TEXAS TECH UNIVERSITY
Natural Science Research Laboratory

OCCASIONAL PAPERS

Museum of Texas Tech University
Number 263 11 December 2006

INVESTIGATIONS IN A NATURAL CORRIDOR BETWEEN TWO NATIONAL PARKS IN CENTRAL ECUADOR: RESULTS FROM THE SOWELL EXPEDITION, 2001

Editorial Comment. Occasional Paper #263 by Michelle L. Haynie and her colleagues explores a natural corridor between two national parks (Parques Nacionales Sangay and Llanganates) in Ecuador. The authors utilize genetic data (mitochondrial cytochrome-*b* haplotypes and karyotypes) from several species of rodents and marsupials to determine the affects of elevational changes between the two national parks, as well as affects of the Río Pastaza that divides the corridor area. Although small samples sizes prevented the authors from conclusively commenting on elevational changes within the corridor and ultimately the effectiveness of the corridor in connecting the two national parks, the authors provide evidence that the two parks may be isolated relative to dispersal of small nonvolant mammals.

To me, the exciting aspect of this study pertains to the finding that a relatively small river (Río Pastaza) may serve as a barrier to gene flow, albeit in this case, across a small geographic area. How many times have we crossed a river that may be acting as a barrier to gene flow? We easily drive over a bridge in a matter of seconds, perhaps never realizing that the populations of small mammals on either side are effectively isolated. I can understand the Mississippi River, Río Balas, Orinoco River, and other large river systems being effective barriers; however, the evidence presented herein brings a new perspective concerning the medium and small rivers we routinely cross.

Finally, this study provides yet another example of just how difficult it is to conduct rodent studies in the tropics. The study produced a trap success of only 2% (well within the average for most tropical studies), making it nearly impossible to generate sufficient samples for robust statistical analyses. On the other hand, the ideas that the authors develop in this paper need to be developed and studied further, which is justification for more fieldwork and taking additional field parties of graduate and undergraduate students on educational trips to experience the New World tropics and to interact with our Ecuadorian colleagues and friends.

RDB
Associate Editor

Front cover: The Río Negro, a tributary to the Río Pastanza within the natural corridor connecting Sangay and Llanganates National Parks, Ecuador. Photograph by Lynda Richardson.

Investigations in a Natural Corridor Between Two National Parks in Central Ecuador: Results from the Sowell Expedition, 2001

Michelle L. Haynie, Joel G. Brant, L. Rex McAliley, Juan Pablo Carrera, Marcia A. Revelez, Deidre A. Parish, Xavier Viteri, Clyde Jones, and Carleton J. Phillips

Abstract

An international team of scientists from Texas Tech University and Pontificia Universidad Católica del Ecuador collected small rodents and marsupials in a natural corridor between Sangay and Llanganates National Parks. The corridor is located between the towns of Puyo and Baños on the Andean eastern slope of Ecuador. The goal for this research was to test the genetic continuity of nonvolant small mammal populations across the Río Pastaza, which constitutes a natural barrier between the two national parks. A total of 15 species was collected (2 marsupials and 13 rodents) including voucher specimens, vital tissues, and karyotypic information. In addition to morphological examinations, sequencing of the mitochondrial cytochrome-*b* gene was used to identify the specimens. Statistical analyses were performed to examine genetic variation among populations. Our results suggest that the Río Pastaza is a barrier to gene flow for small nonvolant mammals between the two national parks. However, lack of additional voucher specimens from both sides of the river constituted a problem at the moment to determine the effectiveness of this corridor. In this sense, we recognize the necessity to continue additional systematic studies within this important region.

Key words: corridor, cytochrome-*b* gene, Ecuador, karyotypes, Llanganates, national parks, Sangay, small mammals

Resumen

Un equipo internacional de investigadores de Texas Tech University y de la Pontificia Universidad Católica del Ecuador colectó roedores pequeños y marsupiales en un corredor natural entre los Parques Nacionales Sangay y Llanganates. El corredor está localizado entre los poblados de Puyo y Baños en las estribaciones orientales de los Andes Ecuatorianos. La meta de esta investigación fue comprobar la continuidad génica de las poblaciones de mamíferos pequeños no voladores a través del Río Pastaza, que constituye la barrera natural entre ambos parques nacionales. Un total de 15 especies (2 marsupiales y 13 roedores) fueron colectadas incluyendo especimenes museológicos, tejidos vitales y cariotipos. Adicionalmente a las revisiones morfológicas, secuencias del gen mitocondrial del citocromo-*b* fueron generadas para identificar los especimenes. Análisis estadísticos fueron ejecutados para examinar la variación génica entre poblaciones. Nuestros resultados sugieren que el Río Pastaza constituye una barrera para el flujo génico de mamíferos pequeños no voladores entre los dos parques nacionales. Sin embargo, la falta de más especimenes museológicos de ambos lados del río constituyó un problema al momento determinar la efectividad de este corredor. En este sentido, nosotros reconocemos la necesidad de continuar estudios adicionales de sistemática dentro de esta importante región.

Palabras clave: cariotipos, corredor, Ecuador, gen del citocromo-*b*, Llanganates, mamíferos pequeños, parques nacionales, Sangay

INTRODUCTION

Studying and maintaining biodiversity has become an issue of great importance to biologists worldwide. Among the issues of concern in conservation biology are loss of natural habitat, habitat fragmentation, and the corresponding loss of biodiversity. Consequently, the focus of conservationists has turned to maintaining disjunct areas in hopes of preserving genetic diversity within isolated populations. Within the realm of conservation biology, scientists have studied the feasibility of using natural corridors as a means of connecting dispersed habitat (Davis-Born and Wolff 2000; Downes et al. 1997; Haddad 2000; Harrison and Chapin 1998; Laurance and Laurance 1999; Perault and Lomolino 2000; Shkedy and Saltz 2000; Sieving et al. 2000).

