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Assessment of Landscape Changes caused by Highway Construction: Case Study of Ruta del Canal Pargua Highway in Chile

Abstract

The constructed infrastructure that has made cities more livable to their human inhabitants not always has benefited the overall ecosystems, which has leading to some fragile land covers being the most affected (i.e., grasslands, wetlands, etc.). In this article, it is analyzed the relationship between the natural landscape and the highway “Ruta del Canal Pargua” in Puerto Montt, Chile. A comparison was performed/implemented based on a Land Use Land Cover Change (LULCC) analysis from a year before the construction of the highway (2012) to the most updated available image (2021). Three field spots were selected to observe the wetland’s landscape visual qualities, landscape natural features, and road management (2022). The results showed that anthropic interventions have been continuing to transform the natural features of wetland’s landscape, especially the native roadside vegetation, and noise pollution. This change was promoted by the lack of management of the highway in its surroundings, and, by the intrusive LULCC. This paper also discusses the persistent lack of ecological management for highways in southern Chile and sparks the conversation about the necessity to include an ecological perspective in road infrastructure design in Chile that could be replicated in Latin America.

Carolina G. Ojeda Leal

Pontificia Universidad Católica de Chile, Doctorado en Arquitectura y Estudios Urbanos, Providencia, Chile.

Universidad de Concepción, Departamento de Geografía, Grupo de Estudios Multiamenazas, Vulnerabilidades y Cambio Climático, Concepción, Chile.

* Corresponding author: Pontificia Universidad Católica de Chile, Doctorado en Arquitectura y Estudios Urbanos, El Comendador 1970, 7500000, Chile. Email: carojeda@udec.cl

Carolina G. Ojeda Leal
https://orcid.org/0000-0002-9830-9203

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1 Introduction

Alongside history, major anthropic interventions in landscapes have been justified to satisfy economic necessities (Arnold 1996; Cronon 2003). Few of them have been more representative of the XX-XXI centuries than highways. These technical innovations could be accounted for the vastly anthropic intervention in the landscapes with human-made obstacles and, sometimes, scarce management by the route concessionaires, undervaluing landscape features such as wilderness/naturalness, roadside vegetation, and hydrological management of stream ecosystems, wetlands, lakes, and rivers. Usually, alluding to costs route concessionaires and governments have systematically diminished other potentialities for scenery tourism by foot or bike, neither improving driver's experience aesthetically nor by reducing noise pollution.

Landscape ecology, road ecology, engineering, marine biology, and urban design/planning have been raising these same concerns about the strong increase of highway construction around the world in the last decades (Forman et al. 2003; Clay and Smidt 2004; Wheeler et al. 2005; Coffin 2007; Jaal and Abdullah 2012; Guo et al. 2023; Zaakour et al. 2023). Since the launch of the classical guidelines from the Bureau of Land Management for Visual Assessment in the USA (1984), these disciplines had been more involved in other aspects of the relationship between landscape and highways, inquiring about visual features and their management/effects on drivers, vegetation maintenance, human-wildlife presence, and scenic qualities. Particularly, for the Chilean case, the assessment of the visual quality of landscapes is still a pending issue due to the intensive focus on the durability to transport extracted natural resources and connect people faster, however, the seminal work of Muñoz Pedreros (2004) in southern Chile changed the way landscape-related disciplines approach the highways until today.

Landscape from La Araucanía to Los Lagos regions is often described as a unique and natural experience and it is promoted by the Chilean government as an idyllic place where *"the rain falls intense and then gives way to an intense blue sky. It smells of the forest and humid soil"* (Chile Travel 2022). These touristic features and the abundance of natural resources had made connectivity a priority for their inhabitants in the Northern Patagonian Andes by the Chilean and Argentinean governments (Piconi 2019) by promoting a notion of progress through the installation of seaports, fluvial navigation, railways, highways, and airports (Donoso and Lara 1997; Gerhart 2014; Robles Ortiz 2020).

In that sense, the Chilean government supported a systematic colonization process since 1880 *"... shaped by ecological conditions. In a territory covered by forests, sharecropping with tenant laborers was crucial for land clearance in the formation of the hacienda system"* (Robles Ortiz 2020). The German settlers, and later the Chilean farmers, cleared the land using controlled burning to expand the fields for livestock, woodchip, fuelwood, and crops during the XIX and XX centuries (Donoso and Lara 1997). These extractive processes changed the landscape and highways, like Ruta del Canal – Pargua, were highlighted as an important part of transporting natural resources faster (Picone 2019) and increasing tourist transit.

