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HIGHWAY NETWORK EXPANSION IN ANDEAN PATAGONIA: A WARNING NOTICE FROM RUFOUS-LEGGED OWLS

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Abstract.—As part of the economic and population growth of Patagonia, several dust/gravel roads crossing well preserved Andean forests are being converted into paved highways. The potential effects of these changes on forest wildlife have been little studied. The Rufous-legged Owl (*Strix rufipes*) was dominant among road-killed birds in our survey of a 27-km section of highway running through forests of Nahuel Huapi National Park, in Argentine Patagonia. Fatalities were not evenly distributed along the surveyed length of the road, so we investigated whether landscape features, roadside slope on both sides of the highway, demography, and/or season explained the aggregation pattern. Patterns of distribution of the road-killed owls were explained by owl abundance and age-class, time of year, and hour, and were weakly related to canopy closure; roadside slope on both sides was unrelated to abundance of fatalities. Traffic-related deaths were likely the primary cause of non-natural mortality of Rufous-legged Owls (especially for young individuals) in the study area. Examination of carcasses indicated that most owls were killed by turbulence behind large vehicles and that deaths occurred early in the night. Semi-trailer trucks capable of carrying large loads, which peak in numbers between dusk and midnight, likely caused most fatalities. A way to reduce owl mortality could be to schedule truck traffic outside the hours when owls are most active at hunting around paved roads crossing natural forests, at least during late winter and spring seasons. Because transportation networks encourage future development that will affect the environment in a variety of ways, it is critical to retain roadless and near-roadless (i.e., having only dirt or gravel roads with slow-moving traffic) portions of the southern Andes to preserve their natural landscapes.

Key Words: *Rufous-legged Owl*; Strix rufipes; *Argentina*; *forest habitat*; *night traffic*; *road kills*; *road-less landscape*.

EXPANSIÓN DE LA RED DE CARRETERAS EN LA PATAGONIA ANDINA: UN MENSAJE DE ADVERTENCIA DE *STRIX RUFIPES*

Resumen.—Como parte del crecimiento poblacional y económico de la Patagonia, numerosas rutas secundarias de grava que cruzan bosques andinos bien preservados están siendo convertidas en carreteras pavimentadas. Los efectos potenciales de estos cambios en la vida silvestre del bosque han sido poco estudiados. *Strix rufipes* fue la especie dominante en un censo de aves muertas en accidentes realizado en una sección de una carretera de 27 km de largo que atraviesa el Parque Nacional Nahuel Huapi, en la Patagonia Argentina. Las bajas causadas por accidentes no estuvieron distribuidas uniformemente a lo largo de la porción de la carretera censada, por lo que investigamos si las características del paisaje, la pendiente de los taludes a ambos lados de la carretera, la demografía y/o la estación explicaban el patrón

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de accidentes. Los patrones de distribución de las lechuzas muertas por atropello fueron explicados por la abundancia y la clase de edad de las lechuzas, la época del año y la hora del día y estuvieron débilmente relacionados con el grado de cobertura del dosel. La pendiente del talud a ambos lados de la carretera no estuvo relacionada con el número de bajas. Las muertes relacionadas con el tránsito de vehículos fueron probablemente la principal causa de mortalidad no natural de *S. rufipes* (especialmente para individuos jóvenes) en el área de estudio. El examen de los cadáveres indicó que la mayoría de las lechuzas murieron a causa de la turbulencia que se genera detrás de vehículos grandes y que las muertes ocurrieron temprano por la noche. Los camiones semi-remolque capaces de transportar grandes cargas y que transitan en mayor número entre el anochecer y la medianoche, causaron probablemente la mayoría de las muertes. Una manera de reducir la mortalidad de lechuzas podría ser programar el tránsito de camiones fuera de las horas en las que las lechuzas se encuentran más activas en sus actividades de caza alrededor de las carreteras pavimentadas que cruzan los bosques naturales, al menos durante el final del invierno y la primavera. Debido a que las redes de trasporte facilitan el desarrollo futuro que afecta al entorno de diversas formas, es crítico mantener áreas sin carreteras o casi sin ellas (i.e., mantener sólo carreteras de grava con tránsito de movimiento lento) en la región sur de los Andes para preservar sus paisajes naturales.

