

Current situation and proposals for improving functionality in the Guadiamar fluvial corridor

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Introduction

Over the last few years, Nature Conservation policies are becoming increasingly based on the establishment of networks of protected areas, in which an important role is played by the ecological corridors as elements of a system that facilitates connection and contributes to the diminution of the effects of the progressive fragmentation of the landscape and the natural areas. These networks had already been devised, at an European level, back in the seventies, but such devising was purely theoretical, since their development would not start until the late nineties (Fernández, 1999). Among the different types of corridors, fluvial corridors, linked to fluvial axes and to their flood plains, stand out due to their importance. It thence follows that, among the main conservation strategies, the establishment of ecological corridors based on the restoration of the fluvial systems is becoming more important every day (Naiman *et al.*, 1993; Naiman and Roger, 1997; Montes, 1999).

In this context, in which ecological corridors are playing and increasingly leading role, the spillage from the mines at Aznalcóllar, which happened in April 1998, brought about the putting into effect of a pioneering project consisting in the creation of an ecological corridor in the hope that it could be used as a standard for other basins in the region, and that it could contribute to the transformation of the Andalusian Network of Natural Protected Areas (RENPA) into a real functional system of interconnected natural areas (Montes, 1999). It is true that the response from the regional government could have been limited to the removal of the polluting elements and to try to bring the area back to the situation existing prior to the spillage. But, as the sludge removal operation was

coming to an end, and taking as a starting point the reports prepared by groups of experts on the Regeneration of the Land Affected and on Environmental Monitoring, in view of the fact that neither the health of the ecosystems nor human health were in any way guaranteed, the acquisition by the government of the land affected with a view to establishing a green corridor free from any farming - related activity, was recommended as the most sensible solution (Consejería de Medio Ambiente, 1999).

This decision will mean a magnificent opportunity for adopting a longer - term restoration project, which consists in the Guadiamar Green Corridor Project. Such a project takes again into consideration an old aspiration, which had been demanded for a long time by the Andalusian ecological movement, namely to transform the Guadiamar basin into an ecological corridor as a solution to the serious problem posed by the isolation of Doñana. The process of fragmentation that the ecosystems located North of Doñana are being subject to, which has taken place over the last few decades, has not only spread in a North - South direction, but also along the East - West axis (Serrano and Molina, 1998) and, in conjunction with the creation of new artificial barriers, is jeopardizing the viability of the dispersal routes of some of the most emblematic species of this protected area (Delibes, 1999).

The following lines basically state the criteria which have been used as the basis for the design and the functionality of the Guadiamar green corridor; they expound how the recolonization processes affecting fauna communities are being developed, by taking as a starting point the results provided by the different research groups related to the project; finally, a series of measures or lines of action are suggested which are deemed to be necessary to increase or improve the operativeness of the corridor.

The process of landscape fragmentation in the Guadiamar basin

Among the actions approved by the Council of Government in order to counteract the effects of the spillage from the mine, the setting on foot was envisaged of a research programme aimed at facing the complex situation brought about by the spillage, and at providing an answer to the knowledge needs at an ecological, territorial and social and economic level for the development of the project of the Green Corridor (Consejería de Medio Ambiente,

1999). This was how a highly ambitious programme of multidisciplinary research took shape, the Green Corridor Research Programme (PICOVER), which is one of the main distinguishing marks of this project, and which has made it possible for the Guadiamar basin, in spite of its small dimensions, to become one of the most widely researched areas in our country (Consejería de Medio Ambiente, 2000).

Among the researches which are being carried out within the PICOVER framework, related to the corridor's functionality, we should draw attention to those concerning the lines of action for the Design of the Ecological Corridor and those aimed at Ecological Restoration. To have a better knowledge of the basin's connectivity, understanding by it the capability of organism dispersal (Taylor, 1993), and the process of landscape fragmentation which has led to the isolation of the forestal ecosystems laying North of Doñana from those in Sierra Morena, the studies deserve special mention which have been carried out within the PICOVER on the recent evolution of the landscape linked to the changes in the use of land in the Guadiamar basin since the American flight in 1956, until the current situation (Jiménez, 2002), and on the structure and functionality of the linear elements in the landscape (De Lucio, 2002).