However, the growing population and intensive natural resource extraction promoted deforestation and fragmentation of southern Chile's vegetal cover (Echeverría et al. 2008). These processes promoted an important land change from traditional evergreen forests and agropastoral landscapes (Donoso et al. 1999) to the proliferation of exotic forestry plantations (*Pinus radiata* – *Eucalyptus globulus*), and invasive shrub species such as zarzamora (*Rubus spp.*) and chacay (*Úlex europaeus*) (Echeverría et al. 2007).

Particularly, transportation infrastructure has been indirectly encouraging major anthropic interventions that enabled the subsequent landscape transformations by Land Use Land Cover Change (LULCC), either by replacement, substitution, or loss of green covers, such as agriculture, native forests, native shrubs, and wetlands (Echeverría et al. 2007; Echeverría et al. 2012). However, since the mid-twentieth century, due to the increasing citizens' ecological awareness (Ojeda Leal and Jaque Castillo 2022; Hervé 2010), the Chilean government has been forced to progressively incorporate landscape ecology principles and citizen participation into road design and implementation (Sagaris 2018) through the creation in 1997 of the Chilean Environmental Impact Assessment System (SEIA in Spanish) (Gamberini et al. 2019; Bergamini and Pérez 2015).

The objectives of this Chilean case study (Ruta del Canal Pargua highway) are to analyze the changes in landscape features through a landscape visual quality, satellite imaging analysis of built-up areas, and roadside landscape management aspects. This study case hopes to contribute to landscape-related practitioners, policymakers, and researchers from the Global South to reflect on how the development of road infrastructure could have long-term effects on landscape ecology, tourism, and driver's experience.

2 Materials and methods

2.1 Study area

Los Lagos region is a Southern temperate climate (Cfb) characterized by cold winds from the West, mean temperatures up to 15ºC, the proximity to the Pacific Ocean, and monthly rainfalls over 200mm in autumn-winter (Sarricolea, Herrera-Ossandon, and Meseguer-Ruiz 2017). It has a vast forest mass and a mountain range visible on the plain side led by Osorno and Calbuco volcanoes.

Figure 1. a) Road infrastructure managed by concessionaires in the Los Lagos region with the capital (Puerto Montt) and the frontier cross point Cardenal Samoré connecting Chile and Argentina, b) Observation points of the fieldtrips in 2022 (b) along the Pargua highway in southern Chile: Point 1 in Alto Bonito, Point 2 in Monte Verde, Point 3 in La Goleta sector. Sources: Google Maps and pictures from personal archive of the author, 2022.

In this region, new transport ways expanded the connectivity through the region with a cross point between Argentina - Chile in Osorno called Complejo Fronterizo Cardenal Samoré (Schweitzer 2002), the development of the Pan-American Highway in the 1950s, and Carretera Austral in 1974. With the arrival of the end of the XXI century, the Pan-American Highway was modernized to connect better the region with Chiloé island through two concessioners: *"Tramo Río Bueno – Puerto Montt"* (130km) and *"Tramo Puerto Montt – Pargua Ruta del Canal"* (55km) (Figure 1a). Unexpectedly, it fomented the expansion of Puerto Montt's and Calbuco's urban sprawl facilitating the installation of new industries, new public services (a prison and a juvenile jail), and new housing developments (houses of less than 68sm and plots of less than 2ha). Ruta del Canal Pargua highway (55km) was designed and constructed between 2008 - 2012 by the route concessioner "Sociedad Concesionaria Rutas del Canal S.A." (MOP 2022). It started its operations using a user-pay principle in 2014 and its extension is going through the communes of Puerto Montt, Calbuco, and Maullín. With its 8 years of non-stop functioning its main function has been promoting the transportation of natural resources (fish, wood, algae, seafood, livestock) and tourism to Chiloé Island. This anthropic intervention created a linear pathway of concrete (4 lanes) across native forests, wetlands, small old farms, and the nearby archaeological site of Monte Verde. Along the route, there are important wetlands that are not protected by RAMSAR qualification or the new Chilean law of urban wetlands Nº21.202 (BCN 2020). Therefore, the route design was not intended to bring information to educate tourists or inhabitants about the necessity of preserving wetlands' typical flora and fauna (Urrutia et al. 2017; Rodríguez and Fica 2020).

For this study, three observation points were selected (Figure 1b) to represent built-up areas of housing developments, rural plots, industries, and the presence of existent wetlands alongside the highway: point 2 in Monte Verde (41°31'42.2"S 73°07'18.7"W) and point 3 in La Goleta (41°33'07.2"S 73°09'50.3"W). In addition, point 1 in Alto Bonito (41°28'58.4"S 73°00'54.9"W) was chosen to compare the landscape changes with the previous study of Ojeda (2018).

2.2 Assessment of landscape visual qualities

During a field trip in the summer of 2022, GPS points were taken alongside photographs of the three points that were taken with sunlight at the same height. Regarding that, the species of flora and fauna found along the roadside were not damaged in this study in any form.

