragmentation on tropical bird communities, most have had to draw inferences from species distribution patterns, rather than examine colonization and extinction dynamics directly [5,6]. Two recent mark-recapture studies [7,8] are welcome exceptions. Contrary to expectations [4,6], these new studies [7,8] show that, not only can tropical forest understory birds (Figure 1) disperse long distances, but their need to use large areas may make mobile species more susceptible to extinction in fragments.

The groundbreaking new findings [7,8] are based on nearly

50,000 bird captures from the Biological Dynamics of Forest Fragments Project (BDFFP) in the Brazilian Amazon. With 11 fragments (1–100 hectares) and 12 intact lowland forest sites (1–600 hectares) in a 41 kilometer-wide area sampled over two decades, the extent of this experiment is unequalled in the tropics [3,8]. Tom Lovejoy began

this experiment in 1979 by convincing loggers to set aside fragments of 1, 10 and 100 hectares [2,9]. Unlike most fragmentation studies, pre-fragmentation sampling enabled natural abundance estimates to be made of all species. Fragment size and distance from intact forest were precisely controlled.

The BDFFP has produced many critical insights into avian responses to fragmentation [2,3,9,10]. For example, Ferraz *et al.* [9] showed that fragments less than 100 hectares lose half their forest-dependent bird species in under 15 years, too fast for forest regeneration to help, and that even isolated 10,000 hectare fragments could lose half their species in a century. Combined with another study [11], Ferraz *et al.* [9] concluded that even a

Figure 1. Ochre-breasted Antpitta (*Grallaricula flavirostris*), a typical tropical forest understory insectivore.

(Photo by Cagan H. Sekercioglu.)



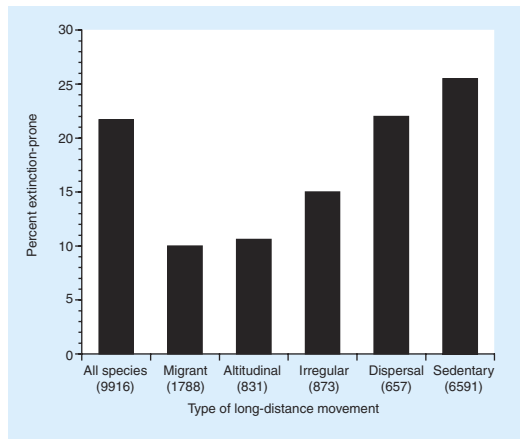


Figure 2. Extinction risk as a function of long-distance movement.

Bird species with regular long-distance movements are less extinction-prone (threatened, near threatened or extinct) than sedentary birds or those that only undertake long-distance post-fledging dispersal (C.H.S. unpublished data). The number of species known to undertake that type of movement is in parentheses.

1000-fold increase in area would reduce the rate of species loss only 10-fold.

Given these findings, many conservation ecologists have been eagerly anticipating the BDFFP mark-recapture analyses. Fourteen years of mist netting in forest understory resulted in 8799 recaptures — far more than the captures of most fragmentation studies — leading to the detection of rare but critical long-distance (>5 kilometer) dispersal [8]. This figure, especially surprising for understory birds, will trigger much research and conservation interest in long-distance movements and in the quality of the habitat that surrounds forest fragments [3,12,13].

Tropical forest understory birds have provided many insights into island biogeography, where the ‘islands’ are forest fragments surrounded by a ‘sea’ of unsuitable habitat. Populations are often unsustainable in fragments, as these birds seemingly disperse little, avoid edges, gaps and open habitats, and rarely use the deforested matrix surrounding the fragments [2–4]. Van Houtan *et al.* [8] quantified forest understory bird dispersal kernels for the first time, that is, they calculated the functions that describe what fraction of dispersing birds reach progressively further distances from their point of origin. Many species had surprisingly heavy-tailed dispersal distributions, meaning quite a few banded birds were recaptured as far as 30 kilometers away, although most were re-caught close to home.

In general, sedentary birds are more extinction-prone than are more mobile species (Figure 2) [14]. Mobility enables species to persist in fragments, so long as forest birds can use the surrounding matrix [3–5]. But specialization is even stronger a correlate of extinction risk (Figure 3) [14]. Many tropical forest birds’ specialized habits of traveling in mixed-species’ flocks or following army ants [10] require such species to forage over wide areas, so even 100 hectare fragments may not be large enough for sustainable populations [15]. These birds are more likely to face dangers — such as predation, starvation or heat shock — when they venture into the unsuitable matrix [10]. Army ant followers are particularly vulnerable because army ants often disappear from fragments smaller than 50 hectares [16].

The most extinction-prone forest birds in BDFFP were those that suffered from relative immobility post-fragmentation [8]. Ironically, these were the species that were more mobile pre-fragmentation. Their mobility after the three-fold decline was still higher than the pre-fragmentation movement rates of persistent species, whose post-fragmentation mobility did not decline. These sedentary birds were ‘pre-adapted’ to the confinement of fragments.

