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Investigating the implementation of the mitigation hierarchy approach in environmental impact assessment in relation to biodiversity impacts

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ABSTRACT

Global loss of biodiversity has directly and indirectly been caused by human activities. Environmental Impact Assessment (EIA) attempts to address the loss of biodiversity caused by development projects, by avoiding, reducing or compensating the loss (in that order following the mitigation hierarchy approach). Evidence suggests that in practice the mitigation hierarchy is not always applied correctly, and that monitoring is frequently absent, or flawed, meaning that the success of the mitigation measures, and their associated biodiversity outcomes, remain unknown. However, there is no literature that has systematically examined the application of the mitigation hierarchy and assessed the effectiveness of associated monitoring in an EIA system. This study fills that gap using Chile as an example because of its high biodiversity setting, and ease of access to EIA-related data. The results indicate that the use of compensation measures exceeded what would be expected from correct implementation of the mitigation hierarchy, and that there was also some misclassification of the measures. Monitoring studies focused on inspecting implementation of mitigation measures rather than measuring biodiversity outcomes (meaning that mitigation effectiveness cannot be fully evaluated). Further, there was a focus on specific elements of ecosystems and lack of consideration for broader biodiversity implications. Thus, the findings raise some concerns over the ability of EIA to achieve its goals of zero net loss of biodiversity. We make suggestions to improve the mitigation and monitoring aspects of the EIA process in Chile and would suggest that the recommendations are likely to have wider relevance to other jurisdictions.

1. Introduction

Anthropogenic threats are mostly acting as drivers of biodiversity change in many environments across the Earth (Bowler et al., 2020). The rapid growth and expansion of the human populations (McKee et al., 2004) and increase in extraction of natural resources and primary productivity (Wackernagel et al., 2021) has become one of the greatest threats to species biodiversity and ecosystem function, producing habitat loss and, consequently, biodiversity loss (Duffy, 2003; Balmford and Bond, 2005; Cardinale et al., 2012). A diverse range of conservation instruments has been applied to protect biodiversity (Tilman et al., 2017) and reduce pressure from infrastructure development (Laurance et al., 2015). Despite these efforts, the latest Intergovernmental Panel on Climate Change (IPCC) and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) reports indicate that the unsustainable use of natural resources derived from anthropogenic activities continues (IPBES, 2019; IPCC, 2022).

Several national and international policy instruments (e.g., article 14 of the Convention on Biological Diversity (CBD)) propose the application of environmental impact assessment (EIA) as a crucial instrument for minimizing biodiversity loss (Slootweg and Kolhoff, 2003). All projects that are likely to have significant adverse effects on biological diversity should use these instruments to avoid or minimise negative biodiversity impacts (CBD, 1992). Chile is one of the signatories of the CBD and implemented environmental legislation in 1994 to meet its CBD obligations, including a requirement for Environment Impact Assessment (EIA). From 2014, EIA in Chile has included a requirement for biodiversity compensation for all the significant impacts that cannot be mitigated or repaired (excluding impacts of low significance), known as ‘appropriate compensation of biodiversity’ in Chile (SEA, 2014), but better known globally as ‘Biodiversity Offsets’ (BBOP, 2009, 2012). The goal of Biodiversity Offsetting is to achieve at least zero net loss of biodiversity by implementing actions designed to compensate for losses resulting from development projects.

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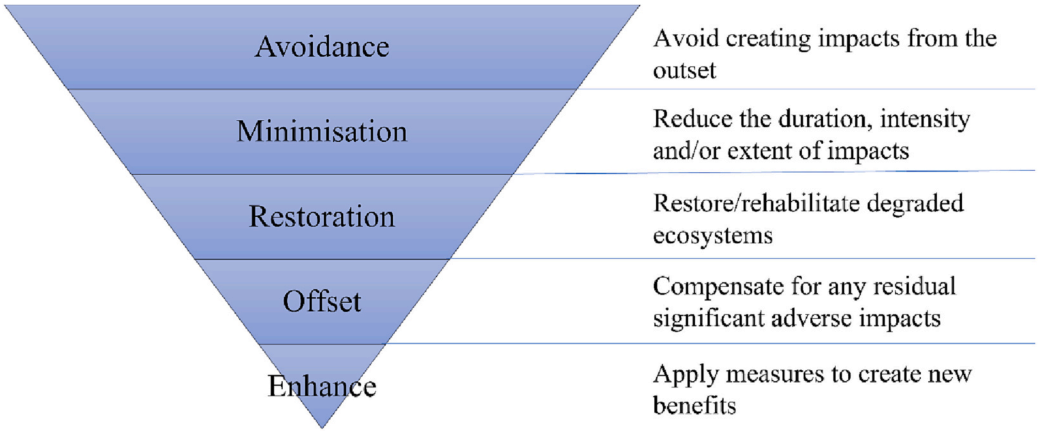

Fig. 1. The mitigation hierarchy (adapted from Glasson and Therivel, 2019).

EIA as a generic process (specific requirements in individual jurisdictions may differ) involves an assessment of the impacts of a proposed development, including the identification of mitigation measures to address potentially significant impacts, and subsequent monitoring to determine the environmental outcomes (Glasson and Therivel, 2019). Biodiversity protection through EIA involves the implementation of the mitigation hierarchy in order to address the environmental impacts of a development project, focussing on avoidance at first, followed by minimisation and reduction as the subsequent steps, and considering offsetting (compensation) as a last resort (BBOP, 2009, 2012; CEQ, 2020; Tucker et al., 2020). Glasson and Therivel (2019) also refer to the inclusion of measures in EIA to create environmental benefits beyond pure mitigation of impacts (enhancement), which can help to highlight the opportunities for the EIA process to deliver benefits as well as controlling negative impacts only (Fig. 1). The correct implementation of the mitigation hierarchy is argued to be better (than incorrect implementation) for biodiversity, reducing the need for short-term restoration and offsetting, and preventing the need to deal with subsequent problems such as long-term restoration, uncertainty over the effectiveness of any offsets, the cost of the monitoring for the duration of the offsets, as well as negative social impacts (Maron et al., 2016; Lindenmayer et al., 2017; Phalan et al., 2018).

The success of the implementation of the mitigation hierarchy relies on the execution of post-decision monitoring to verify the effectiveness of the mitigation measures (Sánchez and Gallardo, 2005; Drayson and Thompson, 2013; Morrison-Saunders et al., 2021). Monitoring in the environmental assessment context is defined as the collection of data after the implementation of the activity to evaluate the environmental performance of a project or plan (Morrison-Saunders et al., 2007). Monitoring involves the measuring of environmental variables and parameters of interest over a period of time, in order to obtain information on the general state of the environment (Arts et al., 2001). To be more effective, monitoring should evaluate those parameters more susceptible to, and expected to be affected by, changes in the environmental conditions, facilitating the reduction of uncertainty associated with the predictions (Glasson, 1994).

As the central objective of the mitigation hierarchy is to at least reach ecological equivalence between biodiversity losses caused by the impacts of a development project and the gains produced by offsetting (Gelot and Bigard, 2021; Boileau et al., 2022), EIA-related biodiversity monitoring is essential to determine the effectiveness of the measures implemented to minimise the impacts on biodiversity resulting from development activities (Bataineh, 2007; Pickett et al., 2013). Once the measures have been implemented, in terms of them being carried out appropriately, the effectiveness of the measures verifies whether they have delivered the intended biodiversity outcome (Drayson and Thompson, 2013). In this regard, biodiversity monitoring programs should focus both on the process and the outcomes to establish whether the results of the process met the expected purposes (Chanchitpricha and Bond, 2013). Also, verifying biodiversity outcomes is needed to provide a feedback loop to increase the effectiveness of mitigation measures and effectively contribute to minimizing development impacts on biodiversity (Quétier and Lavorel, 2011; Gelot and Bigard, 2021).

