Gauging the Ecological Health of a Costa Rican Cloud Forest: Birds as Bio-Indicators

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Summary

As deforestation and fragmentation pose a constant threat to rainforests and the biodiversity they harbor, conservation and preservation are of the utmost import. To evaluate the overall ecological well-being of an ecosystem and by extension its conservation priority, the degree of disturbance and fragmentation should be determined. One way of examining the disturbance status of an area is to examine the local avifauna using birds as bioindicators. The overall ecological state of the Costa Rican tropical cloud forest in which the Savegre Lodge is situated can be inferred by examining the avifauna cataloged through mist netting and observation during one week studies in March of 2003 and 2005. Because this area is a rainforest preserve which relies heavily on ecotourism, it is hypothesized that the biodiversity and health of the ecosystem have been preserved, as disturbance is kept to a minimum. Of the 116 species cataloged, 34 species were caught in the mist nets. Nine of the cataloged species are considered rare or uncommon and 13 are highly sensitive to human disturbance. The presence of a number of rare and/or highly disturbance-sensitive species at Savegre, in addition to the plethora of common species, suggests that this habitat has not been disturbed or significantly fragmented and points to the overall good health of the environment. The area around the Savegre Lodge stands as an example of a well managed preserve where biodiversity remains intact even in the presence of ecotourism.

Introduction

Deforestation and fragmentation have become issues of ever-increasing importance in tropical forests as human encroachment breaks up large tracts of forests into smaller areas. Within these smaller areas, multifaceted changes take place which affect community composition and structure. The variety of plant and animal interactions differ at the edges of fragments from the interior of the forest and some species cannot survive under edge conditions (Hagan et al. 1996).

There are a number of mechanisms behind species loss due to fragmentation. One of the most apparent of these mechanisms is the restriction of population size. This leads to a number of problems that can result in the local extinction of a species. Local extinction occurs when the reduced species population size decreases the genetic viability of the species because genetic drift and inbreeding reduce genetic variation and increase homozygosity (Turner 1996, Hagan et al. 1996). A significant population reduction could plunge the species below some minimum size needed for recovery, resulting in the local extinction of that species (Terborgh 1992).

Fragmentation also prevents or reduces immigration of new individuals into an area, which places more strain on an already reduced gene-pool, and increases the immigration of exotic species (Turner 1996, Terborgh 1992). Alien species often dominate the fragmented landscape and overwhelm native species because the native species are not tolerant of the new conditions (Turner 1996). This invasion of alien species is part of what is called the edge effect. Edge effect changes in microclimate can reduce inhabitable fragment size even more for some species (Turner 1996). Deforestation related disturbances, such as felled trees, altered water courses, and the introduction of smoke and fire into the forest, as well as higher order effects which change the dynamic of interspecies interaction, also have negative effects on biodiversity (Turner 1996, Terborgh 1992).

Therefore, in order to gauge the ecological well-being of an overall ecosystem, the degree of disturbance and fragmentation should be determined. One way of examining the overall health and disturbance status of an area is to examine the local avifauna. Birds are often used as a bioindicator because they are easy to quantify and a number of studies have outlined the effects of disturbance on tropical bird populations (Turner 1996, Terborgh 1977). The overall ecological state of the Costa Rican tropical cloud forest in which the Savegre Lodge is situated can be inferred by examining the avifauna cataloged through mist netting and observation during one week studies in March of 2003 and 2005. By examining the milieu of species composing the bird community, their abundance and distribution, one can determine if this area has suffered the effects of fragmentation. Because this area is a rainforest preserve that relies heavily on ecotourism, it is hypothesized that the biodiversity and health of the ecosystem have been preserved as disturbance is kept to a minimum.

Results

A total of 116 bird species were cataloged which represent 17 families (Table 1). Approximately thirty-eight percent of the species recorded were members of 4 families—Tyrannidae (Flycatchers), represented by 15 species; Parulidae (Warblers), represented by 11 species; Thraupidae (Tanagers and Honeycreepers), represented by 9 species; and Emberizidae (New World Sparrows, Finches, and Grosbeaks), represented by 9 species.

