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Potential impacts of petroleum exploration and exploitation on biodiversity in a Patagonian Nature Reserve, Argentina

SANDRA MARCELA FIORI* and SERGIO MARTÍN ZALBA
*GEKKO Grupo de Estudios en Conservación y Manejo, Departmento de Biología, Bioquímica y Farmacia, Universidad Nacional del Sur, San Juan 670, 8000 Bahía Blanca, Argentina; *Author for correspondence (e-mail: sfiori@criba.edu.ar; fax: +54-291-4595130)*

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Abstract. Petroleum exploration and extraction are common on the Patagonian steppe, but their impacts on the native biodiversity have not been properly evaluated. We describe both activities in a Patagonian nature reserve and consider their potential impacts on biodiversity. More than 2025 km of seismic lines inside the reserve resulted in 87.21 m^2/ha (0.9%) of directly affected land, and 793 fragments of native habitats were defined with a mean area of 1.26 ± 0.74 km^2. Vegetation recovery on seismic lines is extremely poor. We discuss the role of seismic lines as barriers to native species, and their significance in encouraging poaching and the expansion of exotic invasive plants. There is a high degree of overlap between current petroleum activities and areas of special conservation concern (high erosion risk, vegetation diversity, abundance of endemic plant species, and habitat quality for native vertebrates). All these have a significant impact on the efficiency of the conservation area and highlight the urgent need to implement appropriate mitigating actions.

Introduction

The Patagonian steppe is one of the largest ecoregions of Argentina, comprising an area of about 54 million ha. Only 4.7% of this ecosystem is included in nature reserves (Bertonatti and Corcuera 2000) and, despite being legally protected, a significant proportion of this terrain is exposed to over-grazing by sheep and goats, as well as to oil and gas exploration and extraction.

The petroleum exploration phase was normally conducted by means of seismographic methods: bulldozers scraped away the topsoil to prepare for lined series of explosive charges to determine the nature and structure of underground rock formations, and to search for potential oil deposits. The result of this is an extensive network of prospecting lines, with scarce or zero vegetation cover, the effects of which have not been properly investigated in relation to the integrity of Patagonian ecosystems.

The petroleum exploitation phase also results in a number of environmental changes, such as the construction of roads, pipelines, tanks and other facilities, vehicle traffic, air emissions, and the risk of oil spills. These activities may interfere directly with the movement and behaviour of wildlife, resulting in changes in their

abundance and distribution, and they also facilitate the introduction and expansion of invasive plant species. The increased access to the area encourages hunters and poachers, and also favours activities such as cattle ranching by providing the required access routes (IUCN and EP Forum 1991; Maki 1992).

The aim of this investigation is to describe petroleum exploration and exploitation in a northern Patagonian nature reserve, in the past and the present, and to discuss their potential impacts on the native biodiversity.

Study area

This study was conducted at the Auca Mahuida Nature Reserve, located in the Neuquén province (Argentina), between 37°30′–38° S and 68°30′–69°15 W (Figure 1). The reserve comprises ca. 118960 ha in a region with an arid climate, having a mean annual rainfall of 130 mm, a mean annual temperature of 14 °C, and a high water deficit, which can reach levels of up to 400–600 mm each year (Arroyo 1980; Departamento de Geografía, Universidad Nacional del Comahue 1982; Pires 1995).

The reserve is located on an extensive plateau with many volcanic cones, the most

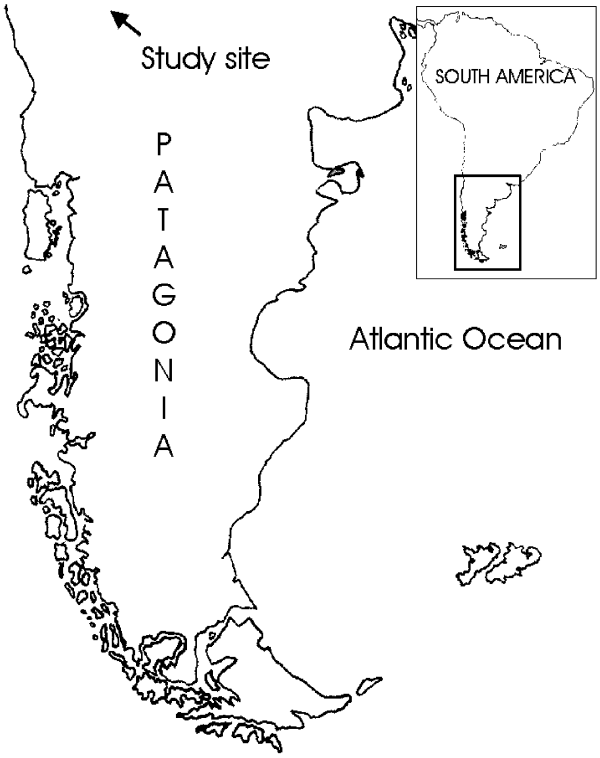

Figure 1. Map of Patagonia with the location of the study site.