Ferraz *et al.* [7] complemented these dispersal kernels [8] with mark-recapture models based on the same dataset. Covering an impressive 55 species, the models show that understory birds’ area needs override isolation effects in determining extinctions. The

authors used patch-occupancy models that calculated the probability that patches will be occupied or not from birds’ chances of becoming extinct in a patch (higher for smaller patches) and their chance of re-colonizing (higher in patches near other patches). These models explicitly deal with detection probabilities, hence factoring in elusive species, typical of tropical forests, that may be present but avoid detection.

Interestingly, isolation, measured in terms of distance from extensive forest combined with intervening matrix quality, affects species with high or low dispersal ability equally. This is partly because many highly dispersive species are specialized ant-followers or mixed-flock attendants, confirming the findings of Van Houtan *et al.* [8]. Although birds in small fragments have consistently higher chances of extinction than in larger ones, isolation effects are more varied. For some species, persistence even increases with more isolation. This can happen if in less-isolated fragments birds leave for extensive forest nearby, but facing larger gaps, more birds stay and breed.

By teasing apart the effects of isolation versus fragment area on equilibrium patch occupancy, Ferraz *et al.* [7] have shown that, for some tropical forest birds, isolation makes little difference to their presence or absence. Unfortunately, this suggests that even with corridors of natural vegetation some species will disappear from small fragments. Furthermore, these birds can disperse more than 5 kilometers but the farthest fragment to continuous forest distance in the study was only 900 meters. In less forested landscapes the effects of isolation will likely be greater.

These studies emphasize the importance of specialization in shaping tropical birds’ responses to habitat modification. It is not mobility *per se* but changes in mobility in response to fragmentation that determine persistence. Birds such as ant-followers and mixed flock members have specializations that require them to move extensively in intact forests. They are no longer

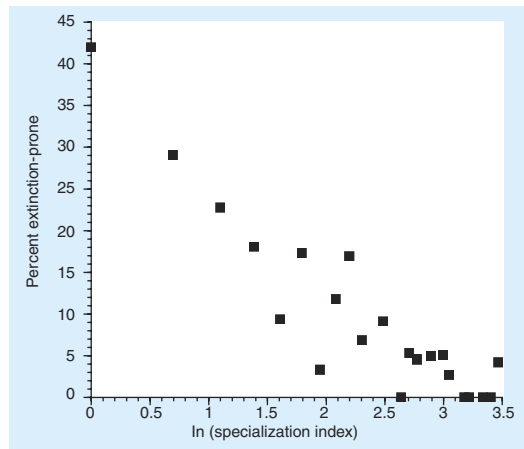


Figure 3. Extinction risk as a function of specialization. More specialization increases the extinction risk of the world's bird species ($r^2 = 0.851$). Specialization index is the product of habitats used and food types consumed. Higher numbers indicate less specialization. (Reproduced with permission from [14]; copyright (2004) National Academy of Sciences, USA.)

able to do so in small fragments and so they disappear. Less specialized sedentary species can increase their movements and persist — but even these birds tend to move to bigger fragments [8].

The interaction of isolation, fragment size, and understory birds' ecologies shape their responses to fragmentation. In agreement with global patterns [14], specialization stands out as a crucial extinction correlate (Figure 3). In the BDFFP, the higher mobility of tropical forest birds is a consequence of dietary and behavioral specializations [10], which, in combination with forest specialization, make mobility a liability in small fragments.

An important conservation implication of these findings is the importance of the matrix surrounding forest remnants [2–4,12,13]. In addition to providing habitat to many 'forest' species [3,12], the countryside matrix plays an important role in the dispersal of even forest-obligate birds.

The new studies [7,8] tease out the confounding effects of area versus isolation and provide rigorous, experimental analyses of the processes underlying species distribution patterns that are too often the only focus of fragmentation studies. We must keep in mind, however, that these birds, caught with 2 meter-high mist nets, are mostly understory insectivores. Although good indicators of a healthy tropical forest, understory insectivores' high habitat and dietary specializations mean that these results do not necessarily apply to

all tropical forest birds. Frugivores, granivores, nectarivores, and omnivores usually tolerate fragmentation better and are more capable of using the deforested countryside [4,12].

Our knowledge of tropical bird dispersal is very limited, but these dispersal patterns clearly affect extinction-colonization dynamics greatly. This is particularly so given the importance of rare long-distance dispersal events [10]. Even with the unequalled BDFFP sampling, however, the true frequency of these events cannot be known. Nothing can replace actual movement data and we need more tropical studies that track the exact movements of individual birds for weeks, months or even years [13,15,17].