[Traducción del equipo editorial]

As the largest human artifacts on earth, roads have become a common feature in contemporary landscapes (Forman et al. 2003). Their effects on wildlife can be negative through a variety of means (Spellerberg 1998), including animal–vehicle collisions, which produce large numbers of fatalities worldwide (Forman et al. 2003, Loss 2014).

The Patagonian region has the fastest population growth of Argentina (I.N.D.E.C. 2010). Along the Andean strip, the economic and population growth is mostly attributable to the revenue from increased recreational use of its natural systems, including renowned national parks such as Nahuel Huapi and Los Glaciares. Both traffic intensity and the road network are increasing for better visitor enjoyment, with several major roads (actual and proposed) crossing and connecting protected areas. Thus, with numbers of both residents and visitors rising quickly, managers are challenged to balance public access to different locations with the environmental and social consequences of motor vehicle use. Moreover, this region has also experienced a sharp rise in freight transport volume in the last decades, and the number of key arterial routes from intraregional transport networks has consequently increased (J.B.I.C. 2002).

There is little information on possible effects of roads on wildlife populations in Patagonia. Among the few studies on this subject (e.g., Fiori and Zalba 2003, Trejo and Seijas 2003, Martino et al. 2008, Barri 2010), only Trejo and Seijas (2003) focused on the Andean (forested) portion of Patagonia. In a 3-yr period, these authors found that 29 bird species were killed along the road in a 27-km section of a main route crossing native forests. The Rufous-legged Owl (*Strix rufipes*) was predominant among the casualties, with carcasses distributed unevenly along the road section surveyed. The Rufous-legged Owl is a forest-specialist endemic to the Andes of southern Chile and Argentina, where it is classified as vulnerable. It is strictly nocturnal in most of its range, feeding on rodents and insects (e.g., Udrizar et al. 2005, Alvarado et al. 2007).

Here, we investigated whether the spatial aggregation of road-killed owls found by Trejo and Seijas (2003) was related to landscape/road features (topography, vegetation), demography (owl abundance, age) and/or season, in order to make recommendations to prevent owl mortality on existing and proposed routes across protected areas in the Patagonian Andes. Additionally, we assessed the potential effect of vehicle collisions on Rufous-legged Owls in northern Patagonia, based on a collection of dead birds from the same area.

METHODS

Study Area. We surveyed a 25-km portion of the national Route 40 that runs north–south across native forests in Nahuel Huapi National Park (ca. 41°15.28′S, 71°27.84′W), in Argentine Patagonia (Fig. 1). The landscape is characterized by lakes, glacial valleys, and mountain slopes covered by native forests. The road segment we surveyed is flanked by lakes (on the west) and by the Ventana mountain range (on the east), and surrounded by stands of evergreen coihue (*Nothofagus dombeyi*) and/or Chilean cedar (*Austrocedrus chilensis*). Stands with sparse Chilean cedar trees dominate the northern (dryer) part of the road (Fig. 1, point A), coihue starts to dominate in mixed stands toward point B (Fig. 1), and dense coihue stands dominate the southern (humid) extreme of the surveyed road (Fig. 1, point C).