conspicuous being the Auca Mahuida Volcano that reaches a height of 2253 m (Holmberg 1964). The reserve includes areas of high-Andean, Patagonian and Monte vegetation (Long 2000). The dominant types of vegetation are shrub-steppe and grass-steppe (Movia et al. 1982). Populations of large Patagonian animals, both herbivorous and carnivorous, are well represented within its boundaries, including one of the largest populations of guanacos (*Lama guanicoe*) in the Neuquén province (Funes 2000).

It is legally designated as a multi-purpose reserve where productive and recreational activities are allowed at a moderate level. The area was subjected to oil prospecting in the past, and at present intensive petroleum extraction activities are being carried out, even though technical recommendations have been made against them (Fiori and Zalba 2000).

Methods

Seismic prospecting lines, roads, quarries and petroleum drilling pads inside the reserve were located by means of visual interpretation of a false colour composition from bands 2, 3 and 4 of a LANDSAT 5TM satellite image taken in February 1999.

Using a GPS we picked up 110 control points from the study area in order to spatially georeference the image. The resampling process was carried out using IDRISI 2.0 (Clark University 1997). We discarded 23 control points because they had low confidence levels and high residuals, and the final correction resulted in a total root mean square error (RMS) of 2.5 pixels (75 m). We made a print-out of the image at a scale of 1/50000 and visually detected the objects of interest (prospecting lines, roads, quarries and petroleum drilling pads) and digitized them by using the GIS CAMRIS (Ecological Consulting Inc. 1998). In some sections of the reserve it was difficult to identify roads and seismic lines, as they had similar spectral signatures to the surrounding land, and so we complemented the interpretation with aerial photographs (scale 1:60000) and maps made by petroleum companies working in the area. All this information was corroborated in the field. The total length of all seismic lines crossing the reserve was measured and the area covered by them was calculated using an average figure for the width, which was taken from measurements made on lines randomly selected in the field. The number and mean size of the remaining habitat fragments were also recorded.

In order to assess the impact of the seismic lines on the vegetation, 16 paired sample areas were surveyed, each pair including one sample on the prospecting line and the other 10 m away in the surrounding vegetation. In each 50 m^2 sample plot we recorded the presence of the most abundant plant species (percentage cover $\geq$ 10%), and estimated the percentage of bare soil and herb and shrub strata (Mueller-Dombois and Ellenberg 1974). The values of the latter three variables were transformed to the square root arcsine in order to make them fit a normal distribution, and were compared using paired *t*-tests.

Using the GIS we evaluated the overlap between the digitalized quarries, roads and drilling pads with respect to areas of greater erosion risk (Navarro 2000),

vegetation diversity, abundance of endemic plant species (Long 2000), and habitat quality for guanaco (*Lama guanicoe*), lesser rhea (*Pterocnemia pennata*), Patagonian cavy (*Dolichotis patagonum*) and chinchillón (*Lagidium viscacia*) (Funes 2000).

Results

The reserve is almost completely divided up by seismic lines, except for the highest sections of the Auca Mahuida volcano. All the lines remain open, many of them being used as roads. The prevailing directions of the lines are from northwest to southeast, and from northeast to southwest, while only a few lines cross the reserve either from north to south, or from west to east, or in intermediate directions (Figure 2). The total length of the seismic lines crossing the reserve has been estimated at 2025 km. The reserve also has an extensive network of about 107 km of trails and roads, mainly associated with petroleum extraction activities, and 57 km of paved roads along its western and southwestern borders.