From the comparison between the maps showing the land use in the Guadiamar basin during the nineteen - fifties, and those for the late nineties, very important changes emerge in the structure of the landscape which reveal a progressive loss of connectivity. In the image for 1956 (Figure 1) it can be clearly seen how the breach between Sierra Morena and the forestal ecosystems laying North of the Doñana marshland was already in existence, through the wide space taken by the dry - farmed herbaceous crops in Campo de Tejada, and their extension through the Gerena countryside. This breach will have been even further amplified during the last decades due to a standardization process of the agricultural space in the countryside, resulting in an absolute supremacy of herbaceous crops to the detriment of other crops. This situation is fundamentally linked to a gradual reduction of the area occupied by olive groves. Even though this crop intensifies in the high ground's most favourable areas, through the replacement of old olive groves by early - harvest olive tree varieties and the establishment of new plantation frameworks of a more geometrical shape, the introduction of irrigation, etc., there is also a replacement of olive groves in countryside soil by yearly herbaceous crops, which brings about the diminution of the wooded land. At the same time, the presence of certain linear elements of natural vegetation which existed in 1956 and which enabled certain connectivity - related functions (small riparian formations

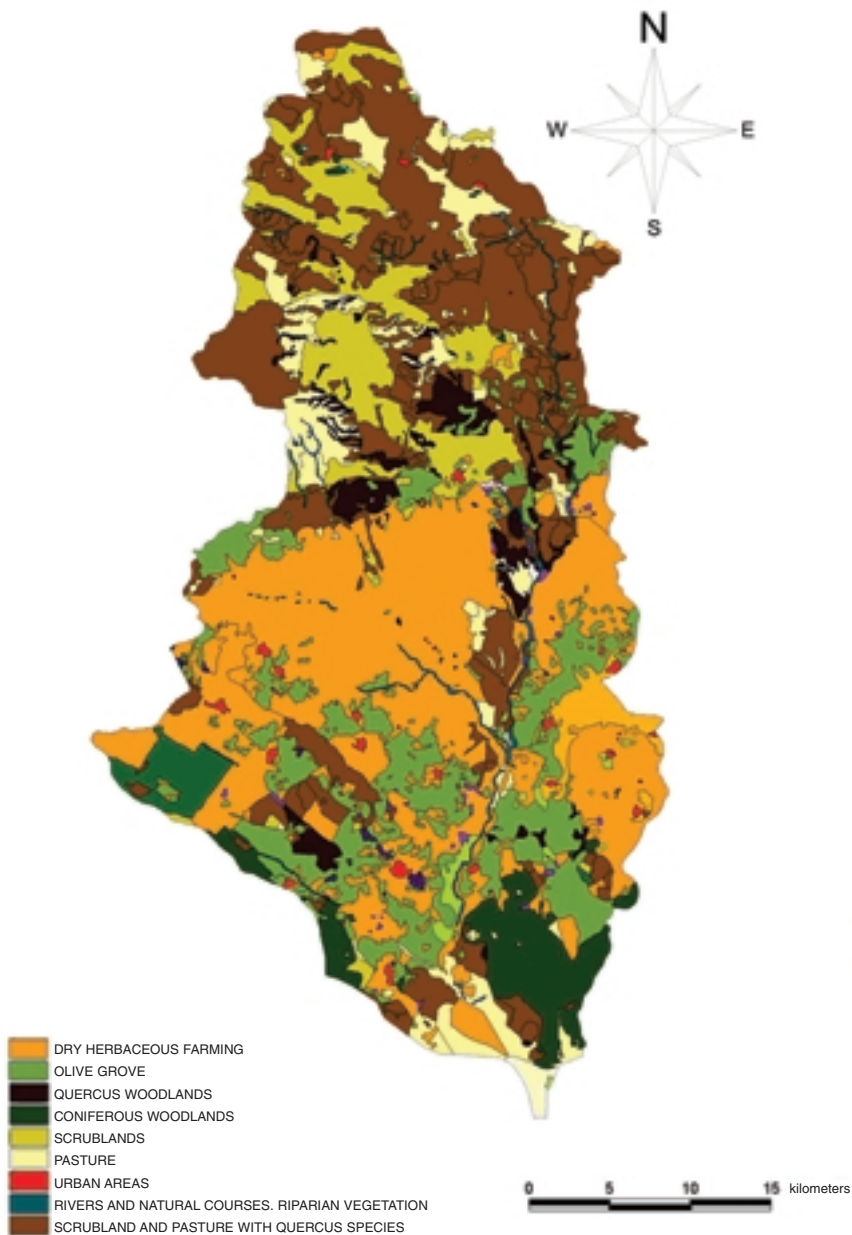


Figure 1. Map showing land use in the Guadamar basin in 1956

linked to some tributaries of the Guadiamar, such as the Ardachón, and small thicket patches scattered throughout the countryside) completely disappears converting this agricultural cereal matrix into an increasingly poorer and more homogeneous landscape from the biological point of view.