Despite this, several weaknesses in the implementation of the mitigation hierarchy have been described in the literature, including the failure to follow the hierarchy sequence and the lack of monitoring to evaluate their effectiveness (Bull et al., 2016; Maron et al., 2016; Bigard et al., 2017; Lindenmayer et al., 2017; Phalan et al., 2018). For instance, although impact avoidance has been described in the literature as the most important step in the mitigation hierarchy (Ekstrom et al., 2015; Gelot and Bigard, 2021), in practice it is often ignored, misunderstood, and poorly applied (Phalan et al., 2018), partly because there is no specific guidance on how to classify certain impacts within the mitigation hierarchy, or clear indications on when to move from one level to another (Bull et al., 2016; Maron et al., 2016; Bigard et al., 2017). According to Bigard et al. (2017), only the total absence of environmental impacts in the area of the project by the change or reduction of the perimeter of the project would be considered as avoidance, therefore other types of activities should be considered as minimisation at best. Bigard et al. (2017) refers to a semantic confusion in the definitions of each type of measure, leading to some measures being incorrectly proposed in terms of their place in the mitigation hierarchy. This is also identified by Bull et al. (2016), indicating that multiple terms in the literature refer to the same level of the mitigation hierarchy, creating a conceptual challenge in its application. Additionally, monitoring is failing to demonstrate achievement of biodiversity outcomes (Lindenmayer et al., 2012; Lindenmayer et al., 2017). The quality and level of the post-decision monitoring has been criticized as being insufficient to ensure the successful implementation of the measures, mainly because of the lack of human and financial resources for the long-term monitoring programmes (Pickett et al., 2013; Gelot and Bigard, 2021).

It should be noted that the term compensation is usually used for economic compensation and the term offset is used for biodiversity compensation (Alonso et al., 2020). However, in Spanish, the term

Table 1
The mitigation hierarchy and the equivalent terms used in Chile.

Mitigation hierarchy (after Glasson and Therivel, 2019)	Equivalent terms in Chile (SEA, 2014)
Avoid	Mitigation
Minimise	Mitigation
Restore	Repair
Offset	Compensation
Enhance	[No equivalent]

compensation is used for both situations, which can cause confusion and, in some cases, can lead to compensation being carried out for aspects not necessarily related to biodiversity, therefore failing to meet the aim of offsetting biodiversity loss (Alonso et al., 2020). In Chile, the term biodiversity compensation is used to refer to biodiversity offsetting (Bull et al., 2016), therefore it will be the term used in this research. Also in Chile, the mitigation hierarchy is called the 'hierarchy of measures', and the terms used differ somewhat from the terms outlined in Fig. 1 as set out in Table 1.

There is no literature that focuses on the application of both the mitigation hierarchy and associated monitoring in a single jurisdiction's EIA system. Such research has the potential to identify specific opportunities for improving practice and, therefore, biodiversity outcomes. This paper aims to investigate the implementation of the mitigation hierarchy in Chile, a country that recently implemented biodiversity offsetting in its national environmental legislation. Therefore, the overall aim is to evaluate the extent to which biodiversity is being protected by the Chilean environmental legislation in practice, specifically through the application of the mitigation hierarchy. Based on this, the following research questions are asked: Is the mitigation hierarchy being followed? Is the monitoring of the measures implemented effective?

The paper is structured as follows. The next section introduces an outline of the current state of biodiversity in Chile and presents the relevant institutional framework (section 2). Section 3 introduces EIA in Chile and sets out the mitigation requirements. Section 4 introduces the reporting process in Chile and associated databases and explains the case study selection. Sections 5 and 6 examine the two research questions in turn, introducing the methods, results, and key findings. Finally, conclusions and recommendations are presented in section 7.

2. Biodiversity in Chile and the Chilean conservation framework

The biodiversity of Chile is known for its high degree of endemism and the exclusivity of some of its ecosystems, caused by the biogeographic conditions (MMA, 2019). Chile presents multiple types of ecosystems (terrestrial, marine, coastal and oceanic islands), which are critical to the economic development and social well-being of the population, and which fulfil crucial functions for maintaining key ecosystem services (Lara et al., 2009). Chile has one of the five Mediterranean-climate regions known in the world (McNally, 1990); is characterised by a high endemicity of plants and animals in the Juan Fernández Archipelago (Ormazabal, 1993); and hosts the Chilean Winter Rainfall-Valdivian Forest which is considered to be one of the 35 global biodiversity hotspots (Mittermeier et al., 2011). Also, it was recently found to possess 88 out of 110 global ecosystems existing on the planet (Keith et al., 2022).

The main pressures on terrestrial ecosystems in Chile are degradation and fragmentation due to human activities, such as changes in the use of land including forest reduction and conversion of shrubland to cultivated land, illegal logging of forests, and the creation of plantations with exotic species (Armesto and Arroyo, 1991; Lara et al., 2009; MMA, 2019). Negative impacts on biodiversity in Chile have been associated with agricultural and forestry industry, urbanisation, and mining, which produce the main pressures on fragile ecosystems through the clearing of native forests, the establishment of pastures and crops, the extraction of groundwater, and the contamination of aquifers (MMA, 2019).

Chile has adhered to numerous international treaties related to the conservation of its natural heritage, such as the Convention on Nature Protection and Wildlife Preservation in the Western Hemisphere (1940), Ramsar Convention (1971), CITES (1973), and CBD (1992), among others (PNUD, 2017). Additionally, in 2003, Chile implemented its National Biodiversity Strategy, which was updated in 2017 and currently runs from 2017 to 2030. The National Biodiversity Strategy is the instrument of public policy integrating the main strategic objectives, actions and goals of the country in terms of conservation and sustainable use of biodiversity (MMA, 2018). Furthermore, Chile agreed 20 targets (known as the 2010 Aichi biodiversity targets) aimed at reducing the loss of biological diversity at the global level, integrated in the National Biodiversity Strategy (MMA, 2018).

In order to administer the increasing number of biodiversity protection commitments, Chile is creating the *Servicio de Biodiversidad y Áreas Protegidas* (Biodiversity and Protected Areas Service). However, this Service is currently in the legislative process (Sierralta et al., 2011; MMA, 2018) and one of the main challenges Chile must address in biodiversity protection is the completion and consolidation of the current environmental institution framework.

3. The EIA system and mitigation requirements in Chile

In 2010, Law N°20,417 modified Law N°19,300 on *Bases Generales del Medio Ambiente* (General Environmental Bases), creating the *Ministerio de Medio Ambiente* (Ministry of Environment), the *Servicio de Evaluación Ambiental* (Environmental Assessment Service), and the *Superintendencia de Medio Ambiente* (Superintendency of the Environment). The Environmental assessment service manages and implements the Environmental Impact Assessment System (EIAS) in Chile (MINSEGPRES, 2010) which includes oversight of impact assessment; mitigation, repair, and compensation planning, and monitoring planning. The Superintendency of the Environment executes, organizes, and coordinates the follow-up and monitoring. Furthermore, from 2014, the projects submitted to the EIAS must be responsible for the environmental impact and loss of biodiversity caused by the execution of the project, since the *Guía para la compensación de biodiversidad en el SEIA* (Guide for the compensation of biodiversity in the EIAS, henceforth referred to as the national guideline) was published.