To date, no single unified definition of a corridor has been accepted. In a review of recent studies, Beier and Noss (1998) defined a corridor as a "linear habitat, imbedded in a dissimilar matrix, that connects two or more larger blocks of habitat." Corridors may include, but are not limited to, riverine basins (Ward et al. 2002), linear riparian areas (Laurance and Laurance 1999), and roadsides (Downes et al. 1997). The premise of a corridor is to provide additional, suitable habitat in which wildlife can live, reproduce, or have a means of movement between patches of core habitat. Little empirical evidence has been generated supporting the usefulness of corridors. However, Shkedy and Saltz (2000) have shown that ibexes in Israel are using corridors to travel between isolated habitats. Additionally, Gilbert et al. (1998) provided evidence that corridors slow rates of extinction, at least within microecosystems.

Corridors have limitations. Collinge (2000) and Bently et al. (2000) have suggested that corridors may be species specific. Size (length and width) of the corridor (Haddad 2000; Sieving et al. 2000) and quality of habitat surrounding the corridor (Perault and Lomolino 2000) can play a role in its effectiveness. Other drawbacks associated with utilizing corridors include an increased level of predation (James and Stuart-Smith 2000), movement of exotic plants and animals (Downes et al. 1997), and increased transmission of diseases (Hess 1994). Despite the debate concerning their usefulness, corridors might provide suitable avenues for colonization and a link between otherwise isolated habitats.

Located between the towns of Puyo and Baños in central Ecuador, is the Eastern Andean Corridor connecting two national parks, Sangay and Llanganates (Fig. 1). This area is bisected by the Río Pastaza and has been heavily cultivated in some parts. An Ecuadorian non-governmental organization, Fundación Natura, is working to determine if this area functions as a natural corridor. Little work has been done in this region (Castro and Rivera 1999; Castro and Román 2000; Fonseca and Carrera 2002; Fonseca et al. 2003; Rageot and Albuja 1994). Faunal surveys have been performed in the national parks to establish faunal lists of mammals present in managed areas. Castro and Rivera (1999) surveyed Parque Nacional Sangay, while Castro and Román (2000) surveyed Parque Nacional Llanganates. Few surveys have been performed within the suspected corridor. Rageot and Albuja (1994) surveyed the region around Mera, which is located within the limits of the designated corridor in Pastaza Province. The Sowell 2001 Expedition was a joint effort among Texas Tech University, Fundación Natura, and Pontifica Universidad Católica del Ecuador planned to assist in obtaining new data about the proposed corridor (Baker 2005; Phillips 2005).

As part of the Sowell 2001 Expedition to Ecuador, specimens were obtained from the vicinity of Puyo and Baños, as well as in the region between these two cities. Specimens also were to be obtained from the north and south side of the river to determine if the Río Pastaza was a potential barrier to gene flow between the two parks. The objectives of this study were: 1) to inventory small mammals located within the Eastern Andean Corridor, and 2) to examine the effectiveness of the Eastern Andean Corridor between Parque Nacional Llanganates in the north and Parque Nacional Sangay in the south.

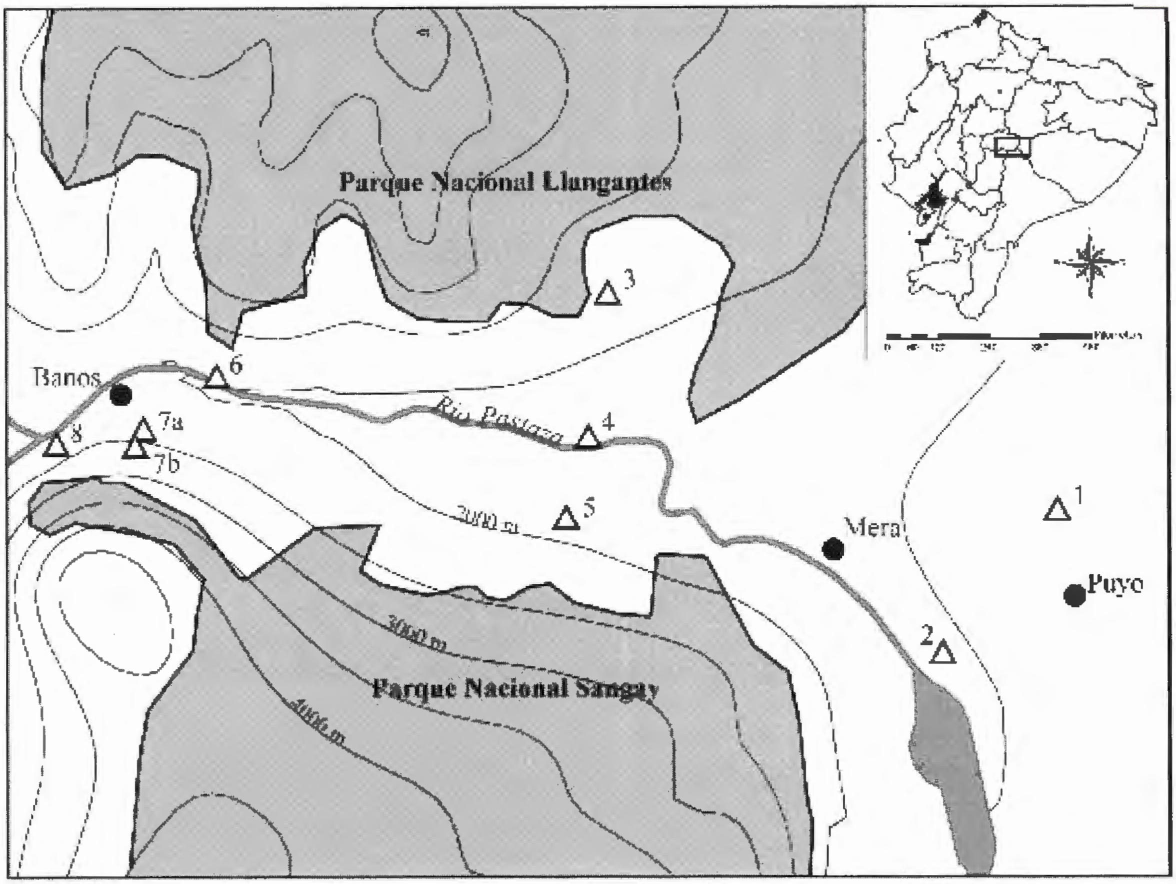

Figure 1. Map of collecting localities in the corridor region within central Ecuador. The collecting localities are as follows: 1) Safari Hosteria; 2) Hacienda Té Zulay; 3) Colonia Azuay; 4) Río Negro; 5) La Estancia; 6) Represa Agoyán; 7a) Runtún (UTM 17-787329E-9846533N); 7b) Runtún (UTM 17-787737E-9844512N); 8) Zona de Lahares.