The density of seismic lines was estimated at a minimum of 1.70 km/km^2, with a mean width of 5.13 $\pm$ 1.21 m, resulting in a directly affected area of 87.21 m^2/ha (0.9%). Due to the distribution pattern and the total length of the seismic lines, more than 17% of the total area of the reserve is located at 50 m or less from the closest

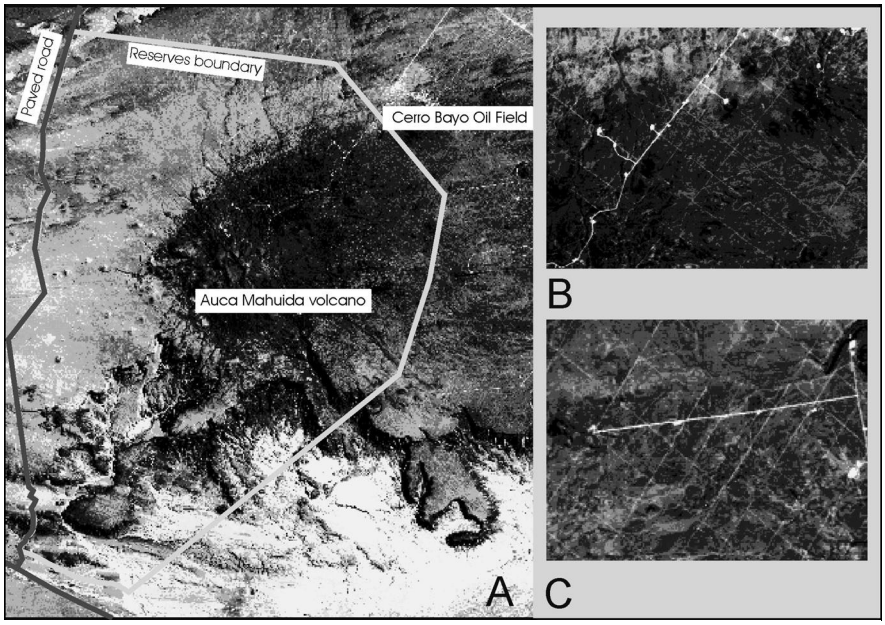

Figure 2. Landsat TM image of Auca Mahuida nature reserve (A), with details of quarries and roads (B), and seismic prospecting lines (C).

line. A total of 793 habitat fragments are found within the lines and have a mean area of 1.26 ± 0.74 km^2. The shape of the fragments is predominantly quadrangular.

Significant differences were found when comparing the percentage of bare soil, which was higher on the seismic lines ($t_{(15)}$ 2.13; $P < 0.01$), and the cover of herbs and shrubs, which were higher in the samples in the surrounding vegetation, away from the lines ($t_{(15)}$ −6.67 and −6.89, respectively; $P < 0.01$) (Figure 3). No significant differences were found in the proportion of herb/shrub covers ($t_{(15)}$ 1.00; $P = 0.33$).

Among the native species, *Grindelia chiloensis* was one of the main colonizers of cleared areas. Some exotic invasive species, like *Hordeum leporinum* and *Erodium cicutarium*, were also associated with seismic lines.

There is a considerable overlap between current petroleum activities (quarries and petroleum drilling pads) and areas of special interest for conservation, i.e. areas with the highest erosion risks, the highest vegetation diversity and/or abundance of endemic plant species and with high quality habitats for guanacos, lesser rheas, or to a lesser extent for Patagonian cavies and chinchillones (Table 1). In the case of the Patagonian cavy and lesser rhea, the disturbance created by petroleum activities is

Figure 3. Seismic prospecting line in Auca Mahuida Nature Reserve, showing almost null vegetation recovery.

Table 1. Spatial superposition (in percentages) between quarries ($n = 34$) and drilling pads ($n = 7$) and areas of greater conservation interest in the reserve

Petroleum activities	Erosion risk	Plant diversity and endemism	Habitat for			
			Guanaco	Lesser Rhea	Patagonian Cavy	Chinchillón
Quarries	58.82	70.59	55.88	26.47	8.82	23.53
Drilling pads	28.57	28.57	57.14	42.86	0.00	14.29

superimposed to the effects of the paved road, as no place in the habitats of these species is located farther from the road than 9.5 and 7.6 km, respectively.

Thirty-four quarries were recorded, at least four of which are currently in use. Materials extracted from them are used for the construction of roads or other infrastructure. Twelve petroleum facilities were visited, including drilling pads, batteries and gas injection plants. There was no sign of any restoration activities at any of these sites.

Drainage pools with no fences, acting as traps for wildlife, were seen in the southern section of the reserve. In the same area we found salty water deposits that had been opened by petroleum companies which continue flowing after the sites were abandoned, thus contaminating the soils.