The national guideline details the minimum essential elements required for appropriate compensation for biodiversity loss, which requires the significant adverse effects identified in the Environmental Impact Study (EIS) to be balanced by the positive effect, promoting a zero net loss of biodiversity as a result of the implementation of projects or activities, or even a net gain (SEA, 2014). The EIS is the single document that provides well-founded background information for the prediction and identification of the environmental impacts (MMA, 2012; Rodríguez-Luna et al., 2021). All the EISs that identify significant impacts as a result of the impact assessment, have the obligation to present a plan with measures to mitigate, repair, or compensate the impacts, and also a monitoring plan. The national guideline is legally binding for the EIAS and points out the principle of the hierarchy of measures (mitigation hierarchy) as the mainstay in the appropriate compensation of biodiversity (Menchaca and Ravera, 2019). The mitigation hierarchy is defined in the national guideline as the sequential application of measures to reduce the potential negative impacts of development projects on biodiversity: (i) mitigation (which includes avoidance and minimisation, the first two steps in international literature); (ii) repair (corresponding to rehabilitation/restoration); and (iii) compensation (referred to as offsets). Mitigation and repair should be prioritised over compensation, in order to prevent biodiversity loss (SEA, 2014). The national guideline was updated in 2022 (SEA, 2022a) to introduce the *Guía metodológica para la compensación de biodiversidad en ecosistemas terrestres y acuáticos continentales* (Methodological guide for the compensation of biodiversity in continental terrestrial and aquatic ecosystems), which aims to deliver a clear and detailed methodology to quantify the biodiversity losses in terrestrial and aquatic ecosystems in projects or activities submitted to the EIAS (SEA, 2022b).

In Chile, the monitoring planning is established in the EIS, indicating the form and location of implementation, details of the measure that will be monitored, the component of biodiversity affected, timing, and the indicator that will be monitored, corresponding to the target to be measured to verify the success of the measure. Monitoring in Chile is mandatory for all the projects which have declared significant impacts, and the duration of the monitoring is stated to be for the lifetime of the

Table 2
Criteria for the selection of EISs for review.

Criterion	Restriction	Potential implication to the practice
Productive sector	Any	Criteria relating to productive sector and region were applied to ensure the final selection was representative enough of the overall cases where environmental impact studies are required in Chile (Wood and Jones, 1997).
Geographical area (region)	Any	The projects are assessed by different authorities depending in which region they are being submitted to the EIAS (Wood and Jones, 1997).
Planning decision	Permission granted	The sample only included approved EISs where the planning permission was already granted by the authority because these projects would generate monitoring requirements which are the focus of the third question.
Biodiversity compensation required	From 2015	EISs were searched from 2015 onwards to ensure that the recommendations of the national guideline (SEA, 2014) on biodiversity compensation had been incorporated or requested by the authority.

project or an equivalent time, which is decided by the relevant authority before the permission is granted. The monitoring reports in Chile are required for all the stages of the project (construction, operation, and decommissioning). The proponents should periodically submit monitoring reports to the *Superintendencia de Medio Ambiente* (Superintendency of the Environment), in charge of the post-evaluation process, which can perform audits to verify the accuracy of the monitoring programs, imposing sanctions or fines if the conditions according to what was established in the EIS are not being fulfilled (MINSEGPRES, 1994; MMA, 2012).

4. Selection of the EISs

EIS selection was constrained by the need to obtain a sample large enough to statistically represent practice yet excluding a sufficient number of EISs to make the analysis practical and focused on biodiversity impacts. This involved developing criteria known to influence the content of EISs (Wood and Jones, 1997), with a focus on biodiversity content. A representative sample of 31 EISs was selected using the criteria presented in Table 2.

All submitted EISs are available on the public online database of the Environmental Assessment Service (https://www.sea.gob.cl/) which is the authority in charge of assessing the EISs.

The 31 EISs selected represent sectors that have impacts on biodiversity components, which are identified as those affecting fauna, flora, vegetation, aquatic ecosystems, terrestrial ecosystems, and priority sites. Also, they correspond to those that have monitoring data available for the proposed mitigation, repair and compensation measures related to some of the components of biodiversity affected (for the remaining projects, monitoring has not yet started, or data are not yet available) (Fig. 2). The monitoring data are available in the public online database of the Superintendency of the Environment (https://snifa.sma.gob.cl/SeguimientoAmbiental/RCA), the authority in charge of monitoring and follow up.

The 31 EISs included cover six sectors, with 17 EISs corresponding to 'energy' projects, followed by eight from 'mining', two from 'hydraulic', two from 'others', one from 'housing' and one from 'sanitation' (according to the categories indicated by the Environmental Assessment Service). These cases are located all over the country, 12 in the north zone, 10 in the centre zone, three in the south zone, with a further six being interregional projects (Fig. 3).

The 31 EISs included in this study were considered representative of the type of biodiversity impacts produced by investment projects in Chile (Table 3). Consequently, the results and conclusions can be extrapolated to represent Chilean practice.

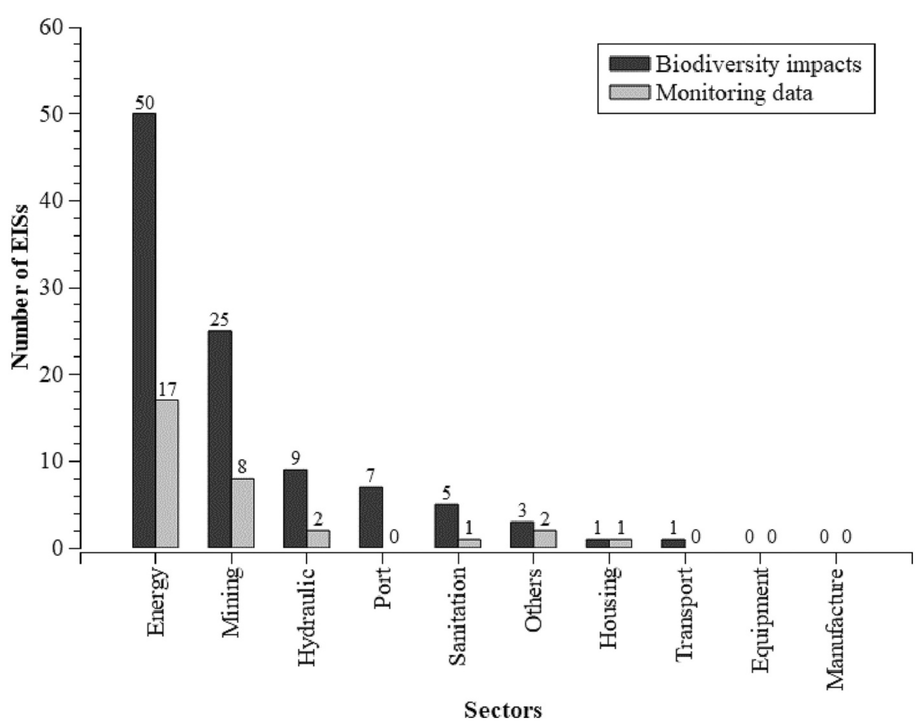

Fig. 2. Number of EISs approved between 2015 and 2022 reporting biodiversity impacts per sector. The total number of EISs in each sector is indicated in black, of which the EISs with monitoring data available are represented in grey (as of March 9, 2022).