MATERIALS AND METHODS

Study sites.—The primary study sites in Pastaza and Tungurahua Provinces were selected to represent localities on each side of the Río Pastaza within the designated corridor. The corridor lies between the towns of Puyo in the east and Baños in the west. The Río Pastaza begins in the Andes just east of the town of Baños and is controlled by the Represa Agoyán. The river flows through the Andean foothills, into the Amazon Basin near Puyo, and ultimately empties into the Amazon River. Eight sites were selected for sampling and included secondary forest and agriculturally-developed areas.

The Safari Hosteria site (elevation 900 m, UTM: 18-166624-9840350) is located on the north side of the Río Pastaza near the town of Puyo. The Safari Hosteria is a local resort surrounded by agricultural fields and secondary forest. Traps were placed along trails in a wooded area, in fields among knee- to chest-high grasses, in cane fields, adjacent to the road within boulder piles, within a dump area, and around earthen fish tanks containing tilapia (*Tilapia*).

Hacienda Té Zulay (elevation 1000 m, UTM: 17-828485-9833168) is located near the town of Shell on the north side of the Río Pastaza. This area is agriculturally developed and contains some secondary forest. Traps were placed in an overgrown cemetery and in fields near the village.

Río Negro (elevation 1450 m, UTM: 17-810439-9844053) is located on the north side of the Río Pastaza and consists of pastures, secondary forest, and banana plantations. The soil at this locality had experienced erosion and there are numerous gullies. Traps were placed along the road, fencelines, and in a banana grove.

Colonia Azuay (elevation 1700 m, UTM: 17-811451-9851351) is located on the north side of the Río Pastaza and comprises secondary forest and fruit orchards. This locality also is bisected by the Río Topo, a tributary of the Río Pastaza. Traps were placed along roadsides and in pastures of knee-high grasses.

La Estancia (elevation 1700 m, UTM: 17-809292-9839992) is located on the south side of the river above the town of Río Negro and includes agriculturally developed land and patches of secondary forest. Traps were placed in grass along the road, a stream bed, a mudslide in the forest, and fencelines surrounding fields.

Zona de Lahares (elevation 2400 m, UTM: 17-782408-9844274) is located west of the town of Baños on the south side of the river. This locality is an old lava flow comprised of unstable rock and thorn scrub vegetation. The lava flows originate from Volcán Tungurahua, which is located within Parque Nacional Sangay. Traps were placed in grassy areas near the lava flow, the rocky-thorn scrub area, and a garbage dump along the highway.

The Represa Agoyán site (elevation 2550 m, UTM: 17-791688-9846533) is located on the north side of the Río Pastaza. This site consists of terraced fields and orchards, and lies at the base of a steep hill. Traps were placed on cultivated terraces, within the orchard, and on the hillside.

Two localities (elevation 2700 m, UTMs: 17-787737-9844512 and 17-787329-9843651) were sampled near Runtún. Runtún is a small resort on the south side of the Río Pastaza. These localities consist primarily of developed land. Traps were placed within woodlands surrounding agricultural fields, around cane fields, and around buildings.

Collection of specimens.—Mammals were captured according to standard techniques for sampling small to medium-sized species (Animal Care and Use Committee 1998; Jones et al. 1996). Sherman live traps were used for rodents and small marsupials. Collections were made over 17 nights between 18 July 2001 and 6 August 2001 using 400 traps for a total of 6800 trap nights. Voucher specimens were made for all captures and were prepared as museum study skins and skeletons and deposited in the Natural Science Research Laboratory (NSRL), The Museum, Texas Tech University, and the Museo de Zoología (QCAZ) of the Pontificia Universidad Católica del Ecuador. Frozen tissue (heart/kidney, liver, muscle, lung, spleen) samples and samples in lysis buffer for all specimens also were deposited in the Genetic Resources Collection, NSRL. Tissues samples stored in ethanol were deposited in QCAZ.

Morphology.—The skull of each individual was measured with digital calipers accurate to the nearest 0.01 mm and rounded to the nearest 0.1 mm. Seven cranial measurements and four external measurements were recorded for all rodents. The four external measurements (total length, tail length, hind foot length, and ear length) were recorded directly from the specimen tag. The seven cranial dimensions used were: greatest length of skull, breadth of braincase, maxillary toothrow length, zygomatic breadth, rostral breadth, interorbital breadth, and depth of braincase. All cranial measurements were taken as described by Hooper (1952). The same cranial and external measurements were recorded for all marsupials, with the exception of the maxillary toothrow length. Means of measurements (Table 1) for all species were used to aid in identification of the specimens.

Karyology.—Karyotypes were prepared in the field following the methods of Baker et al. (2003). A minimum of ten chromosomal spreads were examined per specimen to determine diploid (2n) and fundamental (FN) numbers. Karyotypes are described for rodent species in Table 2. Cell suspensions were deposited in the Department of Biological Sciences, Texas Tech University.

Genetics.—The mitochondrial cytochrome-*b* gene was used to genetically identify specimens.

Table 1. Mean and standard deviation (in parenthesis) of each morphological variable for each species. All characters were measured in millimeters with the exception of weight. The characters are as follows: greatest length of skull (SKL), breadth of braincase (BBC), zygomatic breadth (ZYB), rostral breadth (ROB), interorbital breadth (IOB), maxillary toothrow length (MTR), depth of braincase (DOC), total length (TTL), tail length (TAL), hind foot length (HFL), ear length (EAR), and weight in grams (WHT).