It is quite striking that in 1956 there was a connection link between the Mediterranean forest formation in Sierra Morena and the forestal areas lying North of Doñana through a series of meadow patches (thicket and ilex - covered grazing land), which created an almost unbroken stretch on the right bank of the Guadiamar, and North of its confluence with the Agrio river. It is very likely that this connection strip consisting less of riparian forest, with a variable development depending on the individual stretch, than of these Mediterranean forest formations with interspersed meadows, should facilitate the connection between both areas in a North - South direction.

In the land - use maps drawn in the nineties (Figure 2) a large degree of fragmentation of the meadow areas close to the Guadiamar can already be seen, the said areas being reduced to just two unlinked patches. If that were not enough, the connectivity function between these fragments is greatly diminished as a result of new soil uses standing in the way and acting as true barriers, such as the two second - home housing developments (Ranchos del Guadiamar and Encinares de Sanlúcar) and the whole mining area South of Aznalcóllar which, due to its dimensions and associated activities (the fencing of the mining compound, infrastructures, excavations, huge dumps and heavy machinery traffic), finally breaks the connection with the first forest formations in Sierra Morena (*Carcabuesos* and *Perro Dehesas*).

As can be perceived by looking at Figure 3, the creation of a fluvial corridor through the Guadiamar succeeds in re - establishing this lost connectivity function within the basin by means of the restoration of a more than 40 Km. - long stretch and an area close to 5000 hectares, which coincides to a great extent with the area affected by the spillage, whose width ranges between 700 and 1200 m. depending on the individual stretch (Consejería de Medio Ambiente, 2001).

However, in order to succeed in making this corridor really effective, it is necessary to overcome the enormous barrier represented by the large intensive agricultural matrix laying in the central sector of the basin, where guaranteeing good connectivity exclusively on the basis of a single linear axis is deemed to be

