Prediction of Iberian lynx road–mortality in southern Spain: a new approach using the MaxEnt algorithm

G. Garrote, J. Fernández–López, G. López, G. Ruiz, M. A. Simón

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Abstract
Prediction of Iberian lynx road–mortality in southern Spain: a new approach using the MaxEnt algorithm. In recent years, the Iberian lynx (*Lynx pardinus*) has experienced a significant increase in the size of its population and in its distribution. The species currently occupies areas in which it had been extinct for decades and new road mortality black spots have been identified. Its conservation requires an intensive risk assessment of road–deaths in potential future distribution areas. Using the MaxEnt algorithm we aimed to identify the roads where there is a greater risk of road collision for the Iberian lynx. More than 1,150 stretches of road were evaluated in Andalusia (southern Spain). Both road–related and habitat variables were included in the model. A total of 1,395 km of the 7,384 km evaluated (18.9 %) were classified as high risk road. Our results could help plan future conservation strategies. To our knowledge, this is the first time that the MaxEnt algorithm has been used to provide spatially–explicit predictions about wildlife road mortality.

Key words: Road mortality, Iberian lynx, MaxEnt, Linear data

Resumen
Predicción de la mortalidad en la carretera del lince ibérico en el sur de España: un nuevo método utilizando el algoritmo MaxEnt. En los últimos años, el tamaño de población del lince ibérico (*Lynx pardinus*) y su área de distribución han aumentado de forma significativa. Actualmente, la especie habita zonas en las que había estado extinto durante décadas y en las que se han identificado nuevos puntos negros de mortalidad en carretera. La conservación de esta especie requiere que se haga una evaluación exhaustiva del riesgo de muerte en carretera en su posible distribución futura. En este estudio se emplea el algoritmo MaxEnt para identificar las carreteras donde hay mayor riesgo de atropellar un lince ibérico. Más de 1.150 tramos de carreteras fueron evaluados en Andalucía (sur de España). En el modelo se utilizaron variables relacionadas con las carreteras y el hábitat circundante. En total, 1.395 km de los 7.384 km evaluados (el 18,9 %) se han calificado como de alto riesgo. Nuestros resultados podrían ayudar a planificar futuras estrategias de conservación. Hasta donde conocemos, esta es la primera vez que se utiliza el algoritmo MaxEnt para predecir de forma espacialmente explícita la mortalidad de fauna silvestre en carreteras.

Palabras clave: Mortalidad en carretera, Lince ibérico, MaxEnt, Datos lineales

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G. Garrote, G. López, G. Ruiz, Agencia de Medio Ambiente y Agua de Andalucía, c/ Johan Gutenberg s/n., Isla de la Cartuja, 41092 Seville, Spain.– J. Fernández–López, Real Jardín Botánico de Madrid–CSIC, Plaza de Murillo 2, 28014 Madrid, Spain; Departamento de Zoología y Antropología Física, Facultad de Ciencias Biológicas, Universidad Complutense de Madrid, 28040 Madrid, Spain.– M. A. Simón, Consejería de Medio Ambiente de la Junta de Andalucía, c/ Doctor Eduardo García–Trivino López 15, 23009 Jaén, Spain.

Corresponding author: Germán Garrote. E–mail: gergarrote@gmail.com

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Introduction

Over the past decade, a set of tools for modelling species distributions has been developed for use in wildlife management and conservation (Elith and Leathwick, 2009). The objectives of these approaches are currently expanding and they are now being used to model a set of processes that are closely tied to biological interactions and conservation biology (Yañez–Arenas et al., 2014). The use of these statistical approaches–predict risks for wildlife helps focus the economic efforts required by conservation plans (Mateo–Tomás et al., 2012). In this context, routinely collected road–kill information can be used in species conservation to mitigate the impact of mortality on roads, one of the most important anthropogenic impacts on wildlife communities in a human–dominated context (Forman and Alexander, 1998; Forman, 2003; Sáenz–de–Santa–María and Tellería, 2015; D'Amico et al., 2015).