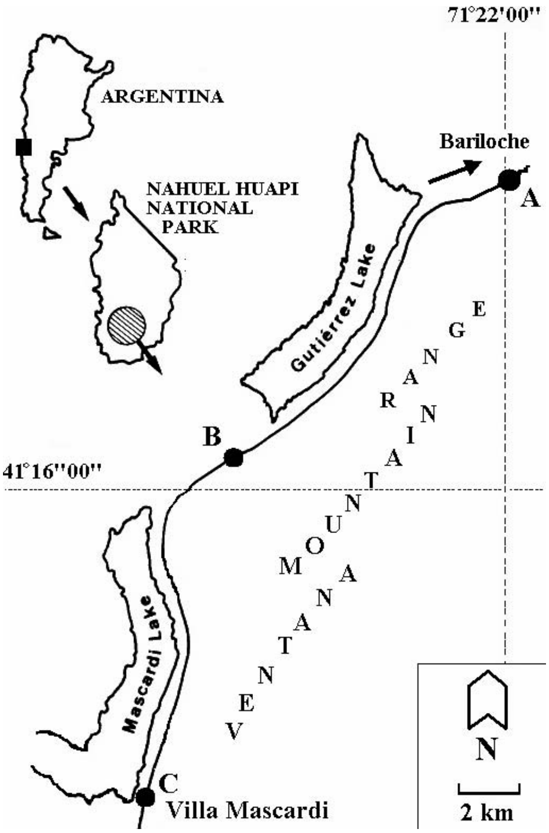


Figure 1. Location of the 25-km portion of National Route 40 surveyed for Rufous-legged Owls road-killed in Nahuel Huapi National Park (Argentine Patagonia) during three years. Stands with sparse Chilean cedar trees (*Austrocedrus chilensis*) dominate the northern (dryer) part of the road (point A), coihue (*Nothofagus dombeyi*) starts to dominate in mixed stands toward point B, and pure coihue dense stands dominate the southern (humid) extreme of the surveyed road (point C).

Routes in Andean Patagonia have little variation (i.e., all are single carriageways with one lane for each direction and no lighting), except for being surfaced with asphalt or gravel/dirt. The highway we surveyed is among the most developed roads in Patagonia, suitable for heavy vehicle traffic (large buses and trucks) traveling at fast speeds. According to statistics from local police (Río Villegas checkpoint, 50 km south of the surveyed section), traffic is moderate to intense (500–1500 vehicles/d) during the day, depending on day of the week. In summer, traffic volume can increase up to 3000 vehicles/d. Vehicle speed ranges from 60–100 km/hr year-round. Independent from tourism traffic, semi-trailer trucks and other transport vehicles use this route all through the year, more intensively after sunset (ca. 2000–2300 H). Traffic (all kinds) is considerably reduced during nighttime hours (2300 – 0800 H).

Survey of Road-killed Birds and Variables Measured. The surveyed road was divided into segments of 1 km, using existing kilometer landmarks. Birds killed by vehicles were collected systematically four times daily between 0715–1600 H (two times driving in each direction), 5 d/wk from February 2000 to February 2003 (excluding weekends). The road and soft shoulders of the road were checked from the car, moving at 30–50 km/hr. Dead animals were frozen until examination. Date, hour, location assigned to nearest kilometer landmark, weather (snowing, raining, no precipitation), temperature, and moon phase were recorded for each carcass (for more details, see Trejo and Seijas 2003).

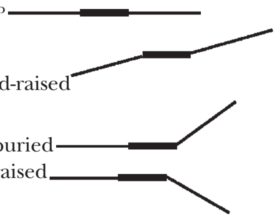
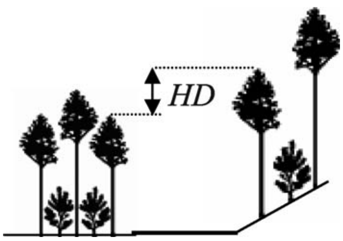
In autumn 2008, we conducted standardized acoustic point-count surveys of *S. rufipes* at the 25 km landmarks (census details in Trejo et al. 2011) and measured six explanatory variables related to topography, road design, and vegetation at both sides of the road (see Table 1 for more details). There was a strip of forest at least 50 m wide between the road and the lake, so the lake itself was not treated as a variable having potential effects on the number of traffic-related deaths.

Although the abundance of owls and the habitat/road features were evaluated 5 yr after the collection of birds killed along the road, these data sets were considered compatible for the analyses herein because the studied road and surroundings did not change (e.g., no logging, fire, or road construction) during that period.