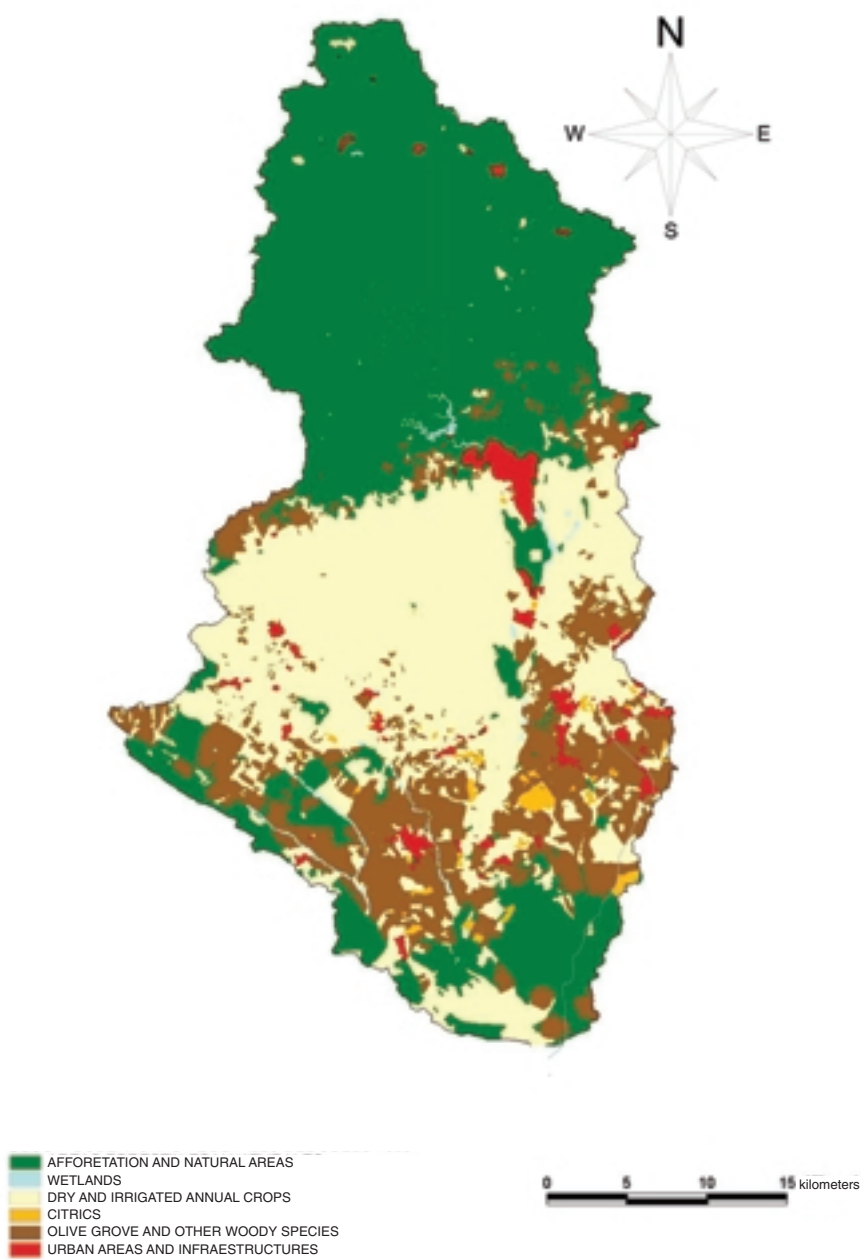


Figure 2. Map showing land use in the Guadiamar basin in 1999

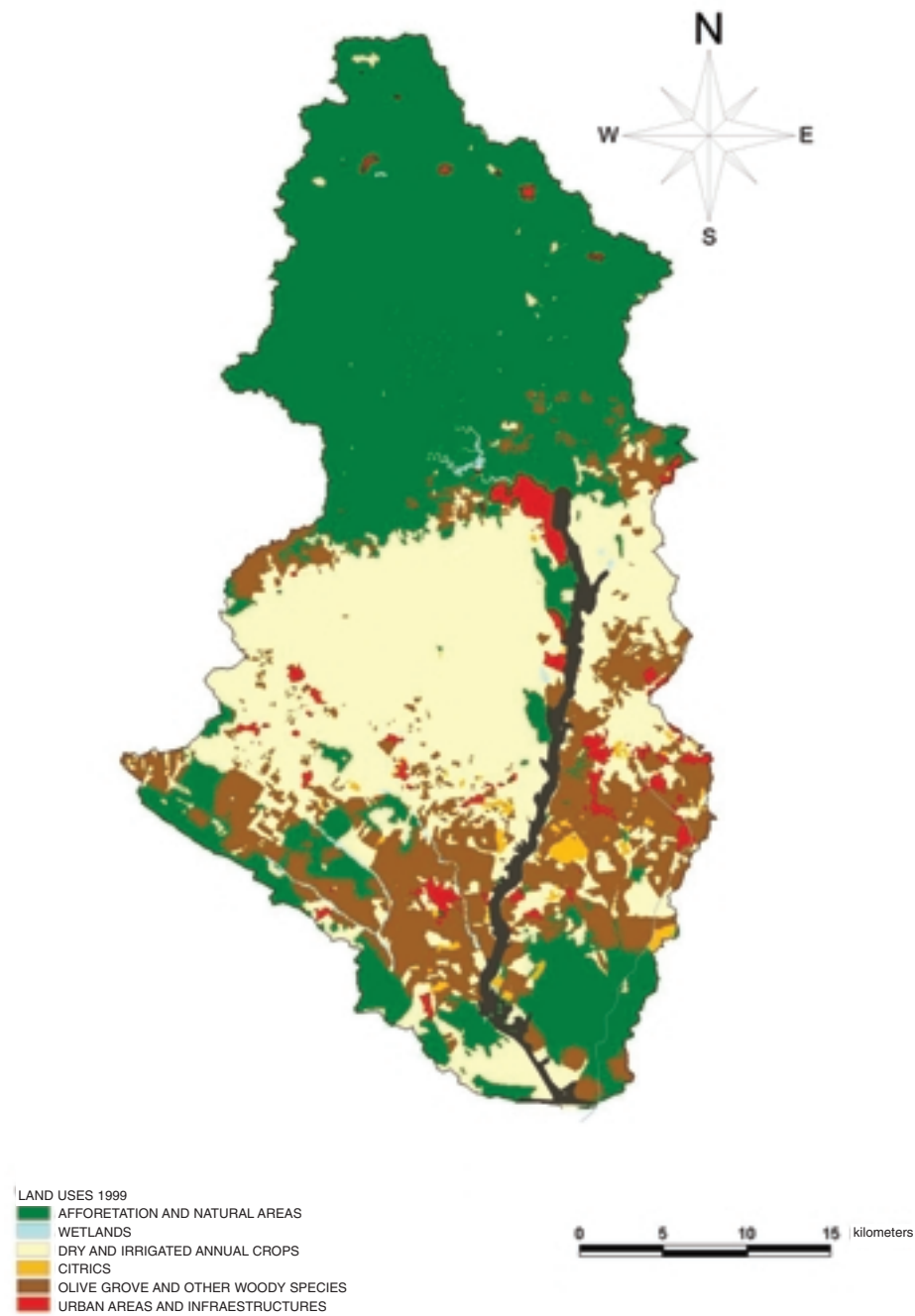


Figure 3. Proposals for enhancing connectivity within the Guadamar basin

extremely difficult. Because of that, the corridor is envisioned as a weft of relations not only in a vertical direction but also in an horizontal one, where, in addition to the Guadiamar fluvial corridor as the main axis, connection through other secondary corridors must be improved by means of the restoration of small riparian copses, vegetal hedgerows, cattle routes and other linear elements consisting in natural vegetation.

A natural laboratory for the study of recolonization processes

In addition to the importance attached to the criteria of functionality and territorial connectivity in designing the Guadiamar Corridor, an aspect of the utmost importance is the one related to the area recolonization processes. We must always bear in mind that this project arises as a response by the Andalusian Government aimed at dealing with the environmental catastrophe created by the spillage from the Aznalcóllar mine. From this point of view, this restoration project does not even stem from what could be conceived as a highly advanced state of ecosystem degradation, but, rather, from a situation of extreme degradation or collapse of all ecological functions in a sixty - two kilometre stretch of the river, which amounts to the whole middle and lower courses of the basin.

On top of the immediate effect of the flooding by sludge and acid waters, which entailed the destruction of the habitats, we must add the perturbation effects resulting from the works aiming at removing the sludge, the elimination of crops, the introduction of correction measures and the harrowing of the soil, etc., which involved the use of a large set of mechanical resources, which lasted almost uninterruptedly for the first year and a half. Accordingly, in a first stage, the Guadiamar will have to work as what it currently is: a drain, a new recolonization area, up to the moment when it comes back into operation as a corridor.

These circumstances invest the project of the Guadiamar Green Corridor with a special scientific interest as a natural laboratory for the study of processes for the recolonization of the environment in areas which have been subject to extreme changes in the conditions of the environment and the uses of land. Besides, based on the scientific basis of the project, the idea has been conceived that the restoration of the ecosystems must be achieved by means of natural