	SKL	BBC	ZYB	ROB	IOB	MTR
Marmosops noctivagus (n = 7)	31.46 (3.38)	12.02 (0.47)	15.72 (1.52)	6.17 (0.72)	5.92 (0.33)	
Monodelphis adusta (n = 2)	25.73 (0.04)	10.78 (0.01)	13.08 (0.13)	6.03 (0.40)	5.80 (0.11)	
Akodon aerosus (n = 10)	27.46 (2.06)	12.81 (0.41)	14.14 (0.72)	4.92 (0.40)	5.58 (0.14)	4.56 (0.28)
Akodon mollis (n = 23)	26.45 (0.96)	12.11 (0.28)	13.33 (0.50)	4.37 (0.31)	5.13 (0.15)	4.26 (0.19)
Microryzomys minutus (n = 13)	21.70 (0.45)	10.46 (0.30)	10.86 (0.23)	3.03 (0.21)	3.19 (0.12)	3.17 (0.13)
Mus musculus (n = 2)	20.31	9.89 (0.20)	10.80 (0.21)	3.16 (0.36)	3.68 (0.08)	3.68 (0.29)
Neacomys spinosus (n = 12)	24.47 (1.40)	11.50 (0.26)	12.80 (0.58)	4.30 (0.16)	4.67 (0.25)	3.44 (0.16)
Oecomys bicolor (n = 2)	26.33 (1.90)	12.34 (0.62)	14.21 (0.81)	4.26 (0.25)	4.67 (0.11)	3.94 (0.11)
Oecomys superans (n = 1)	27.62	12.87	14.53	5.21	5.09	4.02
Oligoryzomys fulvescens (n = 32)	22.92 (1.44)	10.62 (0.40)	12.05 (0.71)	3.75 (0.38)	3.77 (0.17)	2.99 (0.17)
Oligoryzomys destructor (n = 3)	24.65 (0.46)	11.29 (0.06)	12.90 (0.14)	3.94 (0.38)	3.67 (0.11)	3.61 (0.19)
Phyllotis haggardi (n = 1)	23.40	12.29	12.61	3.25	4.43	4.28
Rattus rattus (n = 1)	39.95	16.62	18.83	5.41	6.04	6.19
Reithrodontomys mexicanus (n = 11)	23.16 (0.58)	11.70 (0.32)	12.25 (0.37)	3.28 (0.33)	3.68 (0.12)	3.47 (0.09)
Thomasomys paramorum (n = 7)	27.52 (0.79)	13.10 (0.24)	14.38 (0.54)	4.15 (0.31)	4.38 (0.14)	4.34 (0.17)
	DOC	TTL	TAL	HFL	EAR	WHT
Marmosops noctivagus (n = 7)	9.55 (0.65)	249.71 (35.07)	149.14 (20.65)	17.57 (1.27)	18.14 (2.67)	25.89 (11.70)
Monodelphis adusta (n = 2)	7.11 (0.13)	136.50 (6.36)	47.50 (0.71)	13.50 (2.12)	11.00 (0.00)	16.90 (0.42)
Akodon aerosus (n = 10)	10.00 (0.36)	166.76 (21.95)	66.38 (9.29)	21.54 (2.80)	15.98 (5.39)	29.09 (9.42)
Akodon mollis (n = 23)	9.53 (0.30)	172.64 (12.12)	75.41 (5.59)	22.00 (1.02)	15.05 (1.17)	24.97 (5.58)
Microryzomys minutus (n = 13)	8.03 (0.27)	178.69 (8.81)	105.62 (7.17)	21.23 (0.93)	13.00 90.58)	11.48 (1.90)
Mus musculus (n = 2)	7.41 (0.28)	153.50 (13.44)	84.00 (14.14)	18.00 (1.41)	11.50 (0.71)	11.65 (0.78)
Neacomys spinosus (n = 12)	8.76 (0.40)	167.09 (33.89)	86.32 (17.77)	22.39 (1.57)	15.33 (2.99)	24.93 96.65)
Oecomys bicolor (n = 2)	9.67 (0.17)	204.50 (36.06)	105.00 (11.31)	20.65 (0.49)	12.80 (1.13)	29.05 (13.93)
Oecomys superans (n = 1)	10.12	205.00	110.00	22.00	15.00	22.10
Oligoryzomys fulvescens (n = 32)	8.13 (0.36)	168.09 (17.83)	90.54 910.00)	19.70 (2.24)	13.03 (2.29)	14.97 (3.78)
Oligoryzomys destructor (n = 3)	8.71 (0.09)	196.33 (9.87)	108.67 (7.37)	24.33 (0.58)	13.33 (1.15)	16.67 (0.72)
Phyllotis haggardi (n = 1)	8.77	168.00	80.00	21.00	19.00	11.90
Rattus rattus (n = 1)	12.76	358.00	180.00	38.00	15.00	127.00
Reithrodontomys mexicanus (n = 11)	8.94 (0.34)	180.09 (6.32)	107.45 (5.24)	18.91 (0.83)	15.09 (1.30)	11.26 (1.56)
Thomasomys paramorum (n = 7)	10.21 (0.29)	213.00 (14.49)	118.71 (10.55)	24.29 (2.21)	14.86 (1.35)	24.57 (6.34)

Table 2. Karyotypic data for rodents collected in eastern Ecuador by the Sowell expedition of 2001. Specimens were karyotyped by yeast stress method of Baker et al. (2003). M = metacentric, SM = submetacentric, ST = subtelocentric, A = acrocentric, and Sterm = subterminal.

Species	# Females	# Males	2N	FN	X	Y	Reference	Origin of Specimens
Akodon aerosus			40	40	SM	ST	Gardner and Patton 1976	Perú
	2	1	40	40	SM	ST	This paper	Ecuador
Akodon mollis			22 or 23	44	M	Sterm	Lobato et al. 1982	Ecuador
			22 or 23	44 or 43			Bianchi and Merani 1984	Ecuador
	1	1	22	44	SM	A	This paper	Ecuador
Microryzomys minutus			57	58			Gardner and Patton 1976	Venezuela
			58				Kiblisky 1969	Venezuela
		3	58	60	SM	A	This paper	Ecuador
Neacomys spinosus			64	68	ST	A	Gardner and Patton 1976	Colombia, Perú
	1	2	64	58	ST	A	This paper	Ecuador
Oecomys bicolor			80	134 or 136			Gardner and Patton 1976	Perú, Dept. Loreto
			80	124	SM	A	Andrades-Miranda et al. 2001	Brazil
			82	110	SM	A	Andrades-Miranda et al. 2001	Brazil
	1		82	106	SM	A	This paper	Ecuador
Oecomys superans			80	108	SM	A	Bechior de Andrade and Rodrigues Bonvicino 2003	Brazil
		1	80	102	SM	A	This paper	Ecuador
Oligoryzomys destructor			60	76	SM	M	Gardner and Patton 1976	Perú
		1	68	70	M	ST	This paper	Ecuador
Oligoryzomys microtis			64	66	ST	A	Gardner and Patton 1976	Perú
(unlike material from			64	66	ST	M	Aniskin and Volobovev 1999	Perú, Bolivia
Venezuela)	1	4	64	66	ST	A	This paper	Ecuador
Reithrodontomys mexicanus			52	52	A	A	Carleton and Myers 1979	Guatemala, Ecuador
	1		52	52	A	A	This paper	Ecuador
Thomasomys paramorum			44	42	SM	SM	Gardner and Patton 1976	Ecuador
		1	44	42	A	A	This paper	Ecuador