The Iberian lynx is the most endangered felid species in the world, listed as Endangered by the IUCN (IUCN, 2015). In 2002, only two populations remained —one in Andújar–Cardeña, in Eastern Sierra Morena, and one in Doñana, Southern Spain)— totalling fewer than 100 individuals (Guzmán et al., 2004). Since then, however, the Iberian lynx has undergone a significant increase in population size due to conservation measures developed as part of conservation projects for the species (Simón et al., 2012). By 2016, the number of Iberian lynx in the wild was 483 (Junta de Andalucía, 2016), almost five times more than just over a decade before. One of the main goals of these conservation projects was to decrease mortality caused by anthropogenic pressure, especially through poaching and road accidents. Road–kills are considered a chief cause of death in the Iberian lynx in the Doñana area, accounting for 16.7 % of the total annual mortality rate (AMR) in the 1980s (Ferreras et al., 1992). During the first decade of the 21st century, conservation programs carried out numerous prevention measures to prevent road kills in the distribution area of the Iberian lynx, particularly in the Doñana area. A recent mortality study based on radio–tracking data found that road–kills had a minor impact on the Iberian lynx population in 2006–2011 (López et al., 2014), with a percentage of the total AMR of 6.6 % in Sierra Morena and 8.6 % in Doñana. In the same period, the average annual number of lynx found dead due to road–kill (tracked and non–radio tracked) was 3.16 SE:1.83 (Junta de Andalucía, 2016). However, road–kills associated with the expansion of the species have decreased notably since 2012 (2012–2015 annual lynx road–killed: 13 SE:6.05; Junta de Andalucía, 2016). Both natural colonisation and reintroductions have led to the species being present today in areas in which measures to prevent road–kills have not yet been implemented and where new road–kill black spots have been identified. Within this scenario, managers need tools that allow them to detect potentially dangerous areas for the lynx before it reaches their areas in order to plan and put conservation measures into practice.

Despite the historical importance of road kills in the conservation of the Iberian lynx, the factors involved have not been identified. Existing studies have been limited to estimating mortality rates (Ferreras et al., 1992; López et al., 2014). Previous studies have found that road–kills involving carnivores depend on population density, species biology, habitat and landscape structure, and road and traffic characteristics (Clevenger et al., 2003; Malo et al., 2004, Grilo et al., 2009). Road–related features that have shown to affect the spatial distribution of casualties include vehicle speed (Jaarsma et al., 2006), traffic volume (Clarke et al., 1998), roadside topography (Clevenger et al., 2003), adjacent vegetative cover (Ramp et al., 2005) and type of nearby passages (Clevenger et al., 2003; Malo et al., 2004).

To date, most studies describing casualty patterns have analysed only the role of proximate causes of road–kill (e.g., local road features), so their management recommendations are difficult to translate to other localities (D'amico et al., 2015). In the present we aimed to identify the roads with the highest risk of road collision for the Iberian lynx. We included road kill data the Andalusian road network and used both road–related feature and land cover features to build a risk map for this critically endangered felid. It uses the MaxEnt algorithm (Phillips et al., 2006; Phillips and Dudík, 2008), which is especially efficient in dealing with presence–only data and a small sample size (Wisz et al., 2008). These aspects make MaxEnt appropriate for modelling road–kills, because absence data cannot be recorded with confidence in many cases, and the only data available are often government reports. To our knowledge, this is the first time that the MaxEnt algorithm has been used to provide spatially–explicit predictions about wildlife road mortality using linear data, i.e. non–raster data.

Material and methods

A total of 99 Iberian lynx road fatalities were recorded by the Andalusian Regional Ministry of the Environment from 1979 to 2013. From these data, we used only the records of deaths on monitorized stretches, i.e. roads with available data about use intensity and vehicle speed. A total of 46 records from 2001 to 2013 were selected for analysis. The predictors we used were four road variables taken from the Basic Spatial Data of Andalusia database (BSDA) (table 1), namely, (i) vehicle speed (SPEED), (ii) intensity of road use (INTENS), (iii) road hierarchy (HIERAR) and (iv) road type (TYPE). We also included as a predictor a categorical land cover variable taken the CORINE Land Cover Map (COVER) because many collisions can be linked to the attraction exercised by a specific habitat (Barrientos and Bolonio, 2009; D'Amico et al., 2015)

We used the MaxEnt algorithm (Phillips et al., 2006; Phillips and Dudík, 2008) to model the distribution of Iberian lynx fatalities on the road network. We used a methodology similar to that described by Elith et al. (2011), concerning the distribution of the freshwater

Table 1. Description of variables included as predictors in the analysis.