recolonization processes, by encouraging it through the improvement of habitat conditions and through the elimination of barriers and other disruption factors which render such processes difficult. It is thought that as the environment recovers the appropriate conditions, it shall make possible the gradual settlement of the different faunistic communities (Arenas *et al.*, 2002).

In order to facilitate this monitoring of the recolonization processes in a coordinated manner by the different research groups, several common reference areas were established in the PICOVER known as Monitoring Plots, which are scattered throughout the damaged area. In addition to these plots, depending on the specific needs of each group, samplings have been carried out in the possible source areas located at the ends of the corridor (Sierra Morena, in the North) and in forestal areas in Aznalcázar, Puebla, Villamanrique and Hinojos (Doñana Natural Park), as well as in side areas which were unaffected by the spillage.

Nowadays, in spite of the short time gone by, quite remarkable recolonization processes are already starting to become apparent, although widely varying from one faunistic group to the next (Table 1). Such variations depend, in the main, on three factors: on the different recovery rhythm of the habitats, on the dispersal capability of the species and on their ecological requirements. As regards the aquatic milieu, the important recolonization experienced by the river's fish and amphibian population, specially over the last year, deserves special mention as well as the presence of stable populations of American crab in different spots in the Guadamar, particularly in the Entremuros sector. The recovery of these groups, which perform an important function as the base of trophic chains, is becoming a key factor for the preservation of mammals such as the otter, which again has a presence in the whole of the river stretch which was affected by the spillage, and the spread towards the North of bird communities characteristic of wet lands, among which several species of storks, which are beginning to be abundant, stand out: the common egret (*Egretta garcetta*) and the imperial heron (*Ardea cinerea*), as well as rallidae such as the bald coot (*Fulica atra*), the common wood - cock (*Gallinula chloropus*) and even the purple coot (*Porphyrio porphyrio*), whose distribution is reaching quite northerly sectors of the river.