Consequently, it is exciting that a recent BDFFP radio tracking study has confirmed the large area requirements of understory insectivorous birds, with only one of 13 species having more than one (1.05) pair per 10 hectares [15]. In contrast, a Costa Rican forest terrestrial insectivore, *Catharus aurantiirostris*, that also thrives in fragments and coffee plantations averages a home range of 1.7 hectares [13]. Nevertheless, even these birds can move >1.2 kilometers in <2 hours across coffee plantations and pastures [13]. At Las Cruces, Costa Rica (8°47' N, 82°57' W) 1.5% of their movements were >500 meters and 0.5% were >1 kilometer (C.H.S., unpublished data). Radio tracking movements of BDFFP birds could produce even more interesting findings.

The ecological consequences of avian extinctions in fragments are another research frontier. Increasing awareness of avian ecological function [18,19] has underlined the importance of insectivorous birds in controlling invertebrate populations, including in the tropical forest understory [20]. Most tropical forest birds that disappear from fragments are expert insectivores, but there has been no research on how their decline affects invertebrate populations. Now that Ferraz, Van Houtan and colleagues [7–10] have solidified our understanding of how forest fragments lose their birds, it is time for equally innovative studies of the ecological consequences of their loss.

References

1. Laurance W.F. and Peres C.A., eds. (2006). *Emerging Threats to Tropical Forests* (Chicago: The University of Chicago Press).
2. Stouffer, P.C., and Bierregaard, R.O., Jr. (1995). Use of Amazonian forest fragments by understory insectivorous birds. *Ecology* 76, 2429–2445.
3. Gascon, C., Lovejoy, T.E., Bierregaard, R.O., Jr., Malcolm, J.R., Stouffer, P.C., Vasconcelos, H.L., Laurance, W.F., Zimmerman, B., Tocher, M., and Borges, S. (1999). Matrix habitat and species richness in tropical forest remnants. *Biol. Conserv.* 91, 223–229.
4. Sekercioglu, C.H., Ehrlich, P.R., Daily, G.C., Aygen, D., Goehring, D., and Sandi, R. (2002). Disappearance of insectivorous birds from tropical forest fragments. *Proc. Natl. Acad. Sci. USA* 99, 263–267.
5. René Borgella, R., Jr., and Gavin, T.A. (2005). Avian dynamics in a fragmented tropical landscape. *Ecol. Appl.* 15, 1062–1073.
6. Lens, L., Van Dongen, S., Norris, K., Githiru, M., and Matthyssen, E. (2002). Avian persistence in fragmented rainforest. *Science* 298, 1236–1238.
7. Ferraz, G., Nichols, J.D., Hines, J.E., Stouffer, P.C., Bierregaard, R.O., Jr., and Lovejoy, T.E. (2007). A large-scale deforestation experiment: Effects of patch area and isolation on Amazon birds. *Science* 315, 238–241.
8. Van Houtan, K.S., Pimm, S.L., Halley, J.M., Bierregaard, R.O., Jr., and Lovejoy, T.O. (2007). Dispersal of Amazonian birds in continuous and fragmented forest. *Ecol. Lett.* 9, 1–11.
9. Ferraz, G., Russell, G.J., Stouffer, P.C., Bierregaard, R.O., Jr., Pimm, S.L., and Lovejoy, T.E. (2003). Rates of species loss from Amazonian forest fragments. *Proc. Natl. Acad. Sci. USA* 100, 14069–14073.
10. Van Houtan, K.S., Pimm, S.L., Bierregaard, R.O., Jr., Lovejoy, T.E., and Stouffer, P.C. (2006). Local extinctions in flocking birds in Amazonian forest fragments. *Evol. Ecol. Res.* 8, 129–148.
11. Brooks, T.M., Pimm, S.L., and Oyugi, J.O. (1999). Time lag between deforestation and bird extinction in tropical forest fragments. *Conserv. Biol.* 13, 1140–1150.
12. Daily, G.C., Ehrlich, P.R., and Sanchez-Azofeifa, G.A. (2001).