The majority of the cataloged species were classified by Stiles and Skutch (1989) as common or abundant with 93% of the species falling loosely into one of these categories (Table 1). Comprising the remainder of the species, however, were nine uncommon to rare species including: the Chestnut-capped Brush-finch (*Atlapetes brunneinucha*), the Summer Tanager (*Piranga rubra*), the Mountain Elaenia

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Order	Family	Genus	Species	CP	Sensitivity	Geographic Range
Ciconiiformes	Ardeidae	Tigrisoma	fasciata	3	Medium	Costa Rica to NW Argentina and SE Brazil
	Cathartidae	Coragyps	atratus	4	Low	Canada to Tierra del Fuego
		Cathartes	aura	4	Low	Costa Rica
Falconiformes	Accipitridae	Elanoides	forficatus	4	Medium	Breeding resident of Costa Rica
		Buteo	platypterus	4	Medium	Breeds in N, Winters in South America
			swainsoni	4	Medium	Winters in South America, occasionally Costa Rica
			jamaicensis*	4	Low	Breeds Alaska to Canada, W Panama to W Indes
	Falconidae	Micrastur	ruficollis	4	Medium	S Mexico to W Ecuador and N Argentina
Galliformes	Cracidae	Chamaepetes	unicolor	3	High	Costa Rica to W Panama
	Odontophoridae	Odontophorus	guttatus	4	High	S Mexico to W Panama
Columbiformes	Columbidae	Columba	fasciata	4	Medium	SW Canada to NW Argentina
			subvinacea	4	High	Costa Rica to W Ecuador
		Geotrygon	costaricensis	3	High	Costa Rica to W Panama
Psittaciformes	Psittacidae	Pyrrhura	hoffmanni	4	Medium	Costa Rica to W Panama
		Touit	costaricensis	3	High	Costa Rica to W Panama
		Pionus	senilis	3	Medium	E Mexico to W Panama
Strigiformes	Strigidae	Otus	clarkii*	4	High	Costa Rica to extreme NW Columbia
		Glaucidium	jardinii	4	Medium	Costa Rica to W Venezuele, Peru, and Bolivia
		Ciccaba	virgata	4	Medium	N Mexico to W Ecuador, Bolivia, and N Argentina
Caprimulgiformes	Caprimulgidae	Caprimulgus	saturatus	4	Medium	Costa Rica to W Panama
Apodiformes	Apodidae	Strepnoprocne	zonaris	4	Low	C Mexico, to Peru, N Argentina, and SE Brazil
		Chaetura	vauxi	4	Medium	Breeds NE US, E and S Mexico, to E Panama and N Venzuela
	Trochilidae	Colibri	thalassinus	4	Low	C Mexico to W Panama; Andes from N Venezuela to Brazil
		Campylopterus	hemileucurus	3	Medium	S Mexico to W Panama
		Panterpe	insignis	4	Medium	Costa Rica to W Panama
		Lampornis	cinereicauda	4	Medium	Costa Rica
		Heliodoxa	jacula	4	Medium	Costa Rica to W Ecuador
		Eugenes	fulgens	4	Medium	SW US to W Panama
		Selasphorus	scintilla	4	Medium	Costa Rica to W Panama
			flammula	4	Low	Costa Rica to W Panama
Trogoniformes	Trogonidae	Pharomachrus	mocinno	3	Medium	S Mexico to W Panama
		Trogon	collaris	4	Medium	Mexico to NW Ecuador and N Bolivia
Piciformes	Ramphastidae	Aulacorhynchus	prasinus	4	Medium	Mexico to N Venezuela and E Peru
	Picidae	Melanerpes	formicivorus	4	Low	W US to Columbia
		Piculus	rubiginosus	4	Low	NE Mexico to NW Peru and NW Argentina
		Picoides	villosus	4	Medium	Alaska and N Canada to W Panama and Bahamas

Order	Family	Genus	Species	CP	Sensitivity	Geographic Range
Passeriformes	Dendrocolaptidae	Lepidocolaptes	affinis	4	Medium	C Mexico to N Bolivia
	Furnariidae	Premnoplex	brunnescens	4	High	Costa Rica to N Venezuela and C Peru
		Syndactyla	subalaris	4	High	Costa Rica to W Ecuador, E Peru, and W Venezuela
		Margarornis	rubiginosus	4	Medium	Costa Rica to W Panama
		Pseudocolaptes	lawrencii*	4	High	E Nicaragua to W Ecuador, SE Parue and Amazonian Brazil
		Thripadectes	rufobrunneus	3	High	Costa Rica to W Panama
		Xenops	rutilans*	4	Medium	Costa Rica to N Argentina and Guiana