Laboratory Procedures. We examined owl specimens internally and externally to determine evident lesions (especially in bones), such as fractures or hemorrhages. We sexed the owls by examination of gonads. Adults (>1 yr) were differentiated from immature birds by a combination of degree of tracheal ossification (ossified, adult; cartilaginous, immature), and gonadal size (testes $>10 \times 5$ mm, adult male; oviduct dilated, adult female, Work and Hale 1996). We also took tissue samples of gonads to confirm sex and of trachea to determine degree of ossification. Tissues were fixed in 10% neutral buffered formalin, embedded in paraffin, cut into 5-μm sections, and stained with hematoxylin and eosin.

To examine the effect of vehicle collisions on Rufous-legged Owls at a broader (regional) spatial

Table 1. Description of variables measured at 25 points (every 1 km) along Route 40 in Nahuel Huapi National Park, Argentine Patagonia.

VARIABLE NAME	DESCRIPTION	STATES OF DERIVED VARIABLES FOR STATISTICAL ANALYSES
Roadkills (RK)	Killed owls	(1) Present (1–2 per point) (2) Absent
Owl abundance (AB)	Owls detected in surveys	(1) Present (1–2 per point) (2) Absent
Road design[a] (RD)	Roadside slope on both sides (combined into a new variable)	(1) Level[b] (2) Buried-raised (3) Part buried (4) Part raised 
Dominant tree species (TS)	Species dominating landscape on both sides of the road	Coihue (1) Ciprés (2)
Canopy closure (CC)	Closure category dominating landscape on both sides of the road	(1) Scattered trees (2) Open forest (most crowns not overlapping) (3) Dense forest (most crowns overlapping)
Canopy height[c] (CH)	Maximum canopy height on either side	(1) Up to 20 m (min. 10) (2) >20 m (max. 40)
Treeline height difference[d] (HD)	Absolute difference in height between the nearest trees on both sides	(1) 0–15 m (2) >15 m  (max. 40)
Road vegetation width[e] (VW)	Vegetation gap due to road.	(1) Up to 35 m (min. 16) (2) >35 m (max. 150)

[a] Adapted from Clevenger et al. (2003); measured with a clinometer.
[b] Slope <5 degrees was considered level.
[c] Measured with a clinometer and optical rangefinder.
[d] Measured with a clinometer and optical rangefinder.
[e] Measured with an optical rangefinder, from the first tree/shrub (>2 m tall) on one side to the first tree/shrub on the other side.

scale, we also examined the owls present in our laboratory collection of birds found dead of any cause near the city of Bariloche (41°08′S, 71°19′W) during the last 15 yr (collection details in Seijas and Trejo 2011). For this report, we included all species of owls in that collection.

Analytical Methods. To assess the differences between the actual and expected numbers of fatalities on the road sections, we used the chi-square (χ^2) goodness-of-fit test assuming an even distribution of road-killed owls in the compared sections. This test was also performed for other selected variables, as needed.

We used a Multiple Correspondence Analysis (MCA) to explore whether the recorded variables explained Rufous-legged Owl mortality in each segment. For this analysis, most variables were dichotomized or reduced to a few states (Table 1); those expressed as presence-absence were coded 0–1. Variables are well represented at the biplot if their quality >0.1 and their states are correlated to one of the components (cosine$^2 \geq |0.45|$). Variables correlated

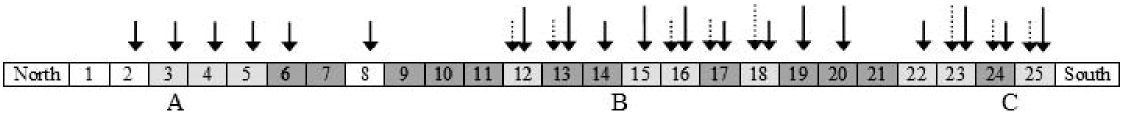


Figure 2. Spatial distribution of surveyed and road-killed Rufous-legged Owls at 25 points (every 1 km) on National Route 40 (Nahuel Huapi National Park, Argentine Patagonia). Solid arrows indicate number of Rufous-legged Owls detected (none = no arrow, one = short arrow, two = long arrow); broken arrows correspond to number of killed owls (none = no arrow, one = short arrow, two = long arrow). Mean canopy closure for each segment is indicated using: white (scattered trees), light grey (open forest) and dark grey (closed forest).

with one of the principal axes explain part of the inertia of that axis (Glynn 2012).