Tabla 1. Descripción de las variables incluidas como factores predictores en el análisis.

Road–related variables		
	SPEED	Continuous. Average speed (km/h) of the total vehicles between 2008 and 2011
	INTENS	Continuous. Average intensity of use (veh/day) of the total of vehicles between 2010 and 2011
	HIERAR	Categorical, 10 levels. Titularity and dependences of each road (see spatial reference for Andalusia Database, SRAD)
	TYPE	Categorical, 5 levels. Physical characteristics of the road, number of road lanes, etc. (see spatial reference for Andalusia Database, SRAD)
Land cover variables		
	COVER	Categorical, 11 levels. Obtained from CORINE Land Cover 2006: non–irrigated arable land; permanently irrigated land; paddy/rice fields; vineyards; olive grove; complex cultivation patterns/farms; agro–forestry areas; natural grasslands/pasture; coniferous forest; sclerophyllous shrub; transitional woodland–shrub

fish *Gadopsis bispinosus* in a water basin (GIS–vector river data). As background data (282 samples for this data set) we used each stretch of road in the entire area in which Iberian lynx populations are stable (fig. 1). All these stretches, that range 0.1 km to 33 km long, are defined as road fragments between kilometer points with homogeneous road features: use intensity, speed, and type of road. Next, we extracted variables for all roads stretches on which an Iberian lynx had been killed and built a second matrix to use as the presence dataset (46 records). These two datasets were managed as section–based (non–gridded) data and included the MaxEnt algorithm as a samples–with–data (SWD) format. We ran 10 replicates of the MaxEnt algorithm following the advice of Merow et al. (2013). We used raw output to avoid post–processing assumptions (Merow et al., 2013); we chose regularization multiplier b = 1 by default since we had no prior information that could be used to optimize these parameters; we removed product and hinge features, avoiding interactions between variables and increasing the interpretability of our models (Merow et al., 2013). The convergence threshold was set at 0.00001. We ran 10 replicates, using as training–data 70 % of the presences and the remaining 30 % for Maxent intrinsic AUC test validation (Fielding and Bell, 1997).

To widen the scope of our results to cover areas of conservation interest (near current Iberian lynx distribution areas and target areas for reintroduction programmes, etc.), we projected the model on all roads in Andalusia, using a third dataset that included variables for all available Andalusian roads, a total of 7,398 km including 1,175 stretches. In order to estimate the transferability of our model areas with stable populations of Iberian lynx to the whole of Andalusia, we explored the clamping scores provided by MaxEnt (see Randin et al., 2006; Barrientos and de Dios Miranda, 2012). We used the Equal test sensitivity and specificity to establish a threshold to categorize roads with a high–low risk of lynx kill to enable a comparative analysis between road stretches.

We used QGIS 2.2.0 (QGIS Development Team, 2014) to plot the projected risk of Iberian lynx road–kills provided by MaxEnt onto a geographical platform to obtain a risk map for the evaluated roads and a hazard index for the Iberian lynx on these roads.

Results

The MaxEnt intrinsic validation test obtained an AUC under ROC score of 0–804 (SD ± 0.056) for the mean of 10 replicates. Clamping scores for model projection ranged 0–0.06, with a mean of 0.00021. Thus, we consider that the values of the background variables provided were robust enough to interpolate the model for the whole of the Andalusian road network.