	Rhinocryptidae	Scytalopus	argentifrons	4	Medium	Costa Rica to Panama
	Cotingidae	Pachyramphus	versicolor*	4	High	Costa Rica to NW Ecuador and N Bolivia
	Tyrannidae	Sayornis	nigricans	4	Low	SW US to NW Argentina
		Tyrannus	melancholicus	4	Low	SE Arizona to C Argentina and Guianas
		Megarhynchus	pitangua	4	Low	Mexico to NW Peru, N Argentina, and S Brazil
		Myiodynastes	hemichrysus	4	Medium	Costa Rica to W Panama
		Myiarchus	tuberculifer	4	Low	SE US to NW Peru, N Argenina and SE Brazil
		Contopus	lugubris*	4	Medium	Costa Rica to W Panama
			sordidulus	4	Medium	Breeds Alaska to Honduras; winters Columbia to Bolivia to Costa Rica
			ochraceus*	3	High	Costa Rica to W Panama
		Empidonax	flavescens	4	Low	SE Mexico to W Panama
			atriceps	4	Medium	Costa Rica to W Panama
		Mitrephanes	phaeocercus	4	Medium	NW Mexico to NW Ecuador and E Bolivia
		Serpophaga	cinerea	4	Low	Costa Rica to N Bolivia and NW Venezuela
		Elaenia	frantzii*	4	Low	Guatamala to Columbia and W Venezuela
		Zimmerius	vilissimus	4	Medium	S Mexico to N Venezuela
		Mionectes	olivaceus	4	Medium	Costa Rica to NW Ecuador and C Peru
	Hirundinidae	Notiochelidon	cyanoleuca	4	Low	Nicaragua to Tierra del Fuego
	Corvidae	Cyanolyca	argentigula	4	Medium	Costa Rica to W Panama
	Cinclidae	Cinclus	mexicanus	4	Medium	N Alaska to W Panama
	Troglodytidae	Troglodytes	aedon	4	Low	S Canada to Tierra del Fuego
			ochraceus	4	Medium	Costa Rica to E Pamana
		Thryorchilus	Browni**			Costa Rica to W Panama
		Henicorhina	leucophrys	4	Medium	C Mexico to W Ecuador and N Bolivia
	Turdidae	Turdus	grayi	4	Low	NE Mexico to N Colombia
			plebejus	4	Medium	S Mexico to W Panama
			nigrescens	4	Low	Costa Rica to W Panama
		Myadestes	melanops	4	Medium	Costa Rica to W Panama
		Catharus	frantzii	4	Medium	Costa Rica to NW Venezuela, N Colombia, to Bolivia

Order	**Family**	**Genus**	**Species**	**CP**	**Sensitivity**	**Geographic Range**
			gracilirostris	4	Low	Costa Rica to W Panama
	Bombycillidae	Bombycilla	cedrorum	4	Low	Breeds Alaska to SW US, Winters Canada to C Panama and N SA
	Ptilogonatidae	Ptilogonys	caudatus	4	Low	Costa Rica to W Panama
	Vireonidae	Cyclarhis	gujanensis	4	Low	NE Mexico to C Argentina and S Brazil
		Vireo	carmioli	4	Medium	Costa Rica to W Panama
			philadelphicus	4	Low	Breeds in Canada, Winters in Yucatan to C Panama
			gilvus*	4	Low	Breeds in Alaska to Mexico, Winters Mexico to Nicaragua
			leucophrys	4	Medium	E-C Mexico to NW Bolivia
	Parulidae	Mniotilta	varia	4	Low	Breeds Canada to US, Winters West Indies to N South America
		Vermivora	chrysoptera	3	Low	Breeds Canada and US, Winters S Mexico to Venezuela
			peregrina	4	Low	Breeds Alaska and Canada, Winters S Mexico to Venezuela
		Parula	gutturalis**			Costa Rica to W Panama
		Dendroica	virens	4	Medium	Breeds Canada and E US, Winters S US to C Panama
			townsendi	4	Medium	Breeds Alaska to NW US, Winters California to Costa Rica
		Seiurus	motacilla	4	Medium	Breeds Canada and US, Winters Florida to Venezuela