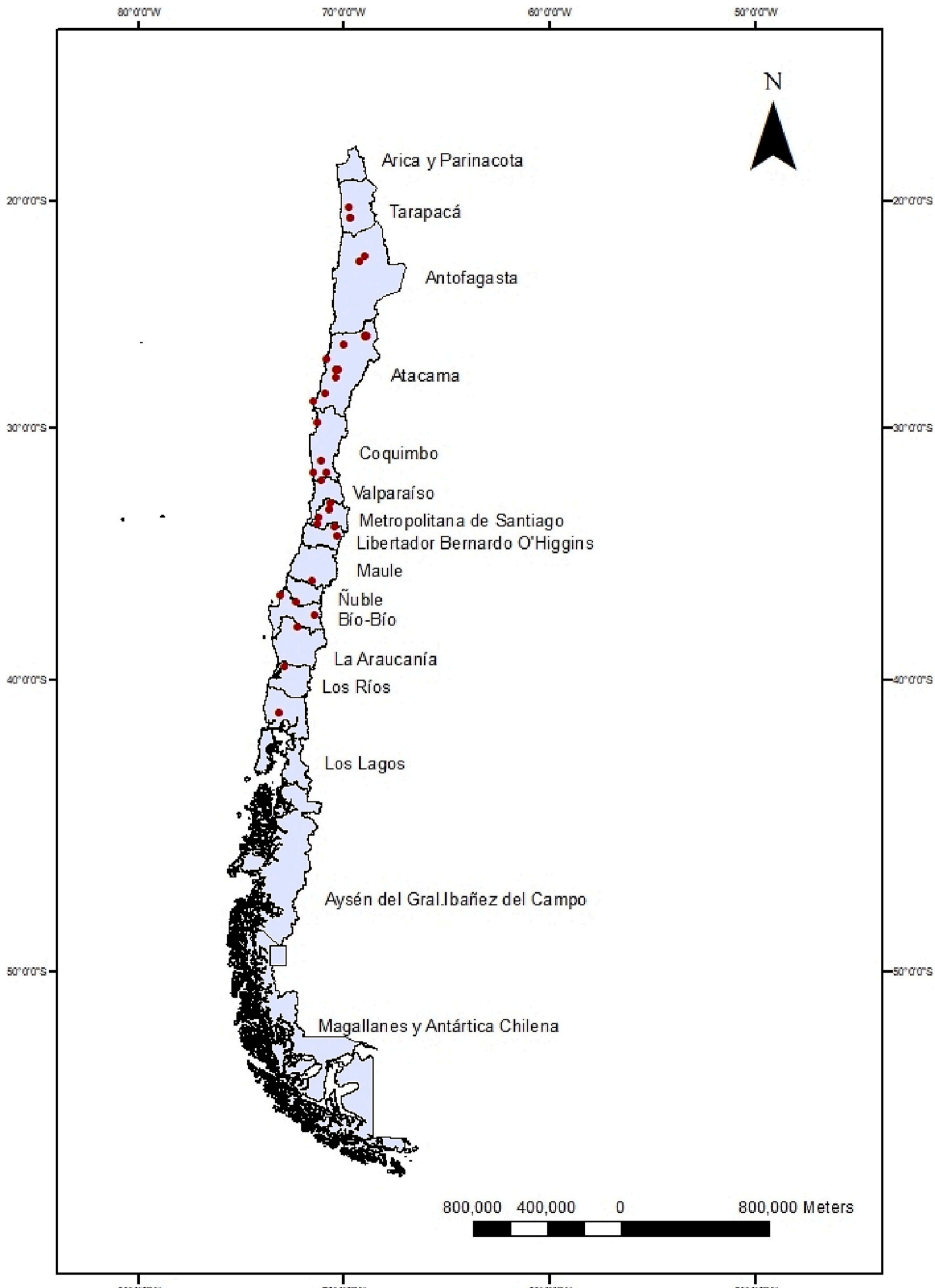

Fig. 3. Map of Chile and location of the 31 projects reviewed in this study (red dots). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

5. Is the mitigation hierarchy being followed?

5.1. Methods

Following the defined mitigation hierarchy in this paper, based on the Chilean EIA System, the mitigation, repair, and compensation measures proposed by the proponents to address biodiversity impacts were reviewed in each of the 31 EISs studied. The number of measures at each level of the mitigation hierarchy (mitigation, repair, and compensation) was counted to analyse the use of the mitigation hierarchy by each development project. To investigate if the measures had been correctly allocated to the right category of the mitigation hierarchy, all the activities involved in each measure proposed were checked and occasionally reclassified by the researchers following the definitions of the national guideline (SEA, 2014) and from the specific National Services with environmental competence in charge of reviewing the

Table 3
EISs selected by sector, region and approval date.

Name of the project	Sector	Region	Approval Date	Measures*			Monitoring*		
				M	R	C	M	R	C
Proyecto Nueva Línea 2 × 500 kv Charrúa-Ancoa: tendido del primer conductor	Energy	Interregional	30-Jan-2015	9	1	3	9	–	2
Línea 2 × 220 kV Ciruelos-Pichirropulli	Energy	Los Ríos	14-Apr-2015	14	1	2	6	–	–
Explotación Minera Oso Negro	Mining	Atacama	18-Jun-2015	7	–	3	2	–	2
Proyecto Parque Solar Quilapilún	Energy	Santiago	24-Jun-2015	–	–	4	–	–	4
Proyecto Santo Domingo	Mining	Atacama	8-Jul-2015	3	–	4	1	–	2
Candelaria 2030 - Continuidad Operacional	Mining	Atacama	28-Jul-2015	2	–	5	1	–	1
Proyecto Parque Eólico Aurora	Energy	Los Lagos	25-Sep-2015	5	–	–	1	–	–
Plan de Expansión Chile LT 2 × 500 kV Cardones – Polpaico	Energy	Interregional	11-Dec-2015	8	–	4	7	–	1
Proyecto El Espino	Mining	Coquimbo	12-Jan-2016	2	–	3	–	–	3
Mini Central Hidroeléctrica de Pasada Cipresillos	Energy	Rancagua	9-Feb-2016	2	–	2	1	–	1
Nueva Línea 2 × 220 kV Encuentro-Lagunas	Energy	Interregional	8-Mar-2016	7	–	1	4	–	–
Ampliación y Modernización Planta Enaex S.A. La Serena	Others	Coquimbo	9-May-2016	8	–	1	2	–	–
Parque Fotovoltaico Santiago Solar	Energy	Santiago	4-Jul-2016	2	–	1	2	–	1
Planta Desalinizadora de Agua de Mar para la Región de Atacama, Provincias de Copiapó y Chañaral	Sanitation	Atacama	19-Aug-2016	8	3	1	1	1	–
Parque Eólico Malleco	Energy	Araucanía	24-Nov-2016	3	–	–	1	–	–
Embalse de Regadío Las Palmas	Hydraulic	Valparaíso	19-Dec-2016	8	–	1	2	–	–
Proyecto Hidroeléctrico Embalse Digua	Energy	Maule	24-Apr-2017	2	1	1	2	–	–
Minicentrales Hidroeléctricas de pasada Aillín y Las Juntas	Energy	Biobío	4-May-2017	9	1	6	4	1	1
Minerales primarios Minera Spence	Mining	Antofagasta	4-Aug-2017	1	–	–	1	–	–
Infraestructura Complementaria	Mining	Coquimbo	14-Feb-2018	4	1	2	2	–	2
Proyecto mejoramiento de la generación, transporte y disposición de residuos arsenicales de división el teniente	Mining	Rancagua	8-Jun-2018	3	–	–	1	–	–
Planta Fotovoltaica Santa Rosa	Energy	Santiago	24-Sep-2018	–	–	3	–	–	2
Parque Eólico Cabo Leones III	Energy	Atacama	17-Dec-2018	2	–	1	2	–	1
Concesión Vial Puente Industrial	Hydraulic	Biobío	17-Dec-2018	3	–	3	3	–	–
Mirador de Lo Campino	Housing	Santiago	19-Dec-2018	4	–	–	2	–	–
Línea de Transmisión Lo Aguirre - Alto Melipilla y Alto Melipilla – Rapel	Energy	Interregional	21-Dec-2018	9	–	7	5	–	1
Nuevas Líneas 2 × 220 kV entre Parinacota y Cóndores	Energy	Interregional	29-Nov-2019	2	–	1	2	–	–
Estudio de Impacto Ambiental Proyecto Salares Norte	Mining	Atacama	18-Dec-2019	1	–	3	1	–	2
Estudio Impacto Ambiental Circunvalación Oriente Calama	Others	Antofagasta	17-Sep-2020	4	–	1	2	–	–
Nueva Línea Nueva Maitencillo -Punta Colorada -Nueva Pan de Azúcar 2 × 220 kV, 2 × 500 MVA	Energy	Interregional	17-Nov-2020	5	3	–	4	–	–
Nueva Línea Transmisión 2 × 220 kV Nueva Pan de Azúcar-Punta Sierra-Centella	Energy	Coquimbo	29-Mar-2021	3	–	1	1	–	–

* Letters in Measures and Monitoring correspond to: M = mitigation, R = repair, C = compensation. Numbers represent the total number of measures of each category proposed in the EIS, and the number of measures with available monitoring data (as of March 9, 2022).