To assess the landscape's visual qualities and the landscape natural features, a field sheet adapted from Ojeda Leal (2018) was used during the field trip. This corresponds to a score based on the weights from the highest value (1) to the lowest value (0) of the attributes and elements of indicators were used to rank the landscape attributes (Table 1).

Table 1. Field sheet for landscape assessment adapted from Ojeda Leal (2018).

LANDSCAPE ATTRIBUTES	INDICATORS	DESCRIPTION	ATTRIBUTES AND ELEMENTS
Natural features	Fractal dimension of linear features	It corresponds to the presence of certain morphologies that defines the observed scenery (i.e., coastlines). On the contraire, its absence indicates that it is an entire human-made landscape	Coastlines = 1
			River networks = 0.75
			Fault traces = 0.5
			Shorelines = 0.25
			None = 0
Structural integrity of vegetation	Vegetation intactness	Indicates the presence or absence of vegetation. Also indicates the vegetation scale, in which the trees are considered a more mature and robust landscape feature than herbaceous.	Trees = 1
			Mixed vegetation (bushes + trees) = 0.66
			Herbaceous + bushes = 0.33
			No vegetation = 0
Water	Presence of superficial water	Indicates the presence or absence of water bodies (natural or human-made). Its presence contributes to more biodiversity and better scenery qualities	Sam or reservoir = 1
			Lake or pond = 0.66
			River, streams = 0.33
			No water = 0

Table 1. (continued)

LANDSCAPE ATTRIBUTES	INDICATORS	DESCRIPTION	ATTRIBUTES AND ELEMENTS
Colors and texture	Number of colors	Indicates the approximate number of distinctive colors observed. Colorful landscapes are considered more appreciated by bystanders and drivers.	Three or more colors = 1
			Two colors = 0.50
			One color = 0
	Internal contrast	Indicates the color contrast, which means the clear and bright observed in the scene. A clear contrast relates to a more defined visual landscape structure	Clear color contrast = 1
			Weak color contrast = 0
	Texture	Indicates the overall texture of the principal(s) feature(s) in a landscape, which means that a more rough or irregular landscape is less visually pleasant for observers (i.e., in an agricultural landscape the texture is smooth due to the vast presence of the grasslands)	Smooth = 1
			Variated = 0.66
			Rough =0.33
			Irregular = 0
Horizon	Horizon	Indicates the possibility to see the farthest point in the horizon from a certain point of view, which is usually taken at the highest.	Mountains dominate the scene = 1
			Some mountains = 0.66
			Slightly wavy = 0.33
			Almost flat = 0
	Focal view	Indicates the presence or absence of a focal view, which is the establishment of a reference point for landscape observation (i.e., a volcano). It could be natural or not.	Clear focal view = 1
			No focal view = 0
Human-made objects	Cultural and heritage elements	Indicates the presence of relevant human-made elements in the landscape (i.e., vernacular architecture, sightseeing places, etc.). They do not make difficult the observation of landscape features	Three or more elements = 1
			Two elements = 0.66
			One element = 0.33
			None = 0
	Number of obstructing objects	Indicates the presence of intrusive human-made elements in the landscape (i.e., roads, industries, power lines, etc.)	None = 1
			One element = 0.66
			Two elements = 0.33
			Three or more elements = 0

That rank is a highly qualitative instrument that relies on the experienced eye of the professional that applies the instrument, which ideally should be an expert in landscape-related disciplines. For example, the landscape attribute “Structural integrity of vegetation” has one potential indicator, which is “vegetation intactness”, so, if the observer saw during the field trip the landscape element “trees” should be marked the value “1” in the correspondent checkbox (Table 1).

2.3 Assessment of the management

The management of natural features in Chilean roads is understood as all *“the activities carried out by the Concessionaire Company to maintain the operating standard of the concession infrastructure at the levels established in the Works Conservation Plan and Annual Works Maintenance Program established in article 2.5.2 of the Bidding Terms (BALI)”* (MOP, 2016). This is opposed to the US definition of management of natural features, which is understood as an activity undertaken on the landscape for the purpose of harvesting, traversing, transporting, protecting, changing, replenishing, or otherwise using the available resources on the highway (Bureau of Land Management, 1984; Allard 2003). In this case, the Concessionaire must do all the efforts for *“conservation of landscaping works and garbage - waste removal”*, however, they are not obliged to give further information on what exactly is done and when will be done (MOP, 2016).

For this study, this feature was observed on the field trip and was assessed by scoring it on a field sheet (Table 2). That rank is a qualitative instrument that relies on the eye of the professional that applies the instrument, which could be an expert in landscape-related disciplines or not.