		Wilsonia	pusilla	4	Low	Breeds Alaska and Canada, Winters S US to C Panama
		Myioborus	torquatus	4	Medium	Costa Rica to W Panama
		Basileuterus	melanogenys	4	Medium	Costa Rica to W Panama
		Zeledonia	coronata	4	Medium	Costa Rica to Panama
	Icteridae	Amblycercus	holosericeus	4	Medium	C Mexico to NW Peru and N Bolivia
		Icterus	galbula	3	Medium	Breeds SE Canada and E US, Winters C Mexico to N SA
	Thraupidae	Chlorophonia	callophrys	4	Medium	Costa Rica to W Panama
		Tangara	icterocephala	4	Medium	Costa Rica to W Ecuador
			dowii	4	High	Costa Rica to W Panama
		Thraupis	episcopus	4	Low	C Mexico to NW Bolivia and Amazonian Brazil
		Piranga	rubra*	4	Low	Breeds N Mexico, Winters C Mexico to Amazonian Brazil
			leucoptera	4	Medium	C Mexico to W Ecuador, NW Bolivia, and NW Brazil
			bidentata	4	Medium	NW Mexico to W Panama
		Chlorospingus	opthalmicus	4	Medium	Costa Rica to E Panama
			pileatus	4	Medium	Costa Rica to W Panama
	Emberizidae	Pheucticus	tibialis	4	Medium	Costa Rica to W Panama
			ludovicianus	4	Medium	Breeds Canada-US, Winters Mexico to Venezuela and Peru
		Tiaris	olivacea	4	Low	C Mexico to Columbia, NW Venezuela
		Acanthidops	bairdii	3	Medium	Costa Rica to W Panama
		Diglossa	plumbea	4	Low	Costa Rica to W Panama
		Pezopetes	capitalis	4	Medium	Costa Rica to W Panama
		Pselliophorus	tibialis	4	Medium	Costa Rica to W Panama
Order	**Family**	**Genus**	**Species**	**CP**	**Sensitivity**	**Geographic Range**
		Atlapetes	brunneinucha*	4	Low	Costa Rica to N Colombia
		Zonotrichia	capensis	4	Low	SE Mexico to Tierra del Fuego
	Fringillidae	Carduelis	xanthogastra	4	Low	Costa Rica to SW Ecuador and C Bolivia

Table 1: Species observed and/or netted March 8-15, 2003 and March 8-15, 2005 in the tropical cloud forest in Costa Rica between 1500 and 3324 meters above sea-level. *Indicates species classified as uncommon or rare by Stiles and Skutch (1989). Sensitivity and Conservation Priority (CP) [1=Urgent, 2=Hight, 3=Medium, 4=Low] classified according to Stotz et al. (1996) ** Indicates species not classified in this source.

(*Elaenia frantzii*), the Ochraceous Pewee (*Contopus ochraceus*), the Streaked Xenops (*Xenops rutilans*), the Barred Becard (*Pachyramphus versicolor),* the Buffy Tuftedcheek (*Pseudocolaptes lawrencii*), the Red-tailed Hawk (*Buteo jamaicensis*) and the Warbling Vireo (*Vireo gilvus*). All of these species, save the Warbling Vireo which is migratory, have a limited area of natural habitat ranging from Costa Rica to as far South as Northwest Amazonian Brazil.

According to the classification system of Stotz, et al. (1996), 13 of the cataloged species, representing 11% of the total number of species, are highly sensitive to human disturbance (Table 1). Sixty-seven, or 58%, of the cataloged species are moderately vulnerable to human disturbance and 36 species, or 31%, were considered to have a low sensitivity to human disturbance (Table 1). Twelve species were given a Conservation Priority rating of 3 or Medium, indicating that they are vulnerable to endangerment or extinction if present trends in habitat destruction continue. The remaining 104 species were classified with a Conservation priority reading of 4 or Low, meaning that their current population status is not at risk (Stotz, 1996). Five of the highly sensitive species—the Black Guan (*Chamaepetes unicolor*), *the* Buff-Fronted Quail-Dove (*Geotrygon costaricensis*), the Red-Fronted Parrotlet (*Touit costaricensis*), the Streaked-Breasted Treehunter (*Thripadectes rufobrunneus*), and the Ochraceous Pewee (*Contopus ochraceus*)—were also given a Conservation Priority rating of 3 or Medium.