Discussion

While a lot of papers remark on the negative edge effects faced by nature reserves from the surroundings lands (Schonewald-Cox et al. 1992; Meffe and Carroll 1994), much less attention has been paid to fragmentation processes occurring inside the boundaries of conservation areas. Our investigation shows that the Auca Mahuida nature reserve is, in fact, an archipelago of patches of natural vegetation that have resulted from oil and gas prospecting in the area. This is not an isolated case, but almost the general rule in the natural ecosystems of the Patagonian steppe. As an example, two thirds of the protected areas under provincial jurisdiction in Neuquén have undergone, or still have, petroleum exploration or extraction activities inside their boundaries (Di Martino et al. 1999).

It is internationally agreed that the impact of fragmentation on natural ecosystems affects all levels of ecological organization (Robinson et al. 1992) and is one of the main causes of biodiversity loss (Wilcox and Murphy 1985; Saunders et al. 1991; Meffe and Carroll 1994). It is therefore important to assess which components or processes of the regional ecosystem might be affected by the described fragmentation situation. Seismic lines could be compared with trails and small roads, which cause many well known ecological effects such as subdividing populations, favouring invasive species, increasing the success of generalist predators, facilitating poaching activities and interfering with ecological processes (Allen et al. 1998; Gucinski et al. 2000).

Roads may act as barriers of low permeability for taxa like clonal plants (Robinson et al. 1992), amphibians (Gibbs 1998), small mammals, snails, and butterflies (Bennett 1991). Even narrow, unpaved roads closed to public traffic would serve as barriers to spiders, carabid beetles (Mader 1984; Mader et al. 1990) and soil macroinvertebrates (Haskell 2000). In Auca Mahuida, the removal of topsoil from the seismic lines probably makes them effective barriers for species like clonal plants, reducing the opportunity of re-invasion by vegetative growth.

The association between seismic lines and roads with exotic plants like *Hordeum leporinum* and *Erodium cicutarium* suggests that they could be favouring the spread and establishment of invasive species, which agrees with a previous study of seed banks and vegetation associated with Patagonian steppe roadsides (Margutti et al. 1996). This could also be the case for the expansion of leaf-cutting ants (*Acromyrmex lobicornis*). Previous studies have shown that this species has expanded its geographical range in northwestern Patagonia in response to road building and maintenance (Farji-Brener and Corley 1998). During this investigation we found winged adults of this species in the vicinity of roads and petroleum drilling pads.

It has already been pointed out that roads may favour the movements of predators, and therefore increase their impact on the populations of preys like small mammals, birds and reptiles (Rich et al. 1994; but see also Yahner and Mahan 1997). This effect has not yet been assessed for seismic lines in Auca Mahuida. However, seismic lines that remain open, particularly those intersecting paved roads, give access to lesser rheas and guanacos poachers who can then go right into the core of the reserve (Funes 2000).

The impact of seismic lines on the dynamics of fires or rainfall infiltration and runoff has not been evaluated either. Nevertheless, it is clear that they increase the intensity of erosion processes in the area (Navarro 2000).

As well as the direct effect of fragmentation by seismic lines, disturbances originating from noise and the movements of people and vehicles associated with petroleum extraction activities can modify the behaviour of wildlife species with broad distribution ranges (Klein 1991; Nellemann and Cameron 1996; Bradshaw et al. 1997). In Auca Mahuida, present extraction activities overlap with guanaco feeding and calving areas, and could therefore have a negative influence on their abundance. This is shown by the movement of herds from their traditional areas of concentration to places where they appear to be more exposed to natural predation and illegal hunting, especially during the calving season (Funes 2000). Petroleum exploitation may also prevent guanacos having access to the only permanent source of water in the reserve.

In the study area, the timing of rainfall causes a seasonal availability of resources that has been crucial in the evolution of the Patagonian ecosystem (Orians and Solbrig 1977), but this situation may be modified by the existence of rubbish deposits associated with the presence of petroleum workers in the area. Rubbish becomes a constant and highly predictable source of food for carnivores and scavengers, probably changing their abundance and distribution in the area and secondarily affecting the populations of preys (Fiori and Zalba 2000). Also the presence of electric lines as part of the petroleum facilities may introduce another

change in the trophic relationships by providing perching sites for raptors and thus aiding their hunting performance (Funes 2000).

Considering the extent and potential impact of past and current petroleum activities described for Auca Mahuida, we think that there is enough information to severely question their development in areas primarily devoted to the conservation of biodiversity, as commonly happens in Patagonian nature reserves. To assume that both activities can coexist could lead to the creation and maintenance of 'paper reserves' where the reality on the ground markedly contrasts with our perception of protected areas.

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