Table 1. Current situation of the corridor's recolonization process

FAUNISTIC GROUPS		DEGREE OF COLONIZATION	OCCUPATION PROBLEMS AND GUIDELINES
FISH		Medium - high	Gradual colonization from the northern and southern ends. Highly sensitive populations to pollution incidents
BIRDS		Medium - high	Expansion process towards the North occupying pools and gravel bars. Increase in the number of birds of prey using the corridor as a hunting ground.
REPTILES	Aquatic <i>Mauremys leprosa</i> <i>Natrix maura</i>	High	Abundant throughout the river
	Terrestrial <i>Lacerta lepida</i> <i>Psammodromus algirus</i> <i>Malpolon monspessulanus</i>	Incipient	Decreasing from the rim sectors towards the centre of the corridor. Increased presence in the areas adjoining mature ecosystems
MAMMALS	General <i>Vulpes vulpes</i>	Medium	Increase in their numbers
	Aquatic <i>Lutra lutra</i>	Alto	Presence everywhere in the river except for the marshland.
	Moderate Mobility <i>Herpestes ichneumon</i> <i>Meles meles</i> , <i>Genetta genetta</i> , <i>Felis silvestris</i>	Low	Present, above all, in the southern half of the corridor. Probable tendency to increase
	High Mobility <i>Cervus elaphus</i> , <i>Sus scrofa</i> .	Without presence	Their presence can only be expected once the vegetation reaches an adequate size.

Source: prepared on the basis of data provided by the PICOVER Research Groups

With regard to the group of reptiles, a difference can be appreciated, again, in the speed of recolonization, it being much faster in the species linked to the aquatic milieu such as the leper turtle (*Mauremys leprosa*) and the viperine adder (*Natrix maura*), which have sizeable populations throughout the river. Terrestrial reptiles are quite a different case, for they are one of the groups whose recovery is being much slower. This is explained, among other things, by their more reduced dispersal capability and by the negative and disturbing effect resulting from the intensive work involved in eliminating the sludge and from the operations carried out at a later stage to clear and repair the soil, together with the scarcity of natural refuges, which has turned this area into a hardly appropriate habitat for the settlement of reptiles. Among the first members of this group to colonize the area, the following should be mentioned: the ocellated lizard (*Lacerta lepida*), the long - tailed wall - lizard (*Psammodromus algirus*) and the bastard snake (*Malpolon monspessulanus*).

As a rule, the samplings carried out with regard to reptiles show a diminution in their number from rim sectors towards the river (with the exception of the well - preserved riparian areas) and an increased presence in the areas adjoining the corridor that have thicket and ilex forest ecosystems, which indicates that the recolonization process is still incipient and that its intensity depends on how far away the thicket and meadow areas, which operate as source areas, are. Taking these results as a starting point, with the advice of the Bird and Reptile Research Group from the University of Granada, the Technical Department is developing a project for the installation of artificial refuges using eucalyptus stumps to foster the settlement of the reptile population. These refuges are being installed above all in those zones being close to the source areas; the monitoring of these refuges has been planned for the immediate future so that their rate of occupancy can be known.

With regard to mammals, following the research that Dr. Delibes' team is carrying out concerning the effects of the Guadamar Corridor on populations of medium - sized and large mammals (Delibes *et al*, 2002), the existence can be presumed of four types of situations: the first would be the one embodied by general species which do not depend on the existence of consolidated forestal areas, which species would experience an increase in their numbers as a result of the reduction of human activity within the Corridor. A clear representative of this group would be the fox (*Vulpes vulpes*).

A special case would be that of the species linked to the aquatic milieu, such as the otter (*Lutra lutra*), which has quickly recolonized the river after the cleaning operations. In this case, it is deemed to be quite probable, since the presence of this species has been verified throughout the course of the Guadamar, that the corridor be fully operational for this species ahead of others which may depend, above all, on the restoration of wooded and thicketed areas in the adjoining zones of the alluvial plain.

A third group would be made up of those species being capable of surviving in mainly agricultural areas, provided that they have refuge zones near by, as the fluvial copses or scattered thicket areas could well be. Species such as the badger (*Meles meles*), the genet (*Genetta genetta*) or the mongoose (*Herpestes ichneumon*), can be considered as examples of this group. All of them have a presence, above all, in the southern half of the corridor and it is highly probable that their distribution through it continues to expand as the riparian vegetation and that of the reafforested margins develops. The wild cat (*Felis silvestris*), whose presence is currently limited to the ends of the corridor, must be added to this list.