Genomic DNA was isolated from 0.1 g of liver using a DNeasy tissue extraction kit (Qiagen, Valencia, California). The mitochondrial cytochrome-*b* gene was amplified from all individuals using primers LGL765 (J. L. Patton, pers. comm.) and L14724 (Irwin et al. 1991). The following polymerase chain reaction (PCR) parameters were modified as described by Saiki et al. (1988): 33 cycles of 94°C denaturation (45 sec), 56°C annealing (1 min), 72°C extension (1 min 30 sec), and 1 final 72°C extension cycle (10 min). Amplifications were performed in 50 ì l volumes and were modified from those described by Allard et al. (1991). Each 50 ì l reaction contained 3 ì l (10 mM DNA), 3 ì l (10 mM) each primer, 3 ì l (25 mM $MgCl_2$), 3 ì l dNTPs (1 mM each), 5 ì l (10X buffer), 0.2 ì l Taq (5U/ ì l), and 29.8 ì l dH_20. The resulting PCR product was purified using the QIAquick PCR purification kit (Qiagen, Valencia, California). Primers LGL765 and H15149 (Kocher et al. 1989) were used to cycle sequence the first 400 bp of the gene. Cycle sequencing was conducted using ABI Big Dye version 3.0 ready reaction mix and samples were analyzed on an ABI Prism 310 automated sequencer (PE Applied Biosystems, Foster City, California).

Vector NTI 7.0 software (Informax Inc., Bethesda, Maryland) was used to align and proof nucleotide sequences. Sequences obtained from the Ecuadorian samples were compared to sequences obtained from GenBank to aid in identification and to determine the taxonomic position of the Ecuadorian samples relative to samples collected from other localities. The aligned data from the Ecuadorian and GenBank samples were analyzed using PAUP 4.0 Beta 10 (Swofford 2002) for construction of phylogenetic trees to examine potential evolutionary relationships. The resultant trees will not be shown as they are beyond the scope of this study and were used strictly for identification purposes.

Arlequin 2.0 (Schneider et al. 2000) was used to estimate haplotype frequency, haplotype diversity, F_{ST} and to calculate an AMOVA for species for which samples were obtained from both sides of the Río Pastaza within the Eastern Andean Corridor. An AMOVA allows for examination of the distribution of genetic variation within and among populations. By identifying shared haplotypes, or lack thereof, on the north and south sides of the river it may be possible to examine what affect the Río Pastaza is having on gene flow within the corridor.

SPECIES ACCOUNTS

The following accounts treat 15 species found in the transition zone between the Andes Mountains and the Amazon Basin in Ecuador. A total of 128 small marsupials and rodents were collected equaling 2% trap success. The following sequence of accounts and scientific names follow Wilson and Reeder (1993). Common names follow Wilson and Cole (2000).

ORDER DIDELPHIMORPHIA
Family Didelphidae
Marmosops noctivagus
White-bellied Slender Mouse Opossum

This opossum occurs at low to mid-elevations on the eastern side of the Andes in the transition zone between mountainous habitat and Amazonian lowlands (Tirira 1999). One female was collected (19 July 2001) from the grounds of the Safari Hosteria. On 20 July 2001, one female and three males were collected in disturbed habitat near the Safari Hosteria. Two additional males were collected from the same locality on 23 July 2001 and 29 July 2001, respectively.

Specimens examined (7).—ECUADOR: Pastaza Province; 5 km N Puyo, Safari Hosteria (TTU 84896-84898, 84923, 84948, 84994, 85227).

Monodelphis adusta
Sepia Short-tailed Opossum

This species occurs east of the Andes at elevations below 2000 m (Tirira 1999). One male was collected from the grounds of the Safari Hosteria on 19 July 2001. An additional male was collected on 20 July 2001 from the same locality.

Specimens examined (2).—ECUADOR: Pastaza Province; 5 km N Puyo, Safari Hosteria (TTU 84865, 84899).

ORDER RODENTIA

Family Muridae

Akodon aerosus

Highland Grass Mouse

This mouse is found at elevations between 1000 m and 3000 m on the eastern side of the Andes Mountains (Tirira 1999). Two females were collected on 19 July 2001 from the grounds of the Safari Hosteria. This locality was trapped four additional nights (20 July 2001, 21 July 2001, 26 July 2001, and 29 July 2001), with four females and three males being collected. An additional male was collected (27 July 2001) from the cemetery at Hacienda Té Zulay, approximately 8 km SW of Puyo.

Specimens examined (10).—ECUADOR: Pastaza Province; 5 km N Puyo, Safari Hosteria, 9 (TTU 84891, 84936-84938, 84950, 84961, 85150, 85229-85230); ECUADOR: Pastaza Province; Hacienda Té Zulay, 1 (TTU 85216).

Akodon mollis

Soft Grass Mouse

This species is found at elevations above 2000 m on both sides of the Andes Mountains (Tirira 1999). The soft grass mouse was collected in four localities near the town of Baños. Seven males and six females were collected (1 August 2001 and 3 August 2001) from Runtún, southeast of Baños. Four males and four females were collected (2 August 2001 and 4 August 2001) from a lava flow west of Baños. One male and one female were collected from agricultural fields near Represa Agoyán on 6 August 2001.

Specimens examined (23).—ECUADOR: Tungurahua Province; 4.75 km E Baños, Represa Agoyán, 2 (TTU 85476, 85481); ECUADOR: Tungurahua Province; 1 km S, 1.5 km E Baños, Runtún, 2 (TTU 85235, 85246); Ecuador: Tungurahua Province; 1.5 km S, 1 km E Baños, Runtún, 11 (TTU 85240, 85241-85242, 85244-85246, 85249, 85252-85253, 85257, 85259); ECUADOR: Tungurahua Province; 1.5 km S, 3 km W Baños, Zona de Lahares, 8 (TTU 85250, 85261-85263, 85266-85269).