2.4 Assessment of LULCC changes

LULCC was analyzed to corroborate the direct and indirect impact of the highway functioning at its surrounding landscape. Three multispectral LANDSAT images (December 2012, April 2014, and November 2021) in RGB normal color combination (30x30m pixel’s size) were downloaded from Google Earth –

Table 2. Field sheet for management assessment adapted from Ojeda Leal (2018).

LANDSCAPE ATTRIBUTES	INDICATORS	DESCRIPTION	ATTRIBUTES AND ELEMENTS
Management (qualitative)	Management intensity (frequency)	It is understood as the constant management of roadside vegetation and waste removal to avoid driver accidents, landslides, and wildfires. Also, in more scenic roads or if the road goes through relevant ecological features (i.e., National Parks, wetlands, etc.) it should include roadside ecological management to avoid invasive species.	Good maintenance depending on the observed road type = 1
			Lack of maintenance depending on the observed road type = 0.5
			None = 0
	Management of human landscape features	This includes a visible effort to highlight to drivers, bikers, and pedestrians the man-made elements that the territory could offer (i.e., typical houses, archaeological sites, etc.). This should include 1) road signs, 2) educational information alongside the road, and 3) specially designed sightseeing places to highlight landscape features.	Good maintenance of the elements that highlight all human landscape features alongside road and include at least 2 of 3 management elements = 1
			Lack of maintenance of the elements that highlight all human landscape features alongside road and include at least 1 of 3 management elements = 0.5
			None = 0
	Management of natural landscape features	This includes a visible effort to highlight to drivers, bikers, and pedestrians the natural elements that the territory could offer (i.e., coastlines, river networks, wetlands, etc.). This should include 1) road signs, 2) educational information alongside the road, and 3) specially designed sightseeing places to highlight landscape features, for example, bird sighting infrastructure.	Good maintenance of the elements that highlight all natural landscape features alongside road and include at least 2 of 3 management elements = 1
			Lack of maintenance of the elements that highlight all natural landscape features alongside road and include at least 1 of 3 management elements = 0.5
			None = 0

USGS and pre-processed in ArcGIS 10.8 for geometric correction. After that, a supervised classification following the methodology of Hassan et al. (2016) was made to highlight relevant anthropic transformations before and after the road construction: housing developments, rural plots, and industries. Local knowledge and the visual analysis from the field trip were used to enhance the classification accuracy and it was added by expert validation in the creation of the field sheet.

3 Results

3.1 Landscape visual scale and management at Pargua highway - Puerto Montt

The overall field measurements obtained from the field sheet were 6.98/13 for Point 1 Alto Bonito, 7.97/13 for Point 2 Monte Verde and 7.64/13 for Point 3 La Goleta (Table 3). The three field spots obtained the highest score in basic landscape visual quality features like focal view, internal contrast, presence of superficial water, and color number. They obtained the same minimal score for fractal dimension of linear features, indicating that it is an entire human-made landscape lacking relevant natural features (Figure 2). The points differed in the number of obstructing objects, texture, vegetation intactness, and cultural and heritage elements, where Alto Bonito obtained the lowest score. That pattern was reversed only for the horizon indicator, where Alto Bonito obtained the highest score due to its impressive view to the volcanoes (Figure 1).

3.2 LULCC at Pargua highway - Puerto Montt

In general, the construction of the Pargua highway between 2012 and 2014 changed its surrounding landscape indirectly in aspects like biodiversity loss,

Table 3. Landscape assessment for Ruta del Canal Pargua highway in 2022 fieldtrip.

INDICATORS		POINT 1	POINT 2	POINT 3
1	Fractal dimension of linear features	0	0	0
2	Vegetation intactness	0.66	1	1
3	Presence of superficial water	0.66	0.66	0.66
4	Number of colors	1	1	1
5	Internal contrast	1	1	1
6	Texture	0.33	0.66	0.66
7	Horizon	1	0.66	0.33
8	Focal view	1	1	1
9	Cultural and heritage elements	0.33	0.66	0.66
10	Number of obstructing objects	0	0.33	0.33
11	Management intensity (frequency)	1	0.5	0.5
12	Management of human landscape features	0	0.5	0.5
13	Management of natural landscape features	0	0	0
TOTAL		6.98/13	7.97/13	7.97/13

Figure 2. a) Landscape features and b) biodiversity along the Ruta del Canal Pargua – Puerto Montt in Alto Bonito (point 1), Monte Verde (point 2) and La Goleta (point 3.) Source: Personal Archive of the author, 2022.

landscape homogeneity, accelerating the introduction of exotic species for monoculture (pines and eucalyptus), and favoring the urban/industrial sprawl alongside the road. These last three consequences were observed through a multitemporal LULCC (2012, 2014, and 2021 maps in supplementary material) focusing on the progression of urbanized areas of industries, housing, and rural plots alongside the main road (Figure 3).