A fourth group consists of large - sized species that require greater extensions of forestal habitat and that possess high mobility. These species, currently not existing in the corridor, are expected to use it as dispersal route once the vegetation reaches a certain level of development and the corridor becomes fully operational. These species include the wild boar (*Sus scrofa*), the deer (*Cervus elaphus*) and, probably, with certain restrictions, the Iberian lynx (*Lynx pardina*).

From the studies carried out so far, it is deduced that there is a greater richness of mammals in the corridor from the southern source area (Aznalcázar pine forests and Dehesas de Villamanrique) than from Sierra Morena, probably due to the existence of a larger side - contact zone between these areas, and to the existence of small forestal fragments, whereas in the northern end there is less permeability as a result of the barrier represented by the mining area and the presence of quite degraded areas (dumps, eucalyptus forests, ploughed up areas, etc.).

Action proposals for enhancing the corridor's functionality and the Guadamar basin connectivity

Taking into account the limited amount of time elapsed since the end of the restoration works, which is why the degree of development of vegetation in the corridor still remains at a very early stage, it would be necessary to continue to monitor the faunistic populations for the coming years, as the new forestal landscape which constitutes the corridor is being consolidated. The results of this monitoring plan will be determining factors in the assessment of its operativeness and the detection of possible disfunctions.

In parallel, and taking as a starting point the first results of the monitoring carried out so far, it is deemed to be appropriate to boost measures aimed at improving the corridor's functionality, specially in the basin's central agricultural sector, the most troublesome of them all, by creating new lines of natural vegetation from the publicly owned areas, cattle ways and boundaries between farms, or by improving the existing ones to enhance the corridor's lateral connectivity.

Some of these measures have already been set in motion by the Technical Office of the Guadamar Green Corridor, such as the construction of artificial refuges or the improvement of the northern end linkage. Others are part of some of the lines of action that the Department of the Environment is currently developing, such as the Plan for the Recovery of Cattle Ways and the Inventory of River Banks, as a stage prior to the development of a Programme for the creation of ecological fluvial corridors. In the case of the elimination of the barriers represented by transversal road infrastructures, it will be necessary to encourage cooperation measures with the proper bodies. The justification and opportunity of these actions is explained below

Improvement of the link between the northern end of the green corridor and Sierra Morena

The monitoring of the populations of middle and small - sized mammals shows that up to now a low level of transfer can be detected from the northern source area, which is probably related to the scarce permeability of this contact strip of the corridor. With a view to correcting this situation, forest restoration works are going

to be started to widen the said contact strip, improving the connection through the *Arroyo de los Frailes* and replacing some masses of eucalyptus forest by means of the reafforestation of indigenous vegetation in some of the non - exploited sections of the mining area which have recently become public property, and which, accordingly could be integrated into the corridor.

Restoration of banks as secondary fluvial corridors

The restoration and recovery of small river stretches would contribute to substantially improve connectivity conditions in the central sector of the basin. In keeping with this same line of action, the preferential river beds to help these processes would be the headwaters of the Guadiamar itself, upstream of the place where it joins the *Agrio*, and the two right - bank main tributaries: the *Alcarayón* stream and, specially, the *Ardanchón*, due to its strategic lay - out which runs across the whole of the basin's central agricultural sector. Within the fluvial corridor section, it is necessary to point out the important function that the river Tinto can perform as a fluvial corridor by complementing the Guadiamar river, an area currently included in the proposal by Red Natura 2000.

Rehabilitation of the cattle - route network

Through the Plan for the Rehabilitation of cattle routes, a classification has been established of this large network by identifying those tracks and trails which due to the route they follow could play the role of small ecological corridors, as connection ways between the different natural areas. Nowadays, work is being carried out in the demarcation and the rehabilitation of some of these cattle ways, such as the Carrascal royal cattle track, which runs parallel to the Guadiamar from the Vado del Quemado to Aznalcóllar.

Permeabilization of transversal barriers

There is no doubt in anybody's mind that the future operativeness of the Guadiamar corridor will depend to a great extent on a greater permeabilization of the road infrastructures transversally cutting it, for the impact of these barriers will become more obvious as the corridor starts to operate as dispersal way.