Microryzomys minutus

Forest Small Rice Rat

This rat occurs between 1000 m and 2000 m on both sides of the Andes mountain range (Tirira 1999). One female was collected on 3 August 2001 from Runtún, located southeast of Baños. This specimen was collected in disturbed habitat around agricultural fields. Six males were collected on 4 August 2001 from Zona de Lahares. Two males and four females were collected on 5-7 August 2001 from an agricultural field near Represa Agoyán.

Specimens examined (13).—ECUADOR: Tungurahua Province; 4.75 km E Baños, Represa Agoyán, 5 (TTU 85470-85472, 85474-85475); ECUADOR: Tungurahua Province; 1.5 km S, 1 km E Baños, Runtún, 1 (TTU 85239); ECUADOR: Tungurahua Province; 1.5 km S, 3 km W Baños, Zona de Lahares, 7 (TTU 85265, 85272, 85464-85467, 85485).

Mus musculus

House Mouse

This species is introduced and occurs near human habitations. One male was collected near a house at Runtún on 1 August 2001. One female was collected (6 August 2001) in cultivated fields near Represa Agoyán.

Specimens examined (2).—ECUADOR: Tungurahua Province; 4.75 km E Baños, Represa Agoyán, 1 (TTU 85243); ECUADOR: Tungurahua Province; 1 km S, 1.5 km E Baños, Runtún, 1 (TTU 85473).

Neacomys spinosus

Bristly Mouse

This species occurs on the eastern side of the Andes at elevations between 200 m and 2000 m (Tirira 1999). One female was collected from a field near the Safari Hosteria on 19 July 2001. On 20 July 2001, 21 July 2001, and 26 July 2001, four males, three females, and one specimen of undetermined sex were collected from the fields surrounding the Safari Hosteria. Three additional males were collected on 27 July 2001 from the cemetery at Hacienda Té Zulay.

Specimens examined (12).—ECUADOR: Pastaza Province; 5 km N Puyo, Safari Hosteria, 9 (TTU 84875, 84900, 84934, 84943, 84959, 85170-85172, 84954); Ecuador: Pastaza Province; Hacienda Té Zulay, 3 (TTU 85218-85220).

Oecomys bicolor
Bicolored Arboreal Rice Rat

This rat occurs at elevations below 2000 m on the eastern side of the Andes Mountains (Tirira 1999). One female was collected near the Safari Hosteria on 20 July 2001, and an additional female was collected on 29 July 2001 from the same locality.

Specimens examined (2).—ECUADOR: Pastaza Province; 5 km N Puyo, Safari Hosteria (TTU 84901, 85228).

Oecomys superans
Foothill Arboreal Rice Rat

This species occurs on the eastern side of the Andes at elevations below 1000 m (Tirira 1999). One male was collected (20 July 2001) from the grounds of the Safari Hosteria.

Specimen examined (1).—ECUADOR: Pastaza Province; 5 km N Puyo, Safari Hosteria (TTU 84945).

Oligoryzomys destructor
Destructive Pygmy Rice Rat

This species is difficult to identify based on available information in field guides. Identification was made based on distribution maps (Eisenberg and Redford 1999) and published measurement data. This species occurs in high elevations of the Andes throughout Ecuador (Tirira 1999). Two males were collected from the lava deposit west of Baños on 2 August 2001 and 4 August 2001. An additional male was collected from Runtún on 3 August 2001.

Specimens examined (3).—ECUADOR: Tungurahua Province; 1.5 km S, 1 km E Baños, Runtún, 1 (TTU 85255); ECUADOR: Tungurahua Province; 1.5 km S, 3 km W Baños, Zona de Lahares, 2 (TTU 85248, 85468).

Oligoryzomys microtis
Small-eared Pygmy Rice Rat

This species is difficult to identify based on available information in field guides. Identification was made based on distribution maps (Eisenberg and Redford 1999) and published measurement data. This species occurs on both sides of the Andes at elevations below 3000 m. On 19 July 2001, two males and one female were collected from the grounds and surrounding agricultural fields of the Safari Hosteria. This locality was trapped on four additional nights (20 July 2001, 21 July 2001, 23 July 2001, and 29 July 2001); 16 males and 12 females were collected. A single male was collected from the cemetery at Hacienda Té Zulay on 27 July 2001.

Specimens examined (32).—ECUADOR: Pastaza Province; 5 km N Puyo, Safari Hosteria, 31 (TTU 84862, 84864, 84874, 84933, 84935, 84939-84942, 84944, 84946-84947, 84949, 84951-84953, 84955, 84958, 84960, 84962, 84978, 85095, 85069, 85097-85101, 85231-85233); ECUADOR: Pastaza Province; Hacienda Té Zulay, 1 (TTU 85217)

Phyllotis haggardi
Haggard's Leaf-eared Mouse

This mouse occurs above 2000 m in the Andes Mountains (Tirira 1999). One female was obtained (4 August 2001) west of Baños on a lava deposit.

Specimen examined (1).—ECUADOR: Tungurahua Province; 1.5 km S, 3 km W Baños, Zona de Lahares (TTU 85469).

Rattus rattus
House Rat

This species is introduced and occurs near human habitations. One male was collected (19 July 2001) near the dining hall at the Safari Hosteria.

Specimen examined (1).—ECUADOR: Pastaza Province; 5 km N Puyo, Safari Hosteria (TTU 84932).

Reithrodontomys mexicanus
Mexican Harvest Mouse

This species occurs in the Andean highlands; its overall range is from Central America at least into the middle part of Ecuador. The actual southern extent of its range is unknown. One male and two females were collected on 2 August 2001 from Zona de Lahares. One additional male and three additional females were collected from this same locality on 4 August 2001. Two males were collected near Runtún on 3 August 2001 and one male and one female were collected (7 August 2001) in disturbed habitat near Represa Agoyán. These specimens represent the southern-most known occurrence for this species. Duke Rodgers at Brigham Young University is currently studying the systematics of *Reithrodontomys* and might designate the southern populations of *R. mexicanus*, including those in Ecuador, as one or more undescribed species (Duke Rodgers, pers. comm.).