The MCA is an exploratory technique used to produce a simplified (low dimensional) representation of the information in a large frequency table. Therefore, a log-linear analysis was then used to analyze multi-way frequency tables considering only those variables that were correlated to the presence or absence of road-killed owls according to the MCA.

The statistical analyses were done with Statistica 5 and Excel software. Results with probability $P \leq 0.05$ were treated as statistically significant.

RESULTS

Ten dead Rufous-legged Owls were found in the segment of road surveyed during 3 yr. The only other owls found were two Barn Owls (*Tyto alba*).

In the collection of dead birds found near the city of Bariloche, we found 45 owls of five species (Barn Owl, Rufous-legged Owl, Great Horned Owl [*Bubo virginianus*], Austral Pygmy-Owl [*Glaucidium nana*], Short-eared Owl [*Asio flammeus*]). At least 28 individuals (62%) were killed by traffic around Bariloche city. Six of eight (75%) of the Rufous-legged Owls in this collection had been killed by vehicles along roads.

Age, Sex, and Condition of Carcasses. Seventy percent of all dead Rufous-legged Owls were immature, and 60% of these were females. All carcasses showed stiffening of muscle joints by the time of collection (early morning). At the examination conducted in the laboratory, three carcasses showed extensive external and internal lesions, suggesting direct collision with a vehicle. The rest had no visible external lesions. Of these, two owls had no visible internal ones. The remaining dead owls had hemorrhages, most frequently of the head and body cavity, and fractures of cranium and limbs. Lesions of this type suggest that most dead owls were probably killed by impact with the ground due to turbulence.

Temporal Pattern of Road-killed Owls. Carcasses were found between August and November (i.e., late winter and spring), at the earliest daily survey (0715–0740 H), before the daily increase in traffic volume. Temperatures were mostly below freezing; no specific precipitation was associated with deaths. Most carcasses were found when moonlight (of variable intensity) was available the previous night; only one death occurred with no moonlight.

Spatial Distribution of Road-killed Owls and Related Factors. Distribution of road-killed owls (0, 1, or 2 carcasses per 1-km segment of road) was not uniform among the 1-km segments of the surveyed road. The greatest number of owls found dead occurred between segments 12–25 (chi-square test, $\chi^2 = 14.5$, df = 2, $P = 0.001$), coinciding with higher numbers of live owls detected in our surveys (chi-square test, $\chi^2 = 13.08$, df = 2, $P = 0.001$) and with greater canopy closure ([CC]; chi-square test, $\chi^2 = 68.7$, df = 2, $P = 0.0$; Fig. 2).

The MCA confirmed that the presence or absence of road-killed owls (RK) was related only to owl abundance (AB) and canopy closure, all of which contributed to PC2 (Fig. 3). Conversely, dominant tree species (TS) and canopy height (CH) contributed to PC1 (inertia >10%), but were not related to the dead owls found. These two dimensions captured 63% of the variation (inertia of the axes). None of the road design variables (HD, RD, VW) were related to the distribution of road-killed owls.

Because we were interested on variables that were related to roadkill patterns, only those correlated to the PC2 were considered for the log-linear analysis. The specified model that included the canopy closure (category 2) and the owl abundance (category 1) was sufficient to explain the observed frequencies of road-killed owls (overall model fit: chi-square test, $\chi^2 = 2.44$, df = 4, $P = 0.66$). The least complex model that fitted the observed values contained the interaction variable for live owl abundance and the number of road-killed owls (chi-square test, $\chi 2 = 3.9$, df = 1, P