The most important variable for Iberian lynx road–kills was COVER, followed by HIERAR and SPEED according to the jackknife plot of testing gain for variable importance provided by MaxEnt (Phillips et al., 2006) (fig. 2). INTENS and TYPE had the lowest scores. When analysing COVER variables, we found that roads with scrub land cover had a greater probability of Iberian lynx road–kills. Within the hierarchy variable (HIERAR), the most dangerous roads were highways and other main roads that link large urban areas. The SPEED variable had a positive relationship with Iberian lynx deaths at speeds over 90 km/h, in

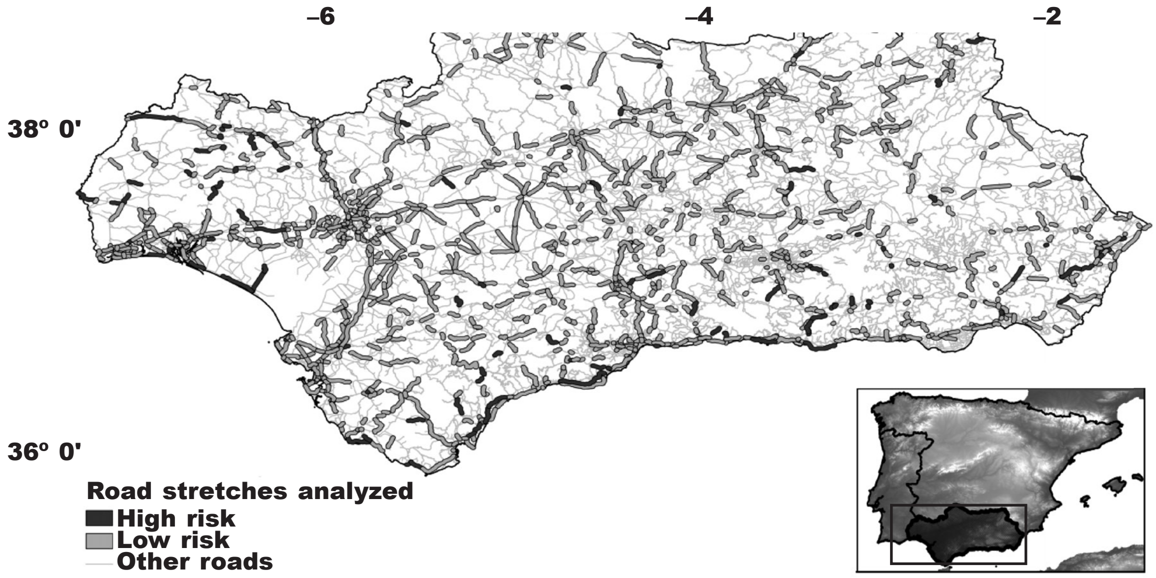


Fig. 1. Risk map for the 1,175 roads evaluated.

Fig. 1. Mapa de riesgo de las 1.175 carreteras evaluadas.

agreement with HIERAR effects. The INTENS variable had little importance in our model and its effect was negative, contrary to our initial expectations (fig. 2).

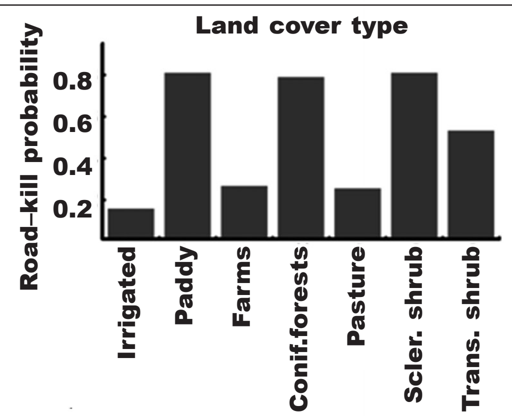
The road–kill risk provided by our model ranged minimum risk of 0 to maximum risk of 1 with a mean of 0.222. Threshold between high to low kill risks was established at 0.233 following equal test specificity and sensitivity criterion. A total of 1,395 km out of the 7,384 km evaluated were classified as high risk road.

Discussion

Our model identified the stretches of the road network at a regional level where road collisions for the Iberian lynx were most likely. An internal validation test provided by MaxEnt obtained an AUC score = 0.804 (SD ± 0.056). A model is usually considered useful if AUC scores are higher than 0.75 (Phillips and Dudik, 2008; Lobo et al., 2007). Our model therefore performed well in predicting Iberian lynx road–kills. To increase performance, further variables such as fine–scale habitat type surrounding a road or the presence of mitigation measures on each stretches could be included in the model (Barrientos and Bolonio, 2009).