Specimens examined (11).—ECUADOR: Tungurahua Province; 5 km E Baños, Represa Agoyán, 2 (TTU 85483-85484); ECUADOR: Tungurahua Province; 1.5 km S, 1 km E Baños, Runtún, 2 (TTU 85254, 85256); ECUADOR: Tungurahua Province; 1.5 km S, 3 km W Baños, Zona de Lahares, 7 (TTU 85234, 85236, 85247, 85258, 85264, 85270, 85271).

Thomasomys paramorum
Paramo Oldfield Mouse

This species occurs in the Andean highlands above 2000 m (Tirira 1999). Two males were collected (2 August 2001 and 4 August 2001) from the lava flow west of Baños. Three males and one female were collected (6 August 2001) from an agricultural field near Represa Agoyán. An additional male was collected from Runtún on 3 August 2001.

This species group has been little studied and specimens are difficult to identify with certainty. Several species are known from our study area, including *T. baeops* (Castro and Román 1999; Castro and Rivera 1999), *T. caudivarius* (Castro and Rivera 1999), *T. erro* (Castro and Román 1999), *T. paramorum* (Castro and Román 1999; Castro and Rivera 1999), and *T. rhoadsi* (Castro and Román 1999). Identification of the specimens used in this study was based on cytochrome-*b* data, karyotypes, and measurements.

Specimens examined (7).—ECUADOR: Tungurahua Province; 4.75 km E Baños, Represa Agoyán, 4 (TTU 85477-85480); ECUADOR: Tungurahua Province; 1.5 km S, 1 km E Baños, Runtún, 1 (TTU 85237); ECUADOR: Tungurahua Province; 1.5 km S, 3 km W Baños, Zona de Lahares, 2 (TTU 85251, 85260).

RESULTS AND DISCUSSION

Difficulties trapping in unfamiliar territory.—Collection of rodents in rainforests is notoriously difficult due to low trap success (2% in our study) (Reed 1997; p. 21). However, despite setbacks and logistics, this expedition provided educational experiences and important baseline information pertaining to the corridor for the Fundación Natura. Species identifications were difficult due to the paucity of zoogeographic and current systematic studies of mammals in this region; there clearly is a possibility that some of the specimens collected represent undescribed or unrecognized species. The specimens of *Reithrodontomys* collected (see discussion of *Reithrodontomys* in results section) are good examples where our specimens potentially represent undescribed species and warrant further study.

Karyotypic data.—Among the 10 species from the corridor for which chromosomal data was available (Table 2), five of these species had karyotypes unlike those reported from other regions of South America (*M. minutus, N. spinosus, O. bicolor, O. superans*, and *O. destructor*). The significance of chromosomal differences is that geographic variation in karyotypes is usually indicative of genetic phylogroups, subspecies, or species. These taxa document genetic variability that can be interpreted as indicating a uniqueness of the corridor fauna. The rodent sample is small relative to the total corridor fauna but the variation found in the limited sample validates setting the corridor aside as a protected area.

Molecular genetic data.—Only three species were collected on both sides of the Río Pastaza (*A. mollis*, *M. minutus*, and *R. mexicanus*) within the Eastern Andean Corridor. *Akodon mollis* and *M. minutus* have an Amazonian origin, whereas *R. mexicanus* has a Central American origin.

Twenty-three specimens of *Akodon mollis* were collected from four localities. Five haplotypes were identified, three from the north side of the river and two from the south side of the river. No haplotypes were shared between localities on the north and south sides of the river. Gene diversity was 0.186 on the north side of the river and 1.000 on the south side of the river.

Thirteen specimens of *Microryzomys minutus* samples were collected from three localities; data from 10 specimens were analyzed using Arlequin. Within these three localities, nine haplotypes were identified, six from the north side of the river and three from the south side of the river. Haplotypes were not shared between populations on the north and south sides of the river. Gene diversity was 1.000 for the north side of the river, as each individual had a unique haplotype, and 0.833 for the south side of the river.

Eleven *R. mexicanus* samples were collected from three localities. Five haplotypes were identified, four from the north side of the river and one from the south side of the river. Again no haplotypes were shared between the north and south sides of the river. Gene diversity was 0.694 for individuals on the north side of the river.

Corridor.—The corridor between Baños and Puyo can be divided into three elevational areas as follows: Amazonian lowland (1000 m and below), Andean highland (above 2000 m), and the intermediate zone (1000-2000 m) (Voss 2003). The present study identified 15 species from two orders. Eight species were collected in the Amazonian lowland zone, seven in the Andean highland zone, and none from the intermediate area between the two zones (Table 3). There was an obvious dichotomy between the Amazonian and Andean zones, with species collected in the Amazonian zone not found in the Andean highland zone, and vice versa. Species from both regions were expected within the intermediate zone, but no specimens were obtained from this region. Further surveys are needed in these zones, with emphasis on the intermediate zone.

Comparison of mammals collected during this survey to mammals collected during other faunal surveys may provide an indication as to which species may benefit from the protection of the Eastern Andean Corridor. Thirty-five species were collected from the area of the corridor (Rageot and Albuja 1994; this study) and the two national parks (Castro and Rivera 1999; Castro and Román 2000) (Table 4). Examining this list of species, patterns of species distribution were determined. Some species (*A. mollis*) were collected in both national parks and the corridor. Other species (*A. aerosus*) are found only in one national park and the corridor, but not in both national parks, suggesting that there is some barrier restricting these populations from extending into both national parks. Finally, some species are found only within the corridor (*M. adusta*) or one of the national parks (*D. marsupialis*). The distribution of species should provide clues to migration through the corridor. For example, species found only within the corridor may be using this area as a means of dispersing from the Amazonian Basin to higher elevations, whereas species found only in the national parks may not be using the corridor for dispersal. However, further sampling is needed both within the parks and within the corridor before recommendations can be made.