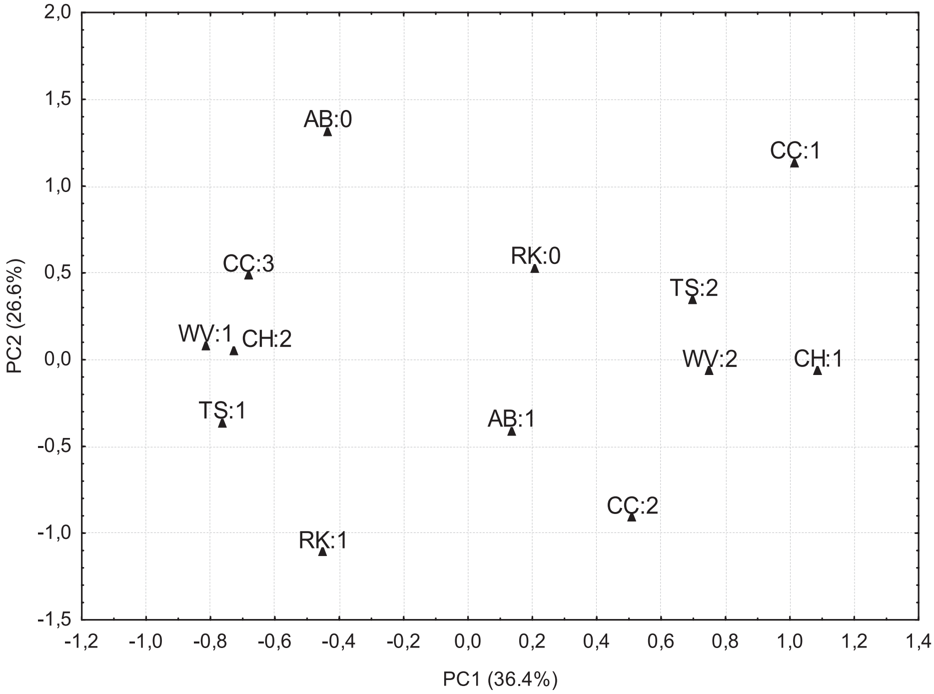


Figure 3. Biplot of the first two components (PC1 and PC2 respectively) of variables recorded at 25 points (every 1 km) on National Route 40 (Nahuel Huapi National Park, Argentine Patagonia), where mortality of Rufous-legged Owls was studied for three years. The PC1 and PC2 explain 63% of the variance. Variable abbreviations are given in Table 1.

= 0.02), but not the interaction variable for canopy closure and number of road-killed owls ($P > 0.05$). Hence, based on log-linear analysis, the only factor associated with number of road-killed owls was live owl abundance at the 1-km segments.

DISCUSSION

In the most lethal section (12–25 km segments), almost one individual every 4 km was killed yearly. These are minimum mortality estimates, because roads were not surveyed on weekends, a 2-d data-gap, which was slightly longer than advised by Santos et al. (2011) based on carcass persistence probability for raptors. It is likely that some carcasses were not collected due to scavenger removal and to imperfect detection, which contribute the greatest sources of uncertainty for road mortality estimates (Loss et al. 2014). In addition to these sources of estimate bias, an unknown number of birds that collide with vehicles fly out of detection range or are carried away by vehicles (Loss et al. 2014).

Traffic-related events were the primary cause of non-natural mortality of Rufous-legged Owls in the Nahuel Huapi National Park area, as indicated by our examination of the collection of dead birds found opportunistically in Bariloche city and the surrounding area (in varied places including along roads, in parks, on trails, or in residential areas). Vehicle collision has also been identified as the primary cause of death for Barn Owls in Europe (Newton et al. 1991, Massemin and Zorn 1998), and has a tremendous effect on populations of other species elsewhere (e.g., Hernández 1988, Loos and Kerlinger 1993, Fajardo 2001, Silva et al. 2012, Borda-de-Água et al. 2014, Grilo et al. 2014). However, as a caveat, we note that raptors killed on roads are much more likely to be detected than those dying in roadless wilderness areas (e.g., McIntyre 2012), so information gained by surveying roads or by opportunistically collecting carcasses cannot be considered unbiased.