Before the implementation of the highway in 2012, the landscape was divided by a two-lane pavement road following the same path as today connecting Puerto Montt with Chiloé Island through the port of Pargua. The landscape was mostly agropastoral with dispersed houses and few industries. It created small nodes of expansion at Pargua and ensured the circular expansion of Puerto Montt's influence over the area. When the major construction works finished in 2014, it started a ripple effect in the urban sprawl that converted former agricultural and forest areas to urban cover at the nodes of Pargua in the south end, Calbuco in the middle, and Puerto Montt in the northeast.

In a more recent image (Figure 3, Figures S4 and S5), the conversion of agricultural and forestry land cover into an urbanized cover was fully consolidated and focused on the northeast side of Puerto Montt dominated by the addition of housing and rural plots. Following this, the Calbuco node, located in the middle of the highway, presented a circular expansion dominated by industrial lots and included a new southern branch to the seaport and the fuel reservoir. The exception was the small southern city of Pargua, for which land cover and urbanization levels remained the same.

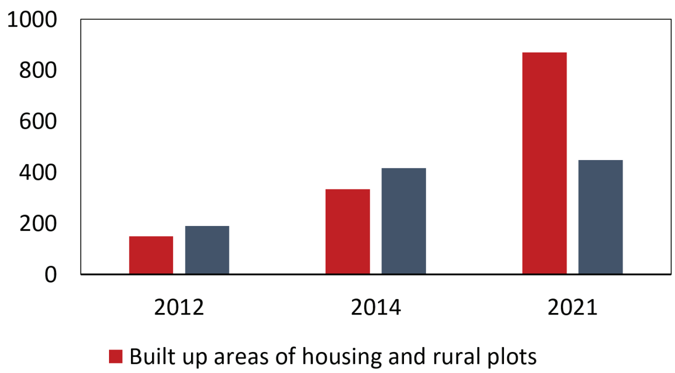

Figure 3. LULCC before the construction of Ruta del Canal Pargua highway (2012-2014), after the construction (2014-2021), and total change (2012-2021).

4 Discussion

4.1 Landscape visual scale and management at Pargua highway - Puerto Montt in 2018 and 2021.

In the previous study of 2018, Alto Bonito obtained an overall score of 5.64/10, and it changed in features like horizon, texture, and cultural and heritage elements (Figure 4). It could be inferred that the fast conversion of land covers and unorganized urban sprawl affected the highway's natural features due to anthropogenic interference: noise pollution, water scarcity, landscape fragmentation, the proliferation of invasive species (i.e., *Rubus spp*., *Úlex europaeus*), and wildlife deaths at the road. Also, it could be inferred that possible causes of this urban sprawl around the highway lie in increasing pressure to buy rural plots during the COVID-19 pandemic to acquire a vacation house, or a cabin to do remote work (Fitzroy 2021; Ciper Chile 2022), falling under the idea of paradise that grew stronger in the social imaginary (Chile Travel 2022; Booth 2010). Furthermore, it was noticed through LULCC analysis in point 1 that industrial factories added more pressure by acquiring more land searching to reduce their operation costs and add space to keep their work supplies, something that Puerto Montt's capital city can no longer offer.

Overall, the management at the highway was improved for point 1 in comparison with the previous study of 2018, especially by mowing the lawn at pedestrian crosses and sideways. This helps to achieve the recommended objectives of limiting possible wildfires and roadside beautification for the driver's benefit (Forman et al. 2003; Bureau of Land Management 1984), which according to the literature reduce driver's anxiety and rage road incidents (Clay and Smidt 2004). Furthermore, it was observed on the field trip that the truck and car noise is less annoying than in the previous study of 2018.

In points 2 and 3, the management observed at the field trip was reserved to maintain the roadside vegetation within the road limits. However, it notoriously lacks protection for roadside wetlands from the constant noise coming from trucks and cars that disturb migratory birds and other wildlife unleashing biodiversity loss of Gaviota Andina (*Chroicocephalus serranus*), Yeco (*Phalacrocorax brasilianus*), Gaviota Dominicana (*Larus dominicanus*) and Gaviota de Franklin (*Leucophaeus pipixcan*) (Figure 2b) (CEAZA 2004).