Our model shows that the main factor affecting road–kill records was the type of land cover around the road, this being the key variable (Malo et al., 2004). Scrub and coniferous forest were identified as the most dangerous land covers. This pattern could be related to two main processes on a large scale: (1) habitat fragmentation caused by linear infrastructures and (2) the increase of the edge effect in areas occupied by terrestrial mammals (Tellería et al., 2011). Since Iberian lynx mainly set up their territories in Mediterranean scrub areas with differing types of forest coverage (Palomares, 2001; Fernandez et al., 2006), this fragmentation and the edge effect could lead–an increase in mortality due to the penetration of dangers non–core areas (animal–vehicle collisions in our case) (Palomares, 2001). On a local scale, these kinds of habitats attract more potential prey. Moreover, high rabbit (the Iberian lynx's staple prey item) densities are recorded near some roads (Garrote, obs. pers.) due to (1) the prohibition of shooting near roads and (2) the suitability of embankments for the building of warrens (Barrientos and Bolonio, 2009). These high rabbit densities increase the probability of incursion by lynxes onto roads and therefore the likelihood of lynx road–kills. Mitigation measures such as clearing scrub alongside roads or ensuring that new roads do not run through this type of habitat could help to reduce lynx to vehicle collisions. Other habitats that seem to favour Iberian lynx road–kills include paddy fields, farms and vineyards. In this agricultural matrix, roadside ditches are a typical refuge for rabbits because they are suitable places to build their warrens (Calvete et al., 2004; Gea–Izquierdo et al., 2006). These concentrations attract carnivores such as the Iberian lynx, thereby increasing the probabilities of road–kills. Similar results were obtained by Barrientos and Bolonio (2009), who suggested that road–kills in dry agricultural landscapes are linked to the presence of a greater number of rabbit warrens in road verges and greater traffic flow and speed.

Variable	Jacknife score
Land cover type	0.60
Road hierarchy	0.42
Vehicle speed	0.18
Toad type	0.10
Vehicle intensity	0.06



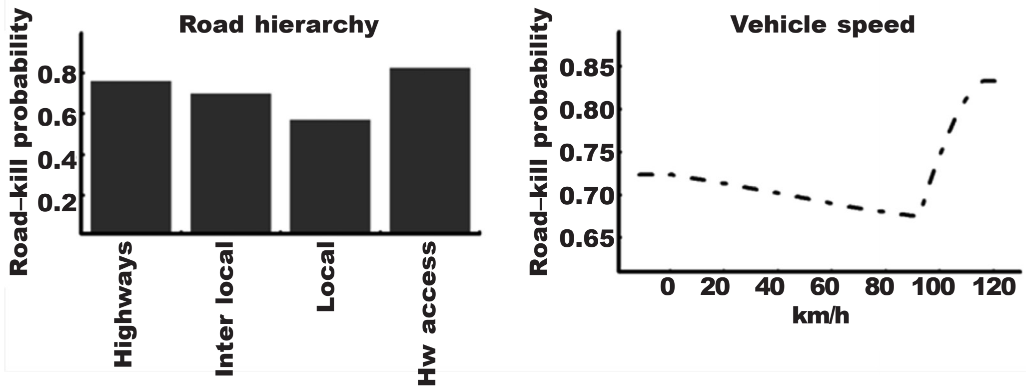


Fig. 2. A, contributions of the variables on Iberian lynx road–mortality. Effect of the three most important variables: B, land cover type; C, road hierarchy; D, vehicle speed.

Fig. 2. A, contribución de las variables en la mortalidad en carreteras del lince ibérico. Efecto de las tres variables más importantes: B, tipo de cobertura terrestre; C, jerarquía de carreteras; D, velocidad del vehículo.

The two other most important variables in our model, HIERAR and SPEED, are intrinsically related. SPEED can be related to lynx mortality due to the fact that driver reaction time decreases with increasing speed (Barrientos and Bolonio, 2009). HIERAR is related to the socioeconomic characteristics (hierarchy levels are mainly related to population connections, and local or state ownership, etc.) and the physical characteristics of the road (width, hard–shoulder size, etc.) (Barrientos and Bolonio, 2009). Therefore, the better the roads, the greater possibility of reaching higher speeds. In agreement with the results obtained for other mammals (Malo et al., 2004; Clark et al., 1998), speeds over 90 km/h were positively related to the probability of the deaths of Iberian lynx.