Table 4
Number of measures proposed by sector.

Measure/Sector	Energy	Mining	Hydraulic	Sanitation	Housing	Others	Total
Mitigation	82	23	11	8	4	12	140
Repair	7	1	0	3	0	0	11
Compensation	37	20	4	1	0	2	64
Total	126	44	15	12	4	14	215

impacts related to biodiversity in the EISs (i.e., the *Corporación Nacional Forestal* (National Forest Corporation) (CONAF, 2020), and the *Servicio Agrícola y Ganadero* (Agricultural and Livestock Service) (SAG, 2016, 2021)).

5.2. Results and discussion

For the 31 EISs analysed in this study, a total of 215 measures were proposed at the various levels of the mitigation hierarchy: mitigation (140), repair (11), and compensation (64). The number of measures proposed for the projects in each sector is presented in Table 4. When the number of measures are compared to fit in the model of mitigation hierarchy proposed by the national guidelines (SEA, 2014), which is a simplification of that presented in Fig. 1 including mitigation, repair and compensation, it is found that most of the identified measures are aimed at mitigating impacts, followed by measures aimed at compensating for impacts. This contradicts expectations according to the mitigation hierarchy, as there is a tendency to use more compensation than repair measures.

Analysing the distribution of the measures in the mitigation hierarchy by project, considering the 31 EISs reviewed, it was observed that 12 projects proposed all stages of the hierarchy: mitigation, repair, and compensation measures (when it was necessary). The majority of the projects (17) however, did not propose any repair measures, whilst a few projects (2) only proposed compensation for all the impacts, confirming the tendency to propose fewer repair measures than expected based on the national guidelines.

The specific activities proposed as mitigation, repair, and compensation measures were extracted from the EISs, and categorised by type of activity as shown in Fig. 4a. Out of 19 categories established, seven had multiple classifications across the EISs. For example, rescue and relocation of fauna was considered to be mitigation in some EISs but also to be compensation in others; and rescue and relocation of plants was categorised differently as mitigation, repair, and compensation. Therefore, the activities described in the EISs were examined in depth, reviewing the content of each planned measure, to determine whether these inconsistencies corresponded to a contextual situation or if some misclassification could be detected.

The multiple classifications disappear after the reclassification (Fig. 4b). Activities related to environmental training, studies, and economic financing were classified as accompanying measures (see next paragraph). Overall, it was found that 178 out of 215 measures correctly

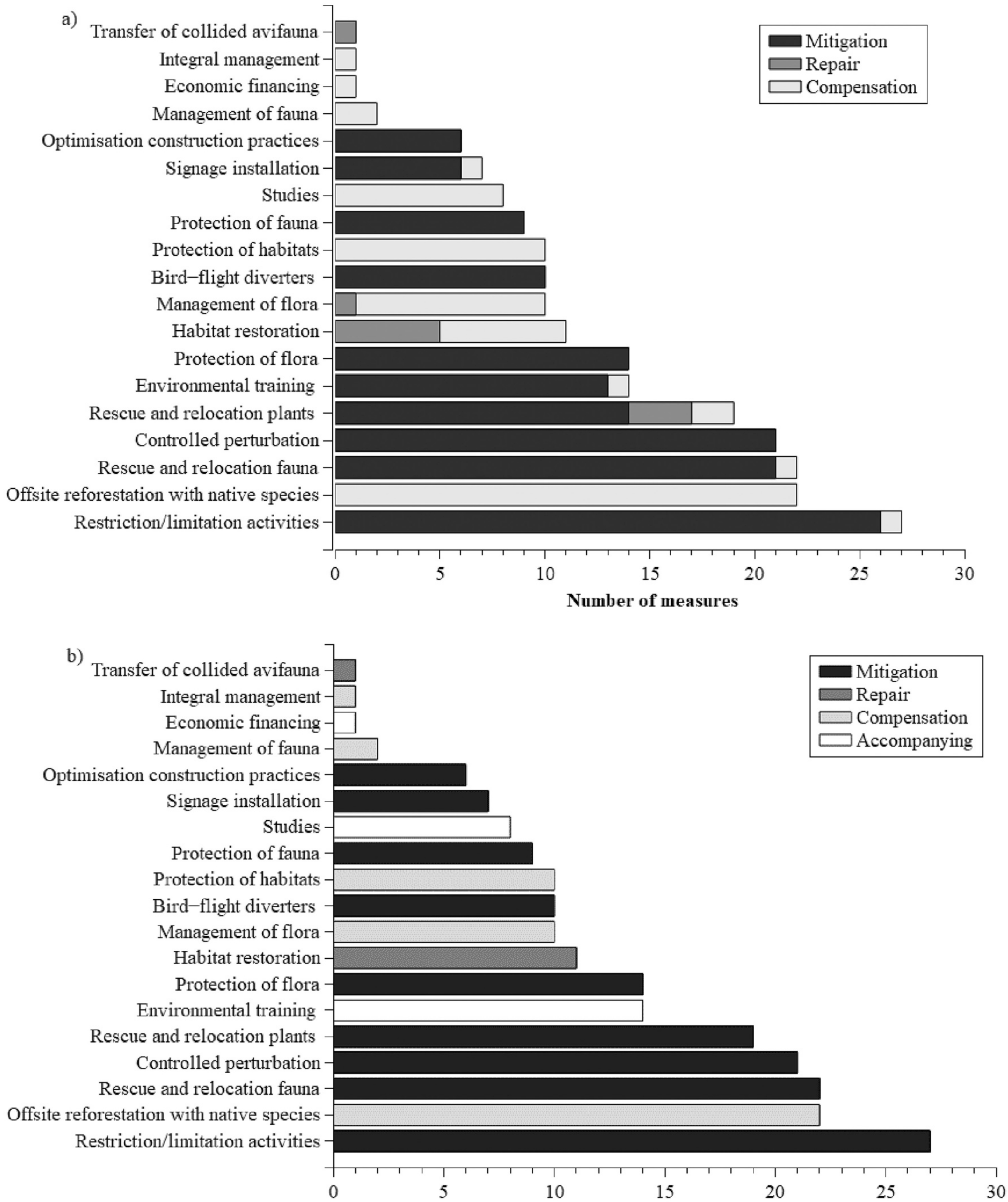

Fig. 4. Number of specific types of mitigation, repair, and compensation measures reported in the 31 EISs selected (a) and once they were reclassified (b).

followed the mitigation hierarchy classification indicated in the national guidelines for each category (SEA, 2014; SEA, 2022a) representing 83% of the total proposed measures. Thus, 37 measures were initially misclassified (17%) (Fig. 5).