4.2 Landscape visual assessment in other studies

According to Clay and Smidt (2004:2), landscape visual assessment is: "As a concept, scenic quality is both elusive and complex". In that sense, dealing

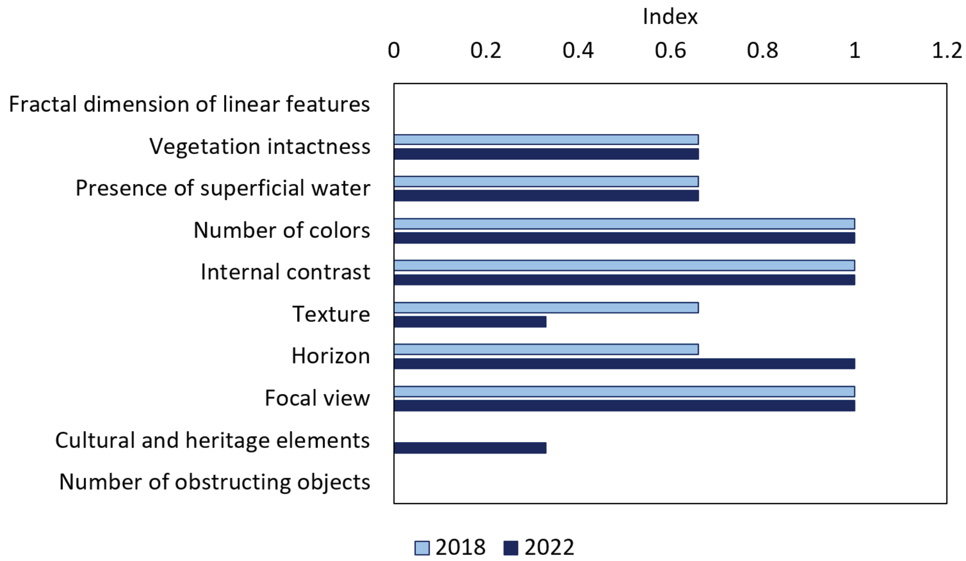

Figure 4. Comparison landscape visual quality and natural features for Point 1 Alto Bonito between 2018 and 2022. Results of 2018 were obtained from Ojeda Leal (2018).

with the phenomenological experience of the human perception has been always a challenge, particularly when the study object of the landscape visual assessment is ephemeral, as Sennet (2002:20) said, *"The speed itself makes it difficult to pay attention to the landscape. The truth is that to the extent that the roads have become straighter and more uniform, the traveler must worry less and less about the people and buildings on the street to move, making minimal movements in an environment that is increasingly less complex."* Nevertheless, after the remarkable works of Lynch (1960), Edney (1972), Ittelson (1978), Smith (1984), and Nasar et al. (1985), most of the following researchers have successfully navigated those waters by using methods derived from environmental psychology such as questionnaires, interviews, and mapping. In this article, it was used a qualitative method with a questionnaire using descriptor variables with a specific weight, which follows the environmental perception of the researcher in the field trip. Its principal limitation corresponds to the natural subjectivity when the questionnaire is applied, photographs are taken, and field points are selected. However, similar studies used different methods to correct this subjectivity using score tables, photography evaluation (e.g., expert panels, drivers, and/or tourists) or using quantitative methods associated with GIS (Kiinkenberg 1994; Arriaza et al. 2004; Joly et al. 2009; Jaal and Abdullah 2012).

4.3 Limitations and future studies

The limitation found during the development of this study was associated to methodological aspects in the field trip points, mainly due to its specificity to be wetlands that restricted the possible range of results, something that will be hopefully addressed in further studies about the area. In this matter, the peer review process was a keystone to reassure the validity of this selection, however, for future studies related to assess the landscape of the road infrastructure the methodological basis of the field point will need to be better justified.

In the field trip was observed high levels of noise pollution, which was an unexpected discovery because it was not considered into landscape assessment and management evaluation. However, it is concerning that the consequences of long periods of noise that have been propelled to community and ecosystem-level processes of wetlands at Pargua Highway remains unknown for their inhabitants: *"nonhuman animal dwelling is similarly invisible to human visitors to nonhuman places in central Chile"* (Root-Bernstein 2014). Nevertheless, the use of pre-existent bridges or tunnels with no -or little- traffic at night may also contribute to animal movement since most animals spread at those hours (Braschler et al. 2020). These elements have been proven to increase species richness (Rheindt 2003) and reduce changes in animal behavior (Barber et al. 2012), pollination, and seed dispersal (Francis et al. 2012). It will be a good change for Chilean roads to add noise pollution risk assessment protocols (Duquette et al. 2021) and promoting the reduction of night traffic especially nearby wetlands and native forests (Ortega 2012; Sordello et al. 2020), so future studies in this matter are a necessity.

5 Conclusions

In this article, the landscape features of Pargua highway located at Puerto Montt in Chile were addressed. A LULCC analysis was carried out to understand the indirect influence of landscape change before and after road construction. A direct observation using a field sheet was made to evaluate the natural features and visual quality in three viewpoints alongside the highway. Reflexing on the results, it will be necessary to upgrade the requirements in the design and management of transportation infrastructure to include noise pollution risk assessment protocols, bridges for animal mobility, and protect certain relevant areas, i.e., wetlands, native forests, pollinator routes, etc.