Mitigation actions in main roads such as (1) increasing the effectiveness of fencing, (2) ensuring the proper maintenance of existing fences, and (3) building of road overpasses or underpasses for animals should be contemplated for the most dangerous roads. These mitigation measures have proven to be the most effective in reducing wildlife mortality on roads (Rytwinski et al., 2016).

From a conservation point of view, the most important contribution of the model described here, is its ability to identify the potentially dangerous stretches of roads on a large scale. This information may be incorporated into the first stages of selecting reintroduction areas for the Iberian lynx. The protocol to select Iberian lynx reintroduction areas includes both the evaluation of road–kill risk and the identification of especially dangerous road stretches (Junta de Andalucía, 2012). Fine–scale analysis/detection of black spots by means of fieldwork can become laborious, expensive and slow if the road network is large. Initially identifying the dangerous stretches using the model may help to guide later work in more detail, concentrating efforts in the areas of greater danger, and thereby optimising resources.

At the 5th Iberian Lynx International Conservation Seminar (Garrote, 2016), a peninsula–wide habitat suitability model was presented to detect potential areas for Iberian lynx reintroduction. It would be very useful to include the results of this study in the model for selecting reintroduction areas and their subsequent priority order or categorisation. Similar exercises should be carried out for the different CCAA and Portugal, with the necessary adaptations depending on the type of data available as they are not homogeneous throughout the peninsula.

The use of the MaxEnt algorithm in species distribution models has been extensively tested in many conservation plans. It has been broadly used to design reserve networks (Meller et al., 2014) and topredict the invasion ability of exotic species (Peterson and Vieglais, 2001). This study describes an approach using this algorithm to conduct a wide–range analysis based on digital information provided by local administrations. Predictive models for animal–vehicle collisions can generate high performance risk maps to be used to channel investment for improving the safety of both drivers and animals.

In summary, the Iberian lynx is categorized as Endangered (IUCN, 2015), but its range is currently expanding. This increase, however, implies the species is present near many more kilometers of roads, so the probability of road kill is higher. For this reason, predicting the most dangerous roads for the Iberian lynx should be a priority in conservation planning reintroduction initiatives.

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Appendix 1. Road stretches with high road mortality risk.

Apéndice 1. Tramos de carreteras analizados con alto riesgo de mortalidad por atropello.

ID	From – to
A–456	Fuentes de Andalucía – Lora del Río
A–4132	Órgiva – Trevélez
A–4127	A–348 – Bérchules
A–2233	Conil de la Frontera – Barbate
A–395	Granada – Sierra Nevada
A–455	Cazalla de La Sierra – Lora del Río
A–475	Calañas – Puebla de Guzmán
A–389	Arcos de la Frontera – Medina Sidonia
A–499	Ayamonte – Puebla de Guzmán
A–7378	A–2300 – A–374 by Arroyo Montecorto
A–352	Cuevas del Almanzora a Garrucha
A–4129	A–4132 – Capileira by Bubión
A–421	Villafranca de Córdoba – Villanueva de Córdoba
A–2226	Benalup – Casas Viejas – A–381
A–4132	Órgiva – Trevélez
A–4132	Órgiva – Trevélez
A–4102	A–92 – Alcudia de Guadix
A–337	Cherín – La Calahorra
A–369	Ronda – Gaucín
A–348	Lanjarón – Almería by Ugíjar
A–314	Vejer de la Frontera – Barbate
A–349	Tabernas – Olula del Río by Macael
A–395	Granada – Sierra Nevada
A–497	Huelva – Punta Umbría
A–479	Aracena – Campofrío
A–422	Alcaracejos – Belalcázar by Hinojosa del Duque
A–7206	Cómpeta – N–340 by Algarrobo
A–332	Cuevas de Almanzora – San Juan de los Terreros
A–387	Alhaurín el Grande – Fuengirola
A–7282	Access – Antequera
A–324	La Cerradura – Huelma
A–92N	Guadix – Límite de Región de Murcia
A–7207	Canillas de Albaida – Torrox – Costa by Cómpeta
A–497	Huelva – Punta Umbría
A–405	Gaucín – San Roque
A–346	Órgiva – Vélez de Benaudalla