- Countryside biogeography: use of human-dominated habitats by the avifauna of southern Costa Rica. *Ecologic. Appl.* 11, 1–13.
13. Sekercioglu, C.H., Loarie, S.R., Oviedo Brenes, F., Ehrlich, P.R., and Daily, G.C. (2007). Persistence of forest birds in the Costa Rican agricultural countryside. *Conserv. Biol.* 21, in press.
 14. Sekercioglu, C.H., Daily, G.C., and Ehrlich, P.R. (2004). Ecosystem consequences of bird declines. *Proc. Natl. Acad. Sci. USA* 101, 18042–18047.
 15. Stouffer, P.C. (2007). Density, territory size, and long-term spatial dynamics of a guild of terrestrial insectivorous birds near Manaus, Brazil. *Auk*. 124, 292–306.
 16. Partridge, L.W., Britton, N.F., and Franks, N.R. (1996). Army ant population dynamics: The effects of habitat quality and reserve size on population size and time to extinction. *Proc. R. Soc. Lond. B.* 263, 735–741.
 17. Powell, G.V.N., and Bjork, R.D. (2004). Habitat linkages and the conservation of tropical biodiversity as indicated by seasonal migrations of three-wattled bellbirds. *Conserv. Biol.* 18, 500–509.
 18. Sekercioglu, C.H. (2006). Increasing awareness of avian ecological function. *Trends Ecol. Evol.* 21, 464–471.
 19. Sekercioglu, C.H. (2006). Ecological contributions of bird populations. In *Handbook of the Birds of the World, Volume 11*, J. del Hoyo, A. Elliott, and D.A. Christie, eds. (Barcelona: Lynx Edicions), pp. 15–51.
 20. Gradwohl, J., and Greenberg, R. (1982). The effect of a single species of avian predator on the arthropods of aerial leaf litter. *Ecology* 63, 581–583.

Stanford University, Department of Biological Sciences, 371 Serra Mall, Stanford, California 94305-5020, USA.
E-mail: cagan@stanford.edu

DOI: 10.1016/j.cub.2007.02.019

Cell Death: Hook, Line and Linker

The programmed death of particular cells in *Caenorhabditis elegans* and *Drosophila* has been shown to occur by non-apoptotic programs regulated by developmental timing. Such alternative programs may be used as a general mechanism to eliminate differentiated, functional cells.

Ashish Kumar
and Joel H. Rothman

“An oil lamp may be extinguished owing to any of the following four causes — the exhaustion of the wick, the exhaustion of oil, simultaneous exhaustion of both wick and oil, or some extraneous cause like the gust of a wind. So may death be due to any of the forgoing four causes.”

Buddha, on the doctrine of
Dependent Origination

The development and maintenance of tissues in animals depends not only on the ability of cells to reproduce, but also on their capacity for self-destruction when they become superfluous, damaged, or otherwise harmful [1]. In 1871, Virchow coined the term ‘necrosis’ as a general description for cell death. The widespread occurrence and biological relevance of an active cell death program was recognized a century later by Kerr, Wyllie, and Currie [2], who proposed a morphology-based classification of cell death into two categories: ‘necrosis’, which is restricted to rapid, violent and passive cell death caused by environmental perturbation; and ‘apoptosis’ or active programmed cell death, which occurs in natural and certain pathological situations.

A molecular hallmark of the latter process of apoptosis is activation

of a cascade of proteases called caspases which cleave a variety of cellular targets, leading to cell death with distinctive morphological characteristics [2,3]. While apoptosis is the most common form of programmed death, it has become apparent that alternative programs can lead to other forms of cell death. Evidence has been accumulating that the apoptosis–necrosis dichotomy is insufficient to encompass the observed spectrum of morphological end-points [4]. Adding to the complexity is the unanticipated finding that, while inhibition of caspase activation can block apoptosis, it does not necessarily protect against cell death [5]. Rather caspase inhibition can reveal, or enhance, alternative caspase-independent cell death processes.

Recent findings by Abraham *et al.* [6] on the male linker cell in the nematode *Caenorhabditis elegans* and by Mazzalupo *et al.* [7] on nurse cells in the fruitfly *Drosophila* show that some types of natural, developmental death in these ecdysozoans occur by non-apoptotic programs. The *C. elegans* linker cell is born during an early larval stage and is essential for development of the male gonad. The *Drosophila* nurse cells are germ-line-derived cells that support oocyte development.

The two papers provide strong evidence that caspases, and likely apoptosis, do not play a role in the natural developmental programs for linker and nurse cell deaths. Indeed, Abraham *et al.* [6] show that the dying linker cell displays a non-apoptotic morphology that is unexpectedly reminiscent of a previously described rare type of developmental cell death.

Since the original classification by Kerr *et al.* [2], three major morphologically distinct types of programmed cell deaths have been described [8] (Figure 1A). Type 1 is apoptotic cell death, characterized by cell shrinkage and extensive chromatin condensation. Formation of autophagic vacuoles inside the dying cell is typical of autophagic or type 2 cell death. Type 3 death is characterized by cellular swelling, often accompanied by “dilation of ER, nuclear envelope, Golgi and sometimes mitochondria, forming ‘empty’ spaces” [8].

An important criticism of the concept of alternative type 2 and 3 cell death programs is that they primarily seem to provide backup suicide mechanisms when the canonical apoptotic machinery is lacking or inhibited [4,9]. Are such ‘non-canonical’ cell death mechanisms relevant during normal development? The existence of non-apoptotic cell death in *C. elegans* [6] and *Drosophila* [7] as parts of natural developmental programs provides a definitive link between *in vivo* and *in vitro* data supporting the biological significance of alternative cell death programs.