Of the 116 cataloged species, 34 were netted in at least one of the netting sites—streamside, hillside, primary, or secondary forest (Table 2). The majority of the netted species are geographically distributed in the area from Southern Mexico to Peru. Only three species, the Louisiana Waterthrush (*Seiurus motacilla*), the Hairy Woodpecker (*Picoides villosus*), and the Wilson's Warbler (*Wilsonia pusilla*) were migratory species with wide geographical distribution. Seventeen species were netted at the primary forest site, 19 at the secondary forest site, 13 at the hillside site, and 23 at the streamside site (Table 2).

Discussion

In previous research, relatively rare species were found to occupy fewer forest fragments than relatively common species, suggesting that rarer species are more vulnerable to local extinction than relatively common ones (Newmark 1991, Turner 1996). The presence of a number of rare and/or highly

Species	Number of Captures			
	Primary	Secondary	Hillside	Streamside
Acanthidops bairdii				2
*Atlapetes brunneinucha**				1
Aulacorhynchus prasinus	1	1		
Basileuterus melanogenys	13	5	3	8
Campylopterus hemileucurus	2	1		
Catharus frantzii	9	18	9	7
Chlorospingus pileatus	4	1		5
Colibri thalassinus			1	
*Contopus ochraceus**				1
Diglossa plumbea				1
*Elaenia frantzii**		1		
Empidonax flavescens	4	2	6	
Eugenes fulgens		1	1	
Henicorhina leucophrys		7	3	3
Lampornis cinereicauda	8	16	7	12
Lepidocolaptes affinis		2		
Margarornis rubiginosus	3		1	3
Mionectes olivaceus			1	1
Mitrephanes phaeocercus				2
Myadestes melanops	3	6	7	6
Myioborus torquatus	7	2		4
Parula gutturalis				2
Pezopetes capitalis	3	1		3
Picoides villosus	1			
Premnoplex brunnescens				3
Pselliophrus tibialis	4	4		1
Seiurus motacilla				1
Selasphorus flammula		1		
Tangara dowii				1
Thripadectes rufobrunneus	2	1	2	
*Troglodytes ochraceus**	1			
Turdus plebejus	1	1	1	4
Wilsonia pusilla	14	1	1	6
Zeledonia coronata				3

Table 2: Habitat distribution of netted species.

* Indicates species with a brood patch at the time of capture.

disturbance-sensitive species at Savegre suggests that this habitat has not been disturbed to the point that fragmentation and edge effects have led to local extinction of vulnerable species. This also points to the overall good health of the forest environment there (Stotz et al., 1996). As Beier et al. (2002) concluded that species richness was conversely related to patch size, meaning that the larger the forest patch, the more diverse its avifauna, it appears that the fragment created by the PanAmerican highway remains large enough to compensate for the break.

Another indication of the lack of fragmentation and edge effects is the presence of many local species. Research indicates that in disturbed areas, alien species overwhelm and dominate the native species because the native species are not tolerant of the new conditions (Turner 1996). While 'weedy' and migratory area tolerant species, such as the Turkey Vulture (*Cathartes aura*), the Clay-colored Robin (*Turdus grayi*), and the Wilson's Warbler (*Wilsonia pusilla*) to name a few, are present, they are found in the same area with low tolerance, native species found only in wet, mountain forests such as the

Barred Forest-falcon (*Micrastur ruficollis*), the Dark Pewee (*Contopus lugubris*), and the Ochraceous Wren (*Troglodytes aedon*). Though some might say the presence of 'weedy' species is indicative of disturbance, the presence of rare species contradicts this notion. Perhaps it is the mild disturbance presented by the clearing of the lodge that provides increased species diversity, following the assertion that species diversity is greatest in areas of moderate disturbance (Connell 1978).

While most of the netted species were common, the majority prefer mountain habitat in higher elevations. The uncommon or rare netted species were the Chestnut-capped Brush-finch (*Atlapetes brunneinucha*), the Ochraceous Pewee (*Contopus ochraceus*), the Mountain Elaenia (*Elaenia frantzii*), and the Streaked-breasted Treehunter (*Thripadectes rufobrunneus*). The netting of these rare species is indicative of their local residency. In order to be netted, birds had to be present in the forest understory which means the area of the net was likely part of their home range. This indicates that these rare species are members of the forest community around Savegre and not merely passing through as could be the case with birds only observed.