In the re-evaluation of the measures, those that "*improve the effectiveness of offset measures or to additionally safeguard their environmental success*" (Jacob et al., 2016, p. 84), such as knowledge acquisition, socio-economic activities, awareness-raising measures, among others (Jacob et al., 2016) were classified as accompanying measures in this study as they have no tangible or measurable biodiversity outcome. They represented 11% of the total number of measures proposed. They also included measures related to "staff environmental training" and "workers training talks", for which CONAF indicates that "*training talks for staff on flora and vegetation will not be considered as a mitigation measure*" (CONAF, 2020, p. 40).

The reclassification also allowed mitigation measures to be separated into avoidance and minimisation by the researchers, which are otherwise combined in the category of 'mitigation' within the EIS (according to the national guideline). This allows a clearer examination of the use of the mitigation hierarchy. In this regard, most of the re-classified measures proposed for mitigation were minimisation (121 being 56% of the total of 215 measures) rather than avoidance (14 measures corresponding to 7% of the total of 215 measures) (Fig. 6). Bigard et al. (2017) found that reduction or minimisation of impacts is by far the most common measure proposed in practice for biodiversity, which is consistent with the results of this study, where most of the measures proposed within the EISs corresponded to restriction or limitation of activities, rescue and relocation of species and controlled perturbation,

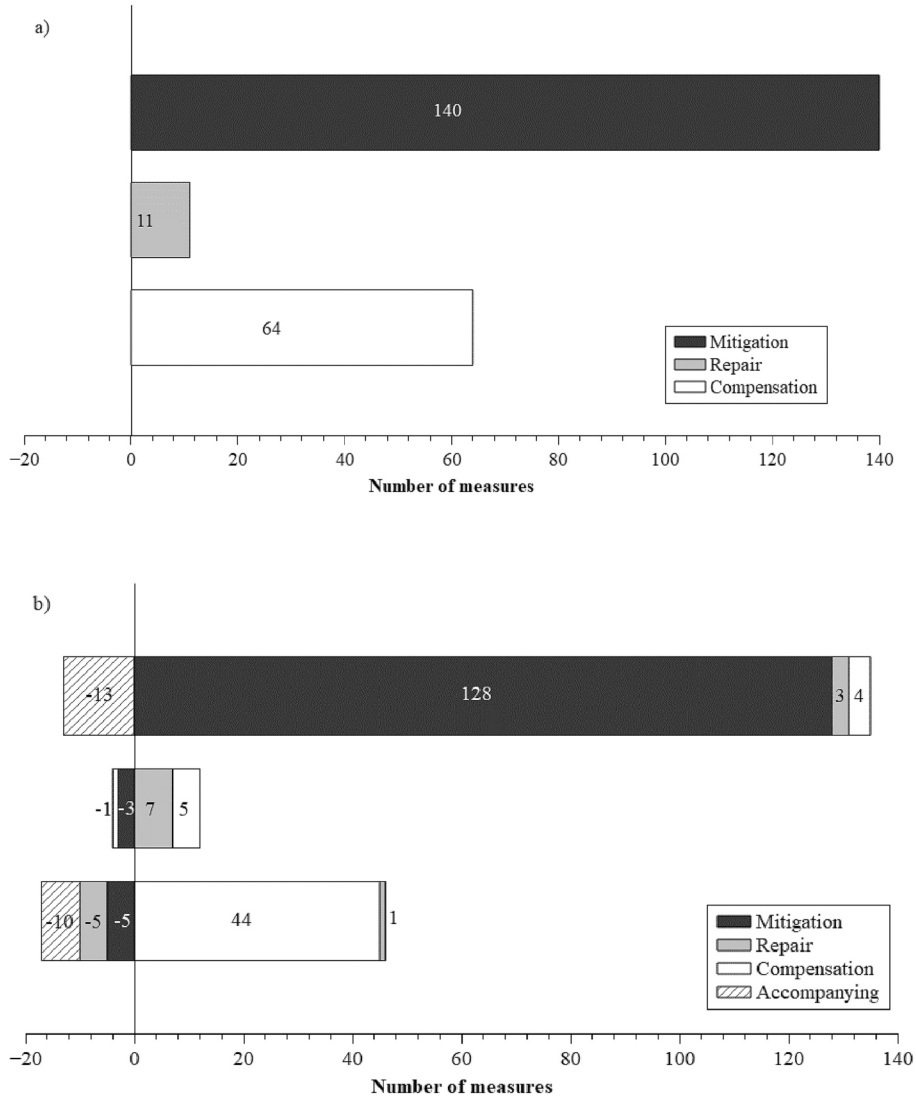

Fig. 5. Total of proposed measures (215 in the 31 EISs) for each category (a) and once they were re-evaluated following the national guidelines (b).

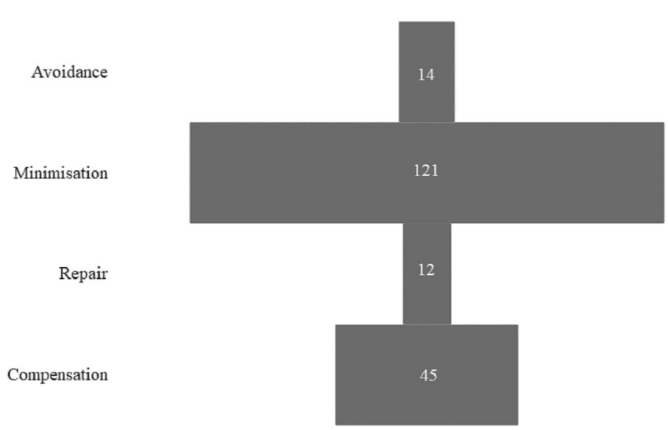

Fig. 6. Representation of the mitigation hierarchy found in this study.

which would often be aimed at minimizing impacts, especially in the construction phase. Avoiding impacts on biodiversity is rarely proposed as the first alternative in the mitigation hierarchy (Bigard et al., 2017; Phalan et al., 2018; Larsen et al., 2018). In this study, the 14 avoidance measures were proposed by energy, hydraulic, and 'others' projects, whereas for mining projects, avoidance measures such as reducing the affected area or changing the location area do not seem viable alternatives due to the nature of the project. Although more emphasis is placed in the literature on the avoidance stage of the mitigation hierarchy (Ekstrom et al., 2015; Maron et al., 2016; Phalan et al., 2018), the context for the project in terms of location, sector, and the nature of the impact, all seem to influence the extent to which this is realistic.

The same arguments apply to repair measures; as shown in Fig. 6, repair measures were the least proposed, even though the national guidelines prioritise repair over compensation (SEA, 2014). Repair measures are designed to replace or restore the basic properties of one or more components to a quality similar to that which they had before the impact (MMA, 2012; SEA, 2014), implying that the repair must be done in the place where the impacts occur. However, in practice, it is not always possible to repair the impacts due to the biodiversity loss that occurs through replacement with infrastructure, which leads inevitably to compensation (offsetting) as the next viable step. In this study, none of the mining projects proposed avoid or repair measures, mostly because it is difficult to recover biodiversity in the place where it has been affected, due to the construction and operation of the project.

Finally, 45 measures were in fact compensation measures, most of them being reforestation, management of flora and protection of habitats. By examining the sequence of the mitigation hierarchy, it was

Table 5
Number of monitoring reports required, available and completed by project to date (as of March 9, 2022).