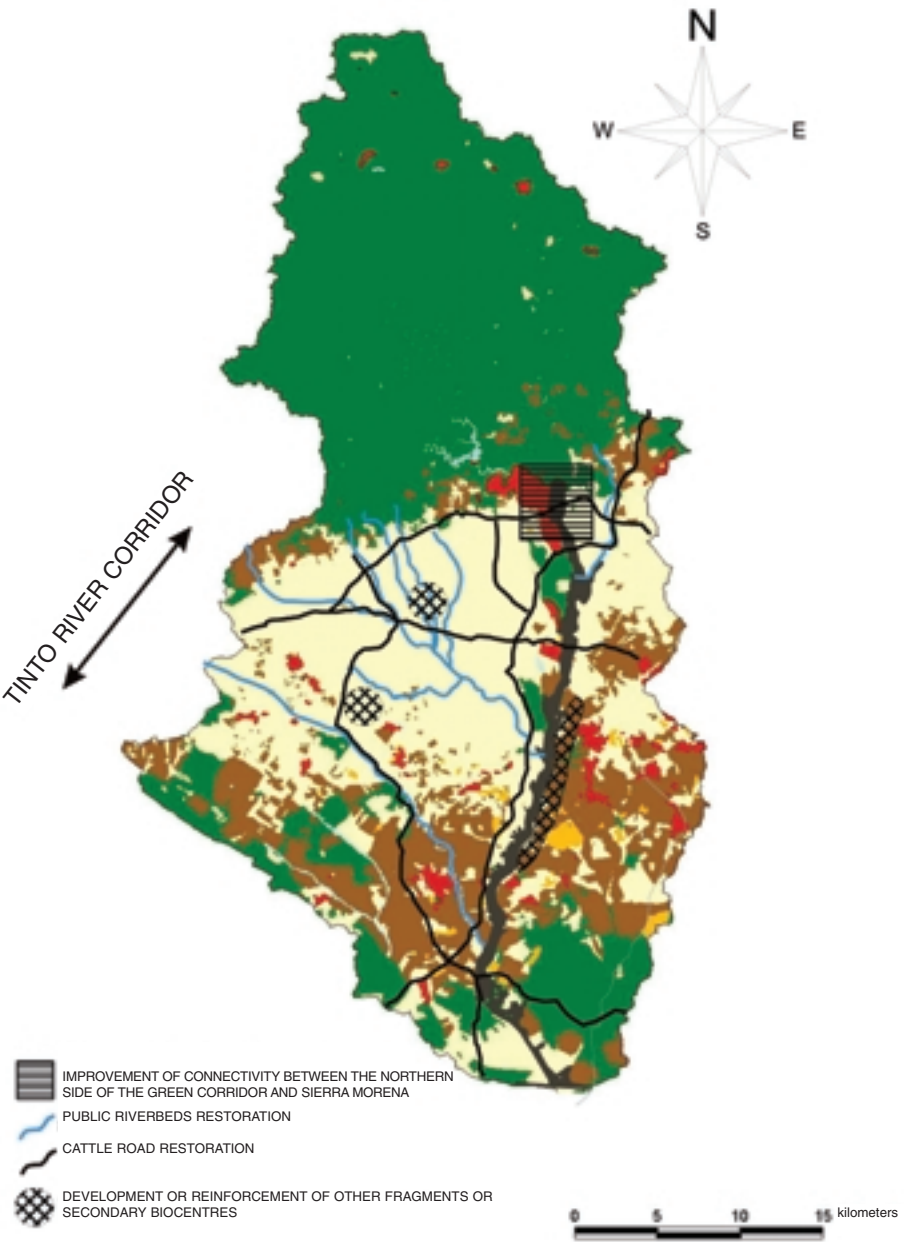


Figure 4. Proposals for enhancing connectivity within the Guadamar basin.

Among the road infrastructures being important barriers stand out, above all, the A - 49 Motorway and the Seville - Huelva railway line, for they run on continuous platforms or embankments. In the latter's case, the project of the new railway route may be a good opportunity to replace the old route by a more permeable viaduct. The Permeabilization of these infrastructures must not be limited to the sector intersecting the Guadiamar corridor but it must also make possible the unbrokenness of other secondary corridors, such as the *Pilas* stream.

Establishment and strengthening of other secondary biocentres

Other strategy that could be suggested to enhance the basin's connectivity must consist in encouraging the establishment of secondary biocentres (island forests within the agricultural area) as stopover points. To that end, advantage must be taken of the presence of public heritage properties (ox pastures, woodlands owned by the municipalities), areas intended for afforestation or specially protected areas intended for urban planning. In this regard, the existence must be highlighted of a special – protection, exempt from development strip of land at the West Corner of the high ground, a precipitous area covering more than 15 Km. in which shrub - like vegetation is predominant, which, should it be rehabilitated, it would noticeably enhance the function of the Guadiamar corridor in its left bank.

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