The slightly higher species diversity of the streamside community perhaps reflects the greater microhabitat variation provided by the stream itself. Greater variation in microhabitat ultimately results in the presence of a greater number of niches which will ultimate be filled by a greater number of species. The Louisiana Waterthrush (*Seiurus motacilla*) was netted at only the streamside site because its habitat is restricted to rocky streams in forested areas (Stiles and Skutch 1989). Therefore, it is a habitat specialist species, most likely incapable of surviving in an alternate habitat in the presence of edge effects and fragmentation, as it requires forest and does not live in open areas. The presence of such specialists indicates that this ecosystem is undisturbed enough to suit such habitat specific species.

If the avifauna species cataloged during 2003 and 2005 in the Costa Rican tropical cloud forest are taken to be indicative of the overall ecological wellness, the rainforest around the Savegre Lodge can indeed be considered undisturbed and representative of optimum species diversity and forest composition. The presence of both common and rare species as well as the diversity of habitat and distribution of these birds indicates that fragmentation and edge effects have not had an impact on this forest community. Therefore, Savegre can be examined as an example of a successful conservation effort where proper management has allowed ecotourism to flourish while maintaining the health of the ecosystem.

This study gives the researchers and monitors responsible for the upkeep and conservation in the Savegre Preserve baseline data with which they can compare future species counts. Clearly, if the avifauna species diversity decreases over time, it may be the result of fragmentation, as the Beier et. al. (2002), Newmark (1991), and Hagan (1996) experiments confirm. If avifauna species diversity falls, it might indicate decreased biodiversity of the forest as a whole. Such continued species composition and diversity monitoring is a way of evaluating fragmentation and edge effects on the whole forest over time, a valuable tool when considering conservation strategies and necessities.

Materials and Methods

The study area near the Savegre Lodge, situated closely to San Gerardo de Dota, Costa Rica (9 34'N; 81 43'W), lies in the northern region of the Cordillera de Talamanca, a volcanic mountain range that stretches from central Costa Rica to western Panama (Wolf et al., 1976). This site is composed of montane cloud forest and harbors vegetation that is both primary and secondary forest growth; there are mainly oak forests with both bamboo and shrubs. The site is nine kilometers West of the PanAmerican Highway and the clearing and orchard of Savegre Lodge transects and interrupts the continuity of this habitat.

Four mist netting stations, each consisting of fifteen, 12x3 meter mist nets, were established at four locations ranging from 2300-2500 meters in elevation. Two, five hour periods were spent at each station. Stations were chosen as examples of specific habitats—hillside, streamside (both in primary forest), old growth primary forest, and second growth forest. Netted bird species as well as species observed from March 8th and 15th of 2003 and March 5th to March 12th, 2005 by experienced ornithologists were cataloged.

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References

Beier, Paul, Maryann van Drielen, Bright O. Kankam. 2002. "Avifaunal collapse in West African forest fragments." *Conservation Biology* 16(4): 1097-1111.

Connell, J. H. 1978. "Diversity in tropical rainforests and coral reefs." *Science* 199: 1302-1310.

Hagan, John M., W. Matthew Vander Haegen, Peter S. McKinley. 1996. "The Early Development of Forest Fragmentation Effects on Birds." *Conservation Biology* 10(1): 188-202.

Newmark, William D. 1991. "Tropical Forest Fragmentation and the Local Extinction of Understory Birds in the Eastern Usambara Mountains, Tanzania." *Conservation Biology* 5(1): 67-78.

Stiles, F. Gary, and Alexander F. Skutch. A Guide to the Birds of Costa Rica. Cornell UP: Ithaca, 1989.

Stotz, D. F., J. W. Fitzpatrick, T. A. Parker, and D. K. Moskovitz. Neotropical Birds: Ecology and Conservation. U of Cicago Press: Chicago, 1996.

Terborgh, John. 1977. "Bird Species Diveristy on an Andean Elevational Gradient." *Ecology* 58(5): 1007-1019.

1992. "Maintenance of Diversity in Tropical Forests." Special Issue: OTS Silver Anniversary Symposium. Resource Availability and Tropical Ecosystems. *Biotropica* 24(2) Part B: 283-292.

Turner, I. M. 1996. "Species Loss in Fragments of Tropical Rain Forest: A Review of the Evidence." *Journal of Applied Ecology* 33(2): 200-209.

Wolf, Larry, F. Gary Stiles, and F. Reed Hainsworth. 1976. "Ecological Organization of Tropical, Highland Hummingbird Community." *Journal of Animal Ecology* 45(2): 349-379.