Project	Approval Year	Required $n = 215$	Available $n = 100$	Completed $n = 73$	Progress %*
Proyecto Nueva Línea 2 × 500 kv Charrúa-Ancoa: tendido del primer conductor	2015	13	11	8	62
Línea 2 × 220 kV Ciruelos-Pichirropulli	2015	17	6	6	35
Explotación Minera Oso Negro	2015	10	4	4	40
Proyecto Parque Solar Quilapilún	2015	4	4	2	50
Proyecto Santo Domingo	2015	7	3	3	43
Candelaria 2030 - Continuidad Operacional	2015	7	2	2	29
Proyecto Parque Eólico Aurora	2015	5	1	0	0
Plan de Expansión Chile LT 2 × 500 kV Cardones – Polpaico	2015	12	8	8	67
Proyecto El Espino	2016	5	3	0	0
Mini Central Hidroeléctrica de Pasada Cipresillos	2016	4	2	0	0
Nueva Línea 2 × 220 kV Encuentro-Lagunas	2016	8	4	4	50
Ampliación y Modernización Planta Enaex S.A. La Serena	2016	9	2	2	22
Parque Fotovoltaico Santiago Solar	2016	3	3	2	67
Planta Desalinizadora de Agua de Mar para la Región de Atacama, Provincias de Copiapó y Chañaral	2016	12	2	2	17
Parque Eólico Malleco	2016	3	1	1	33
Embalse de Regadío Las Palmas	2016	9	2	2	22
Proyecto Hidroeléctrico Embalse Digua	2017	4	2	2	50
Minicentrales Hidroeléctricas de pasada Aillín y Las Juntas	2017	16	6	3	19
Minerales primarios Minera Spence	2017	1	1	1	100
Infraestructura Complementaria	2018	7	4	2	29
Proyecto mejoramiento de la generación, transporte y disposición de residuos arsenicales de división el teniente	2018	3	1	1	33
Planta Fotovoltaica Santa Rosa	2018	3	2	0	0
Parque Eólico Cabo Leones III	2018	3	3	2	67
Concesión Vial Puente Industrial	2018	6	3	3	50
Mirador de Lo Campino	2018	4	2	0	0
Línea de Transmisión Lo Aguirre - Alto Melipilla y Alto Melipilla – Rapel	2018	16	6	4	25
Nuevas Líneas 2 × 220 kV entre Parinacota y Cóndores	2019	3	2	2	67
Estudio de Impacto Ambiental Proyecto Salares Norte	2019	4	3	1	25
Estudio Impacto Ambiental Circunvalación Oriente Calama	2020	5	2	2	40
Nueva Línea Nueva Maitencillo -Punta Colorada -Nueva Pan de Azúcar 2 × 220 kV, 2 × 500 MVA	2020	8	4	3	38
Nueva Línea Transmisión 2 × 220 kV Nueva Pan de Azúcar-Punta Sierra-Centella	2021	4	1	1	25

* Note: % progress is calculated based on the proportion of required reports which are completed.

found that compensation measures (compared to the number of repair measures proposed) are included more often than expected, especially considering that they should be used as a last resort (SEA, 2014). However, as discussed earlier, repair measures are not always a viable alternative to be considered before compensation, based on the nature of the projects. Usually, compensation measures are proposed in specific locations where nature has been replaced by infrastructure, especially in mining or energy projects in Chile. In these cases, the choice of compensation measures is likely a standard response where it is not possible to mitigate or repair. Further investigation would be needed to understand why compensation seems to be the preferred course of action rather that repair, considering the nature of the project, and operational and financial costs.

6. Is the monitoring of the measures implemented effective?

6.1. Methods

To address the implementation of the measures, the monitoring reports published and available to date were reviewed for the 31 projects from which the sample of EISs was drawn. The number of completed monitoring reports was determined to assess the level of progress of each project. For each monitoring report, the type of monitoring was identified as well as the indicator (which is the parameter that is being measured) that was being monitored, to determine whether they were biodiversity-related, and whether they were measuring biodiversity outcomes (which means the actual state of the biodiversity parameter). The distinction is important, as indicators are typically divided into measurements of pressure, state, or response, after OECD (1994). For example, where visitor pressure threatens a plant species, an indicator counting visitor numbers would record pressure, the number and condition of the threatened plant species would be the state, and the erection of a fence to keep out visitors a response. Whilst indicators can exist for pressure, state, and response, it is only the state indicator that shows the outcome for the biodiversity element of interest.

6.2. Results and discussion

Overall, out of 215 monitoring reports required from the total of 31 projects (those that should be presented to the authority as a requirement for construction permission), 100 reports were available for examination (47%). Table 5 shows the level of completion or progress for each project, on average the level of progress is 34% across the 31 projects that have monitoring data. The number of 'completed' reports corresponds to monitoring that has taken place and has already finished (it should be noted that that the scope and duration of monitoring programmes influence the level of completion of each report), while 'available' includes those which are completed, and those taking place over a longer term where the monitoring is still ongoing and therefore the data are only partially collected (the amount of time that the monitoring lasts has not finished yet). The information obtained from the public online database of the Superintendency of the Environment does not give the reasons why there are some reports missing (the difference between the number of reports required, and the number available).

The type of monitoring and the indicator that is being monitored was extracted from each monitoring report. Overall, out of 100 reports, 69 aimed to monitor some biodiversity-related indicator, delivering biodiversity outcomes. Whilst 31 reports included other types of indicators derived from visual inspections and studies, which were considered to be implementation indicators (Table 6).

Almost one third of the reports (31%) reported the success of the measures based on the implementation of the measures (qualitative outcomes), e.g., if the measure was carried out according to what was indicated in the monitoring planning in the EIS (methods, place, timing). Most of them relied on visual inspection-based monitoring (29%) where

Table 6
Types of monitoring that projects have implemented and the indicator that is being monitored.

	Type of monitoring	Indicators	Number of reports
Biodiversity-related indicator	Systematic fauna surveys	Richness and abundance	18
		Presence of individuals	6
		Number of individuals	2
	Wildlife observations	Presence of individuals	9
		Number of individuals	1
	Systematic flora surveys	Survival of individuals	18
		Number of individuals	5
		Richness and abundance	2
		Plant cover	2
		Number of seeds	1
		Germination and flowering	1
		Plant density	1
		Presence of individuals	1
	Systematic flora and fauna surveys	Richness and abundance	1
	Measure of habitat	Area	1
Implementation indicator	Visual inspection	Activity recorded	19
		Installation of equipment	8
		Attendance record	2
	Studies	Report delivered	2
Total			100

the activity is recorded through photographs or checklist (being the most common indicators of success of the measures), followed by the verification of the installation of devices such as bird-flight diverters or signage. However, these monitoring reports do not provide quantitative information for biodiversity as the results are based mainly in the implementation of the measure, rather that the effectiveness of the measure in terms of biodiversity outcomes.

Activities such as attendance records for worker environmental training, as well as the delivery of scientific studies carried out to generate knowledge about the component of biodiversity affected, were classified as accompanying measures in this study. Therefore, they are not expected to quantify biodiversity outcomes. They accounted for 4% of all the monitoring reports reviewed in this study.

In terms of biodiversity outcomes, 69% of the monitoring reports used a biodiversity-related indicator (quantitative outcomes). However, the outcomes on biodiversity were based on proxies for biodiversity (e.g., the most common indicators were richness and abundance for fauna (18%) and survival of individuals for flora (18%)), rather than on detailed quantification of biodiversity losses or gains. The biodiversity-related indicators tend to be species-specific as the monitoring is focused mainly on fauna and flora species, rather than habitats or ecosystems (Quétier and Lavorel, 2011; Gardner et al., 2013). For example, the monitoring reports provided data on the number of native trees planted, or the number of flora/fauna species rescued and relocated, but none reported data on the dynamics of new animal/plant communities or ecosystems created that would indicate the impacts were successfully mitigated, repaired, or compensated as a result of the implementation of the measures. There was only one monitoring report (one out of 31 projects) that quantified the residual impacts on biodiversity throughout the process that would allow a justification of a decision on whether compensation was required.