Indeed, road ecology management for highways in southern Chile is not a direct responsibility of the concessionaire, unless it cleans roadside vegetation and retires garbage. It will be expected a change that could be made to propose new laws to enhance the requirements in future works to include bridges for animals to connect the landscape patches disaggregated by the roads.

Conflicts of Interest

The author declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

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Supplementary material

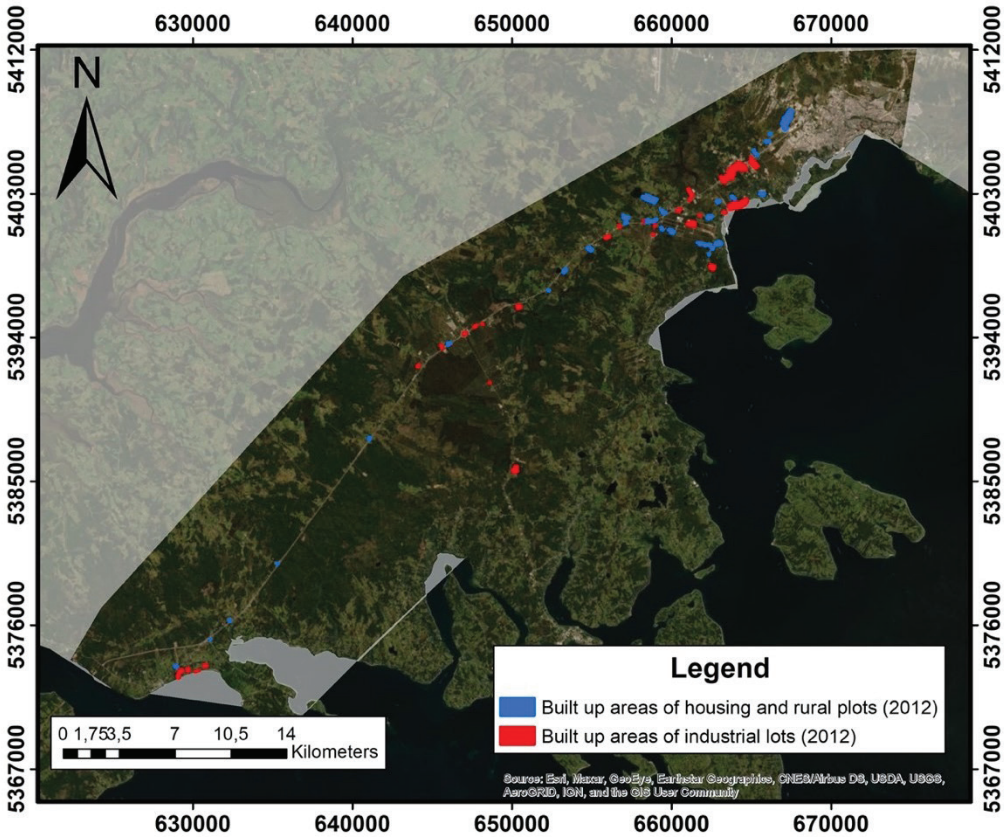

Figure S1. LULCC observed at Pargua Highway before the construction (2012) highlighting the changes in housing and rural plots (blue) and industrial lots (red). Source: Made with ArcGIS 10 by César Muñoz.