ID	From – to
A–8126	Morón de la Frontera – Algodonales
A–486	San Juan del Puerto – Bonares
A–5052	El Rompido – Punta Umbría
A–4105	Access – La Peza and Lopera
HU–4402	Villanueva de los Castillejos – Sanlúcar de Guadiana
HU–6400	El Granado – Puente del Chanza (Pomarao)
HU–7104	N–435 – Cabezas Rubias
Old A–382	Old road Jerez de la Frontera – Arcos de la Frontera
A–476	El Castillo de las Guardas – Minas de Riotinto
A–363	Morón de la Frontera – Olvera
A–4133	Vélez de Benaudalla – Motril
A–2229	A–2230 – Vejer de la Frontera
A–402	Moraleda de Zafayona – Viñuela
A–4050	N–323 – Almuñécar
A–366	Ronda – Coín
A–3176	Villaharta – Puerto del Caballón by Obejo
A–496	Valverde del Camino – Cabezas Rubias
A–493	La Palma del Condado – Valverdel Camino
A–373	Villamartín – Algatocín
A–355	Casapalma – Marbella
A–7200	A–92 – Estación de Salinas by Archidona
A–483	Bollullos del Condado – Matalascañas
A–480	Chipiona – Jerez de la Frontera
A–369	Ronda – Gaucín
A–310	Puente Génave – Siles
A–319	Peal de Becerro – Hornos por Cazorla
A–355	Casapalma – Marbella
A–2325	N–340 – Punta Paloma
A–494	San Juan del Puerto – Matalascañas por Mazagón
A–1100	N–340a – A–334 por Uleila del Campo
A–395	Granada–Sierra Nevada
A–315	Torreperogil – Baza por Pozo Alcón

Appendix 1. (Cont.)

ID	From – to
Old A–483	Bollullos del Condado – Matalascañas
N–340	Malaga – Almeria
N–433	A–66 Ruta la Plata – Rosal de la Frontera
MA–20	Malaga – Almeria
N–630	Ruta de la Plata (Sevilla – Gijon)
N–435	Huelva – Zafra
N–435	Huelva – Zafra
N–433	A–66 Ruta de la Plata – Rosal de la Frontera
A–49	Sevilla – Huelva – Ayamonte
A–44	Linares – Motril
A–4	Sevilla – Córdoba – Madrid
N–435	Huelva – Zafra
A–45	Cordoba – Malaga
A–48	Cádiz – Algeciras
CA–34	Algeciras – Málaga
N–340	Cádiz – Algeciras
N–435	Huelva – Zafra
AP–7	Algeciras – Málaga (peaje)
AP–7	Algeciras – Málaga (peaje)
N–442	N–442
N–435	Huelva – Zafra
N–433	A–66 Ruta de la Plata – Rosal de la Frontera

ID	From – to
N–435	Huelva – Zafra
N–630	Ruta de la Plata (Sevilla – Gijon)
A–7	Almeria – Murcia
A–7	Almeria – Murcia
N–340a	Almeria – Murcia
N–340a	Almeria – Murcia
N–435	Huelva – Zafra
AP–7	Algeciras – Málaga (peaje)
AP–7	Algeciras – Málaga (peaje)
N–340a	Almeria – Murcia
N–433	A–66 Ruta de la Plata – Rosal de la Frontera
A–7	Almeria – Murcia
A–7	Algeciras – Málaga
A–7	Algeciras – Málaga
N–340a	Almeria – Murcia
A–44	Linares – Motril
N–340	Malaga – Almeria
N–420	A–4 Montoro – Toledo
N–340a	Almeria – Murcia
N–331	Cordoba – Malaga
A–49	Sevilla – Huelva – Ayamonte
SM	No name
SM	No name
N–340a	Almeria– Murcia