Based on several studies (e.g., Massemin and Zorn 1998, Clevenger et al. 2003, Orłowski 2008), we expected road design and forest variables to be related to mortality rates. Our results were not conclusive on the role of landscape and road features as determinants of the rate of roadkills, possibly due to a small sample size. For example, the canopy closure appeared to be an important factor in the exploratory analysis (multiple regression), but only the abundance of live Rufous-legged Owls was supported as an explanatory variable when fitting models (log-linear) to the observed frequency of roadkills, suggesting that fatalities occurred most commonly where the Rufous-legged Owls were most abundant.

Most dead owls were young killed during the owls' pre-nesting and nesting season (Estades et al. 1998, Trejo et al. 2011). Natal dispersal of juveniles, during which individuals wander across unfamiliar landscapes, may increase the risk of accidents. Immature birds' lack of experience in foraging might also contribute to increased flight-hunting time and distance flown, which in turn increase the risk of colliding with vehicles (Massemin et al. 1998). Most deaths occurred when at least some degree of moonlight was available. Ibarra et al. (2014) found that brighter moonlight was positively correlated with detection rates for Rufous-legged Owls in forests in southern Chile, suggesting a general preference for this owl to be more active during more illuminated nights, as also suggested for other owl species (Penteriani et al. 2011).

No dead owls were found during the high season for tourism (summer), when the number of small vehicles (i.e., gross weight under 3500 kg) increases during daytime. Massemin and Zorn (1998) also found the amount of traffic had little effect on owl mortality rate in France, compared with, for example, the high speed of the traffic (>80 km/hr). The road studied herein, like most roads typical of the Patagonian Andes, is very curvy, mostly cut into mountain slopes, and danger itself prevents high speeds (i.e., drivers can rarely surpass 80 km/hr). Thus, neither the amount of vehicle traffic, nor the traffic speed, appear to be useful management variables to reduce owl mortality in major roads of Andean Patagonia.

However, the time of night may have been an important factor affecting mortality patterns in our study. All carcasses were found early in the morning (before the increase in traffic) in advanced *rigor mortis*, indicating that owls died several hours before. Most carcasses had no signs of direct impact with vehicles and were probably killed by impact with the ground due to turbulence. These facts suggest that deaths probably occurred between sunset and midnight, when the owls begin their activity and the road is still busy, especially with large commercial freight trucks, which are likely responsible for the lethal turbulence. The number of semi-trailer trucks (>12 tonnes, category N3 of the United Nations Economic Commission for Europe) increases shortly after sunset, in order to avoid the peak automotive traffic that precedes sunset (logbook statistics from police checkpoint at Río Villegas, Argentina). Hence, although demography and age-specific behavior (and possibly also canopy closure) were related to forest owl fatality rate in northern Patagonia, the number of large trucks using the highway during the owl's most active hunting hours likely also contributed to the observed mortality pattern.

Future research should include radiotelemetry studies designed to compare owl movements and roadkill rates among forests of different ages and types, in order to assess the effects of forest structure on the risk of mortality by collision with vehicles. Future management should focus on regulating the hours of activity for large trucks (>12 tonnes) and buses (>5 tonnes) that produce the strongest turbulence. Ideally, these large vehicles should be excluded from paved roads crossing heavily forested portions of wild areas (such as the studied route, or the scenic ''Siete Lagos route,'' now converted into a fast highway) between dusk and midnight, when owls are especially active.

Roadless areas are decreasing worldwide (Trombulak and Frissell 2000, Forman et al. 2003), and the southern corner of South America is no exception. Land and park managers from Andean Patagonia face strong pressures to convert scenic dirt/gravel roads crossing well preserved continuous forest into high-speed, paved highways for tourists (e.g., Parque Nacional Los Alerces route) or into commercial routes for large trucks (e.g., Cardenal Samoré International Pass, in Nahuel Huapi National Park), to comply with international agreements. Before more gravel roads are converted into high-speed, paved highways, research is needed on the effects of these roads on the potentially affected biota. It is also critical to retain some of the remaining roadless or near-roadless (i.e., containing only dirt roads) portions of the southern Andes in order to preserve traditional natural landscapes.

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