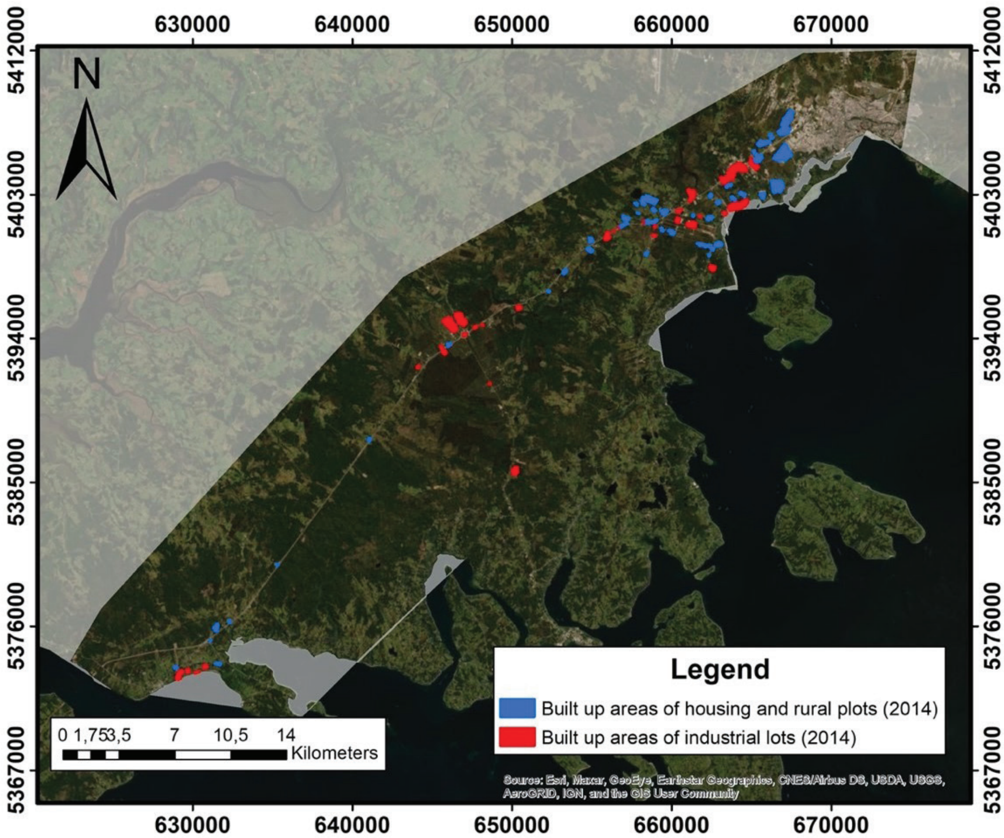

Figure S2. LULCC observed at Pargua Highway after the construction (2014) highlighting the changes in housing and rural plots (blue) and industrial lots (red). Source: Made with ArcGIS 10 by César Muñoz.

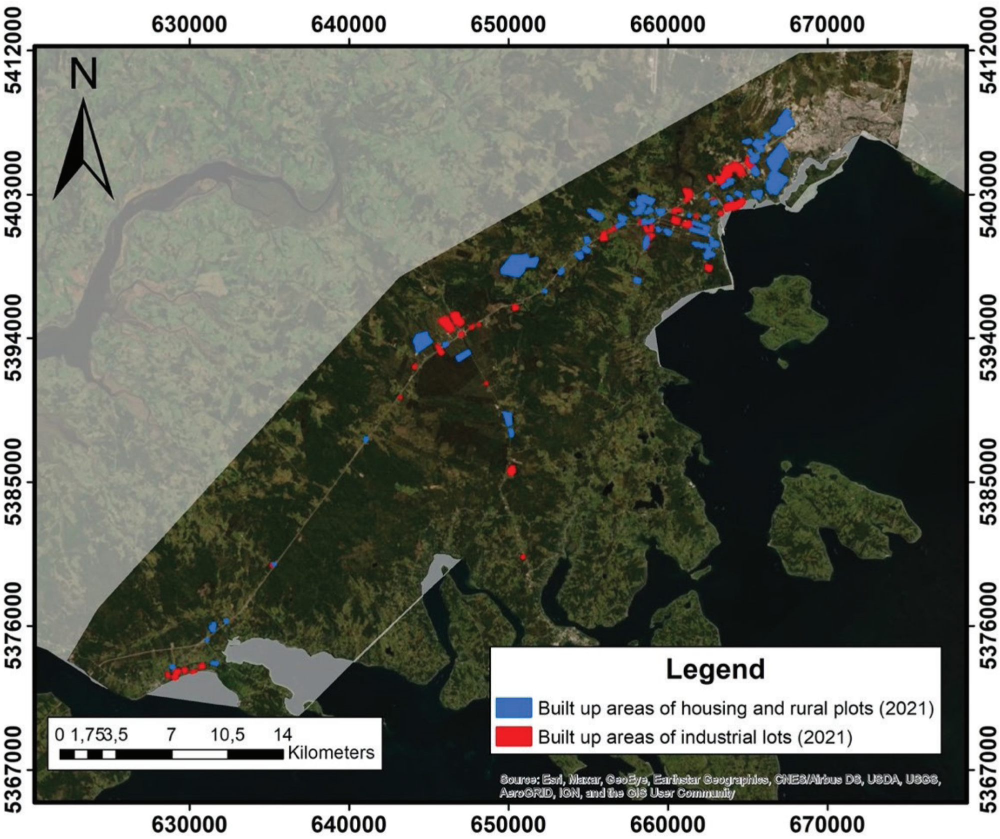

Figure S3. LULCC observed at Pargua Highway last year (2021) highlighting the changes in housing and rural plots (blue) and industrial lots (red). Source: Made with ArcGIS 10 by César Muñoz.

Figure S4. Concrete plant of Cemento Melón located a few km north to point 3 La Goleta which is a typical industrial plot. Source: Google Street View, 2023.

Figure S5. Housing plots observed in point 1 Alto Bonito, which is representative for the area. Source: Google Street View©, 2022.