Table 7
Number of measures implemented (report available to March 9, 2022), and the number of implementation/biodiversity-related indicators proposed for each measure.

Project	Measures implemented	Implementation indicator		Biodiversity-related indicator	
	n = 100	n = 31	%	n = 69	%
Proyecto Nueva Línea 2 × 500 kv Charrúa-Ancoa: tendido del primer conductor	11	3	27	8	73
Línea 2 × 220 kV Ciruelos-Pichirropulli	6	4	67	2	33
Explotación Minera Oso Negro	4	–	–	4	100
Proyecto Parque Solar Quilapilún	4	3	75	1	25
Proyecto Santo Domingo	3	1	33	2	67
Candelaria 2030 - Continuidad Operacional	2	–	–	2	100
Proyecto Parque Eólico Aurora	1	–	–	1	100
Plan de Expansión Chile LT 2 × 500 kV Cardones – Polpaico	8	2	25	6	75
Proyecto El Espino	3	–	–	3	100
Mini Central Hidroeléctrica de Pasada Cipresillos	2	1	50	1	50
Nueva Línea 2 × 220 kV Encuentro-Lagunas	4	2	50	2	50
Ampliación y Modernización Planta Enaex S.A. La Serena	2	–	–	2	100
Parque Fotovoltaico Santiago Solar	3	–	–	3	100
Planta Desalinizadora de Agua de Mar para la Región de Atacama, Provincias de Copiapó y Chañaral	2	–	–	2	100
Parque Eólico Malleco	1	–	–	1	100
Embalse de Regadío Las Palmas	2	–	–	2	100
Proyecto Hidroeléctrico Embalse Digua	2	2	100	–	–
Minicentrales Hidroeléctricas de pasada Aillín y Las Juntas	6	4	67	2	33
Minerales primarios Minera Spence	1	–	–	1	100
Infraestructura Complementaria	4	1	25	3	75
Proyecto mejoramiento de la generación, transporte y disposición de residuos arsenicales de división el teniente	1	–	–	1	100
Planta Fotovoltaica Santa Rosa	2	–	–	2	100
Parque Eólico Cabo Leones III	3	1	33	2	67
Concesión Vial Puente Industrial	3	–	–	3	100
Mirador de Lo Campino	2	–	–	2	100
Línea de Transmisión Lo Aguirre - Alto Melipilla y Alto Melipilla – Rapel	6	5	83	1	17
Nuevas Líneas 2 × 220 kV entre Parinacota y Cóndores	2	–	–	2	100
Estudio de Impacto Ambiental Proyecto Salares Norte	3	–	–	3	100

(*continued on next page*)

Table 7 (*continued*)

Project	Measures implemented	Implementation indicator		Biodiversity-related indicator	
	n = 100	*n* = 31	%	*n* = 69	%
Estudio Impacto Ambiental Circunvalación Oriente Calama	2	–	–	2	100
Nueva Línea Nueva Maitencillo -Punta Colorada -Nueva Pan de Azúcar 2 × 220 kV, 2 × 500 MVA	4	1	25	3	75
Nueva Línea Transmisión 2 × 220 kV Nueva Pan de Azúcar-Punta Sierra-Centella	1	1	100	–	–

Twenty-nine out of 31 projects reported biodiversity outcomes at some level, as they proposed at least one biodiversity-related indicator (Table 7). Seventeen of these were entirely focused on biodiversity-related indicators, delivering the results in terms of biodiversity outcomes, even when they did not quantify biodiversity, as discussed above.

Although the mitigation hierarchy effectiveness depends on the full implementation of the measures (Sánchez and Gallardo, 2005; Drayson and Thompson, 2013; Morrison-Saunders et al., 2021), it is not possible to assess the effectiveness of the measures implemented without monitoring information about the biodiversity outcomes targeted by the intervention (Panfil and Harvey, 2016). Measurable and quantitative targets should be stipulated in the monitoring plan in the EIS, as it is established by the law (MMA, 2012). However, it was found that 31% of the monitoring are reporting qualitative outcomes. Measurable and quantitative targeted monitoring is essential for verifying the effectiveness of the mitigation measures (Sánchez and Gallardo, 2005; Drayson and Thompson, 2013; Morrison-Saunders et al., 2021). This research suggests monitoring can be improved and give greater focus to the quantification of the biodiversity outcomes resulting from the mitigation measures.

7. Conclusion and recommendations

This study evaluated the extent to which biodiversity is being protected from impacts of development projects by the Chilean environmental legislation implemented in 2014. The country's policy framework includes legislation to deliver the mitigation hierarchy within its EIA System. However, in practice the implementation of the mitigation hierarchy and the monitoring of quantifiable biodiversity outcomes remains challenging.

This review of all information available up to 2022 showed projects have a tendency to use more compensation measures than would be expected from the implementation of the mitigation hierarchy. There is limited use of repair measures, and avoidance measures were rarely proposed. This bias towards compensation may indicate a poor use of the mitigation hierarchy (Glasson and Therivel, 2019). However, in some contexts, for example mining projects, where the impacts on the area affected cannot be avoided and repaired, as the projects cannot be relocated or reduced in scale, compensation may be the only option available. Other project types, such as, energy, hydraulic, sanitation, housing, and others, could potentially make a greater effort to include measures that avoid impacts on biodiversity.

Thus, the inverted mitigation hierarchy pyramid expected based on theory and guidance, is not relevant to all project types. Further research is needed to determine the underlying causes for the preponderance of compensation measures in the majority of the projects in this study, to determine whether this is due to financial and logistical expedience. At the time of writing, there was no mandated limit on how much to compensate, and for most projects compensation seemed to be the preferred option (where repair was not feasible), therefore some of these factors might be influencing the decision on the level of compensation.

This study has also shown that misclassification of the measures throughout the mitigation hierarchy whilst present, is not a major issue in relation to biodiversity outcomes. Nevertheless, practice can be improved to ensure that misclassification does not subvert the correct use of the mitigation hierarchy.

Regarding EIA-related biodiversity monitoring, this study identifies some missing reports that either have not taken place yet or have not been submitted to the public database. A subsequent long-term assessment would be required to understand whether this was evidence of omission, or simply a facet of timing. Nevertheless, some measures were being claimed as successful based purely on implementation (the verification of the activity being conducted), rather than on evaluation of biodiversity outcomes.

Despite many projects delivering biodiversity-related indicators, there was rarely an attempt to quantify biodiversity outcomes through all the levels of the mitigation hierarchy that would allow the measurement of net gains (Drayson and Thompson, 2013; Ekstrom et al., 2015; Gelot and Bigard, 2021). Additionally, the focus was on selected elements of biodiversity which paint a partial picture of the outcomes, without considering the wider consequences for ecosystems (Gelot and Bigard, 2021; Boileau et al., 2022). Even though it depends on the component of biodiversity whether it can be mitigated, repaired, or compensated, the measures should aim to conserve unique ecosystems or threatened species that depend on specific conditions in their environment. The introduction into the national legislation of the 'Methodological guide for the compensation of biodiversity in continental terrestrial and aquatic ecosystems' (SEA, 2022b), may lead to some improvements in quantification of all the components of biodiversity, allowing the achievement of biodiversity net gain.

CRediT authorship contribution statement

Rocío A. Cares: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Funding acquisition. **Aldina M.A. Franco:** Conceptualization, Validation, Formal analysis, Writing – review & editing, Visualization, Supervision, Project administration. **Alan Bond:** Conceptualization, Methodology, Validation, Formal analysis, Writing – review & editing, Visualization, Supervision, Project administration.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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