Based on karyotypic data, there are four species (*N. spinosus, O. bicolor, O. superans,* and *O. destructor*) that appear to be unique to this region of Ecuador (Table 2). Based on genetic data from the three species found on both sides of the river, one can hypothesize that the Río Pastaza is a barrier to gene flow because no haplotypes where shared between populations. Nevertheless, additional samples, especially from the south side of the river, will be required before we can statistically assess the role of the Río Pastaza as a barrier to gene flow. Although cytochrome-*b* is an excellent marker for species identification, it is not the optimal marker for population studies. If the rodent species occupying the study area are Holocene arrivals (i.e., in the last 12,000 years), then a higher resolution genetic marker will be needed to assess the Río Pastaza as a physical barrier to gene flow.

Table 3. The capture indices for small nonvolant mammals from the three elevational zones along the Río Pastaza. Both the Amazonian Lowlands and the Andean Highlands were sampled for 2800 trap nights each and the Intermediate Zone was sampled for 1200 trap nights.

	Amazonian Lowlands	Intermediate Zone	Andean Highlands
Oligoryzomys fulvescens (n = 32)	0.0114	--	--
Neacomys spinosus (n = 12)	0.0043	--	--
Akodon aerosus (n = 10)	0.0036	--	--
Marmosops noctivagus (n = 7)	0.0025	--	--
Monodelphis adusta (n = 2)	0.0007	--	--
Oecomys bicolor (n = 2)	0.0007	--	--
Rattus rattus (n = 1)	0.0004	--	--
Oecomys superans (n = 1)	0.0004	--	--
Akodon mollis (n = 23)	--	--	0.0082
Microryzomys minutus (n = 13)	--	--	0.0046
Reithrodontomys mexicanus (n = 11)	--	--	0.0039
Thomasomys paramorum (n = 7)	--	--	0.0025
Oligoryzomys destructor (n = 3)	--	--	0.0011
Mus musculus (n = 2)	--	--	0.0007
Phyllotis haggardi (n = 1)	--	--	0.0004

Table 4. A list of the small nonvolant mammals recorded from both national parks and the connecting corridor.

	Llanganates National Park (Castro and Román 1999)	Corridor, Mera (Rageot and Albuja 1994)	Corridor, Puyo to Baños (this study)	Sangay National Park (Castro and Rivera 1999)
Chironectes minimus		X		X
Didelphis albiventris		X		
Didelphis marsupialis				X
Marmosa murina		X		
Marmosa sp.	X			X
Marmosops noctivagus		X	X	X
Metachirus nudicaudatus		X		
Monodelphis adusta		X	X	
Philander andersoni				X
Philander opossum		X		
Akodon aerosus	X	X	X	
Akodon mollis	X		X	X
Microryzomys altissimus	X			X
Microryzomys minutus	X		X	
Mus musculus			X	
Neacomys spinosus		X	X	
Oecomys bicolor		X	X	
Oecomys superans			X	
Oligoryzomys fulvescens			X	
Oligoryzomys destructor			X	
Oryzomys albigularis				X
Oryzomys auriventer	X	X		X
Oryzomys capito		X		
Oryzomys longicaudatus		X		
Phyllotis haggardi			X	X
Rattus rattus			X	
Reithrodontomys mexicanus			X	
Rhipidomys leucodactylus		X		
Scolomys melanops		X		
Thomasomys baeops	X			X
Thomasomys caudivarius				X
Thomasomys erro	X			
Thomasomys paramorum	X		X	X
Thomasomys rhoadsi	X			
Thomasomys sp.	X			X

The potential for the river to limit gene flow does not negate the possibility of a riverine corridor from the Amazon basin up into the Andes (East-West).

The key element missing in this study is the lack of specimens from the intermediate zone (Table 3). Further surveys are needed within the two national parks and the North-South corridor between the parks, especially within the intermediate zone, to determine the range and usage of the corridor. Additionally, the aim of this survey was to collect small rodents and marsupials. Attention was not given to larger mammals and other vertebrates. These organisms need to be studied to elucidate patterns of distribution, dispersal, and gene flow through the corridor.

CONCLUSIONS

Based on the data available, the corridor between the two parks appears to be segregated by elevation. This area might serve as a corridor for animals moving up from the Amazonian Basin into higher elevations, however, we were unable to collect specimens within the intermediate zone between high and low elevations. Specimens from this region may help clarify the relationships of the dispersal patterns within the corridor. Further study within the corridor and the national parks is needed.

ACKNOWLEDGMENTS

This study was funded through a grant by James E. Sowell. We thank the other members of the field crew from the 2001 Sowell Expedition for help with collecting these specimens (Robert J. Baker, Jana L. Higginbotham, Federico G. Hoffmann, Trashonda Johnson, and René M. Fonseca). We also thank Vicki Swier for her help with analysis of karyotypes. Special thanks go to Laura Arcos-Terán and Luis A. Coloma of the Pontificia Universidad Católica del Ecuador for signing the interinstitutional agreement of scientific cooperation with Texas Tech University, the Fundación Natura based in Quito for allowing us to work within its project "Design and Identification of an Ecological Corridor between Llanganates and Sangay National Parks," Fuerte Militar Amazonas "IWIA" in Shell (Pastaza Province), and the farmers from Río Negro, Colonia La Azuay and La Estancia for allowing us to conduct field research on their surrounding properties. The Ministerio del Ambiente in Ecuador provided permits for collecting specimens.

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Institutional subscriptions are available through the Museum of Texas Tech University, attn. NSRL Publications Secretary, Box 43191, Lubbock, TX 79409-3191. Individuals may also purchase separate numbers of the Occasional Papers directly from the Museum of Texas Tech University.

Layout and Design: Jacqueline B. Chavez
Cover Design: Lynda Richardson

This book was set in Times New Roman and printed on acid-free paper that meets the guidelines for permanence and durability of the Committee on Production Guidelines for Book Longevity of the Council on Library Resources.

Printed: 11 December 2006

Library of Congress Cataloging-in-Publication Data
Occasional Papers, Number 263
Series Editor: Robert J. Baker

Investigations in a Natural Corridor Between Two National Parks in Central Ecuador: Results from the Sowell Expedition, 2001

Michelle L. Haynie, Joel G. Brant, L. Rex McAliley, Juan Pablo Carrera, Marcia A. Revelez, Deidre A. Parish, Xavier Viteri, Clyde Jones, and Carleton J. Phillips

ISSN 0149-175X

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Lubbock, TX 79409-3191 USA
(806)742-2442

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